

SANTA BARBARA

Land of Dynamic Beauty

A Natural History



Santa Ynez Mountains from the Santa Barbara Botanical Garden. Photograph by Tom Muneio

Edward A. Keller
with Assistance from
Valery Rivera Keller



Ecotourism is important to Santa Barbara.

Santa Barbara, Land of Dynamic Beauty: A Natural History

Edward A. Keller

With assistance from Valery Rivera Keller

Publisher

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USA

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1991 Las Canoas Road

Santa Barbara, California 93105

USA

ed.keller@cox.net

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PREFACE

This book is an extension of my imagination, training, and wish to communicate the natural history of Santa Barbara where I have lived and worked for several decades. Our children were raised in Santa Barbara, and this book is dedicated to the people of Santa Barbara today and the next generation who will become responsible for the land we love.

The purpose of this book is to present the complex natural history and environment of Santa Barbara within a framework of sustainability.

The book is arranged in six chapters, starting with the geologic history and natural hazards, and then arranged by locations including: Santa Barbara, Montecito, Carpinteria, La Conchita, Goleta, Ellwood, and the Santa Barbara Channel. The final chapter of the book discusses sustainability and links between Santa Barbara and the global environment. Of particular importance are the topics of global warming, ecosystems, water supply, waste management, energy, and ecotourism.

The book is written to provide a history and understanding of the Santa Barbara landscape and environment. I also discuss some of the interesting aspects of our landscape, including: the history of Mission Creek; the origin of Skofield and Rocky Nook Parks; the origin of our coastal lagoons and salt marshes; our natural hazards, especially earthquakes, landslides, and wildfire; and long-term management of land and water resources such as Goleta Beach.

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ABOUT US

Ed Keller is a professor, researcher, teacher, writer, and mentor. He teaches undergraduate and graduate courses at the University of California, Santa Barbara in the Department of Earth Science and Environmental Studies Program. Ed was born in Los Angeles, California and has Bachelor's Degrees in Geology and Mathematics from California State University at Fresno, Master's Degree in Geology from the University of California, Davis and Ph.D. in Geology from Purdue University. While a graduate student at Purdue University, Ed wrote the first edition of *Environmental Geology* published by Prentice Hall. The book became a foundation in environmental geology curricula. Since he has been at the University of California, Santa Barbara, he has been chair of the Environmental Studies and Hydrologic Science programs. Ed is the author of more than 100 articles and several books. His research areas are natural hazards, river processes, and, more recently, habitat for endangered southern steelhead trout. Academic honors include the Don J. Easterbrook Distinguished Scientist award from the Geological Society of America in 2004. He was elected a fellow to Emmanuel College, Cambridge University in 2000. Ed holds Distinguished Alumni awards from California State University at Fresno and Purdue University.



Valery and Ed, 2010.

Valery Rivera Keller was born in New York City, and Santa Barbara, California is now her home, in the mountains of Rattlesnake Canyon or along Arroyo Burro Beach. Valery earned Masters Degrees in both Education and in Educational Administration and Supervision. Education is her passion and life work. As a former school administrator, teacher, and curriculum writer, she has influenced and mentored young children and adults alike through example and purpose to help them define their dreams. Valery is a lifelong learner, educator, and advocate. She continues to help her husband Ed Keller in his writing of books and textbooks by assisting with curriculum, organization, and conceptual content development.

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Geologic History: Millions of Years of Action

The Big Picture

Four decades ago, when I was a beginning graduate student at the University of California at Davis, the hypothesis of plate tectonics was put forward to explain the origin of ocean basins and continents. It was a revolution that resulted in a new paradigm in our understanding of how the Earth works. The basic idea is that the outer shell of Earth is broken into several large and small plates, like the shell of a cracked egg (Fig.1.1). Rigid plates (the lithosphere) about 70 miles thick are moving over a hot plastically flowing layer of relatively low strength called the asthenosphere. Some plates are spreading apart, making ocean basins, and others are in collision, producing mountain ranges. The hypothesis is now a well-tested theory, and earth scientists use it to explain the origin of the landscape at regional to global scales. We will return to plate tectonics in our discussion of how the land we know as Santa Barbara came to be from 20 million years ago, when Santa Barbara was part of the North American plate, to today, when it is now part of the Pacific plate.

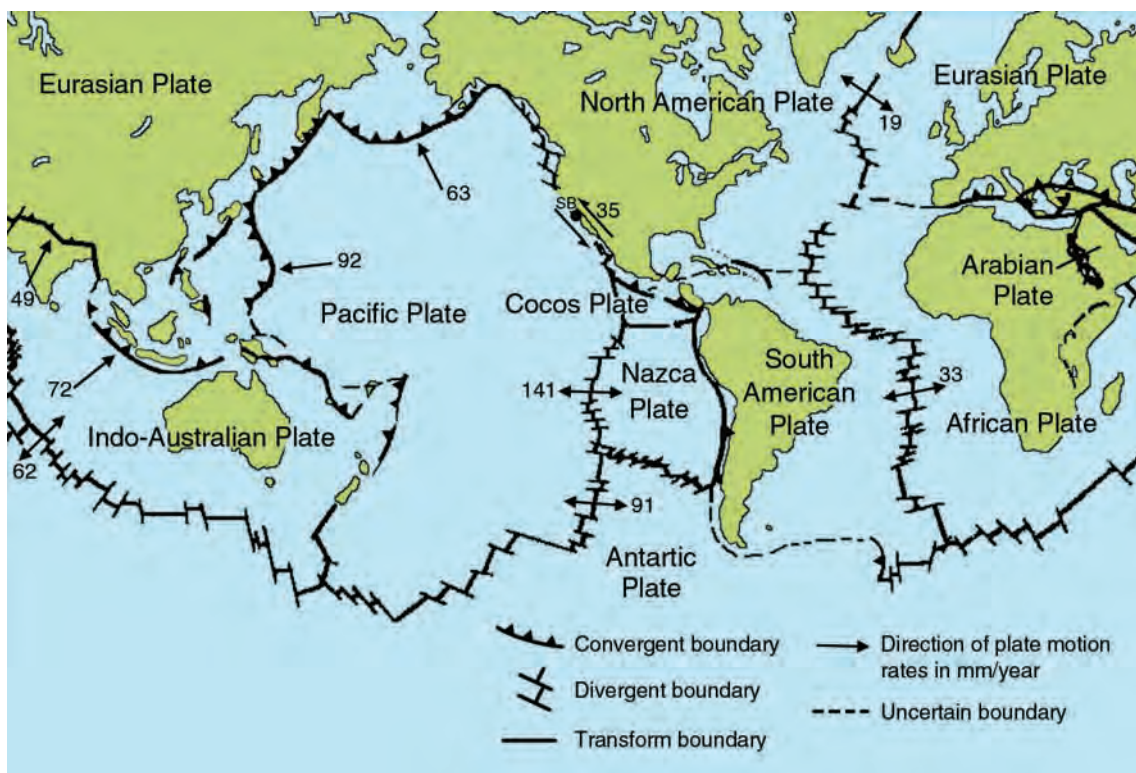


Fig.1.1. Map showing the major tectonic plates, plate boundaries, and direction of plate movement (with rates mm/yr). SB is Santa Barbara. Modified from U.S. Geological Survey

Santa Barbara: The Dynamic Land

A thousand years ago, the equivalent volume of a million truckloads of boulders roared down Rattlesnake Canyon. The churning wall of fast moving boulders changed the look of the landscape of Santa Barbara from Rocky Nook Park west to State Street. A repeat of that event would destroy hundreds of homes and take hundreds of lives. Uplift from many earthquakes has formed our most visible landscape, including the Santa Ynez Mountains, Mission Ridge, the Mesa and sea cliffs below Shoreline Park, Hope Ranch, UCSB, and More Mesa. The city was heavily damaged in the earthquake of 1925, and the next big one could cause several billions of dollars in property damage. Floods occasionally inundate some of our homes, and landslides damage or destroy others. Sea cliffs and beaches are eroding, threatening property and destroying parklands. Periodic wildfire is, perhaps, the most serious threat to homes. These natural processes, which we term hazards, are part of our natural environment. More correctly, these processes have formed and maintained the landscape we know as Santa Barbara. The landscape of mountains, canyons, and coast is the direct result of geologic and hydrologic processes that continue to cause us problems. We need to learn more about hazardous natural processes, so that we might be better prepared for them and minimize potential adverse consequences. The ultimate goal is to live with and to sustain our environment for what it is, a gift from our geologic heritage.

Listen to the Land: It Speaks to You

The natural history of Santa Barbara can be told through a series of stories. Inspirational places to view the land that have helped us understand that history include: Santa Barbara Point, at the east end of Shoreline Park, to view coastal hills and mountains to the east, sometimes all the way to the Santa

Monica Mountains; Franceschi Park, on the Riviera, to view the City and Mesa, west to UCSB and beyond; St. Mary's Seminary, off Las Canoas Road near Skofield Park, to see Rattlesnake Creek, a view of the large landslide above Skofield Park and south to the Santa Barbara Channel; the site of the former Mount Calvary Retreat House, off Gibraltar Road, with a commanding view from the Santa Ynez Mountains to the sea and Channel Islands; the steps of Old Mission Santa Barbara, with views to the sea; and the Santa Barbara Botanic Garden, to experience the view to the north, up Mission Canyon, framed by white to honey-colored sandstone cliffs of the Coldwater and Matilija Formations, which, along the crest of the Santa Ynez Mountains, supports Cathedral Peak (Arlington Peak) on the west and La Cumbre Peak to the east. Visit these locations on clear days to observe the big picture of the landscape. Concentrate on the form and texture of the landscape, and it may speak to you and reveal part of its story. If it doesn't speak to you, drink something stronger and ask again. Observing the landscape and letting it tell its story is how I have made most of my discoveries about the natural history of Santa Barbara that I share with you in this book.

I first learned to listen to the river over thirty years ago on Mallard Creek near Charlotte, North Carolina, where I was teaching before coming to UCSB. I was studying pools and riffles - not too different from my research on Mission Creek today. I was looking for a good stretch of creek to study pools and couldn't find a bit of creek that was not greatly influenced by large trees that had fallen into the channel. I was about to give up, thinking I couldn't find any place to study "naturally formed pools," when I heard a great cracking and snapping of big tree limbs, followed by a large splash, as a big hardwood tree hit the stream bed. The river spoke to me that day and a little light went on—the presence of tree trunks and

root wads in forested streams is natural and forms pools, as stream flow is forced around, over, and under the large woody debris. That insight led to several decades of stream research that helped open a new research area, linking biological processes to physical processes in river form and process that we now call forest geomorphology. The falling tree got my attention, and I was able to listen to the message.

Listening to the land is part science and is part a spiritual quest. While science can remove some of the mystery of how the world works, scientific discovery heightens our wonder of Earth and its complex web of life, with its flow of energy and cycling of air, water, rock, soil, and land that defines our very existence and evolution over billions of years.

When you observe the land at different vantage points near and far, take in the texture, color, and fabric. Listen to the sounds the land makes as water flows, waves crash, or small to large rock particles move down a slope. The land you are communicating with is composed of numerous forms at various scales that are produced by geologic processes over thousands to millions of years. The interaction of running water, uplift from earthquakes, and beach processes, where the land meets the sea, have produced the landscape we know as Santa Barbara.

The Santa Barbara landscape is ever changing and, to understand its history, we look to the rocks, soils, and water and consider how Earth processes, such as earthquakes, waves, and floods, have shaped and modified the land. If you were here during the thousands of years of the Chumash heritage in Santa Barbara, the landscape would look fairly similar to today, but there would be some noticeable differences. Streams and beaches would be in similar places, but specific rock formations, such as sea caves or arches, would be different, as would the shape of some canyon walls.

The Mesa and Riviera would be a little lower in elevation and not as long. If you could go back about 60,000 years ago, Mission Creek would be flowing through what is now the rose garden in front of the Mission, past Roosevelt School and through Santa Barbara High School, into a large salt marsh or El Estero.

Realtors and people building houses prefer a constant landscape, a never-changing environment. This is seldom the case for long. Changes, resulting from coastal erosion and causing homes to be flooded or to tumble down hillsides, are not part of a repertoire that those who sell our homes want to talk about. Fortunately, most of the time, changes are small, and catastrophic change occurs only seldom, as, for example, in 1925 when a magnitude 6.8 earthquake nearly destroyed the city of Santa Barbara. That event heralded many changes in architecture that led to the beautiful Spanish buildings with red-tile roofs we have today. But enough of modern history; let's go back a bit in time.

How Are We Connected to Mexico and San Diego?

Connecting the geology of Santa Barbara to Mexico and San Diego, at first thought, seems far-fetched. What could our landscape possibly have in common with the landscape of northern Mexico or San Diego? One of the wonderful things about science is that, as we learn about the earth we live on, we remove some of the mystery about how things happen, but not the wonder. The white sandstones and other rocks of the Coldwater and Matilija sandstones, which are the most observable part of the Santa Ynez Mountains (Fig.1.2) that we gaze up to on clear days, have an origin near where San Diego is today. From the work of Professor Tanya Atwater at UCSB, we learn that, from about 18 to 6 million years ago, big changes occurred. A large coastal block (actually, several blocks that we treat

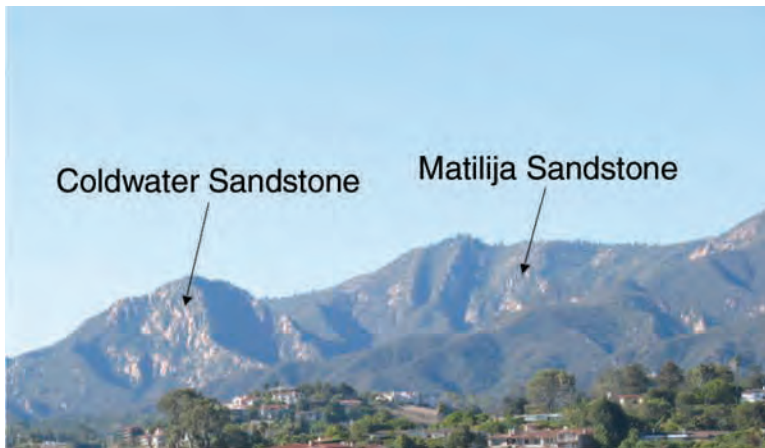


Fig.1.2. Santa Ynez Mountains (2007)

as a single block, to simplify the story), as long as from Los Angeles to Point Conception and as wide as from Santa Barbara to a few miles south of Bakersfield, was torn off of the North American plate and dragged by plate tectonic processes that move continents to become part of the Pacific plate. The giant block was moved northwest (translated) and rotated clockwise about ninety degrees. As part of this process, depressions, such as the Los Angeles and Santa Barbara Basins (now the Santa Barbara Channel), formed and, when the blocks collided with North America, mountain ranges from near Los Angeles to west of Santa Barbara formed. We call these mountains the Western Transverse Ranges, and The Santa Ynez Mountains are part of these ranges. About 6 million years ago, Baja California broke off from North America and also has been moving northwest, opening the Gulf of California. To view an ani-

mation of how Santa Barbara arrived at its present location, visit <http://emvc.geol.ucsb.edu>.

As stated above, some of the rocks brought with the translating and rotating blocks crashed into our area and were eventually uplifted to form the Santa Ynez Mountains. We know this by careful study of the types of sediments and where they originated, and we can say with some confidence that, were it not for the geologic process described above, the white sandstone rocks in the mountains that frame the city of Santa Barbara would not be with us. During the period of rifting, spreading, rotating, and basin formation millions of years ago, there were volcanic eruptions. When the crust of the earth thins by spreading, it breaks, and molten rock tends to leak upwards. The volcanic rocks of the Santa Monica Mountains, as well as volcanic

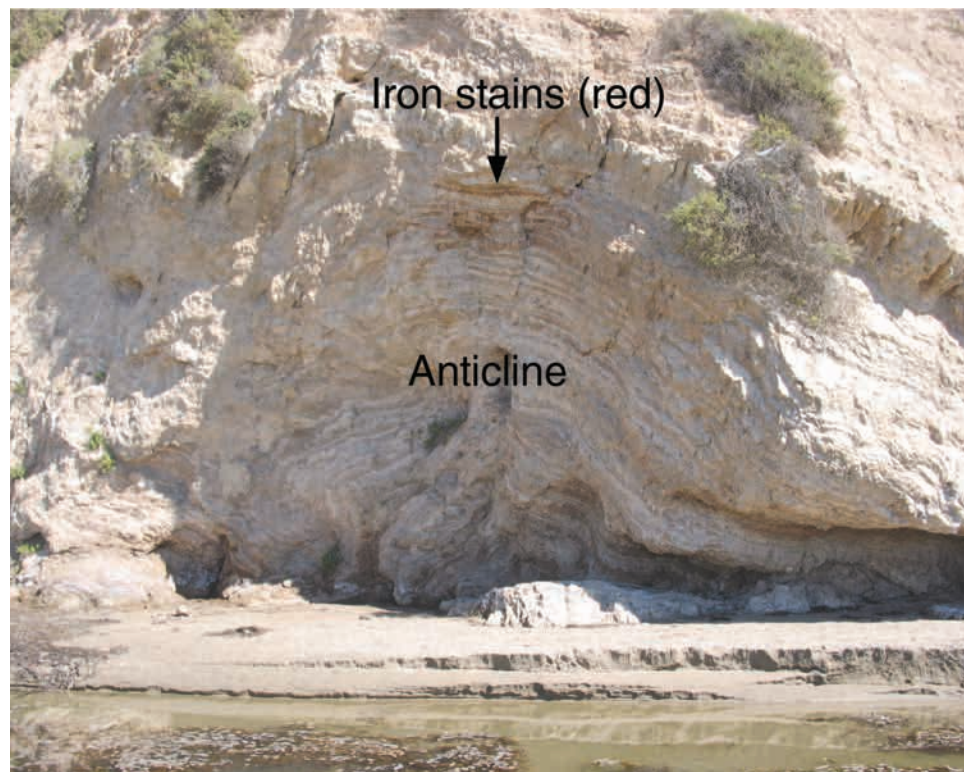


Fig.1.3. Folded Monterey Shale at Arroyo Burro Beach (2007)

rocks found on Santa Cruz Island, are evidence of past volcanic activity. The deep ocean basin that received sediment at that time contains volcanic ash. If you look at the white shale sea cliff found along much of Santa Barbara, in which the rocks are of the Miocene age (about 6 to 18 million years old (Fig.1.3), you can often find volcanic ash that has been altered to a yellow-brown clay mineral known as bentonite. When present at the surface, bentonite can cause us some problems because soils on it may expand and contract, which can cause cracking of sidewalks, streets, walls, and the foundations of buildings.

The Land Is Shortening And Rotating

Remarkably, as stated above, the rocks of the Santa Barbara area have rotated clockwise about 90 degrees during their northward journey from offshore of San Diego. That is why our coastline is nearly east-west. Imagine an entire landscape being spun on a vertical axis. Professor Bruce Luyendyk at UCSB discovered this. The rotation is believed to have been accommodated by left-lateral displacement on a number of east-west faults in our area. A fault with left-lateral horizontal displacement is one in which, if you are looking along the fault line, the left side is moving toward you. The Santa Ynez fault, to our north, over the mountains along the Santa Ynez River, and the Santa Cruz Island fault, to our south, which divides the island (looking like a knife cut through butter), have left-lateral horizontal displacement that may have facilitated clockwise rotation. Rotation of the Santa Barbara area continues today. A few million years ago, the San Andreas fault to our north cranked up, and the so-called “Big Bend” of the fault formed. The bend is most apparent north of Ventura, where the trend of the fault changes from roughly east–west to more northwest.

Santa Barbara and The San Andreas Fault

The San Andreas fault, about 40 miles to the north of Santa Barbara, has right-lateral horizontal displacement and last produced a great earthquake in 1872. Right-lateral displacement during the earthquake was about 30 feet, deforming a round horse corral into an “S” shape. Total displacement across the fault is about 130 miles. That is, rocks that were once side-by-side are now far apart. Two Santa Barbara geologists, Professor John Crowell (UCSB - and a member of the National Academy of Sciences) and Tom Dibblee (a famous local geologist and member of the well-known Santa Barbara de la Guerra family who worked at UCSB after retiring from the U S geological Survey) worked out this incredible fact. At the present rate of displacement, Santa Barbara, which is on the Pacific plate, and San Francisco, which is on the opposite side of the fault, will be side by side in about 20 million years. That is, Santa Barbara will be a suburb of San Francisco.

The Big Bend of the San Andreas fault (Fig. 1.4) causes shortening to occur across the mountains behind Ventura and Santa Barbara, which are known as the Western Transverse Ranges. As the land is moved through the bend, it is compressed. The amount of the shortening is not great, about a quarter of an inch a year, or two feet per one hundred years. However, this is more than enough, over thousands to hundreds of thousands of years, to produce a lot of uplift and folding of the rocks and to build mountains.

So what we’re saying is that, in the last few million years, the great spreading that produced the volcanic rocks and basins changed to one of shortening, where rocks were moving together; it’s sort of like pushing on a tablecloth on your breakfast table. A series of elongated folds, known as anticlines, formed, and, in between, we find basins, or

synclines. We have named this system of folds in the Santa Barbara area the Santa Barbara Fold Belt. The two biggest folds on land are the Santa Ynez Mountains to the north and the Channel Islands to the south. The fold belt extends all the way from the Santa Ynez Mountains, out across the Santa Barbara Channel, where there are also numerous folds on the floor of the sea, and to Santa Cruz Island.

Isla Calafia: An Ice Age Island in the Santa Barbara Channel

About halfway across the channel from Santa Barbara Harbor to Santa Cruz Island is what fishermen call the 12 mile reef and what geologists call the mid-channel high. Water depths today at the

location are about 300 feet. Approximately 20,000 years ago, or during what is called the Last Glacial Maximum (LGM), about 30% of the land area was covered by glacial ice. The Laurentide Ice Sheet covered much of Canada, extending well south of Chicago, and sea levels dropped as much as 430 feet below what they are today (Fig.1.5) The low sea levels resulted because, during the LGM, some of the water of the oceans evaporated and fell as snow to become glacial ice on land. A part of the mid-channel high, which is along a submerged topographic ridge (Fig.1.6), was exposed above sea level. Geologically, the ridge is a fold, known as an anticline, and is shaped like a giant banana cut in half lengthwise and placed on the ocean floor,



Fig 1.4. Plate tectonics setting for Santa Barbara. The Big Bend near “35”. Courtesy of Tanya Atwater(2000)

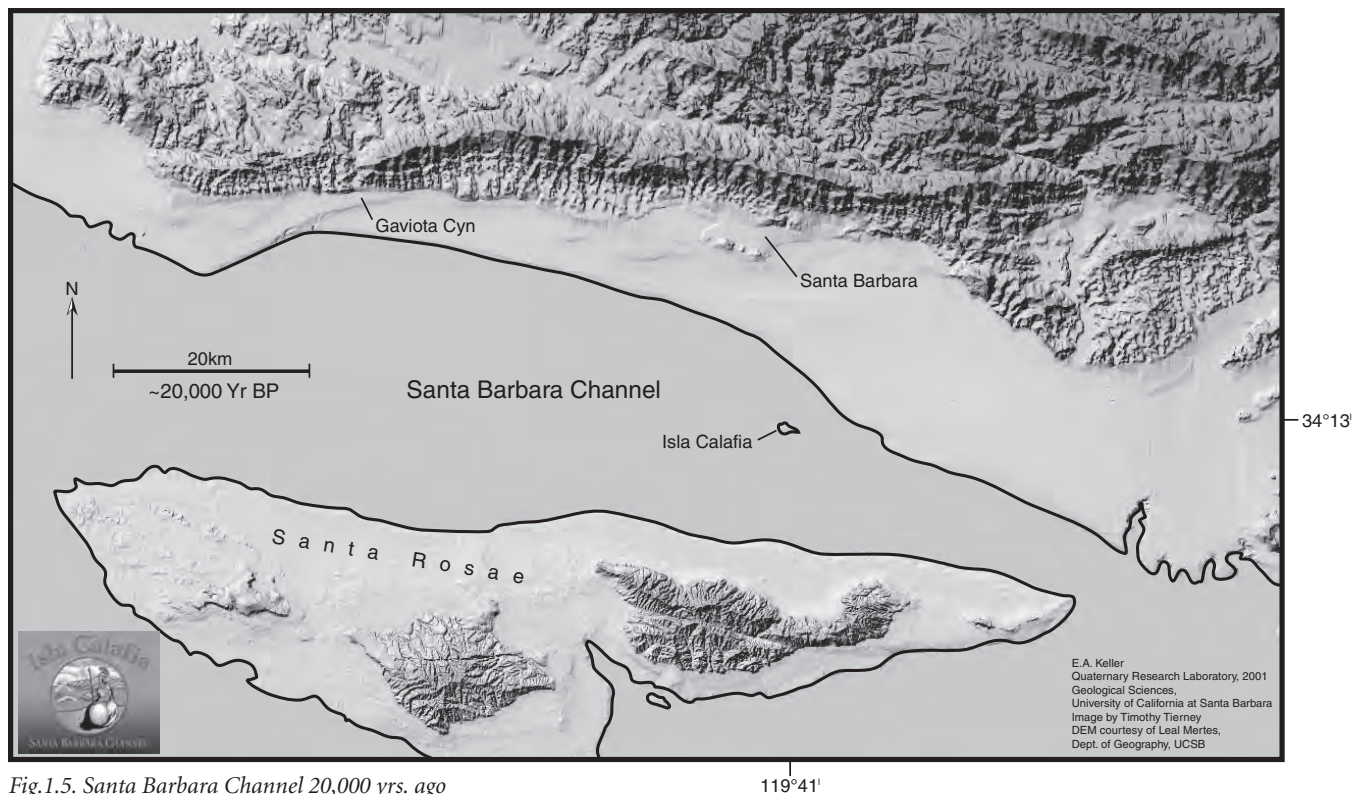


Fig.1.5. Santa Barbara Channel 20,000 yrs. ago

flat side down. The land that was exposed near the top of the anticline above the sea surface formed a small island I named, at the suggestion of Professor Art Sylvester at UCSB, Isla Calafia. It was about the size of Anacapa Island today. Calafia was the name given to a mythical female warrior queen who ruled a kingdom that the Spanish explorers and sailors speculated about hundreds of years ago. The legend of Queen Calafia most likely started with a book (*The Adventures of Esplandian*) written in the 16th Century by the Spanish author Garci Rodriquez de Montalvo. The sailors probably drank a lot of wine (those were the days before rum) in dreaming up, reading about, and elaborating the story that became an early California legend. Queen Calafia is sometimes associated with the name “California” and, thus, may be part of the origin of the name of the state.

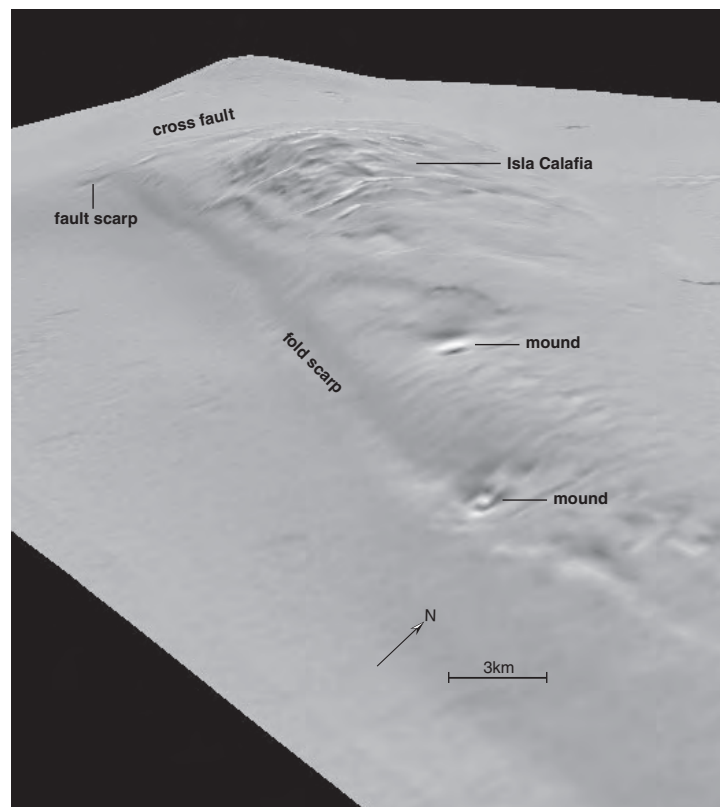


Fig.1.6. Shaded relief view of Isla Calafia in the Santa Barbara Channel

Some of the interesting aspects of Isla Calafia include the fact that it was formed by vertical movement and folding along large earthquake faults that could conceivably produce earthquakes of magnitude 7 to 7.5. The formation of the ridge (anticline), which is part of the Santa Barbara Fold Belt, is due, in part, to the Oak Ridge fault in the Channel. The crest, or highest point, on Calafia has several features that could be small stream channels. The rough topography looks like what might be expected from erosion by running water on land.

Erosion processes have not been limited to running water and wave erosion on Isla Calafia. There are also a number of pits and mounds that are often several tens of feet to several hundreds of feet in diameter and exceed tens of feet in relief. These features are thought to result from emissions of tar and methane gas. As the fold formed, due to shortening of the Santa Barbara Basin, high fluid pressure evidently developed within the structure. As a result of this, fluids and gas were expelled. If this was done rapidly, pits may have

developed. The large mounds are more difficult to explain but, apparently, resulted from tar seals over places where emission of tar slowly occurred (Fig.1.7). If tar was slowly emitted, then a slowly growing hill would have developed. If it burst or collapsed, then a pit would have resulted. Some of the largest pits and mounds are of similar size, consistent with the possibility of mound formation preceding failure of a tar mound. In the summer of 2007, Professor David Valentine at UCSB dove in a small submarine to the largest mound, about three times the size of the New Orleans Superdome, and confirmed that it is a tar mound.

Just to the west of Isla Calafia, and about five miles or so off the shore of Goleta, is a landslide that, judging from its topography, must be young (Fig.1.8). The total area of the slide is several tens of square miles, and it is a prominent feature on the sea floor. Large submarine slides are interesting, and their movement and instability are probably a result of rapid deposition of sediment and shaking by earthquakes. If a large landslide were to

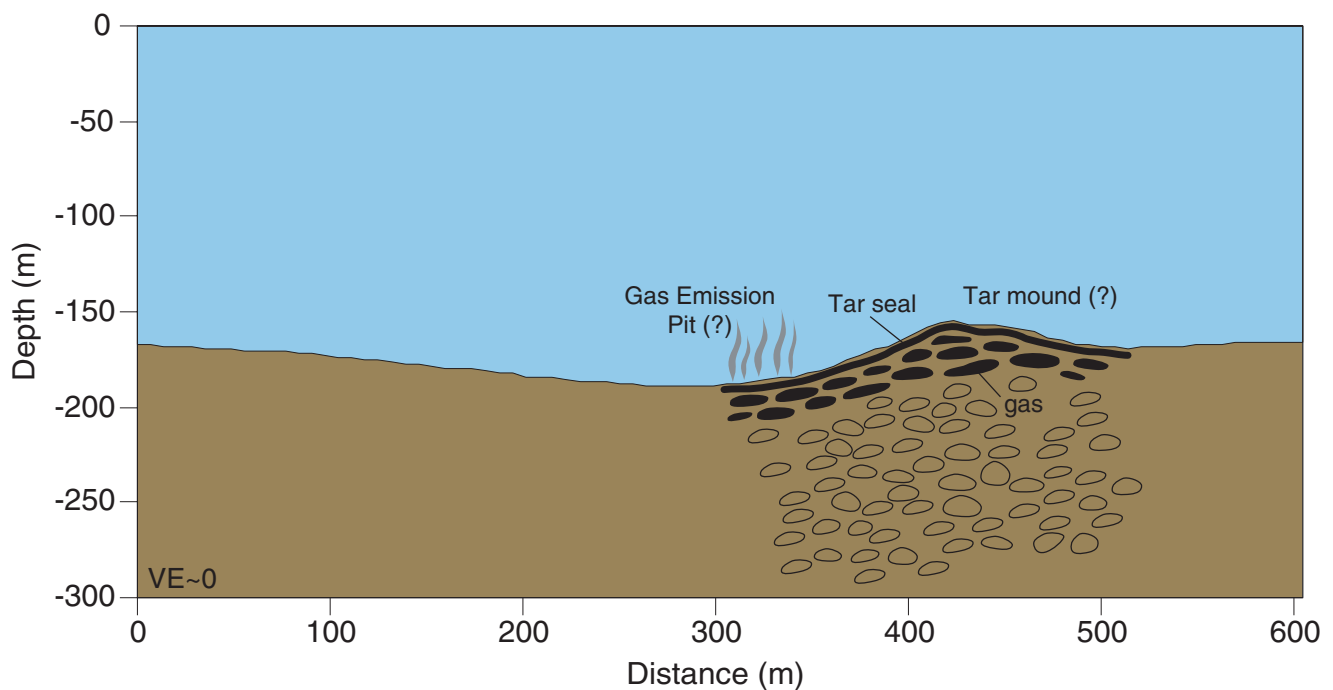


Fig.1.7. Tar mound at Isla Calafia in Santa Barbara Channel

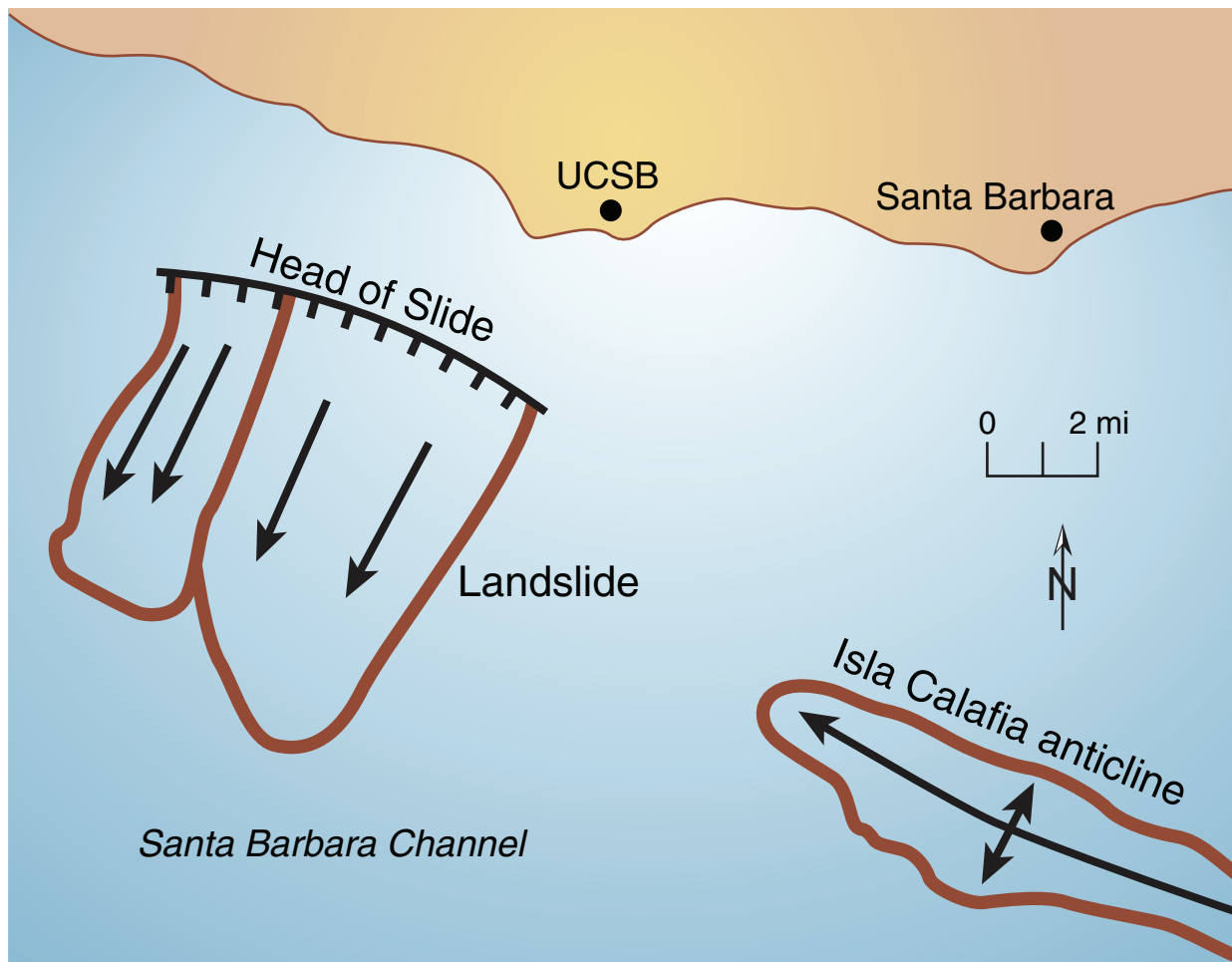


Fig. 1.8. The large landslide is about 75 square miles in area and is just offshore of UCSB. Also shown is the Isla Calafia anticline. There is a large fault under the anticline and a large earthquake on that fault could have caused the landslide. Data from Monterey Bay Aquarium Research Institute.

move quickly, then a tsunami, or sea wave, might be produced. Such a wave may have occurred with the earthquake in December of 1812, but there is much controversy about both the size of the wave and where it was observed. If it did happen, it was probably fairly small, and it didn't cause substantial damage to the coastline of the Santa Barbara area.

One Big Channel Island: Santa Rosae, 20,000 Years Ago

Santa Cruz Island is the furthest southern point of the Santa Barbara Fold Belt (the series of east to west folds, such as Mission Ridge and the Mesa). About 20 thousands years ago, Santa Cruz Island was combined with the other neighboring

islands of Anacapa, San Miguel, and Santa Rosa to form one large island that is called Santa Rosae (also called Santarosae, but I prefer Santa Rosae). The Channel Islands were never part of the mainland, as the water was too deep. However, 20,000 years ago, when the sea level was hundreds of feet lower than today, it wasn't as far out to the island and was even a shorter distance from Ventura. At Santa Barbara, the distance across the channel was greatly reduced, and the small island (Isla Calafia) was located about halfway across the channel.

The Channel Islands, prior to about 12,900 years ago, had a species of elephant that we call mammoths. On the islands, they evolved to become miniature versions, known as pygmy mam-



Fig. 1.9. Island Fox, courtesy of Eric Zimmerman (2000)

moths. This is not uncommon on islands, which may have a limited food supply, and, if you visit the Santa Barbara Museum of Natural History, you can see the bones of one of these specimens collected by one of my former graduate students, Tom Rockwell, now a professor at San Diego State University, which is the most complete pygmy mammoth skeleton ever found in the world. So, how did the elephants get out there to begin with? It seems likely that they simply waded into the water, smelled plants they like to eat on the islands, and swam across. Other animals also got there, such as the island fox (Fig. 1.9), and the fox also became miniaturized. Today, the island fox is an endangered species, resulting for the most part from the legacy of the use of DDT, which wiped out the bald eagles, which ate fish, on the island. The pesticide caused their eggs to thin, and bald eagle chicks died before hatching as eggs collapsed. Loss of the bald eagles led to golden eagles invading the territory, and it turns out that golden eagles like to eat young pigs (an introduced species) on the island. They also eat fox! When we visited Santa Cruz Island in the 1980s, there were lots of fox. They seemed tame; one, named Josephine, visited the UCSB research station nearly every day, some-

times jumping on our lap as she moved through the area. The island fox had no natural enemy before the arrival of the golden eagles and lived several years longer than fox on the mainland. They lived long enough that older fox sometimes had cataracts and were nearly blind. They would slowly stumble around on the beach looking for food, stopping to sniff our boots or steal an unguarded lunch. It seems a no-brainer that, to bring back the fox, we need to somehow remove the golden eagles and re-establish the bald eagles. That has proved more difficult than we first thought. The food for the golden eagles also includes young pigs, which were abundant on the islands, and eagles are very territorial – and, so, exchanging one species of eagles for another has turned out to be tricky, at best. Nevertheless, most golden eagles have been removed, the pigs have been removed, and bald eagles have been reintroduced. Fox raised in captivity have been released, and, in 2006, the first bald eagle chick successfully hatched. Recovery of island fox may be on its way.

People also like the Channel Islands, and there were many Chumash villages on them. The people weren't there long enough, nor were they isolated enough, to undergo changes similar to those of the fox and the elephant, but there is abundant evidence that they interacted with the island fox, probably keeping them as pets. There has been speculation that early people may have occasionally held barbecues that may have helped lead to the demise of the pygmy mammoths; however, that is not well founded. More likely, they became extinct due to changes or events that wiped out the mammoths on the mainland. A recent hypothesis (based on abundant data, albeit controversial to some), championed, in part, by Professor Jim Kennett at UCSB, his son Douglas, who is an anthropology professor at the University of Oregon, and 24 other scientists, is that a large comet exploded

over the Laurentide Ice Sheet, near what today is Chicago, 12,900 years ago. The explosion, fireball, and huge amount of soot and dust affected much of North America, perhaps causing or hastening the extinction of large mammals, such as horses, camels, and mammoths, across North America. If we were present, the fireball might have overwhelmed us. The impact may also have ended the Clovis Culture of the Southwestern USA.

Santa Barbara Landscape: It's All about Folds

On land, folds forming linear hills or ridges have familiar names such as The Mesa, The American Riviera (Mission Ridge), More Mesa, and Ellwood Mesa, among others. These folds (called anticlines) are not static features, but, in fact, are growing, due to earthquake faults imbedded within them that present a potential hazard to us. The areas between the linear ridges are relatively flat lands, but, below the flat land, there are folds we call synclines, which form basins rather than ridges. The city of Santa Barbara is located on one of these synclines, as is the Goleta Valley and the Carpinteria Valley.

Santa Barbara Point: A View of Three Anticlines

The eastern end of Shoreline Park, provided it's a clear day, is a great place to view Santa Barbara Harbor, Stearns Wharf, and eastward, sometimes all the way to Rincon Point and even the Santa Monica Mountains (Fig.1.10). As you look down toward the City from the stadium at Santa Barbara City College, which is the last bit of folding of the Mesa, you view the lowlands of Santa Barbara, which is a

synclinal basin. An anticline is a fold shaped like an upside down spoon - a hill, like the Mesa. Sometimes, they look like a banana which is split in half the long way, with flat side down, as, for example, Mission Ridge. Turn the spoon right side up, and you have a syncline or basin. Folds in the Santa Barbara area form because the land is shortening north to south about one-fourth of an inch per year or 250 inches (20 feet) per 1000 years. Over a relatively short geologic time of, say, 125,000 years nearly one-half mile of shortening occurs, sufficient to form anticlinal hills, such as the Mesa or Mission Ridge.

East of Stearns Wharf at the Zoo and Cemetery the land gets higher again. It is higher because it is an anticline (actually two adjacent anticlines that are part of the same general structure). Our Zoo Anticline provides the interesting topography that houses the animals. Between the Zoo and Cemetery, there is a gap through which water from the Andree Clark Bird refuge drains to the ocean at East Beach. Such a gap with a stream in it is called a "water gap." Sycamore Creek, where it flows through the Riviera, is another water gap.



Fig.1.10. Overview from Shoreline Park to the east (2000)

The bird refuge probably occupies a small synclinal basin. Then, further east, you go down again to another synclinal basin where the Biltmore Hotel is sited, then up to Ortega Hill (an anticline). Thus, from Santa Barbara Point, you can see three anticlines in the Santa Barbara area: the Mesa, Santa Barbara Zoo-Cemetery, and Ortega Hill. Along the Santa Barbara coast, if you're on a sea cliff, then you're on the flank of an anticline. If you're in a low-lying area, you are in a synclinal basin. It's as easy as 1-2-3 to see these folds from Santa Barbara City College or Santa Barbara Point, at the east end of Shoreline Park.

Santa Barbara Beaches: Golden Eggs That Keep on Giving

The beaches of Santa Barbara are a magnet to visitors and locals alike. We head to the beach when it is hot for a swim. Some of us ride the waves by body surfing or by using a surfboard, buggy board, or kayak. We like to play games, such as volleyball, relax, sunbathe, dig holes in the sand, bird watch, beachcomb, jog, or walk. Lots of us go to the beach to see the sunset to end the day, and, if lucky, see the green flash as the sun disappears over the horizon. We visit the beach at night to view the grunion run or to experience romantic moonlight moving across the water on to beach sand. When we do these activities, we commune with nature and reaffirm our need for nature in our lives.

Santa Barbara has several types of beaches: 1) small, narrow, secluded pocket beaches at the base of a sea cliff, as, for examples, below Shoreline Park and Isla Vista; 2) longer, narrow, straight beaches below a sea cliffs, as, for example, west of Arroyo Burro Beach; 3) beaches on a sand spit in front of a salt marsh (el estero) or slough, as, for example, Goleta Beach and much of East Beach that is part of a sand spit from Sterns Wharf east to

near the volleyball courts in front of the now filled Santa Barbara El Estero of Mission Creek ; and 4) wide, long sand beaches, usually located seaward of low land without a prominent sea cliff – examples are Ledbetter Beach and Carpinteria Beach. From the air, we view our coastline as a continuous ribbon of sand (sometimes wide and sometimes narrow) that we call beaches, and the sand is constantly moving and changing. In general, the sand on the beaches comes from streams draining the south flank of the Santa Ynez Mountains, including, from west to east, Gaviota Creek, Refugio Creek, San Jose Creek, Mission Creek, Rincon Creek, and Carpinteria Creek. Some unknown amount of sand also comes around Point Conception from the Santa Ynez and the Santa Maria Rivers. The sand moves, most of the year, to the east along our coast because the offshore waves are usually moving down the channel (Fig.1.11). The waves arrive at the beach at a small angle to the shore (forming a “V,” open to the east) and a component of wave power transports the sand along the beach. Waves striking the shore at an angle produce a longshore current (sometimes called a river of sand) in the surf zone (where the waves peak up and break). The transport process is called longshore drift. Sand on the beach face in the swash zone (where waves rush up and back) moves in the same general direction as the longshore current, but in a zigzag pattern up and down the beach face. This process is called beach drift. Most sediment is transported by longshore drift. Occasionally, when storm waves arrive from the south, the process is reversed, and sand is transported west along our coast. When you play in the surf, you are slowly moved in the direction of the longshore current. If you leave your towel on the beach and swim for a few minutes, you will find yourself surprisingly far down the beach from your towel, having been carried by the longshore

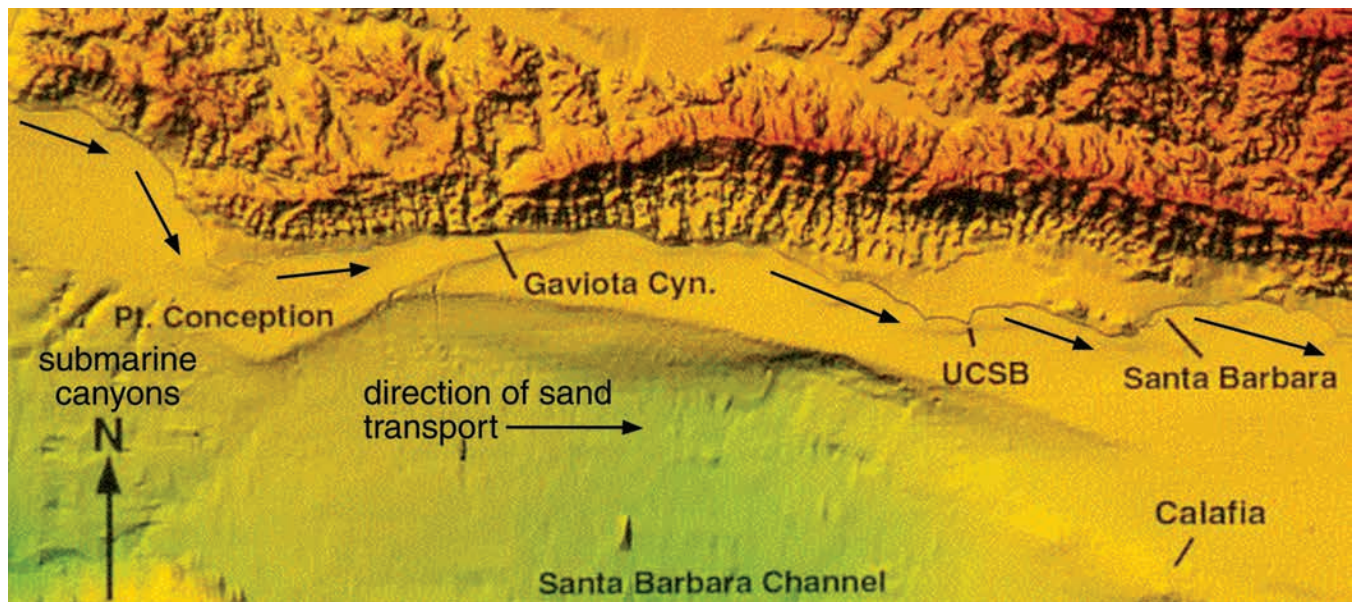


Fig.1.11. Sand transport along the coast by wave action. Data from USGS and image from Leil Mertes and Tim Tierney.

current. The amount of sand being transported east along our shore is large, about two to three hundred thousand cubic yards per year (most is transported during storms with large waves). Considering that a large dump truck holds about ten cubic yards, we have many thousands of dump truckloads of sand moving along our beaches every year. The entire cycle of sand produced by erosion of rock in the mountains, transport to the beach by streams, movement along the beach by longshore currents, and deposition in the deep ocean offshore is known as a littoral cell. The Santa Barbara cell (Fig.1.12) starts north of Point Conception and extends east to just beyond the delta of the Santa Clara River (Oxnard Plain). There, longshore sand transport ends at the head of the Hueneme Submarine Canyon, and the beach suddenly ends. The canyon heads in the surf zone, and the sand is transported down the canyon by gravity flows to deep water. With our discussion of natural beach processes behind us, let's talk about the enjoyable human activity of beachcombing.

Have you ever been beachcombing at a low tide? Most of us have, at one time or another, enjoyed exploring the beach and tide pools, picking up shells, small rocks polished by moving sand and waves, and interesting pieces of driftwood. After winter storms, many beautiful shells are washed up on our beaches, and each low tide offers a new opportunity.

All sorts of interesting things (natural and human made) end up on the beach after a storm. Sometimes, we see long pieces of kelp, with a rock attached to one end. That rock is called a holdfast. Kelp attaches to the rock on the seabed with the root-like holdfast. Storm waves may knock the holdfast loose, and the kelp and bit of rock is then transported and deposited on the beach. This is one way rock is moved from the sea to the land. Another interesting find on our beaches is beach glass (also called sea glass). It is a resource produced by our littering that is valuable to collectors and jewelry makers around the world. Beach glass originates from bottles or glass containers, or from household items, such as a broken candy dish. Most

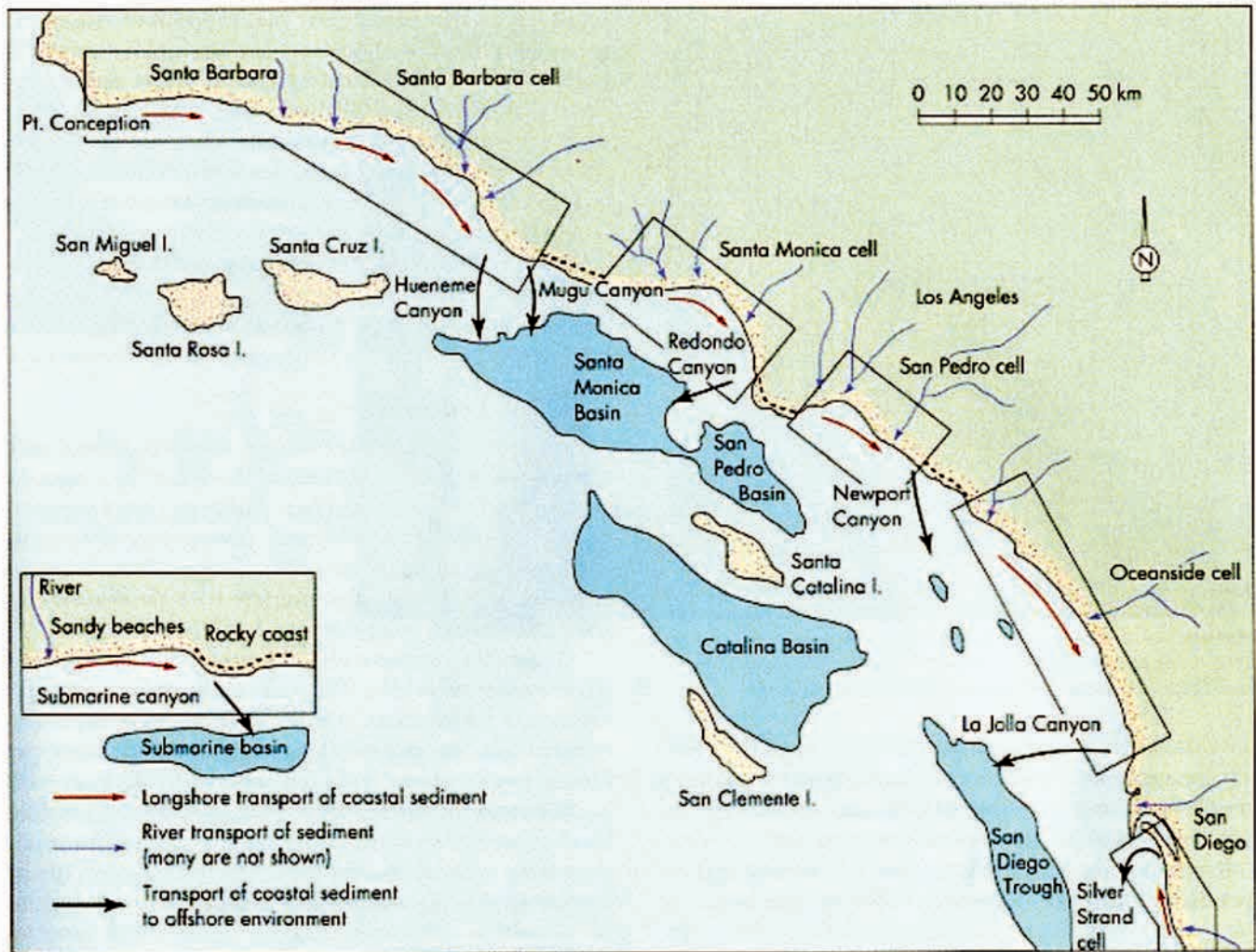


Fig.1.12. Littoral cells for Southern California. From D. L. Inman, 1976. Some sand may move around Pt. Conception in the Santa Barbara cell.

is discarded deliberately as litter, but some washes out from old dumps (such as near the west end of Goleta Beach, where I found parts of coke bottles almost 100 years old eroding out below the parking lot after a storm. Some also originates from shipwrecks or is delivered from rivers in flood that transports glass with sand to the beach. Beach glass is considered by some to be a semi precious material. We know that, because counterfeit beach glass is turning up and being sold. Beach glass is becoming harder to find (particularly larger pieces), since plastic containers have replaced many containers

formerly made of glass. Common colors of sea glass are white and amber, with less frequent green and rare blue or red. It may start as litter, but, after being tumbled in the waves for a few years, it is transformed into an attractive material. After a few years in the beach environment, the surface of glass becomes rounded, pitted and takes on a frosty, crystalline appearance. Walk the beach at low tide and find some! Try your luck at the more rocky beaches below a sea cliff, especially after a winter storm. Perhaps you will find the beach I call green glass beach.

Our East–West Coastline: Faults and Lagoons, Salt Marshes, and Sloughs

Drive up and down U.S. 101—by up and down, we mean up to the west and down to the east, not in the north to south orientation. Our coast and mountains are east-west trending. This is somewhat of an anomaly in California and, in fact, in the western United States. Were it not for the clockwise rotation of the region, discussed earlier, we would not have an east-west coastline. The structures that define the Santa Barbara landscape, such as the folds (linear ridges) and the sea cliffs, are also arranged roughly east to west.

Driving from Carpinteria west towards Goleta, you cross the Carpinteria Slough, the mouth of Mission Creek (Fig. 1.13), and, eventually, Goleta Slough. There are also a number of other salt marshes that are smaller, such as Devereux Lagoon and Campus Lagoon. Salt marshes, sloughs, *el esteros*, and lagoons are all variations of the same theme. They are landforms that form where a stream or river enters the ocean.

It's interesting to speculate on why we have these lagoons and sloughs. Of course, where the rivers meet the sea, there often are lagoons of various sizes. Even small creeks, such as Montecito Creek, have a small lagoon. A lagoon is separated from the ocean part of the year because the sand along the beach produces a barrier beach or sandbar in front of the mouth of the stream. A better term for a lagoon with a barrier beach is a blind estuary, but most people use lagoon, so we will use lagoon in this book. A stream with low flow in the summer has salt water from the ocean seeping through the beach, and, where a stream enters the ocean, a small pond or lagoon may form behind the barrier. If there is significant water storage, then a larger lagoon or slough may form. Along our coast, the development of sloughs, salt marsh-



Fig. 1.13. Mission Creek Lagoon, October 2007

es, and lagoons is facilitated by east–west faults that are present near the mouth of the lagoon or slough. Faults in Santa Barbara are often south-side-up (the displacement caused by faulting is up to the south). This tends to block or dam groundwater trying to move toward the ocean. As a result, in low-lying areas, water is ponded, and lagoons and sloughs are enhanced and, in some cases, formed by the folds and faults that dam the water. Examples of fault-bounded sloughs include the Carpinteria and Goleta sloughs and, to a lesser extent, Devereux slough. The ancient lagoon and salt marsh that once covered much of Santa Barbara, known as *El Estero*, was the result of the Mesa fault that blocked groundwater moving south from the mountains.

Lagoons are an important habitat for birds and fish, including the endangered southern steelhead trout. When steelhead enter a stream from the ocean to spawn, they first encounter a lagoon. After the transition to fresh water, they move upstream, assuming there are no barriers, such as concrete channels or road crossings that impede their migration to upstream spawning areas. Young fish a year or so old and reared upstream may move downstream to reside in the lagoon.

What Are Our Mesas?

Along the Santa Barbara coast, the coastline is often characterized by the presence of sea cliffs that are often several tens of feet high. The tops of these sea cliffs are relatively flat, and, so, we use the term “mesa,” which is Spanish for “table.” In the Santa Barbara Fold Belt, where we find a sea cliff and mesa, we are on the flank of an anticline (linear, arch-shaped fold). The age of the most prominent mesas in the Santa Barbara area varies from about 45,000 years to 100,000 years. The mesas are “marine terraces,” and, often, there are flights of marine terraces resembling a set of stairs in the landscape at a particular site. A flight of marine terraces includes several levels of terraces from the lowest terrace at the seacoast to higher terraces further away from the coast. Most of the marine terraces were formed during periods with a warm



Fig.1.14. Shoreline park, marine terrace, sea cliff, and wave-cut platform. Courtesy of Don Weaver (1978)

climate, called an interglacial, when sea level was relatively high. Today, we are in an interglacial; if you walk along the beaches where sea cliffs are present, you may see the modern wave-cut platform at the base of the sea cliff (Fig. 1.14), which is

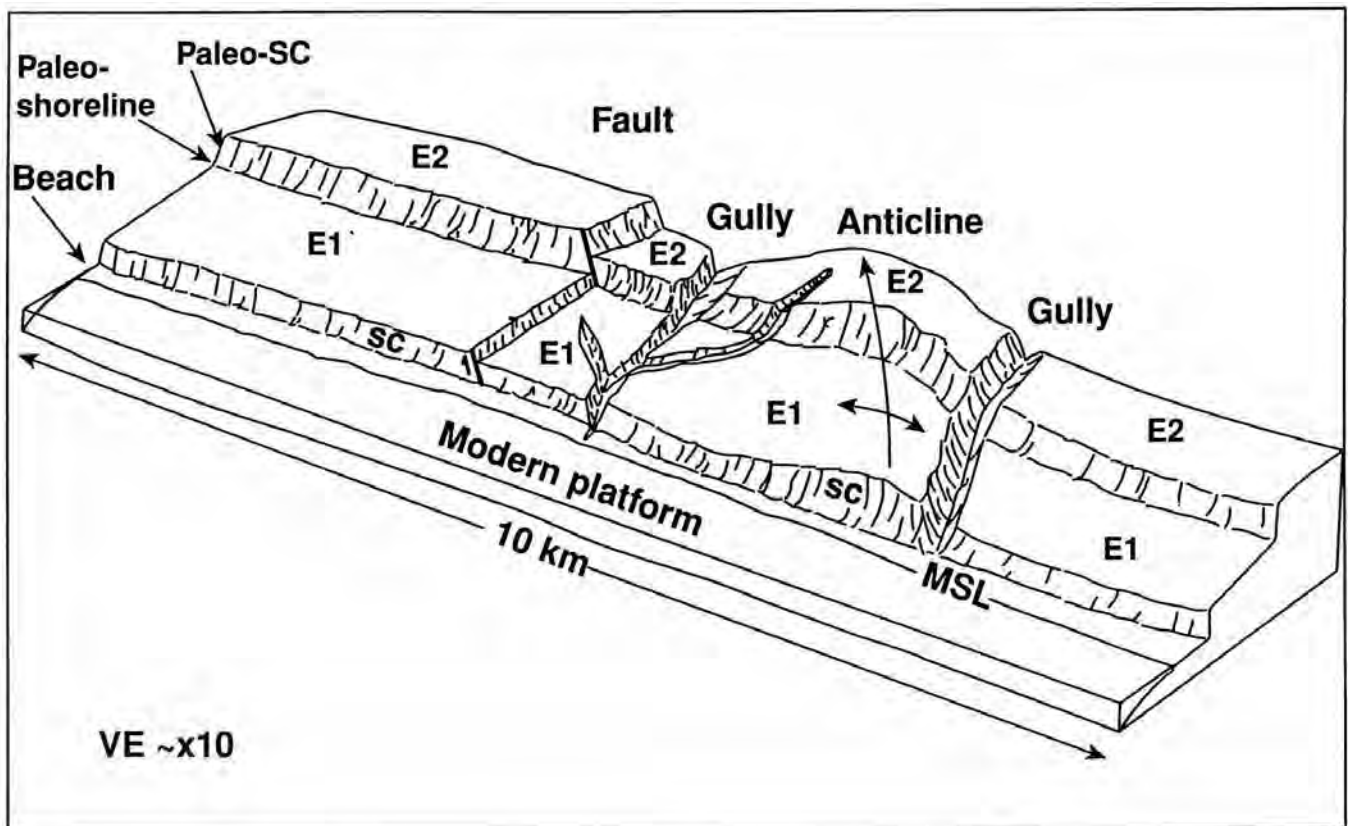


Fig.1.15. Idealized diagram of marine terraces that are folded and faulted.

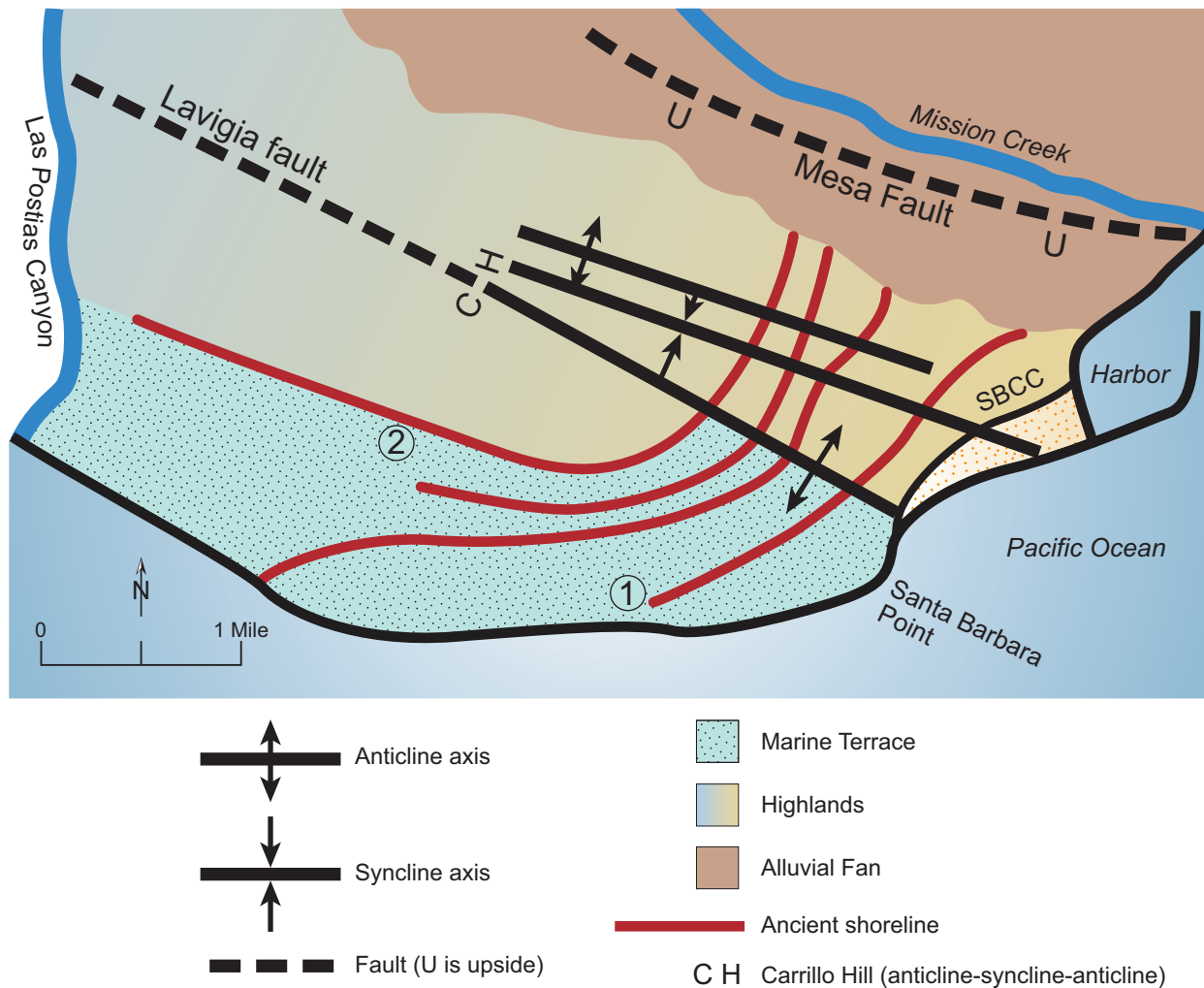


Fig.1.16. Sketch map of La Mesa (two hump hill) with ancient shorelines. The youngest shoreline (1) is 60,000–70,000 years old near Santa Barbara Point. The oldest shoreline (2) is estimated to be about 125,000 years old. Driving east along Cliff Dr. from Meigs Rd. to Castillo St. you will drop down from the older to younger shorelines (terraces).

forming today and is the first step in the formation of a marine terrace. Overlying the wave-cut platform are shells, beach sand, and gravel.

The marine terraces on the Mesa are some of the most interesting in the Santa Barbara area. If you go to the beach below Shoreline Park in the winter, when most of the sand is gone from the wave-cut platform, you can find the “shoreline angle” where the platform meets the sea cliff. The elevation of the shoreline angle is important because it is a record of the elevation of mean sea



Fig.1.17. Barranca Rd, Mesa: T= marine terrace (2007)



Fig.1.18. The Riviera (Mission Ridge), an active anticline that diverts Mission Creek to the west (2007)



Fig.1.19. View south (2007) from near the Bacara Resort to the Elwood Anticline along the Mission Ridge Fault System (More Ranch fault)

level when the platform was eroded by waves. Thus, when we observe a flight of marine terraces, we can map the base of each old sea cliff (the shoreline angle) as a line on the map (Fig. 1.15). The set of lines is analogous to a graph of sea level. The Mesa is nearly surrounded by flights of terraces, and their ancient shorelines appear like bathtub rings on the landscape (Figs. 1.16 and 1.17).

In summary, the general mode of formation of our marine terraces starts with the cutting of a wave-cut platform that is subsequently uplifted by earthquake activity or abandoned by a drop in sea level, due to climate change. The major platforms are cut during interglacial times, and, so, the large platforms and marine terraces in the Santa Barbara area generally date to those periods. A prominent interglacial occurred about 125,000 years ago, when the sea level was a few feet higher than today.

Recapping Geologic Highlights

Rocks of the Santa Ynez Mountains come from near San Diego and Mexico. They were moved to the Santa Barbara area as a result of translation, rifting, spreading, and volcanic activity that formed numerous basins in Southern California. In the last

few million years, spreading changed to shortening, caused by the “Big Bend” of the San Andreas fault to the north, producing the Santa Barbara Fold Belt. The folds are east-to-west linear hills (anticlines), and between them are low-lying areas (synclines) where the city of Santa Barbara, the Goleta Slough, and the Carpinteria Slough are located. Everywhere there is a sea cliff you will find an anticline. This includes Ortega Hill, the Zoo and Cemetery area, the Mesa, the American Riviera (Fig. 1.18), Hope Ranch, More Mesa, and Ellwood Mesa (Fig. 1.19). The series of folds that affects our landscape continues offshore in the subsurface of the Santa Barbara Channel and re-emerges again on the Channel Islands as a continuation of the fold belt.

The lesson we learn from our discussion of our regional natural history is that we live in a dynamic land. Were it not for the folding, faulting, uplift, and erosion (see summary of uplift in Figs. 1.20 and 1.21), the landscape we know as Santa Barbara would be flat and featureless, more like Nebraska and Kansas. The geologic hazards that we fear, including earthquakes, tsunamis, and flooding, have produced our landscape. Were it not for these natural processes, our landscape would be much different and less interesting. Geologic processes cause occasional, rare, catastrophic changes of the landscape, and we must learn to live with them and to understand them. Earthquakes are extremely hazardous, with the potential to produce catastrophes. We build our homes to withstand earthquakes of a given intensity of shaking. Moderate and even large earthquakes in Southern California kill far fewer people and seriously damage fewer buildings than in countries where not enough attention is given to engineering and construction of buildings to withstand shaking. As a result, a magnitude 6.5 earthquake in California might kill a few tens of people, but a similar event in some parts of the world could kill upwards of 100,000 people!

We Are Children of The Pleistocene

Whether it is clear to us or not we are a children of the Pleistocene Our genes gives us away Nearly invariant over more than one hundred thousand years of deep time

We remain connected to nature in many fascinating and mysterious ways

Vision connects us with our universe Children playing Star light Sunrise and set

*Natural sounds make us feel alive Music of frogs at night
Flow of stream over pebbles on streambed
Swish of water on the beach Rustle of leaves from wind
Crunch of grass from foot steep Howl of wolf
Scream of mountain lion Shriek of hawk
Rattle of snake Scratch of predator claw on rock*

*Quiet places comfort us Deep valleys Forest floor
Snow covered wild land Silence of night*

*Smells awaken our senses Wet forest soil following rain
Salty air kicked up by waves Morning mist
Fresh barriers Our loved ones We are more at ease in nature than with the horn screech of tires and jackhammer*

Fire provokes an image of contentment safety and community We dance play instruments sing and tell stories about other tribes and predators perhaps another football team around a fire as we always have

*Hike with a group during the day we spread out
At night hike and we group together with flashlights on
We feel safer when closer together*

We walk our property Marking territory with signs or acts

We seek romantic natural places such as meadows beaches or forest to be with our mate at intimate times

When we are not connected to nature we deprive ourselves and our children of our heritage and our souls suffer We are a children of the Pleistocene Embrace our heritage and our souls sing

— Ed Keller

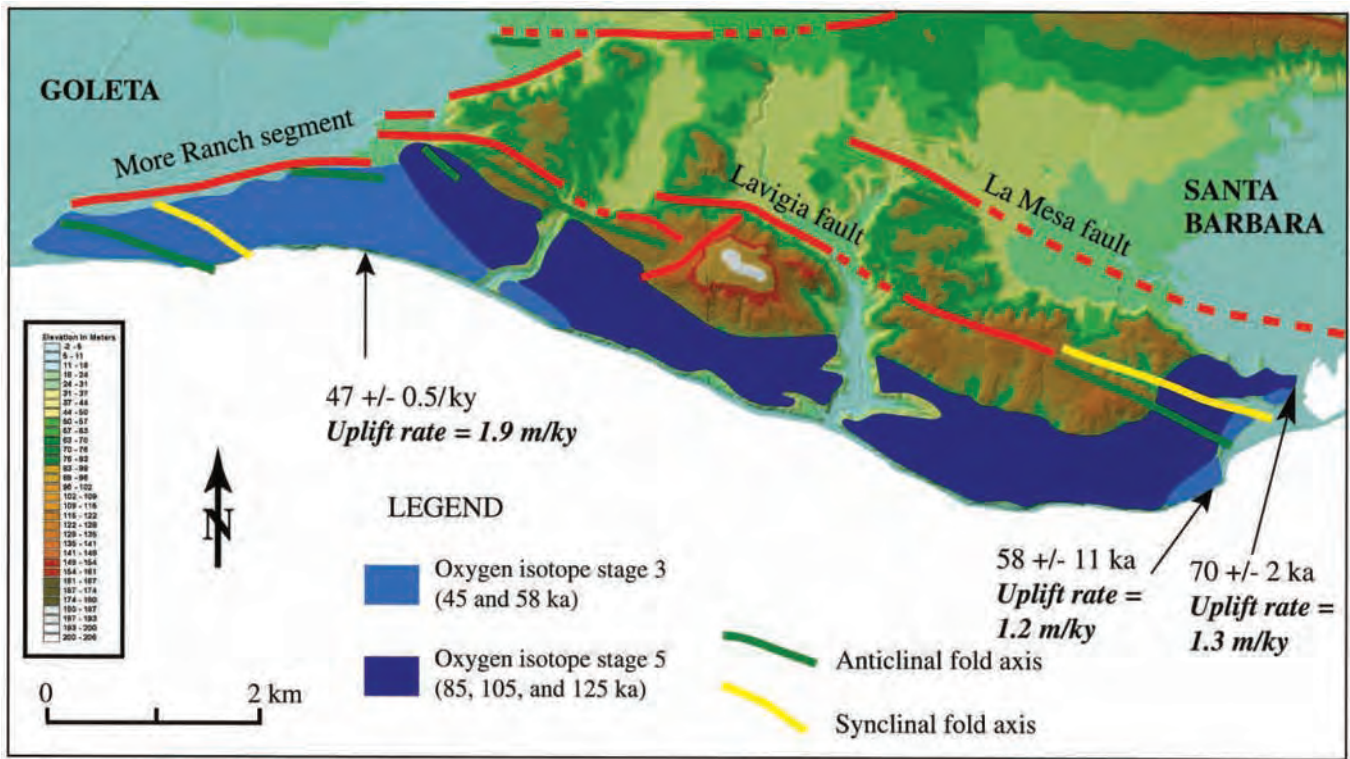


Fig.1.20. Age of marine terraces and uplift rates along the Santa Barbara Coast. From Keller and Gurrola, 2000.

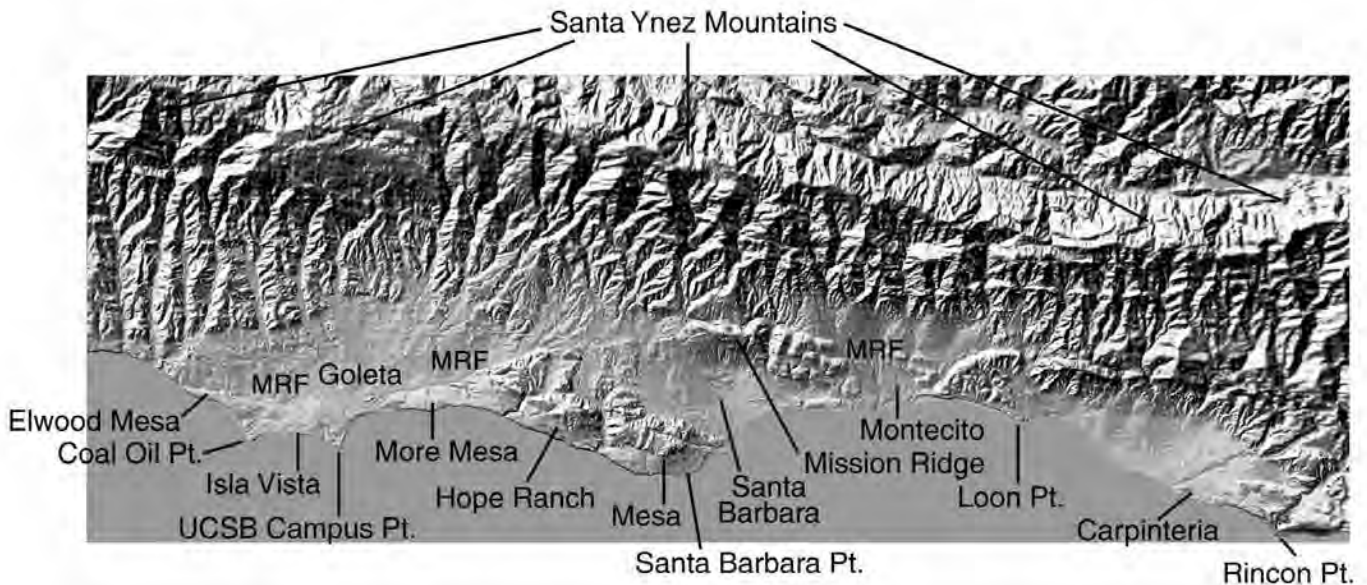


Fig.1.21. Some points of interest in the Santa Barbara landscape. MRF is the Mission Ridge fault.

natural Hazards in Paradise: Disasters to Catastrophes

Natural Processes as Hazard

Earthquakes, tsunamis, floods, landslides, and wildfire are all natural processes that are intimately related to our concept of nature and how we relate to it. We like to think of ourselves as modern people with our cell phones, iPods, and navigational systems in our cars, but we are really creatures of the Pleistocene. That is, genetically, we are not far removed from our ancestors who lived on Earth long ago in small numbers, wandering in search of food and shelter. Our roots in the Pleistocene become apparent whenever we venture outside on camping trips or hiking in the mountains. We huddle around campfires at night for light, warmth, and companionship. We endure the smoke in our eyes, and we feel safer. When conversation turns to large predators such as bears or lions, we become very attentive. We are also similarly attentive when we talk about rattlesnakes and other dangerous creatures we know are out there. If we want to really get your attention around a beach campfire, we can start telling stories about great white sharks and their encounters with surfers and swimmers. Your chances of ever even seeing a great white shark or a mountain lion in the Santa Barbara area are remote, and yet, when we go out in and beyond the urban fringe, it may be on our minds. Think about taking night hikes. When we hike during the day, we are often spread fairly far out along the path, talking, enjoying, and looking at small things, ranging from birds and small mammals to insects, flowers, and mushrooms. Take a night hike, and people naturally move closer together. The dark is

scary and unknown. Why do we feel this way? I believe it is due to our Pleistocene heritage, when we walked at night with primitive weapons to protect us from predators.

So what does our Pleistocene heritage have to do with talking about earthquakes, wildfires, and tsunamis? Our natural heritage determines, in part, how we perceive nature, and this is important in how we deal with natural processes that continue to cause loss of life and damage to property year after year. Do we try to control these processes—that is, do we draw a line in the sand and say no coastal erosion shall occur beyond this point? Do we try to pave over our rivers in hopes of controlling floods? Do we attempt to stabilize large landslides through building walls and other structures? The approach we take in our relations with natural processes and hazards depends on how we perceive nature, our role within the natural environment, and our values.

When we talk about natural hazards, we're talking about natural processes that would occur with or without people. These processes are physical, hydrological, and biological changes with specific and linked effects. In Santa Barbara, our common hazards are wildfires, earthquakes, floods, coastal erosion, and landslides, but we are also concerned about soils that expand and contract, tsunamis, and radon gas. Of particular importance to us is how these natural processes become hazards and how we choose to adjust to them. Some of the processes operating in the Santa Barbara area result from changes that are going on deep in the earth.

We try to understand earthquakes by understanding what is happening several miles below the surface, with fracturing and displacement of rock. The rocks are part of tectonic plates, which are huge (many thousands to millions of square miles) blocks of solid earth about 70 miles thick. We map these plates, and, in Santa Barbara, we live on the Pacific plate (See Fig.1.1). If we go north a few tens of miles, we cross the San Andreas fault onto the North American plate. The boundary or plate margin is a dynamic zone that is broad, including land from near Bakersfield, south into the Santa Barbara Channel. Faulting, folding, uplift, and subsidence of the land linked to earthquakes control the development of the topography, including the mountains, canyons, marine terraces, and beaches.

Another group of processes operate very near the surface of the earth. Driving these is the energy from our sun that warms Earth's atmosphere and surface. Differential warming produces winds, as well as evaporation of water. The circulation of wind and water is primarily responsible for producing Earth's climatic zones that govern processes, such as violent storms, flooding, and coastal erosion.

In Santa Barbara, we live in one of the most desirable climates on Earth. It is generally not too hot or not too cold, but just right, as in the story of Goldilocks and the Three Bears. We have two major seasons: the dry season, which is most of the year, and a generally shorter wet winter season. Our Mediterranean climate is characterized by a variety of ecosystems, including the chaparral, oak woodlands, and coastal sage, among others. These ecosystems give rise to specific processes, such as wildfire, which is a regularly occurring event in the chaparral environment.

Finally, there is a third set of processes that involve some aspects of shallow internal processes and some of the external processes. These are

mostly gravity-driven and include land sliding on hill slopes, as well as erosion of sea cliffs. The reason there is an interaction between the internal and external processes for land sliding and hill slope failures is that many of the hill slopes are the result of uplift of marine terraces and anticlines that form steep, landslide-prone terrain. Also, winter rains, which can be real deluges in some years, are associated with increased landslide and erosion processes.

The processes that we consider to be natural hazards are the result of natural forces. These forces include the internal heating of the earth that moves the giant tectonic plates that comprise the outer layer of our planet, as well as external energy from the sun. Some of these processes generate incredible amounts of energy. For example, a tsunami can move the waters offshore to depths of hundreds, if not thousands, of feet as a mass, and then move this mass onshore where it may rise up as a giant wave. Large-magnitude earthquakes, in addition to perhaps generating tsunamis, also release incredible amounts of energy, far more than anything we can make or, for most of us, even imagine.

In the final analysis, a hazardous process depends on our relation to it, and we are learning that, in many cases, we must adjust to potentially harsh and changing conditions. Today, we are worried about the burning of fossil fuels and the potential warming of our atmosphere, which will warm the oceans and, thereby, increase the strength of hurricanes and raise the sea level, increasing coastal erosion. This is a chain of events that emphasizes the "Principle of Environmental Unity" that everything affects everything, and it is not possible to do only one thing.

We know that events we consider as natural hazards are natural earth processes, but activities of people can change the intensity and perhaps the rate of occurrence of some of these processes. It is

apparent that a lot of these natural processes become hazards when people live or work near where they occur. Our primary goals are to understand natural hazardous processes and to reduce the number of lives lost and the amount of property damage sustained by natural processes. Therefore, we must be better able to identify these hazards and transfer as much information about them as possible to planners and decision makers, as well as to the general public. When we consider what to do about hazards and try to minimize effects of natural events, we often become aware of a philosophical barrier. For example, when we recognize that landslides are a natural part of how slopes are created and maintained, we need to ask ourselves if it is wiser to attempt to control the landslides, or to be sure that people and property are out of harm's way when they occur. This is not an easy question. Some landslides are so large that trying to stabilize whole mountainsides is impractical. At a smaller scale, we can build retaining walls and do things to make our slopes more stable and less prone to land sliding. Along the sea cliff we can choose to try to arrest or stop coastal erosion or choose to try to find a way to live with the marine environment. In the long run, it has become painfully obvious that trying to control Mother Nature and her processes can be very difficult, expensive, and, in many cases, impossible. However, this is not an all or nothing proposition. On a case-by-case basis, we have made important improvements in where we develop and live in an attempt to partially control or reduce impacts of processes such as flooding and erosion. On the other hand, wherever possible, we should attempt to work with the natural processes and avoid construction on floodplains where inundation by floodwaters regularly occurs or on active landslides, which are impractical to control. When you consider the sea cliff environment, funds to try to control erosion of a 100 foot high sea cliff are usually

impractical. One of my colleagues, Professor Norris, once told me that, if you want to try to control coastal erosion, you are going to suffer the consequences. He said you might just as well take all the money you were going to use and put it in a wheelbarrow and throw it over the sea cliff. In the end, his argument is essentially correct. Some features of the landscape are just not amenable to a technological fix, given the constraints of our available funds and our knowledge of the natural world. Also, is it fair for governments to protect, at great cost to all, the small percentage of people who choose to live on the edge of a sea cliff? Appropriate development, such as parks along the sea cliff, like Shoreline Park, provides another answer to the problem. No houses are directly on the sea cliff and, as a result, managed retreat from the usually slow, insidious process of sea cliff erosion is possible. In more technical jargon, what we are saying is that the best approach to reduce natural hazards is to first identify these processes, know where they exist and occur, and know their frequency of occurrence. Secondly, we should make every effort to avoid putting people and property in harm's way. This is especially true for hazards that we have little control over, such as high-magnitude flooding, earthquakes, most sea cliff erosion, and very large landslides.

In the final analysis, how we approach natural hazards and adjust to them will reflect our values and the scale of what is threatened. New Orleans is a major city that was severely damaged by Hurricane Katrina in 2005. The flood control plan that included floodwalls and levees, constructed over a period of years, failed, and the city was inundated. Decades ago, people living in the region, which is sinking due to tectonic subsidence, loss of wetlands, and withdrawal of oil and gas, decided to protect their homes in low areas with a flood protection system. Unfortunately, there were never sufficient funds to do it right, and scientists

warned that a large hurricane and storm surge could flood the city. Other than those who studied hazards, people seemed surprised that the city had flooded. In spite of the daily warnings that the storm was large and headed for New Orleans, people remained optimistic, and emergency planning was inadequate. Each day, people watched the hurricane approach on network news and the Weather Channel. Yet, when the storm and flooding arrived, we were still not prepared for the scale of the disaster, as 80% of the city was flooded. The sight of thousands of homeless, tired, hungry, and thirsty Americans driven from their homes to inadequate shelters was a tragedy we were not prepared for. Being proactive about natural hazards is the key to minimizing their impacts; this was the important lesson we should have learned from Katrina. We will know if the lesson was learned when the next big flood, tsunami, or earthquake occurs. What this means to us in Santa Barbara is that we need to remain vigilant and prepared for possible disasters. We need to be self-reliant and proactive at personal and local levels, particularly in the first hours and days following a disaster.

Service Functions of Natural Hazards

Natural events that cause loss of human life and property, such as earthquakes and floods, may provide us with important benefits. This may sound to some like an oxymoron, or, at best, ironic and subject to misinterpretation. When we refer to hazardous events as having benefits, we are referring to what are called “natural service functions” of natural processes. For example, floods and debris flows from our mountains produced the alluvial fan that the city of Santa Barbara is constructed upon. The mountains that provide the scenic backdrop for the city of Santa Barbara are the result of earthquakes and the folding of the rocks that has been going on for about a million years. At the

coast, uplift from earthquakes has produced some of our well-known landmarks, such as the Mesa and highly scenic areas that provide views of the Pacific Ocean. Sea cliffs produced by uplift from earthquakes, and their pocket beaches, provide much of the charm of the Santa Barbara coastal environment. If it were not for the uplift and folding resulting from geologic processes deep in the earth and accompanied by earthquakes, our Santa Barbara landscape would look nothing like it does today. In addition to the uplift, the steeper slopes resulting from uplift increases runoff and erosion that have produced scenic canyons such as Mission Canyon, Sycamore Canyon, the canyons above Carpinteria, and Rincon Creek Canyon, among others. The streams, with their large boulders delivered from floods and debris flows with rock exposures, produce waterfalls and deep pools for a summer swim or rock sit. When floodwaters from these canyons emerge from the mountain front, they carry all sorts of debris that is deposited on the front or piedmont areas, as well as delivering large amounts of gravel and sand to our local beaches. Without these processes, our beaches would be starved of sand and be much different.

We don't have to think very much about our landscape and what we appreciate about Santa Barbara to realize we are in a place where dramatic processes occur. If it were not for these processes, then our scenic coastline, consisting of geologically constructed points such as Devereux Point, Goleta Point, Santa Barbara Point, and Rincon Point, among others, would not provide the variety of scenery and coastal environments that motivates people to flock to the Santa Barbara area. Without the natural process of earthquakes, there would not be nearly so many offshore reefs that result from uplift and folding, nor the promontory points that produce the surf breaks that are praised by our local surfing community. Think

about our sloughs and salt marshes. These are fault-dammed and down-warped landscapes that are the result of earthquakes. Many people are attracted to wetlands for a variety of activities, including bird watching and for seeking solitude. In sum total, the tremendous variety of our landscape is related to these natural processes, some of which occasionally cause us great problems. For example, significant portions of the city of Santa Barbara were nearly destroyed in 1925 by an earthquake similar in magnitude to the one that struck Northridge a few years ago. People from the middle of the United States often ask, “How can people in California live with the earthquake hazard, knowing that a moderate or large earthquake can occur at almost any time without warning?” For the most part, people choose to live in California for a variety of reasons, including employment opportunities, wonderful climate, and scenery. Some newcomers are unaware of the extent of our natural hazards, but most people believe that the potential risks are worth the experience of living in a varied environment with an accommodating climate and beautiful scenery.

Human Population Increase: Disasters to Catastrophes

The number of people on Earth has more than tripled in the last 70 years! Furthermore, the increase is accelerating. For example, between 1830 and 1930, the world’s population doubled from about one to two billion people. Then, only 40 years later (1970), it had nearly doubled again; by the year 2000, there were over 6 billion people on Earth. In 2011, about 7.0 billion people lived on Earth (our home). These billions are about 10 percent of all people who ever lived! The explosive increase in human population in the last 100 years is sometimes known as the “population bomb.” One consequence of the explosive popula-

tion increase has been the movement of people to less desirable lands, and, in many cases, to lands where natural processes that continue to take human life are more common. At this point it might be useful to distinguish between what is a hazard or natural hazard and what constitutes a disaster or catastrophe. First, a hazard, or natural hazards, as we sometimes refer to them, is a process that poses a threat to human life and/or property. It’s important to recognize that the event itself is not a hazard, unless it threatens us. A disaster, which is commonly called a natural disaster, is an event that occurs over a limited time span and is limited to a particular geographic area. The event causes a significant loss of life and property damage. A catastrophe is a massive disaster, where there is a large loss of human life and/or property, and recovery will be a long and arduous process.

There is growing awareness that what used to be natural disasters are now becoming catastrophes. The increase in the number of catastrophes results because there are more people living in hazardous areas. By 2008, about one-half of all people on Earth were living in cities in urban regions, where impacts from hazardous events are most apparent. We have transformed the land from forest to agriculture and from rural to urban, and, along the way, we made land use decisions, such as building on floodplains, unstable slopes, or the sea cliffs, that have left us more vulnerable to hazardous processes, such as flooding, landslides, coastal erosion, and wildfire.

One of the largest catastrophes the people of this planet have ever encountered occurred in 2004, when a massive earthquake just off the Indonesian island of Sumatra produced a giant tsunami that struck around the Indian Ocean, killing close to 250,000 people. This great earthquake, with a magnitude of about 9, caused displacement of the bottom of the ocean by about 40 feet

in some places, which displaced the entire column of water above it. The displacement sent waves racing at speeds that jet planes fly at into nearby coasts and far-away locations. The damage and loss of life was so horrendous, in part, because so many people lived in low-lying coastal areas where population in the last few decades has greatly increased. Because the beaches are beautiful in Thailand and other parts of Indonesia, people flocked there for recreation, and the last thing on their mind was a tsunami.

So what do tsunamis in Indonesia and the Indian Ocean have to do with Santa Barbara? Some of the same forces that led to a tremendous increase in population in Indonesia are also occurring in California. Santa Barbara is not immune to this, and the size of the community and surrounding communities has grown significantly in recent decades. Think about the small number of people who were in Santa Barbara in 1925, when the city was nearly destroyed by a magnitude 6.8 earthquake. If that event were to re-occur today, the consequences could include significant loss of life and, perhaps, a billion dollars or more in property damage. Also, a hundred years ago, far fewer people lived up in the mountain canyons where we find the fragrant brush land that we call the chaparral. When European people first moved to the Santa Barbara area, they knew little, if anything, about the fire cycle that dictates that the chaparral environment naturally burns, on the average, every 40 to 60 years. As a result, our greatest natural hazard is probably wildfire. A whole series of hotels have burned at the site of the Montecito hot springs, and five fires in recent decades burned hundreds of homes.

The flood hazard in Santa Barbara has also increased as a result of human population pressure. More people live in the lower parts of Santa Barbara that comprise the old El Estero or salt marsh

that was abandoned thousands of years ago when Mission Creek was diverted by earthquakes and uplift to a different location. However, the old salt marsh still occasionally fills with water from the runoff from the Riviera and when Mission Creek overflows near the ocean and backfills part of the old lagoon. During floods in the 1990s, several feet of water covered a large part of lower Santa Barbara in this old lagoon system. If you go there today, you will see signs warning of the flood hazard, and yet it is in this area that we are developing condominiums and other buildings in our rush to get close to the beach. This area is also vulnerable to liquefaction from earthquake shaking, and, so, we may be setting ourselves up for more loss of property as a result of natural processes by developing this natural lowland.

The bottom line is that Santa Barbara is continuing to develop. More people are moving here, and there is pressure to build more homes. We are expanding into the mountains and into some of the low-lying areas. We recognize that some of these areas are more prone to natural hazards, and we must pay particular attention to locating and designing development in such a way as to minimize loss of property and human life. We will return to this subject near the end of the chapter, when we discuss some of the adjustments to hazards and how we should be more anticipatory in our view of these processes that can cause us so much trouble and pain.

Wildfire: Santa Barbara’s Greatest Hazard?

Wildfire in the chaparral environment above Santa Barbara is capable of destroying hundreds of homes in a matter of a few hours. Santa Barbara area wildfires, during the 45 year period from 1964 to 2009, burned over 1,000 homes! it is not impossible that a wildfire could move from the chaparral through the city, causing a true catastrophe. That was the worry from the giant Zaca Fire in the summer of 2007 that burned for two months in the mountains behind Santa Barbara, causing some evacuation orders near Painted Cave and generally causing a lot of anxiety.

Early July 2008 was a time of great anxiety for the people of the city of Goleta and adjacent mountain communities, including the Trout Club and Painted Cave near San Marcos Pass. The Gap

Fire started in the afternoon of July 1. The fire started along West Camino Cielo (west of San Marcos Pass) near the “playground” where people go to hike and climb rocks. The fire was small for the first day or so, but, with afternoon and evening sundowner winds, it grew in a few days to nearly 10,000 acres (Fig. 2.1). Hundreds of homes and thousands of people were threatened above Cathedral Oaks Blvd. Over the course of the fire, about 1,700 homes were evacuated. Over the holiday weekend, the flames consumed dense chaparral vegetation that had not burned in half a century. Flames approached very close to some homes on several occasions. Avocado orchards provided a buffer to the urban areas of Goleta. Exceptional, intense fire fighting and, probably, some luck saved the threatened homes, and catastrophic loss



Fig.2.1. The 2008 Gap Fire from St. Mary's Seminary. Photograph courtesy of Patrick Mullin



Fig. 2.2. Home along Gibraltar Road destroyed by the Tea Fire in 2008.

of property was avoided. About 2000 fire fighters were on the fire at various times, with air support from helicopters and airplanes that dropped flame-retardants. The cost of the fire fighting was about \$20 million. Direct agricultural losses included many acres of avocado trees with about \$1million of fruit. The cost of replacing the trees will be much greater.

As I wrote this at UCSB, my wife and I were evacuated from our home near Skofield Park, due to the Jesusita Fire of May 2009. Thirteen of our neighbors lost their homes. Our home survived, thanks to the oak forest and the work of the fire fighters; our thoughts and prayers went out to all in Santa Barbara, as this fire was threatening the city itself. Thirty thousand people living far inside the city lines were evacuated, and the fire was stopped by fire fighters just north of Foothill Road. The Jesusita Fire started below Cathedral Peak along or close to the Jesusita trail.

The Jesusita Fire and Tea Fire (November 13, 2008) remind us that wildfire in the wildland-urban

interface (land that is developed, but near to and surrounded by wildland) of the chaparral environment above Santa Barbara is capable of destroying hundreds of homes in a matter of a few hours (Fig. 2.2). It is not impossible that a future wildfire could move from the chaparral wild land-urban interface through the city, causing an even larger catastrophe. A hazard related to wildfire is exposure to particulate pollution from ash. Exposure to ash can cause or make worse lung function, particularly for children, older adults, and people with existing lung disease.

We have learned that the exposure occurs during burns and for weeks or months following a burn, as ash is mobilized from slopes by windstorms.

Wildfire, from a scientific perspective, may be defined as a self-sustaining, rapid, high-temperature biochemical oxidation reaction (what a mouthful). The fire itself releases heat, light, and other products, such as ash and soot (smoke). Wildfire moving across the landscape is all about wind and fuel. Of the two, the wind is the primary driver in our area. Fires usually burn uphill, but fires in the Santa Barbara area can move very fast in the direction the winds move usually northwest to southeast, but, sometimes, more southerly, throwing burning particles (firebrands pieces of burning wood driven through the air by wind) far in front of the fire and producing dangerous spot fires—fires ignited by a firebrand—outside or in front of the main fire perimeter. Sometimes, high winds create strong updrafts of flames (that can exceed 100 feet high), whirling like a tornado from hell. These can spread firebrands in all directions.

During wildfire, organic material (chaparral plants in the natural environment and many other introduced species, including fire-adapted eucalyptus from Australia in the urban fringe and more urbanized areas) are rapidly oxidized and broken down by burning. Eucalyptus trees collect a lot of leaves and twigs beneath them. The trees burn very hotly. I believe that, during the Tea Fire, a group of about 17 moderate to large eucalyptus trees on both sides of Gibraltar Road and just down slope of the Mount Calvary Monastery played a role in the loss of the monastery (Fig. 2.3). As the hot fire moved up the slope, driven by wind and fueled by the trees, the monastery had no chance. As of May 5, 2009, the eucalyptus trees were already recovering from the fire. A car left behind the monastery was partially melted, suggesting a very hot fire. In other areas in Rattlesnake Canyon near Skofield Park, some high large eucalyptus did not burn or were singed and are now recovering. Other eucalyptus trees may sprout from these fire-adapted trees. Eucalyptus trees burn very hot and can spread fire-brands. The abundant, natural aromatic oil of these trees (useful in medications for a sore throat) increases the fire hazard, and there are reports that, in hot fires, the trees may explode. As the Tea Fire approached Rattlesnake Canyon, I heard a series of explosions, some of which may have been trees (most were probably burning automobiles and, possibly, propane tanks). In summary, I believe eucalyptus trees increase the fire hazard at the wildland-urban interface and that their planting should be discouraged. I have removed eucalyptus trees on my property

and encourage native, fire adapted oak trees that I believe can help retard the advance of a fire.

The plants of the chaparral are fire-adapted, in that they have evolved to depend upon fire for reproduction. The fire triggers the release of seeds or stimulates flowering. Fire is also an important aspect of the chaparral ecosystem because, following fire colonization and replacement of species, there is a regular pattern known as secondary succession—the burning of the organic material recycles nutrients while reducing competition among species for sunlight and water. Over the long-term of hundreds of years, wildfire helps balance the carbon cycle. Therefore, a primary reason we have fire is that we have vegetation that removes carbon dioxide from the atmosphere, while producing organic matter through photosynthesis. It is important for the chaparral environment, and for Earth, for that matter, that the carbon cycle be roughly balanced. Fire is one mechanism by which this occurs. Unfortunately for us, the return period for fires in the chaparral is relatively short, being a few



Fig. 2.3 Mount Calvary Monastery was destroyed by the Tea Fire in 2008.

decades, under natural conditions. This is different from forest fires, which may have return periods of a hundred years or more.

If you look along the crest of the Santa Ynez Mountains and down to the coastal plain areas, you will see that most of the landscape consists of chaparral plants. In our area, these would naturally burn every 40 to 60 years. In recent decades, the return period of fire has become longer, due to attempts to suppress natural burns. In the long run, this will not be successful, and some fear that, as a result of fire suppression, when fires do occur, they will not only be bigger, but more intense and cause more damage.

Some of the recent fires that claimed homes in the Santa Barbara area include the Coyote Fire of 1964, the Sycamore Canyon Fire of 1977, the Painted Cave Fire of 1990, the Tea Fire of 2008, and the Jesusita Fire of 2009. With the exception of the Jesusita Fire, and Gap fire of July 2008 these started in the wildland-urban interface. That is where the most damaging fires occur because they start close to homes and may burn structures before a fire fighting response can be completely mobilized. We owe a big debt of gratitude to the brave firefighting units and other people who are risking their lives to protect our property.

Let's Remove Eucalyptus Trees from The Fire Hazard Story!

When the Tea Fire broke out, my wife and I had to evacuate the first night, as flames roared down Rattlesnake Canyon. After the fire, I observed that, in some cases, dense oak trees provided a partial barrier to the fire's advance in Rattlesnake Canyon. I noticed that the fire burned some of the oaks only half way through (Fig. 2.4), stopping with a knife edge line (a vertical line between burned and unburned tree). I spoke with a fireman who said he observed oaks releasing water vapor (he could actually see it) from heating as

the fire approached. Large oaks live several hundred years and usually survive a number of fires. Oak trees, even those that appear dead after a fire, will usually sprout quickly and recover. Of course, extremely hot, intense, and lingering fire may kill oak trees and set homes on fire, but the trees and homes around them have a better chance of surviving. Based on my observation, it is much more difficult for fire to advance through oak trees than through chaparral. The possible natural service function of oak trees to retard fire moving across the land needs to be studied in more detail.

Eucalyptus trees (imported from Australia) are also well adapted to wildfire, but, in an entirely different way from oak trees. Eucalyptus trees have loose bark that hangs down, inviting fire to move up into the canopy. Fire is important in enabling eucalyptus seedpods to open. During fire, wind and flames may disperse the pods. On hot days, a faint blue flammable gas from the rich oil the trees produce has been reported. I believe that burning eucalyptus trees can significantly increase the temperature of the fire, greatly increasing the hazard in the immediate area.

We had to evacuate on Tuesday May 5, 2009 during the Jesusita Fire, which started west of Mission Canyon. My wife called me to report the fire from her vantage point along Las Positas Road, near Earl Warren Showgrounds, as I was writing about the Tea Fire at our home near Skofield Park. She told me to load the dogs and evacuate! I did - out to the east, where the tea Fire had burned. When we built in the canyon, I based my evaluation of the fire hazard on the limited observation that the oak trees around our house were less likely to burn than the chaparral, and that the site was defensible (that is fire trucks could get in easily). Oak trees can live two hundred years or more and, therefore, survive several fires (the return period for fire is several decades).



Fig. 2.4. Rattlesnake Canyon after the Tea Fire. Notice the oak tree that only burned halfway through. The tree evidently helped slow the spread of the fire and it abruptly stopped.

We nearly lost our home on the second night of the Jesusita Fire. More than 10 homes in our canyon (some very close to ours) were not as fortunate as we were. Extreme wind and high flames can burn any structure. Fire fighters, as soon as they could safely move in, camped at our home and others in Rattlesnake Canyon, saving many. Our hearts go out to those that suffered the loss of their homes. I can only imagine the pain they experienced. Those homes surrounded by oak trees (even those I thought were particularly vulnerable from a materials perspective including lots of exposed wood) on the creek side of Rattlesnake Canyon did remarkably well. An exception was a home with several large eucalyptus trees just upslope of it, along the road (Fig. 2.5). A man who stayed to fight the fire and could see the eucalyptus trees said that as the trees burned they produced a wall of fire, and a single eucalyptus burned like a tall torch. His home is wood sided and surrounded by oaks that barely burned. He did use a hose to put

out large fist sized firebrands that landed on his property. I believe that, without the eucalyptus trees, the home that burned on the creek side might have survived, as did some of the immediate neighbors. The building site is being prepared for rebuilding, and the eucalyptus are being removed – a wise decision.

The relationship between the home that burned and the eucalyptus trees, as with the monastery, may be coincidental –but I do not think so. Fire ecology of eucalyptus trees is well known and documented. A government report from Austratlia

states that eucalyptus trees are known to be highly flammable and should not be planted near homes. This is especially true in the wildland-urban interface where the threat of wildfire is substantial.

As more development is pushed into the chaparral environment, the potential for a catastrophe increases. People living in high fire hazard areas need to have a well-thought-out plan of what they will do, should a wildfire occur. If they are going to evacuate, where are they going to go? Evacuation itself can be dangerous if not planned carefully. This was tragically shown in a wildfire in the Oakland Hills in 1991, when some people lost their lives in automobiles while trying to evacuate burning neighborhoods. There is a lot of information concerning what to do before a fire, and much of this is concerned with planning and helping to fireproof your home. One important detail is to make sure that the roof of your house will not burn, or at least not burn easily, and that roof vents do not draw in fire. Beyond this, vegeta-



Fig. 2.5a. Home lost in Rattlesnake Canyon during the Jesusita Fire in 2009 on the creek side of Las Canoas Road. Note burned eucalyptus trees just upslope of the burned home



Fig. 2.5b. Mount Calvary Monastery burned during the Tea Fire in 2008. Note grove of burned eucalyptus trees just down slope from the monastery. These trees burned very hot as the fire moved up slope to the monastery.

tion needs to be cleared around the house to ensure there are not “ladders” of vegetation leading to the house itself. There is abundant information from local fire departments concerning what can be done to minimize your chances of suffering the loss of your home during a wildfire.

After the Flames

Wildfire may be our greatest natural hazard because it reoccurs frequently, relative to other potential catastrophic hazards, such as large earthquakes. A truly large catastrophic earthquake is likely to occur about every century or so, but large wildfires can be expected on a much more frequent basis.

The Painted Cave Fire, which is one of our recent events, raced from the mountains to the sea in just a few hours. The Painted Cave Fire, as with other wildfires, had a two-fold effect. The first was that the fire moved across the land, burning 450 homes and causing one death. Following the fire, the first rainstorms on land denuded of protective vegetation caused a significant increase in runoff and the production of large volumes of sediment. The result was a flushing of sediment that was deposited in stream channels. The sediment filled pools, damaged fish habitat, and reduced the capacity of the channels to carry water, significantly increasing the potential flood hazard. To reduce the hazard, debris basins on East and West Maria Ygnacio Creek were constructed in the foothills above Cathedral Oaks Road following the fire. The basins were designed and constructed to store 30,000 and 60,000 cubic yards of coarse sediment (enough to fill 3,000 to 6,000 large trucks), respectively. The idea was to store the sediment and keep it from being transported down stream where it could fill the channel (reducing the channel’s capacity to hold water) and increase the flood hazard. In the two years following the fire, the basins were partially filled with sed-

iment. About 40,000 cubic yards were stored, and this helped reduce the downstream flood hazard to Goleta. The sediment was eventually dredged from the basins and disposed of. In those two years, about 147,000 cubic yards of sediment washed through or went over the top of the basins and reached Goleta Slough, where it was removed by dredging. The increase in sediment due to the fire over pre-fire conditions was about 200%.

Wildfire has a potential double impact. First, the fire moves across the landscape, removing vegetation and some of our homes and other structures that are in the way of the flames. Which homes burn (independent of fire fighting) depends, in part, on local conditions of wind, topography, vegetation, design and building materials used, and fire preparedness. Second, in wet months following the fire for at least two winters, flash floods may result from increased runoff of water. Runoff increases can be very significant because there is little vegetation to hold back the overland flow from intensive rain. Soils may not be able to soak up the rain that falls on the land through infiltration because they become hydrophobic (water repellant) as a result of the fire. What happens is that waxy materials from intense burning (very hot fire) of chaparral vegetation penetrate the soil, forming waxy coatings around soil particles that form a layer an inch or so below the surface. When it rains, the water runs off along the hydrophobic layer that is parallel to the slope. I have tested this after a fire by pouring water from a water bottle on the soil and observing it runoff, as if over a sheet of inclined glass. Hydrophobic soils, after a fire, may be widespread or patchy. When present, they greatly increase runoff and the flash flood hazard. After a few storms, the vegetation begins to recover, and the soils regain their ability to take in water. Along with the increased runoff comes an increase in sediment eroded from the burned slopes. Sedi-

ment can fill stream channels with gravel, decreasing their capacity to hold water and increasing the flood hazard. Sediment may move down slopes in a landslide (such as an earth flow or slump) or in a channel as a debris flow. A debris flow (a type of landslide) is a relatively fast moving mass of rock particles and water. A landslide is classified as fast moving if you can see it moving with the naked eye. Debris flows can move at speeds of a few to about 40+ miles per hour. Particle size (sand size and larger) can be very large (up to and exceeding 10 feet in diameter). Many small debris flows (a few hundred to a few thousand cubic yards of debris) in the mountains and foothills are likely to occur in response to rainfall in the first year or so following wildfire. These can cover roads, damage homes, and even cause deaths. Catastrophic debris flows, consisting of many thousands to a few million or more cubic yards of debris following wildfire, are possible, but, fortunately, are relatively rare, compared to smaller debris flows. You can observe the deposits from a very large (10 million cubic yard) debris flow at Rocky Nook Park near the Mission. The boulders scattered around the park were deposited about 1,000 years ago by a debris flow about 15 feet thick that probably moved about 30 miles per hour. The flow carried giant boulders through what is today the Museum of Natural History west to State Street and north to Foothill Road. A repeat of that event would destroy hundreds of homes and kill many people. The City of Santa Barbara is constructed on an alluvial fan largely composed of debris flow deposits about 60,000 years old. There were many debris flows during the period of fan building. This explains why there are so many large boulders in the city, especially near the Mission. The street name "Pedregosa" means "many stones," and rock walls are everywhere. A giant debris flow from Mission Canyon or Sycamore Canyon (or any other can-

yon along the mountain front from Carpinteria to Goleta) would probably start with a large landslide in the mountains that becomes mobilized into a debris flow. The reason landslide deposits become a debris flow is that they become saturated from the stream flow (landslides often happen during the winter when stream flow is high). Saturation reduces the internal strength of the deposits, and they become a fluid. The density of the fluid is about the same as the boulders, and, so, the boulders bob up and down and move with the flow (they are part of the flow). During their journey down the canyon, internal forces of the flow cause boulders to migrate to the top, front (nose), and sides of the flow. The flow, with mud, boulders and trees all churning together, could quickly move onto the alluvial fan from a canyon mouth, causing catastrophic damage. If the landslide blocks (dams) a stream channel and canyon, we might have time to mechanically remove the blockage before a debris flow is released from the water saturated landslide deposits. Debris flows can also be mitigated by construction of debris basins to catch or hold back the flows. This has been done in the Los Angeles and the Salt Lake City areas, where significant debris flow hazards exist. A number of debris basins have been constructed in the Santa Barbara area, including one in Rattlesnake Canyon above Skofield Park. Debris basins cannot be expected to mitigate giant debris flows (hundreds of thousands to a few million cubic yards of debris), but can help control smaller ones that could cause downstream damages.

Disastrous, giant debris flows and floods in 1934 buried and killed about 100 people in the La Crescenta to Montrose area of the Los Angeles Basin. New Year's Eve of 1934 brought a flood and debris flow catastrophe that followed a wildfire. Conditions in the Los Angeles area below the San Gabriel Mountains were so terrible that Woody

Guthrie, who had a popular radio program in Los Angeles at the time, wrote a song called “Los Angeles New Year’s Flood” to remember and honor the approximately one hundred people who were killed by flood water or buried in debris flows. Many bodies were never found. A catastrophic debris flow in the near future in Santa Barbara is possible but very unlikely. The most recent large debris flow in Mission Canyon and Rattlesnake Canyon was about 1,000 years ago, and older events that partially fill the canyon bottoms are apparently several tens of thousands of years old.

One of the more interesting processes following wildfire is *dry ravel*. Between fires, chaparral vegetation holds back some sediment on slopes. Usually, the sediment consists of small, angular particles of rock, up to about one-half inch in diameter. Each plant supports a small amount of sediment upslope of the plant stems. The amount of stored sediment from thousands of plants is a large volume. When the plant burns, and before sprouting of new growth, the sediment is unsupported and begins to creep on gentle slopes and fall or visibly dribble (ravel) down steep slopes. If you sit and listen, following a fire, you can often hear the sediment raveling down to the base of the slope and into a stream channel. A rock type very susceptible to raveling in the Santa Barbara area is shale - the Cozy Dell Shale in Rattlesnake Canyon above Skofield Park (Fig. 2.6) and the older Juncal Shale near Flores Flat further up the canyon are examples. Shale will experience dry ravel even without fire, but the rate greatly increases after fire.



Fig. 2.6 Dry ravel track and deposits (white trails of debris) in Rattlesnake Canyon following the Jesusita Fire in 2009. Photograph taken in early July from Gibraltar Road.

Dry ravel deposits may collect in dry stream channels following fire (most fires occur in the dry season; some say that Santa Barbara has two seasons—the dry season and the mud season). Large accumulations of ravel deposits in stream channels may be easily mobilized during the first of even moderate storms in the winter. If there is a very large volume of ravel-derived deposits in the channel, the stream is not able to transport them all during a moderate winter flow, and they are deposited (distributed) along the channel. The deposits may fill pools, and, sometimes, the entire boulder bed channel that is usually present and defines our mountain streams. The stream channel may be transformed from a boulder bed stream with step-pools (produced by large boulders organized into steps) to what looks more like a gravel road, with most boulders buried by the deposits. Pools in local streams, including Rattlesnake Creek and Mission Creek, filled with 2 to 3 feet of sediment flushed from the land following the fires in 2008 and 2009. Rain storms in 2010-2011

produced sufficient flow to scour the pools to nearly pre-fire condition. When this happens, the habitat for steelhead trout is greatly reduced and damaged (with luck, adult steelhead may be in the ocean at the time). The deposits may be transported downstream to larger streams in subsequent moderate flows. There is a positive side to the gravel deposits. Gravel delivered by ravel and landslides to a stream channel following wildfire is an important (perhaps the most important) source of spawning gravels for fish. Without adequate gravel, fish production is limited.

We were lucky after the Gap and Tea Fires, in that large, intense rainstorms did not occur the first winter. The winters of 2010 and 2011 did cause concern for the burned areas, but flooding, debris flows, and landslides were not catastrophic. The potential effects of fire to increase the landslides and flood hazard can last several years until the vegetation has recovered. We continue to hope for the best and prepare for possible flooding, landslides, and debris flows

Earthquakes: Contrary to Some of Our Beliefs, Santa Barbara Does Have Its Faults

It is impossible to live very far from an earthquake fault in the Santa Barbara area (Fig. 2.7). Major faults are oriented roughly east-west and occur with a spacing of every few miles from the top of the Santa Ynez Mountains to the seacoast and out to Santa Cruz Island. The map shows the major faults, and maximum expected earthquakes that could be generated by these faults are listed on the Table 2.1. Earthquakes from Magnitude 5 to 7.5 can be expected, with many more being Magnitude 5 to 6 than 6.5+. Some of the biggest and potentially most dangerous faults are found in the Santa Barbara Channel.

The process of faulting produces earthquakes. Faulting occurs when rocks break along a fault

plane and release seismic energy and waves. The actual process of fault rupture, or faulting, is sometimes compared to sliding two rough boards past one another. Friction exists along the boundary between the boards and temporarily slows their motion. Eventually the rough edges break off and motion occurs in various places along the plane. We view this simplistic model as being analogous to what is happening along our major geologic boundaries, some of which are faults. As the large plates of earth material, such as the Pacific plate and the North American plate, move by each other, stresses along the boundary result. The result of the stress is deformation or strain; when the stress exceeds the strength of the rocks, rupture occurs, and this is recorded as an earthquake. In geologic terms, we say faults are seismic sources, and the first step in evaluating the risk of an earthquake is to identify the seismic sources of an area. We are most concerned about active faults; we define an active fault as one we can demonstrate has moved or ruptured in the Holocene (past 10,000 years). A potentially active fault has moved in the Pleistocene (past 2.6 million years).

We often refer to a “fault line” because that is what we see on a map. However, like our two rough boards, a fault is not a line, but a plane. A rupture of an earthquake generally begins a few (generally less than 15) miles below the surface, and the rupture can propagate from a small beginning to an ever-larger area in any direction. The size or magnitude of an earthquake is, in part, a function of the area of rupture and the amount of displacement. Sometimes an earthquake ruptures up and other times down or laterally and, often, in all three directions along a fault plane. When the rupture occurs, seismic waves are produced that travel within the rocks and along the surface. Some of the waves can travel through both solid and liquid materials, and others may only travel through

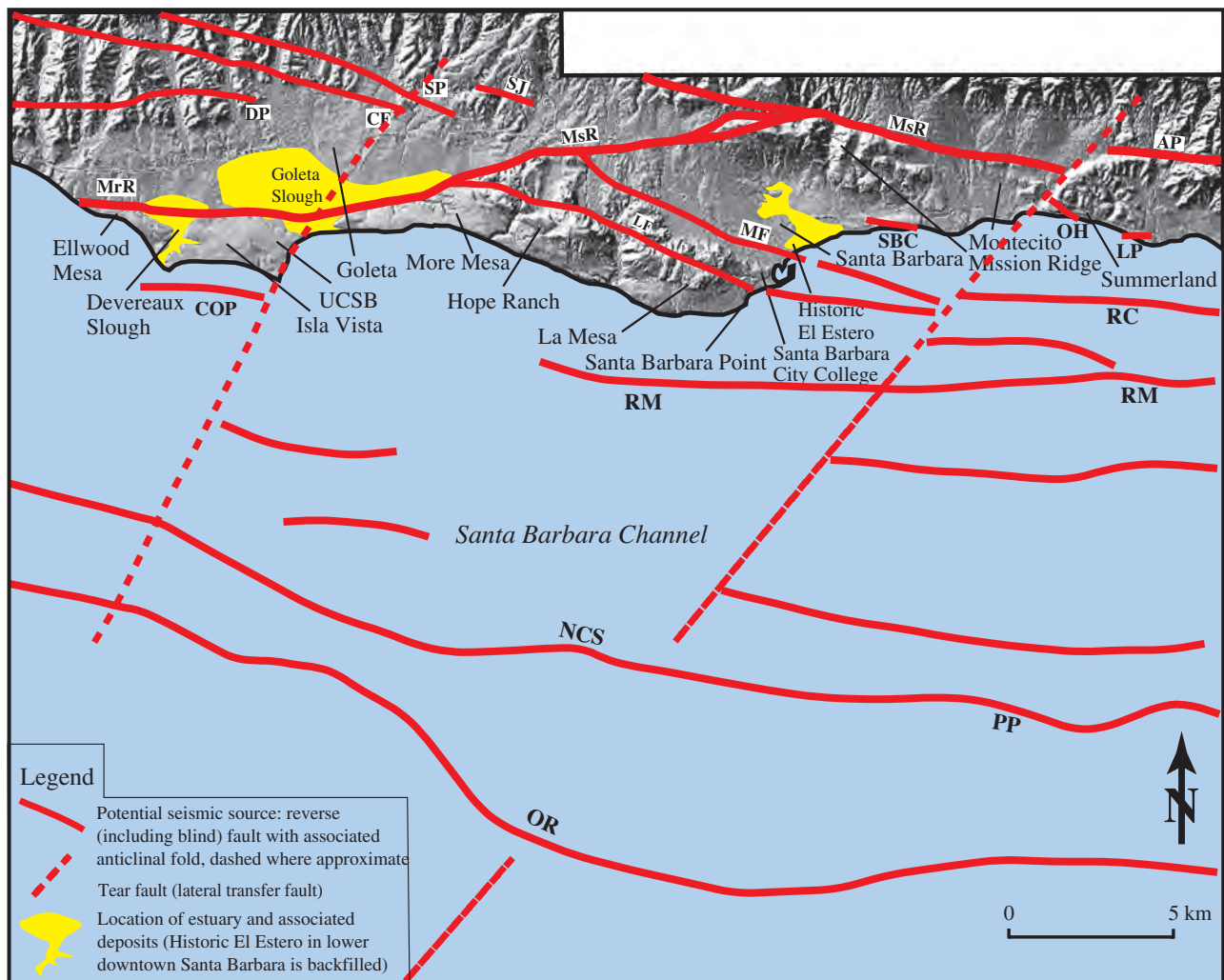


Fig. 2.7a. Seismic sources of the Santa Barbara Fold Belt showing reverse faults, some of which are blind, with anticlinal folds. Offshore sources are approximately located (Kamerling, pers. comm., 1999). The Mission Ridge Fault System is subdivided into the More Ranch (MrR), the Mission Ridge (MsR), and the Arroyo Parida (AP) segments. Additional onshore seismic sources include the Dos Pueblos (DP), the Carneros (CF), the San Jose (SJ), the San Pedro (SP), the Lavigia (LF), the Mesa (MF), the Santa Barbara Cemetery (SBC), and the Ortega Hill (OH), faults. From Keller and Gurrola, 2000.

solid rock. Earthquake waves travel very quickly, often at speeds of several miles per second. When the seismic waves reach the surface, they become more complex and can produce the rollers that people commonly describe during an earthquake. The actual motion at the surface depends, in part, on the near-surface geology and topography. If there is weak or soft sediment, such as valley fill found at places like Goleta Slough or the old lagoon in Santa Barbara, then the surface shaking will be accentuated. The intensity of shaking can

also change because of the propagation of a fault rupture in a particular direction. In Santa Barbara, many of our ruptures propagate from the east to the west, and this focuses the energy and shaking to the west. Professor Ralph Archuleta, a UCSB seismologist, recently discovered that, if propagating surface waves from an earthquake encounter a mountain, the topography reduces the intensity of shaking on the far side of the mountain. In other words, mountains buffer seismic shaking. If a large earthquake occurs on the Santa Ynez fault

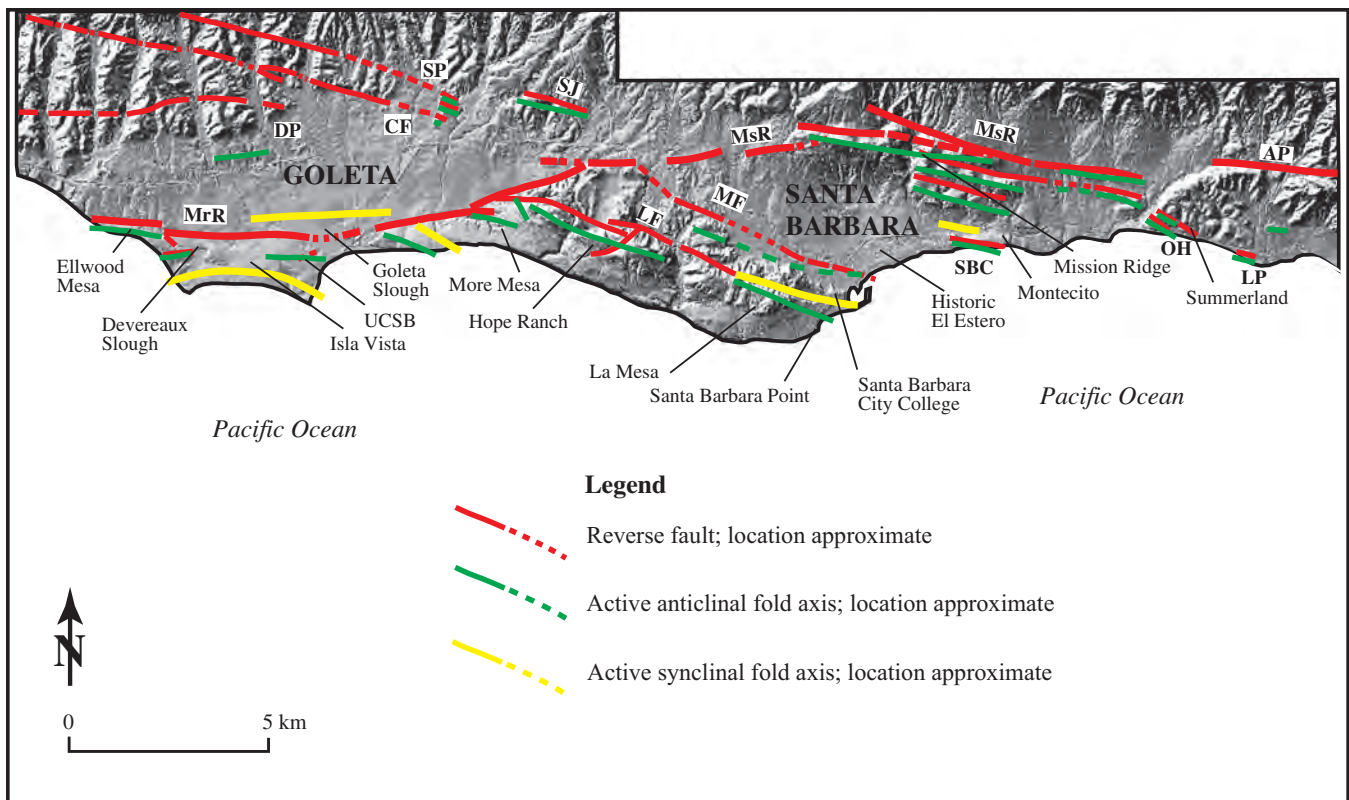


Fig. 2.7b. Seismic sources of the onshore Santa Barbara Fold Belt showing south-dipping, reverse faults, some of which are blind, with associated north-verging, hanging wall anticlines and footwall synclines. The Mission Ridge Fault System is subdivided into the More Ranch (MrR), the Mission Ridge (MsR), and the Arroyo Parida (AP) segments. Additional onshore reverse faults include the Dos Pueblos (DP), the Carneros (CF), the San Jose (SJ), the San Pedro (SP), the Lavigia (LF), the Mesa (MF), the Santa Barbara Cemetery (SBC), and the Ortega Hill (OH) faults. From Keller and Gurrola, 2000.

located to the north over the mountains, then the shaking in Santa Barbara will be less than if the mountains were not there. This is an unexpected natural service function of mountains.

You may hear an earthquake approaching. This results because some of the waves that move from the earth into the air have a frequency that our ears can pick up; that is, they are audible. The noise of an approaching earthquake often sounds like a low rumbling that gets louder and louder, and then fades away. This is partly due to the propagating waves, similar to listening to a loud motorcycle approaching with ever-louder noise which fades as it moves further away.

Before leaving the discussion of faulting in relation to Santa Barbara, we need to recognize

that many of our seismic sources are faults that do not reach the surface of the earth. These kinds of faults are termed “blind faults” or “buried faults,” and they occur within the folds of the rocks. For example, there is a fault buried below the Mesa, but we do not see it at the surface. There are also faults found beneath Mission Ridge and all along the Mission Ridge fault system, but we seldom see these faults at the surface, as they are hidden below in the fold. One place we can see the fault is where it goes offshore at Ellwood Mesa (Fig. 2.8). On Ellwood Mesa, the faulting has produced a linear hill (up to the south) which is a young anticline.

So how do we know that faults exist within folds? First, we can observe faults in smaller folds where the faults are closer to the surface. Prob-

ably the best evidence that these folds have faults in them, though, comes from other areas where seismologists have recorded fault motion within the earth that never reaches the surface. This was apparent during the 1994 Northridge earthquake, when several feet of displacement occurred at depth, while, at the surface, there was some uplift and folding, but no surface fault rupture.

When we talk about the faults and folds of the Santa Barbara area, we are talking about the discovery of the Santa Barbara Fold Belt. The belt is a series of east to west linear hills and mountains (anticlines), including the Santa Ynez Mountains above the city to the Riviera (Mission Ridge) uplift, the Mesa uplift, the Hope Ranch uplift, the More

Mesa uplift, the Ellwood Mesa uplift, and smaller uplifts such as Ortega Hill. Prior to the discovery of the fold belt, it was thought that the elongated hills in Santa Barbara were related to geologically old faulting and erosion, rather than to recent active uplift and folding.

A well-exposed and easily observed (in the field) young anticline is Ortega Hill, near Summerland. You can observe the uplift if you drive on US 101 south past Montecito and on to Summerland. As you drive, you pass over Ortega Hill just outside of Summerland, but the best way to observe the anticline is to stop at Lookout Park (in Summerland) and walk down to the beach. Go at low tide (it is dangerous at high tide) and walk west toward Santa Barbara. There is a beach house and sea wall at the site of the anticline, and the uplift has produced a small point (Fig 2.9a).

The sides of the hill are fold scarps. A scarp is a relatively steeper part of the landscape that can be produced by several processes. A sea cliff is one type of scarp, and a scarp is often located at the head of a young landslide. A fold scarp is produced by folding and a fault scarp by surface displacement during an earthquake or series of earthquakes. Fold scarps are parallel to the long axis of the anticline and are produced by folding. A given anticline may have a fold scarp on both sides of the fold. An easy place to see a fold scarp is to visit the Santa Barbara Museum of Natural History. Walk behind the museum across Mission Creek (stopping to admire the young steelhead in the large pool) and observe the hill to the south. That hill is mostly a fold scarp (modified by erosion from Mission Creek) along the north side of the Mission Ridge anticline.

Returning to our discussion of Ortega Hill, the rock being folded is the Pleistocene Casitas Formation, which I believe to be less than 500,000 years old. The Casitas includes beds of sand, gravel, and

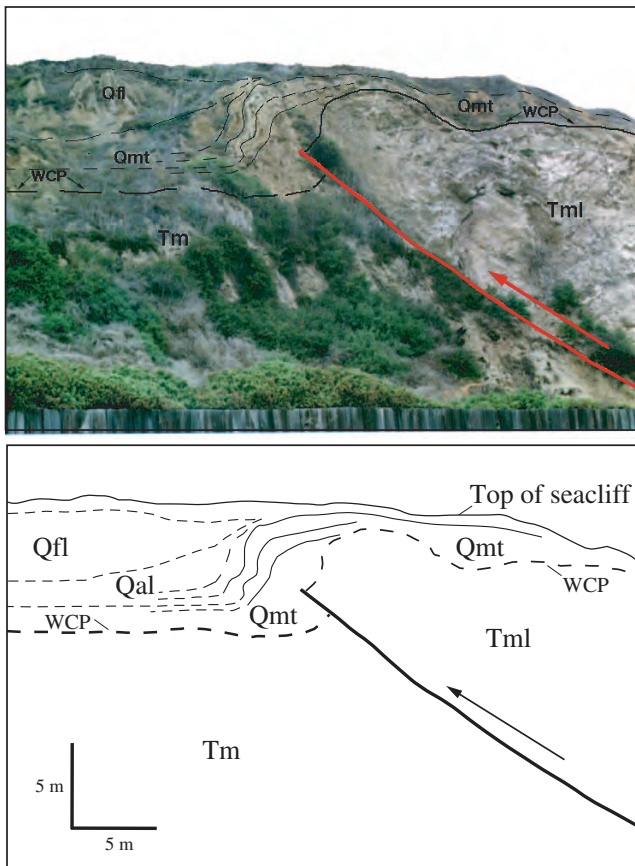


Fig. 2.8. Photograph and sketch of the More Ranch fault seaciff exposure at Ellwood. The drape anticline folds Quaternary marine terrace (Qmt), alluvial (Qal) and fluvial (Qfl) sediments. The wave-cut platform (WCP) on top of Tertiary Monterey Formation (Tm and Tml-lower member) is vertically offset about 6 m. From Keller and Gurrola, 2000.

boulders shed from the rising Santa Ynez Mountains to the north. The depositional environment includes stream deposition and debris flow deposition (for the large unsorted boulders), probably on alluvial fans of a coastal plain. The rock that is below and older than the Casitas Formation is the Santa Barbara Formation, which includes near-shore marine sands. The Santa Barbara Formation is younger than about 800,000 years old. I believe the deposition of the Casitas heralds the start of the uplift of the Santa Ynez Mountains. The Casitas beds at Ortega Hill were originally deposited nearly horizontally and have been tilted to their present orientation by uplift and folding.

Ortega Hill and the Ellwood uplift to the west are important folds because they serve as “type localities” for the anticlines that we believe comprise the rest of the Santa Barbara Fold Belt, including Mission Ridge and the Mesa anticline, as well as anticlines at Hope Ranch, More Mesa, and UCSB to the west. As you stand on the beach below Ortega Hill looking northward at the fold and fault, imagine what it must have been like before that structure was present. The land in general would have been nearly flat, sloping gently toward the ocean. A wave-cut platform was cut on the Casitas Formation about 100,000 years ago. That surface is preserved today as the uplifted marine terrace at Lookout Park. Today, the rocks of the Casitas Formation have been warped up steeply on the north side (Fig. 2.9b) and less steeply on the south side (see Fig. 2.9c). In other words, the anticline (in cross section) is asymmetric (steeper on the north). This means that the fault buried in the fold must be inclined to the south, and displacement is south side up. We call this kind of fault a reverse fault (the displacement is mostly vertical, but some horizontal displacement may be observed on the reverse faults of the Santa Barbara Fold Belt). All this folding has taken place in the



Fig. 2.9a. View to the west from Lookout Park to Ortega Hill, 2011.

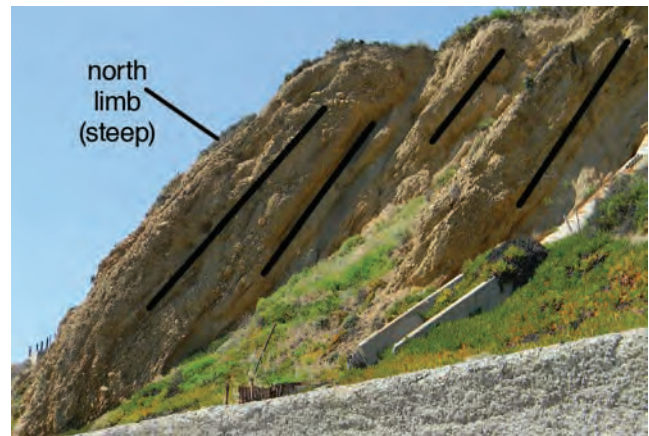


Fig. 2.9b. Steeply inclined north limb of the Ortega Hill anticline, 2011.



Fig. 2.9c. Gently inclined south limb of the Ortega Hill anticline, 2011.

last hundred thousand years or so. To many, this sounds like a very long period of time, but, when you compare the time necessary to form mountains, which is often several millions of years, to the age of the earth at several billions of years, it is an instant in geologic time.

The longer the fault, the longer its potential rupture, and rupture length is an important factor in potential earthquake magnitude. A rupture length of about 1 mile can produce a magnitude 5 earthquake, and a rupture length of about 12 miles can produce a magnitude 6.5 earthquake. It takes a rupture length of about 63 miles to produce a magnitude 7.5 earthquake (about as large as we can expect from local Santa Barbara faults). The magnitude 9 earthquake that hit Japan in 2011 had a rupture length of about 200 miles. This is a relatively short rupture length for a magnitude 9 earthquake. We believe, based on historical earthquakes, that a rupture length of 200 miles is more likely to produce a magnitude 8 earthquake. A magnitude 9.5 earthquake offshore of Chile in 1960 had a rupture length of about 650 miles.

The Ortega Hill fault is too short to have produced large earthquakes. A maximum magnitude would be about 5 (see Table 1.1). The Ortega Hill fault is probably connected in the subsurface to a deeper, larger fault that causes displacement on the Ortega Hill fault during an earthquake.

To visualize how the Ortega Hill anticline formed, put your palms and fingers together (in a vertical position) as if you are praying. The plane between your palms is the fault plane. Then, rotate your palms about 45 degrees to the left. Keeping your fingertips together, slide your upper palm up and notice the fold (anticline) that forms in the upper palm and fingers (your right hand). That is how the asymmetric anticline at Ortega Hill and others in the Santa Barbara Fold Belt formed.

Some people have told me they moved to Santa Barbara to escape the earthquake hazard of the Los Angeles area. What short memories we seem to have! Santa Barbara was heavily damaged in 1925 by a Magnitude 6.8 earthquake (Fig. 2.10) that must have been similar to the Magnitude 6.7 Northridge earthquake that shook up the Los Angeles area in 1994, causing over \$30 billion in damages and killing 61 people. Earthquakes in the mid-to high-Magnitude 6 range are moderate events, but we can expect larger earthquakes at some time in the future. Some of our on-land faults, such as the Mission Ridge fault system, are clearly capable of producing Northridge-type earthquakes, but some of the faults in the channel could produce a Magnitude 7 to 7.5 event (Table 2.1). In addition, there is a fault just over the Santa Ynez Mountains called the Santa Ynez fault, that the Santa Ynez River flows along, as well as a major fault on Santa Cruz Island, both of which could produce a Magnitude 7 earthquake.

Damages to Santa Barbara from 10 past local and regional earthquakes since 1800, while significant, have not been catastrophic (Table 2.2). This resulted from the fact that past earthquakes were mostly relatively small to moderate, and, in the case of large earthquakes, the area had not been nearly as developed as it is today. Today, we have earthquake codes for construction of buildings, and our wood-framed homes tend not to completely collapse during intense shaking. Thus, if we have a large earthquake, there will probably not be catastrophic loss of life, although property damages could exceed several billion dollars.

The following information concerning the damages from local earthquakes has been gleaned, in part, from the wonderful book by Professor Robert Norris (UCSB) on the geology and landscape of Santa Barbara County. The 4th of July

Fault	Folds(s)	Length (km)^a	Slip	Vertical rate of faulting (mm/yr)	Activity^b	Max. M_w
<i>Mission Ridge System</i>						
More Ranch segment (MrR)	Ellwood, UCSB, More Mesa anticlines	15	Oblique: reverse-left	0.3	Apparently active	6.4
Mission Ridge segment (MsR)	Mission Ridge, Montecito, Eucalyptus Hill, and Barker Pass anticlines	17	Reverse-(left?)	0.3 – 0.4	Apparently active	6.5
west and east Arroyo Parida segments (AP)		17 15	Oblique: reverse-left	0.4 (Ojai, CA)	Potentially active	6.5 6.4
<i>Northwest striking sources</i>						
Mesa (MF)	Mesa anticline Honda Valley syncline	12	Reverse	Unknown	Potentially active	6.3
Lavigia (LF)	Hope Ranch anticline	15	Reverse	0.1	Potentially active	6.4
San Jose (SJ)	Goleta Valley anticline	7	Reverse-(oblique?)	Unknown	Potentially active	6.1
San Pedro (SP)	unnamed anticlines	8	Oblique: Reverse-left	Unknown	Potentially active	6.1
Ortega Hill (OH)	Ortega Hill anticline	1	Reverse-(oblique?)	Unknown	Potentially active	5.1
Santa Barbara Cemetery(SBC)	Santa Barbara Cemetery anticline	1	Reverse	0.1	Apparently active	5.1
Los Carneros (C)		7	Left	Unknown	Potentially active	6.1
Dos Pueblos (DP)		6	Left	Unknown	Potentially active	6.0
<i>Offshore sources</i>						
Oak Ridge(OR)	Oak Ridge trend	90	Reverse	3.5 to 6.0	Active	7.5 ^c
Pitas Point (PP)	Pitas Point trend	22	Left-reverse	Unknown	Potentially active	6.6 ^c
Red Mountain (RM)		39	Reverse	0.4 to 1.5	Apparently active	6.8 ^d
Rincon Creek (RC)	Rincon Creek anticline	20	Reverse	0.3	Apparently active	6.6
North Channel Slope(NCS)		60	Reverse	2.0	Apparently active	7.1 ^d
Mid Channel (MC)		20	Reverse	Unknown	Active	6.6
Coal Oil Point (COP)	Coal Oil Point anticline	4	Reverse	Unknown	Apparently active	5.8
<i>Other sources</i>						
Santa Yñez		130	Left-reverse	0.1 to 0.7	Active	7.5 ^c

- a. We assume fault length is the surface rupture length and may be slightly different than map lengths of seismic sources shown in Fig. 2.7.
- b. Active = demonstrated Holocene (last 10,000 yr.) activity;
Apparently Active = very young (probably Holocene) topographic expression of activity;
Potentially Active = active in Pleistocene (last 1.65 million years)
- c. Data from Southern California Earthquake Center (SCEC, 1999)
- d. Data from California Division of Mines and Geology (1999)

Table 2.1. Seismic sources of the onshore and offshore Santa Barbara Fold Belt with fault/fold dimensions, activity, and maximum expected earthquake (M_w) are determined using the methodology of Wells and Coppersmith (1994). Names of seismic source abbreviations for Fig. 2.7 are in parenthesis. From Keller and Gurrola, 2000.

Date	Magnitude	Location	Modified Mercalli Scale (MM)	Damage	Measured or Inferred Peak Accel. (g)	Estimated Peak Accel. at Santa Barbara	Distance to Santa Barbara (km)
24 Mar., 1806	?	?	?	Damage to Mission Santa Barbara and Royal Presidio	?	0.05-0.10	?
21 Dec., 1812	7.1+	Santa Barbara Channel	X-XI	Destroyed La Purisima Mission (near Lompoc) and Santa Barbara Mission;; tsunami?	0.60+	0.20-0.40	< 50
9 Jan., 1857	8.2 +	San Andreas fault	X+	Ruptured 300 km of the San Andreas fault; intensity VI-VII at Santa Barbara; > 90 sec. of shaking	0.80+	0.10+	60-190
27 July to 12 Dec., 1902	6.0?	near Los Alamos	VIII-IX	Several EQ's totally destroy Los Alamos	0.40-0.50	0.05	60
29 June, 1925	6.3 or 6.8	Santa Barbara	VIII-IX	Extensive damage to downtown Santa Barbara and city	0.50-0.60	0.40-0.60	< 5
29 June, 1926	5.5?	Santa Barbara	VIII	Moderate damage to Santa Barbara; aftershock of 1925 EQ	0.30	0.20	< 5
4 Nov., 1927	7.3	off Pt. Arguello	VIII+	Tsunami (2m) generated along coast; slight damage to Santa Barbara	0.60++	0.10	100
30 June, 1941	5.9	offshore Carpinteria	VII	Slight damage to Santa Barbara	0.40-0.50	0.10	10
21 July, 1952	7.7	Kern County	XI	Moderate damage to Santa Barbara; liquefaction along Laguna Street paleochannel	0.80+	0.15	85
5 July, 1968	5.2	Santa Barbara Channel	VI	EQ swarm with largest event causing slight damage to Santa Barbara	0.20	0.07-0.10	15
13 Aug., 1978	5.9	off Goleta Pt.	VII-VIII	Moderate damage mainly to UCSB campus	0.44	0.28	< 5

Table 2.2. Table of regional historic seismicity of the Santa Barbara Fold Belt (Nicholson, pers. comm., 1999).



Fig. 2.10. 1925 Santa Barbara earthquake. "Welcome to the hotel California."
Source of photograph is unknown.

earthquake of 1968 was a relatively small one of Magnitude 5.2. It was most strongly felt in Goleta and was one of a swarm of earthquakes that also caused slight damage to Santa Barbara. There was some suggestion that the damage was greater to the west and might have been a result of propagation of the earthquake rupture in that direction. This was emphasized further in the earthquake of August 13, 1978, which was a Magnitude 5.9 event that occurred offshore off Goleta Point, probably somewhat to the east of the point. There was a strong focusing of the energy to the west. Several million dollars of damage were sustained at the University of California, Santa Barbara. Something like a million books were knocked off shelves in the library and office bookshelves. The acceleration, or intensity of shaking, caused the Marine Science building to shift about one inch on its foundation. Had the event taken place at a time when students were present on campus, injuries and deaths undoubtedly would have occurred. It's also interesting that, further to the west at Ellwood, a train derailed when it ran over a place where the rails had been spread by the shaking.

What really seems clear from this event is that the intensity of shaking and damage clearly increased from east to west, which was the direction of propagation of the faulting during the earthquake.

Talking about what produced the 1978 earthquake brings to mind a humorous story that a friend of mine told me. She was living in Santa Barbara, and the earthquake occurred about four in the afternoon. She had been gardening and was pulling on a particularly tough

weed, grasping it with both hands and pulling hard. Just as the weed was finally pulled free, the earthquake occurred. She said something like, "Oh my God, what have I caused now?" and tried to put the weed back in the hole to stop the seismic shaking. Who knows? Maybe pulling the weed was the straw that broke the camel's back, but somehow I doubt it.

Santa Barbara and the channel is part of the so-called "earthquake hot zone," which runs from Los Angeles through Ventura and up through the Santa Barbara Channel. Frequent moderate to large earthquakes characterize this zone. Santa Barbara has not sustained a Magnitude 6 to 7 earthquake in over 80 years, but we probably have been lucky.

Seismic shaking, from rupture of the Mission Ridge fault that uplifted the American Riviera (Mission Ridge) during numerous earthquakes over the past 125,000 years, is likely to be intense in the City of Santa Barbara because much of the town is on the hanging wall, or upper plate, of the fault. The fault is part of an extensive fault system that runs from near the Ventura River west to offshore near Ellwood Beach. If the entire fault were

to rupture, we could expect about a Magnitude 6.5 to 7.0 earthquake. If a shorter segment of the fault, say, in the Santa Barbara area, ruptured, we could expect a 6.5 event. The problem is that the fault dips to the south beneath the city, and the city is built on the upper plate. Upper plates of faults are particularly prone to seismic shaking, compared to the lower plates below. This is because the upper plate tends to flop about, increasing the shaking. We don't know how often we get large earthquakes on the Mission Ridge fault system. The last one was about the late 1700s, just prior to the establishment of the Santa Barbara Mission which maintained written records of earthquakes. We know this because Dr. Larry Gurrola, a UCSB geologist and my former graduate student, identified deformation from that event near Sheffield Reservoir just north of Mission Ridge. The return period on the Mission Ridge fault system at any particular location is probably several hundreds of years to a thousand years or longer, but we can't rule out the possibility that earthquakes along the fault are clustered in time. A new idea concerning earthquakes is that the place where you recently had a large earthquake is where you might expect another one in the relatively near future. Regardless of what happens on the Mission Ridge fault system, the Mesa fault, or a number of other faults on land, the most serious seismic hazard is in the Santa Barbara Channel. That is also where most of the small earthquakes occur.

Our instruments that record earthquakes record many more earthquakes out in the channel than on land. A Magnitude 4.3 earthquake in the channel near Santa Barbara occurred in November of 2007. There are several large faults in the channel, including the Red Mountain, Oak Ridge, and the Mid-Channel faults. These have produced ridges and fault scarps on the floor of the ocean and present a potentially serious earthquake haz-

ard to the Santa Barbara area. This is because earthquakes in the Santa Barbara Channel would be felt almost instantaneously on land. Seismic waves and shaking travel very fast (a few miles per second), so, once an earthquake occurs in the channel, we would soon know about it. Areas of particular concern include the old El Estero or salt marsh (very roughly from East Beach south, Anapamu St. north, State Street west, and Milpas Rd. east) that is now filled in, because shaking of that area would likely result in liquefaction of the land. The shaking rearranges fine sediment and water, causing solid earth to turn into a liquid. Other areas that might be subject to liquefaction are the Goleta Slough and some of the soft soils with high water tables around the Andre Clark Bird Refuge. Evaluation of the soil at a particular site is necessary to estimate the liquefaction hazard.

The good news about the Santa Barbara earthquake hazard is that nearly all of us will survive a Magnitude 6 to 7 earthquake. Many of our houses are well built and designed to survive an earthquake. Some older buildings, constructed before modern building codes, are more vulnerable and may sustain substantial damage from seismic shaking. Garden walls will fall, as will chimneys, and foundations will crack. Some buildings may collapse, resulting in a potential loss of life. The number of people that might be killed is difficult to predict. Having said that, Santa Barbara is in the southern California "hot zone" that stretches from Los Angeles west through the channel, where future earthquakes are likely to occur (Fig. 2.11). A Magnitude 6 or greater earthquake occurs somewhere in the hot zone about every 10 years.

Earthquake scientists have approached earthquake hazards in terms of short-term and long-term prediction. There has been much more success with long-term forecasts (from decades to centuries) and intermediate forecasts (from

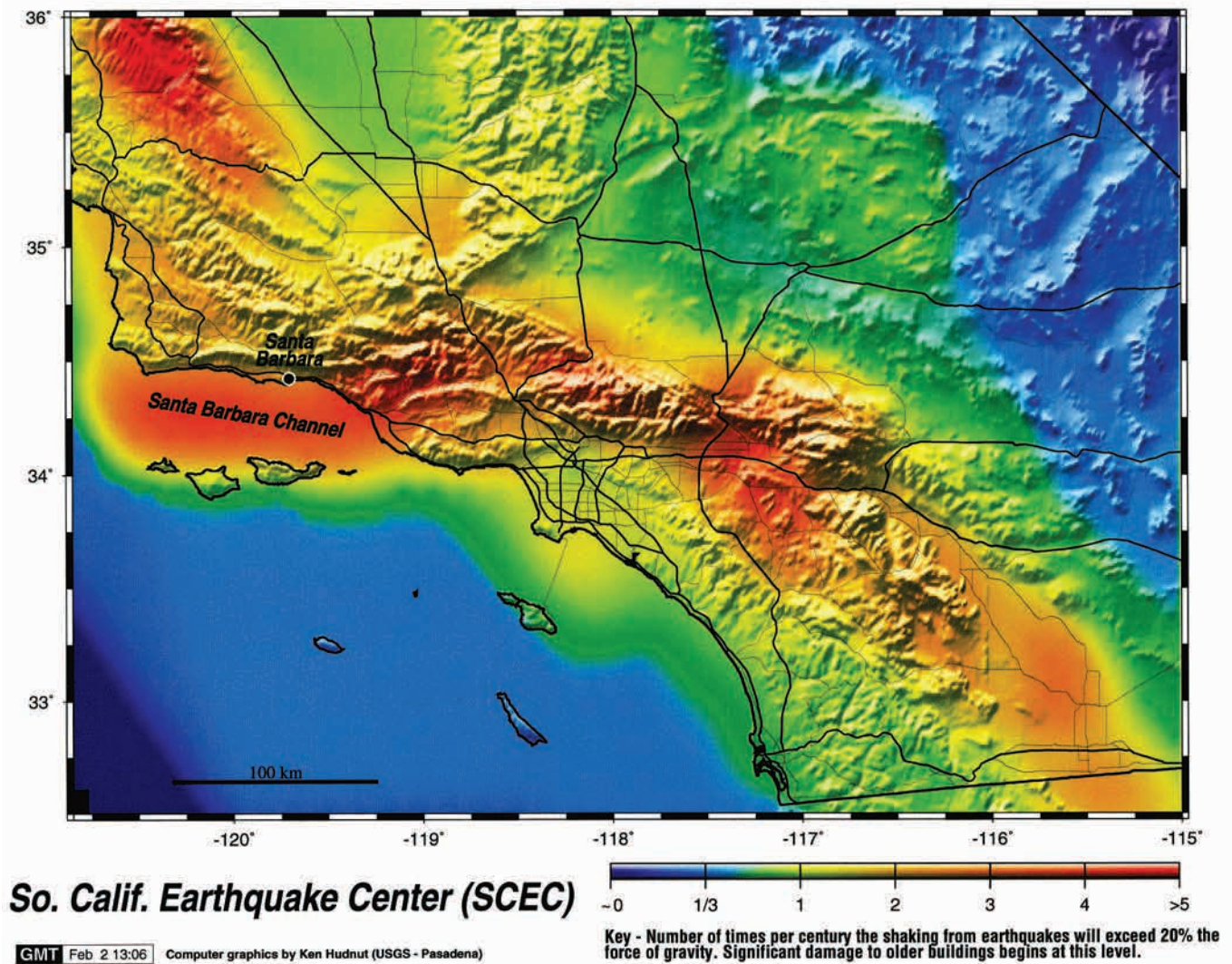


Fig. 2.11. Southern California earthquake hot zone.

months to decades) than we have with short-range prediction on a matter of weeks or days. We cannot yet say an earthquake will occur on a particular day with a particular magnitude and probability. If we ever do predict earthquakes, it will probably be more like a weather forecast, with a percent chance over a period of time.

Short-term prediction (hours, days to weeks) of earthquakes relies on what are known as precursors, which are events or changes that occur before the main shock of an earthquake. For example, there may be foreshocks, or the shape of

the ground may change prior to an earthquake - such as uplift or subsidence. Sometimes, changes in the Earth's gravity, magnetic field, and ability to conduct electrical currents have been observed before earthquakes. In addition, changes in groundwater level, temperature, and chemistry have been noted prior to earthquakes. In particular, the radioactive gas radon has been observed sometimes to increase, even hissing in water wells, prior to an earthquake.

Ever since earthquakes have occurred and caused problems for people, there have been ob-

servations concerning unusual behavior of animals prior to earthquakes. One of my graduate students from China told me that, after the 1976 Magnitude 7.5 Tan Shan earthquake that killed over 250,000 people, there were observations of strange behavior by rats. He observed what he thought were birds on power lines with their tails hanging down in rows. When he got closer, however, he realized they were rats that climbed the poles and were perching on the wires. We don't know if the rats went up the power lines prior to the earthquake, but they likely did. People have reported all sorts of strange animal activities prior to an earthquake, such as dogs barking or running in circles and snakes crawling out of the ground in the winter and freezing. One person even reported that he had a goldfish that could predict earthquakes. It seems the fish would turn over on its belly a few hours prior to an earthquake. In spite of all the anecdotal evidence and stories that make for very interesting reading, there is no scientific evidence to show how unusual animal behavior might predict earthquakes. This does not mean there's not something going on. Some animals are sensitive to ground motions, and subtle changes do occur in the land and rocks prior to an earthquake. We're a long way, though, from being able to place ground squirrels in cages along faults and observe their behavior in order to predict when an earthquake is likely to occur.

In the Santa Barbara area, we had precursor events prior to the large earthquake of 1925. People working along the coast noticed that, a few hours before the earthquake, there was a large amount of oil seeping out onto beaches and into the waters of the Santa Barbara Channel. Probably, what was happening was that, prior to the main shock, there were small shocks that were shaking up the underground plumbing system and opening up new conduits for oil and gas. So, I would advise that,

if you are on the beach on a nice day (or any day) and oil starts seeping up through the beach sands and into the waters of the channel, you might take this as a possible warning that an earthquake may occur in the next few hours.

Even though we haven't been very successful at short-term prediction, we have made breakthroughs in our ability to make long-term (months to a few years) forecasts of earthquakes. We can map those faults that have had recent earthquakes and are more likely to have earthquakes in the future. This is the strategy behind much of our earthquake hazard reduction in California. That is, we identify faults that have moved in the recent geologic past and term these "active faults." We then zone the land (not allow building within 50 feet) on both sides of these faults to avoid ground rupture damages to property from future earthquakes.

One of the most successful approaches for making long-term earthquake forecasts has been the study of the seismology, or patterns, of earthquakes that have been observed. Along active fault zones, seismic gaps have been identified that, eventually, will be filled by an earthquake. In the past 40 years, identification of seismic gaps has been used successfully in making long-range forecasts for at least 10 large earthquakes. One seismic gap that could affect the Santa Barbara area is along the San Andreas fault near Fort Tejon to the north. The last rupture was in 1857, and that section of the San Andreas fault is thought likely to rupture in coming decades. When that happens, we certainly will feel strong seismic shaking in Santa Barbara, as the earthquake is likely to be a Magnitude 7 to 8 event.

Tsunami Hazard In Santa Barbara

We became painfully aware of the tragic consequences of large sea waves in 2004 and 2011. The Japanese tsunami of 2011 killed over 20,000 people. About 250,000 people were killed in 2004 by a series of waves that struck the shorelines around the Indian Ocean. The sight of giant waves, measuring from 20 to more than 50 feet, rushing through areas populated by many thousands of people, was nearly unbelievable. Entire towns and urban areas disappeared in a matter of minutes. A giant Magnitude 9 earthquake in the Indian Ocean offshore of Indonesia generated the tsunami waves, and another magnitude 9 earthquake generated the 2011 tsunami in Japan.

What exactly are these waves? A tsunami is a sea wave caused by large-scale and short-duration vertical disturbance of the seafloor and the water. Most tsunamis are the result of earthquakes of magnitude 7 or greater. However, any large-scale disturbance on the floor of the seabed may generate a tsunami. Submarine volcanic eruptions, landslides, or impacts of asteroids have generated huge tsunamis. Tsunamis (the Japanese word for large harbor wave) are sometimes called tidal waves, but this is a misnomer; and we have seen that all of them are not caused by earthquake activity, so the term “seismic sea waves” is somewhat inappropriate as well.

The remainder of our discussion will be concerned with tsunamis that are generated by earthquakes. When the floor of the seabed is uplifted significantly, it lifts the entire column of water above it as well. When the uplifted water reaches the surface, it organizes itself into concentric or linear waves that travel across the ocean at great speed. This is like throwing a large rock in a pond, producing rings of outgoing water. Both local and distant tsunami waves are produced. Local tsunami may reach the shoreline minutes after the earth-

quake, while distant tsunami can travel hours across the sea to locations thousands of miles away. For example a large tsunami generated near Seattle might arrive in Hawaii in about 6 hours and Japan in 12 hours. In the open sea, a tsunami will travel at hundreds of miles per hour (about the speed of a commercial jet airliner) and have a wavelength from crest to crest of hundreds of miles. The height of the tsunami in the open sea may only be about a foot, but it involves the entire column of water in the ocean. When all this water reaches the shore, where the depths are much less, the energy is concentrated, and the height of the wave dramatically increases. Because it is a wave, it has low spots and high spots, much like when you grab a clothesline, pull down, let it go, and watch the waves go back and forth. If the trough of the wave is first to arrive at the coastline, then the first sign that a tsunami is coming would be a withdrawal of the seawater from the shore. This often happens and can mesmerize people, who wonder what is going on.

When the water recedes from a beach or rocky coast, this is not a time to go out and collect stranded fish! If people have been educated about the tsunami process or have a cultural, collective memory from long-past events, they take the receding water as a warning and head inland to higher ground. That is exactly what some elephants did. Elephants at a beach resort in Thailand started trumpeting about the time the Magnitude 9 earthquake struck off the island of Sumatra in Indonesia in 2004. About one hour later, elephants that were not carrying tourists on rides became so upset that they broke loose from their strong chains and headed inland. Some elephants already had tourists aboard for a ride, and they didn't respond to their handler's attempts to turn them back. They climbed a hill behind a resort where about 4,000 people would soon be killed by the tsunami.

Tsunami waves surged about one-half mile inland. The elephants stopped moving inland just beyond the reach of the waves. Did the elephants know something that people did not? Animals have sensory abilities that differ from humans. Perhaps they heard the earthquake as it generated sound waves with low tones, called infrasonic sound. Some people are also able to sense these sound waves, but they perceive them as a strange experience, not necessarily a hazard. The elephants may also have sensed the movement of the ground as it vibrated from the approaching earthquake. The elephants fled inland, which was the only way they could go. The above story is what happened, but the linkages between the elephants' sensory ability and their behavior are speculative. Nevertheless, about a dozen people were saved by elephants that somehow were able to sense danger that most people did not.

When we speak of "the wave," we are speaking in general, as there is a whole series of waves produced in tsunamis, and sometimes, the later ones are higher than the first ones to arrive. Damage is done as the waves surge onto land and as the water drains back to the ocean.

What about the tsunami hazard in Santa Barbara? There are postcards that show Stearns Wharf with a tsunami crashing over the Moby Dick and the Harbor restaurants. Rest assured that this is not a likely scenario. The most likely source for a damaging tsunami to Santa Barbara would come from a large earthquake generated in the channel. A Magnitude 7.5 earthquake could uplift the seafloor by 10 or more feet and generate a local tsunami. Tsunamis generated in far locations of the Pacific Ocean, say Alaska or Japan, could also reach Santa Barbara, but their size would be diminished, as we are somewhat protected by the Channel Islands. For example, in 1964, the great Alaskan earthquake caused tsunamis in Alaska that killed many people. A number of people were also killed in Crescent

City, but the wave in Santa Barbara was not significant. This does not mean that, under some circumstances, a distant tsunami could not reach our shores, but only that it is not very probable. Fortunately, the Pacific Ocean has a working tsunami warning system that provides us hours of advance notice of waves approaching California and other parts of the Pacific. On the other hand, should a large earthquake occur in the channel, the actual warning time, or time between the generation of the wave and its arrival, would be short (probably a few minutes at most). Therefore, the best advice we offer people is that, if you're at the seacoast in the Santa Barbara area and feel a large earthquake, the prudent thing to do would be to move inland to higher elevation. This doesn't mean you have to drive to the top of San Marcos Pass, but it might be wise to move up onto the Mesa or another place at least 40 feet above sea level.

The evidence for past tsunamis in Santa Barbara is somewhat mixed. To say the least, it is a controversial subject among scientists and other people interested in the history of Santa Barbara. A giant tsunami overtopping Stearns Wharf is not in the cards, but what does history tell us about past events and the potential for future tsunamis? Here, we use the concept of uniformitarianism, which is a powerful tool in the earth sciences. Generally, we say that the present is the key to the past, but, in environmental geology, we turn it around and say that the past is the key to the future. That is, we look for evidence of past events and use that evidence to estimate what is likely to happen in the future.

Returning to our discussion of tsunamis in Santa Barbara, about the only event that is talked about much may have resulted from the December 21, 1812 earthquake, which was thought to be a Magnitude 7+ event that struck in the Santa Barbara region. Intensity of shaking was high, and numerous aftershocks occurred for years following the event.

There is some evidence that foreshocks also occurred, which prompted some people to leave their residences - so lives may have been saved. Nevertheless, the earthquake damaged the missions at San Buenaventura, Santa Barbara, Purisima, and Santa Ynez. It is not known for certain where the epicenter (the point on the surface of the earth above where the rupture occurred at depth) was located, but it probably was in the Santa Barbara Channel.

There are many anecdotal reports and stories from the 1812 event that a tsunami inundated part of the coastal area from Ventura to Santa Barbara and perhaps north to Refugio Creek. One of the more interesting stories is told and retold to every generation of geology students at UCSB. The story goes something like this: During the earthquake, a series of large tsunami waves inundated the coastal area. One of these waves carried a ship up Refugio Canyon with one wave and carried it out with the next. Is this story true? No real evidence has been found to support this story, as the ship captain's logs have never been found, nor are the experiences of people somehow hearing of the event completely believable. The Mission records at Santa Barbara and Ventura both have comments about a tsunami during this period; over 50 years later, in 1864, a man named John Bordman Trask gave a paper to the California Academy of Sciences after he did some research on old records concerning the 1812 tsunami. He came to the conclusion that there was a small tsunami, which was preceded by withdrawal of the seawater in the Santa Barbara area. Evidently, inhabitants were aware of the possible hazard and withdrew to adjoining hills, presumably above the city on the Riviera or the Mesa. When the sea returned in a series of five or six tsunami waves, he reported that it flowed inland for about one-half mile, reaching the lower part of town. He concluded by saying that there was little damage from the floodwaters, which damaged or destroyed

a few adobe buildings that tend to dissolve when inundated. If we take this to be anything close to true, then, probably, the wave moved up through the old El Estero. At that time, the elevation of the area, as it is today, was close to sea level and was part salt marsh and mud flat. A street name in the area was Salsipuedas (now S. Calle Cesar Chavez), which roughly translates to "get out if you can," because wagons moving through the area often got stuck in the mud. According to Santa Barbara historian Walker A. Tompkins, by 1886, part of the El Estero became an agricultural park that extended to East Beach and included a half-mile racetrack with a covered grandstand. Events such as rodeos, carnivals, circuses, and hot air balloon ascensions were held there.

The tsunami of 1812 probably moved inland to somewhere in the vicinity of US 101. If such an event occurred today, much of the lower part of Santa Barbara would be inundated by tsunami driven floodwaters, and damage would be extensive. Thus, we conclude that there is a tsunami hazard to Santa Barbara, whether or not the 1812 event was larger or smaller than the historical record indicates. What is apparent is that Santa Barbara is not yet ready for a tsunami.

The Magnitude 7.3 earthquake of 1927 offshore of Point Arguello, near Point Conception, offers an example of what we might expect at Santa Barbara, should a large earthquake occur nearby in the channel. The earthquake generated a well-documented local tsunami of 4 to 6 feet, observed near Pismo Beach and Port San Luis. A 6-foot wave, if it occurred at high tide, would inundate low places near the beach at Santa Barbara and Goleta.

In the Santa Barbara area, UCSB has developed tsunami-ready status, as have a couple of other places in California, including Dana Point and Crescent City. The requirements that must be met to be tsunami-ready include the establishment of an emer-

gency operations center that has 24-hour capability; development of ways to receive tsunami warnings from the National Weather Service or other agencies and with ways to alert the public; development of a tsunami hazard plan with emergency drills; and promotion of community awareness with an education program. At first thought, you might ask, why does UCSB need a tsunami plan? After all, the sea cliff is about 40 feet high in many places, and much of the campus would be above all but a truly gigantic wave. Part of the problem is that there are low-lying areas on the campus and adjacent to it. Should a tsunami occur, the wetlands surrounding the university would be inundated, isolating the university and forming what might look for a bit like an island on the 45,000-year-old marine terrace that most of the university is constructed on.

It would seem prudent that the city of Santa Barbara develop tsunami-readiness; there has been some work in that direction, and a plan will undoubtedly be forthcoming. Most people in Santa Barbara don't know what to do if a tsunami warning is issued. In 2005, there was an earthquake far away in the Pacific that, as it turned out, did not generate a tsunami, but warnings were placed up and down the California coastline. Another tsunami warning for Santa Barbara was issued following the March 10, 2011 magnitude 9 earthquake that occurred in Japan. After racing across the Pacific causing damage in Hawaii and Northern California, several small waves (surges) of about 0.5 to 1.5 feet high were recorded at Stearns Wharf starting about 8:30 a.m. on March 11, and lasting to about noon. Some people told us that on learning of the warning in 2005 they drove to the top of San Marcos Pass! There are good reasons to visit San Marcos Pass; escaping a tsunami is not one of them. It was also reported that some people were perched on sea cliffs or even in palm trees with binoculars at night (if you can believe that) to alert people

if a tsunami struck the shoreline. Some people on March 11 lined the top of the sea cliff at Shoreline Park to view the expected tsunami. What is clear is that we are not as prepared as we could be for a tsunami, and that we had better get our ducks in order (pardon the pun) and have a warning system, an evacuation plan, and more public education.

Santa Barbara: Where It's Slipping and Sliding

Santa Barbara, with many steep slopes, weak sedimentary rocks, intense rainstorms in the foothills, storm driven Pacific Ocean waves, and a history of shaking from earthquakes, is destined to have many landslides, both large and small. This is not to say that the entire Santa Barbara area, from the mountains to the sea, has a serious landslide risk. Particular rocks (weak shale, highly fractured rocks or sedimentary layers inclined in the down slope direction, and tightly folded sedimentary rocks, in particular), steep slopes (in some canyons and the sea cliff in general), and some particular environments (tar-filled rock or shale that has burned) have a known landslide hazard.

There are two types of forces on slopes that determine the landslide hazard. The first of these is the driving force, which is basically gravity that moves materials down slopes. The second is resisting force, which results from the internal strength of the rocks themselves or strength between layers that otherwise might slide. If the resisting forces that tend to stabilize a slope exceed the driving forces that tend to destabilize a slope by at least 50%, then we say the slope is stable and is not likely to fail due to a landslide. The ratio of resisting to driving forces is defined as the Factor of Safety (FS) that is often calculated by geological engineers evaluating the landslide hazard of a slope. If the driving forces exceed the resisting forces (FS is less than 1), then failure is inevitable. Where resisting

forces exceed driving forces by less than 50% (FS 1.5), we are in a grey area of potential instability. In the Santa Barbara area, with its many steep slopes on weak rock with high rates of uplift and erosion, the FS of natural, steep slopes in our geologic environment is seldom greater than about 1.4.

A troubling problem is that both driving and resisting forces change through time by a variety of processes. For example, some erosion at the top or bottom of a slope, whether by wave action along a sea cliff or by grading to produce house pads, increases the slope and, therefore, the driving forces. Resisting forces often decrease over time as the moisture content in slopes changes. Santa Barbara has a semi-arid Mediterranean climate with wet winters and dry summers. However, when we build houses, plant orchards, and otherwise transform the land, we often change the local hydrologic environment. Extensive irrigation, and, especially, the use of septic systems, can add a lot of water to a slope that increases the driving forces over time. Water may also reduce the resisting forces by increasing the water pressure “lubricating” potential planes along which landslides may occur. Water doesn’t actually lubricate potential slip planes, but it can cause uplift forces to increase and, thereby, reduce the resisting forces—thus we say that water has a lubricating effect.

The most common natural causes of landslides are: adverse soil water conditions that add weight to a slope (that increases the driving force) and increase water pressure that reduces the strength of the slope materials (lowers resisting forces); weak rocks on steep slopes (lower resisting forces); erosion of the toe of slopes that reduces support to the upper part of slopes and increases driving forces (sometimes the toe area may be undercut, as in the formation of a wave-cut notch at the base of a sea cliff); loss of vegetation on a slope (for example, wildfire may kill plants, and, as the roots decay

over subsequent months, the binding strength from roots, as with steel in concrete, holding soil particles together is reduced, weakening the soil and increasing the probability of a landslide by reducing the resisting forces); slow changes (often over years or decades) in slope processes, such as weathering (for example, chemical breakdown of strong rock to weak clay) that reduces the strength (resisting force) of soil and rock; and landslide triggering events, such as high magnitude storms or earthquakes that may quickly (and, in the case of an earthquake, instantly) increase driving forces on slopes. The Magnitude 6.7 Northridge earthquake in 1994 caused more than 10,000 landslides, most of which were relatively small rock falls and shallow slips (lateral landslides a few feet thick).

The most common processes that increase the landslide hazard attributable to human use and interest in the land include: cutting and filling slopes to produce home pads or other structures that locally increase the slope; construction of road cuts that locally increase the slope above a roadbed; irrigation on slopes for fruit trees; increase in water in a slope from septic systems; and broken or leaking water pipes or swimming pools.

Some landslides are easy to see in the landscape, and others, especially those with very slow movement, are more difficult to recognize. Some general guidelines for homeowners concerned about landslides are:

- 1) Landslides are often complex geologically. Evaluation by a professional geologist is recommended. Fixing a landslide, while often possible, can be expensive, and it is usually a better decision not to purchase land with a known or suspected landslide hazard.

- 2) Contact local city and county agencies, such as flood control, planning, and engineering, that are often aware of the landslide hazard in a particular area.

3) Be wary of the mouth of a canyon, even a small one, where debris flows or mudflows may emerge and spread out.

4) Watch out for small landslides on a part of your property. Landslides generally grow larger, not smaller, with time.

5) When purchasing a home, look for cracks in the walls and foundation, especially those that cross the entire foundation and continue on the land outside of the foundation. Look for retaining walls that are cracked or are leaning.

6) Be wary of small springs, because landslides often leak water. Look for green areas where water-loving plants may be present.

7) Be wary of a leaking swimming pool, trees tilted downslope, utility wires that are taught or sagging.

8) Landslides often have curved surface fractures, concave down slope (like a horseshoe with open-end downslope) that, with time, produce hummocks or steps in the topography.

Noticing some of the above features is not proof that a landslide hazard is present. For example, cracks in the ground may be caused by soils that shrink and swell.

Landslides we see today may have originated long ago during a different, often wetter, climate than that of today. A number of the larger landslides in southern California date back to about 20,000 years ago, when the climate was cooler (wetter in some places and drier than others today). This was during the Last Glacial Maximum, when glacial ice advanced into New York and way south of Chicago, Illinois. A number of larger landslides from the geologic past have been reactivated as a result of human activities that change water processes on and in slopes. For example, building roads that routes and concentrates surface run-off and installing septic systems that add water to otherwise drier slopes in old landslides may desta-



Fig. 2.12a. Mesa landslide in 1978, note bulge in coast. Photograph courtesy of Don Weaver.



Fig. 2.12b. Mesa landslide 1978.



Fig. 2.12c. Mesa landslide 1978.

bilize them enough that they start moving again. The most famous of these prehistoric landslides in our area is probably the slope above La Conchita. The lower steep slope, directly above the community, is an ancient sea cliff that partially failed in a 1995 landslide that damaged some homes. Part of the same slide was tragically reactivated in 2005, killing 10 people.

Other prehistoric slides that are part of the present landscape occur along the Mesa near the lighthouse (Fig. 2.12) and at Skofield Park, among

others. These slides range in age from about 1,000 years to 15,000-20,000 years old, but could be reactivated and move again as a result of urbanization, earthquakes, coastal erosion, or other natural processes. Some have been reactivated and have moved in recent years, causing loss of property.

Sycamore Canyon Landslides

Sycamore Creek has eroded a path through Mission Ridge. The creek has been able to cut down nearly 600 feet and maintain its path through the ridge as it was being uplifted at a rate greater than a foot per 1,000 years. Uplift of the ridge occurs every few hundred to few thousand years, as a result of earthquakes of Magnitude about 6.5 (similar to the Northridge earthquake in 1994).

Sycamore Creek was present prior to the ridge being uplifted and, thus, is an antecedent stream (antecedent to the uplift). A canyon that is occupied by a stream (in this case Sycamore Creek) that has eroded through a rising uplift (in this case Mission Ridge) is called a water gap. Such gaps are occupied by an antecedent stream or river. Barker Pass, just to the east of Sycamore Creek, was formed by erosion from a creek (perhaps an ancestral channel of Sycamore Creek or Montecito Creek) that, for a while, maintained a channel across Mission Ridge. However, the uplift defeated the stream, leaving an abandoned valley. This process, along with further uplift and folding, produced the wind gap called Barker Pass. It is called a wind gap because the stream that cut the gap is no longer present. The stream was defeated by the uplift of the ridge (in this case the Mission Ridge fault and anticline), and the stream that once flowed into Barker Pass was deflected west to Sycamore Creek or east to Montecito Creek.

Sycamore Canyon became deeper and wider as it cut through Mission Ridge during the past 100,000 years or so. As it cut deeper, the stream ex-

posed weak sedimentary rocks forming steep slopes on both sides of the valley. The canyon grew wider by processes that include landslides. A large, deep slide on the west side of the valley formed thousands of years ago. The valley was occasionally partially blocked by landslides. When this happened, a landslide dam would allow a small lake to form. When a lake overtopped a landslide dam, floodwater and debris flows would race down the valley to the ocean. We do not know how many times this occurred, but the large size of the ancient slide suggests that it must have happened. The parent slide (also called a megaslide) is a large, deep feature that underlies much of the western side of Sycamore Canyon south of Stanwood Drive, and it has been the subject of recent studies by Professor David Rogers with the Missouri University of Science and Technology. The risk of reactivation of the large parent slide (with a FS of about 1.42) is low when compared to the 75-year lifespan of most buildings in the slide area. Recall that the factor of safety (FS) is the ratio of resisting forces (those that promote stability of a slide) to driving forces (those that promote sliding). Ideally, we like to see a FS value of 1.5 for stability. According to Rogers, in active tectonic areas with weak rocks, steep slopes, and a high rate of erosion, a FS above 1.4 on natural slopes is not common. Therefore, a FS of 1.42 is considered a relatively safe condition. While reactivation of the parent slide is unlikely in the near future, continued smaller, shallower landslides, at intervals of 10 to 15 years during intensive precipitation, are highly probable. Recent winter storms in 1994-95, 1997-98, and 2005 all caused widespread landslide problems in the Santa Barbara region. During the recent 1997-98 El Nino winter sequences of storms, hundreds of landslides occurred in our region.

Part of Sycamore Canyon Road was closed due to the landslide hazard. That is nothing new for this canyon. On both the east and west sides of the

canyon, ancient and active landslides have been identified by geologists for decades. These landslides appear on all geologic maps of the area and continue to cause problems to people in the area (Figs. 2.13 and 2.14). The problem is apparent along both sides of the canyon south of Highway 192. Landslides in the area have, in recent years, claimed several homes and damaged several more. Some of the slides are deep-seated and slow moving, while others have been shallow and much more rapid, moving quickly down slope. The land sliding is most common when the rocks on the slope are the notorious Rincon Shale, which is early Miocene, 18 to 23 million years old. The mud and other fine materials of the Rincon Shale were deposited in quiet and deep marine water, along with a significant component of organic material. This rock is relatively dark; as are the soils that developed on it, and only supports grass vegetation, compared to older sandstone sedimentary rock that supports chaparral brush lands and oak woodlands.

The soils that develop on the Rincon Shale present a hazard to development, because they tend to expand and contract with wetting and drying, causing problems to the foundations of homes, driveways, walls, and swimming pools. Because the Rincon Shale



Fig.2.13 Landslide east side of Sycamore Canyon (2007)



Fig.2.14. Landslide west side Sycamore Canyon (2007)

(or mudstone, as it's sometimes known) is very weak, when it occurs on steep slopes, such as in Sycamore Canyon, it is highly susceptible to a variety of types of landslides, particularly following winters with unusually high rainfall. The Monterey Shale overlies the Rincon Shale, and the lower part of the Monterey Shale has volcanic ash deposits called tuff (up to 30 feet thick and 16-19 million years old) that have been converted by chemical weathering into several weak clay minerals. Both the Rincon and Monterey shales have beds (layers of sediment, originally deposited nearly horizontally in the ocean) that, today, are steeply inclined to the south. The change from Rincon Shale to the north to Monterey Shale to the south occurs along an east to west contact just south of Stanwood Drive in Sycamore Canyon. A major strand of the buried Mission Ridge Fault also trends east to west through the same area of the canyon.

We have learned that there are many reasons why Sycamore Canyon has a history of landslide activity. The canyon will remain an area of elevated risk for future slides and must be carefully monitored.

Las Positas Canyon Landslides

The streams flowing through canyons and valleys south from near the crest of the Santa Ynez Mountains to the sea are primary paths of water and sediment from the mountains to the sea. Las Positas Canyon is the major feature that crosses the Mesa Hills to emerge at Arroyo Burro Beach. The canyon is similar to Sycamore Canyon, in that it has incised deeply through an uplift and has exposed weak rocks, including the Rincon Shale and Monterey Shale, producing steep slopes and landslides. The Lavigia Fault crosses the canyon east to west, above and near the tennis courts. The ancient sea cliff of the marine terrace that hang gliders and paragliders launch from, just north of Cliff Drive

at Eilings Park, is about 100,000 thousand years old, and the rate of uplift is several feet per 1,000 years, in response to earthquakes and folding. The same terrace is the platform for the Douglas Family Preserve above and east of the lagoon at Arroyo Burro Beach. Take a walk across the head of the lagoon (there is a bridge across Mesa Creek) and walk up to the preserve for a fine view to the north of Las Positas Canyon.

Las Positas Canyon is, in part, a water gap, because Arroyo Burro Creek, which eroded the canyon, still flows through it. Arroyo Burro Creek, near Veronica Springs Road, heads more to the west and north, while a northern branch of Las Positas Canyon continues toward US 101. The northern part of the canyon is a wind gap, insofar as the stream that formed it is no longer present. You can follow the wide, relatively deep canyon with well-defined side slopes north and observe where it crosses Modoc Road, and, further upstream, through Earl Warren Showground. This part of the canyon may have been cut by Mission Creek many thousands of years ago before it was diverted to the east to where it is today in the downtown area of Santa Barbara.

South of Veronica Springs Road, the canyon on the west side is nearly 450 feet high (there is a big hill with a large, white, red-tiled home on top with lots of palm trees, easily seen from Las Positas Road). As the canyon was eroded, it exposed weak Rincon Shale and Monterey Shale. Several moderate sized landslides that are most likely prehistoric in age are present along the west side of the valley along the steepest part of the hill across from the tennis courts on Las Positas Road, upslope from a group of condominiums. That steep, high slope has been the location of numerous small and moderate size landslides in the past few decades. These slides have been studied by Professor David Rogers with the Missouri University of Science and Technology, as well as by several local

geologists. The largest slides have been on geologic maps for many years. One landslide in 1998 was a deeper slump in the Rincon Shale behind the condominiums on the west side of the canyon that was caused, in part, by an accidental rupture of a city sewer line. Slide debris temporarily blocked Arroyo Burro Creek. When the landslide dam overtopped and washed out, as much as 8,000 cubic yards of slide debris (according to Rogers) was transported downstream to the lagoon and ocean at Arroyo Burro Beach.

Periodic landslides, in what are known as zero-order basins, have occurred during wet winters in the small depressions on the slope. This requires some explanation. A drainage basin is the land contributing water to a particular stream system. The furthest and smallest upstream channels are first-order streams. If you walk up a stream channel as far as you can go and it still maintains a channel (even if there is not water all year round), then you are in the stream environment. If you go far enough, the channel will cease to exist and there will be a shallow depression that is filled, generally, with sediment derived from surrounding slopes that incline into the depression. These elongated or pear-shaped depressions are called zero-order basins. They are also known as colluvial hollows, because they are filled with colluvium, which is a material that moves down slopes to lower areas, by slow, slope processes, such as rock and soil creep, and are stored in the hollow. Analysis of a drainage basin includes determining the drainage basin area and stream order. When two first-order streams join, we have a second-order stream, and, when two second-order streams join, the order of the basin becomes three, and so on. Large river systems will often have a stream-order exceeding 10.

Colluvial hollows or zero-order basins (located upslope of first-order streams) provide much of the beauty of a mountain slope. When you look

up at the Santa Ynez Mountains and see the rough, corrugated appearance of the mountains that define the basic hill-shape, the colluvial hollows are prominent features. Of course, we see the larger streams and canyons, but much of the upper part of the mountain slope is composed of the hollows. At any rate, returning to the discussion of Las Positas Canyon, the steeper, higher slopes have a number of colluvial hollows or zero-order basins, and these occasionally evacuate the colluvium by way of long (relative to width), shallow landslides called shallow soil slips. Sometimes, these may coalesce to form larger landslides, and this has occurred in Las Positas Canyon in recent years. Generally speaking, the shallow landslides heal quickly over a year or so but can be recognized by the vegetation that is greener and more water-loving, as the colluvial hollows tend to have shallow groundwater held above the deeper regional watertable by a bedrock that retards water infiltrating downward. Geologists say the groundwater is perched. The presence of perched groundwater increases the landslide hazard by increasing the fluid pressure in the slope which decreases the strength of the slope materials.

Las Positas Canyon has what appear to be old spring deposits present on the east side valley wall above the tennis courts. From Las Positas Road, you can see the outcrop of Santa Barbara Sands, well up the hillside (the only rock you can see). Weathered to sediment, Santa Barbara Sand is clean, nearshore marine sand, with occasional fossil shells (it looks much like sand on the beach). The sand represents the most recent time that the Santa Barbara area was below sea level. The age of the sand is younger than 780,000 years and older than about 200,000 years. We know it is younger than 780,000 years because paleo-magnetic work by Dr. Larry Gurrola, formerly of UCSB, suggested it has normal magnetic polarity. Prior to 780,000 years ago, the magnetic field of Earth was the re-

verse of what it is today. That is, the North Pole and the South Pole were reversed, and a compass would point to what today is the South Pole. Reversals of Earth's magnetic field have periodically occurred throughout geologic history (most recently 780,000 years ago, at what is called the Brunhes-Matuyama Boundary). The cause of magnetic reversals is not well known, but it is assumed to be related to dynamic processes deep in the earth that are associated with rotation and convection of the core and mantle. Returning to the canyon, some of the rock above the tennis courts has white carbonate coatings and weathering that appears to have been produced by spring flow. You can hike to this site from Eilings Park, but be careful, as the trail is steep and can be treacherous. The rock exposure (with some interesting fossils) is close to the Lavigia Fault that crosses the canyon from west to east. The process of faulting over many thousands of years has resulted in porous, younger Santa Barbara Sands with rapid infiltration of precipitation to overlie older Rincon Shale, which is much more impervious (it is more difficult for water to infiltrate). As a result, groundwater moving through the Santa Barbara Sands is ponded at the shale (forming perched groundwater), moves up along the fault, and may be forced to the surface to discharge as a spring. Springs present today are common along the bottom of the valley, particularly just north of the tennis courts along the east side of Las Positas Road, where the fault was mapped by Tomas Dibblee Jr., a the famous field geologist who grew up in Santa Barbara as a member of the well known de la Guerra family.

The famous Veronica Springs (where it is labeled on maps) are located on the western side of the valley, up a small draw with a small young alluvial fan that merges with the valley floor. The fan has forced Arroyo Burro Creek several hundred feet east and is most likely composed of a

series of earthflows. A few small active landslides are present at the toe of the fan where bank erosion from Arroyo Burro Creek has steepened the slopes. These slides, according to David Rogers, were likely triggered by winter storms in 1995 or 1998. A good place to see the fan is from the hills of Eilings Park to the east.

Sea Cliff Landslides along La Mesa Hills from Hope Ranch to Shoreline Park

La Mesa Hills are the east to west hills above and north of the marine terraces from Santa Barbara City College, west through Hope Ranch. The hills are a system of active anticlines (elongated arch-shaped folds) being uplifted and folded, mostly by movement on the Mesa fault. The hills at the western end of Hope Ranch are uplifted by the Mission Ridge fault system. There may have been movement on the Mesa fault during the 1925 Magnitude 6.8 earthquake that heavily damaged Santa Barbara. But that is speculation because it is based on the intensity of shaking estimated by people after the earthquake. Sufficient earthquake recording instruments (seismometers) to properly locate the fault that produced the earthquake were not present in 1925.

The top of the sea cliff along the base of La Mesa Hills is often wavy, and each small indentation (a few tens of feet long, as measured along the top of the sea cliff) is a small landslide. Landslides are particularly common along the sea cliff because of the steep slope, resulting from wave erosion at the base. Most of the landslides associated with the local sea cliff are relatively small (e.g., at Shoreline Park), but others (e.g., below Hope Ranch) may be much larger. A large prehistoric landslide on the Mesa near the lighthouse was reactivated 1978, claiming two houses. The slide was relatively slow moving, and people had time to remove many of their furnishings before the major failure oc-

curred. It is clear that this landslide has been with us for thousands of years. The coast bulged out at that location prior to the landslide, and the area remains a continuing, potential landslide hazard.

Several moderate-sized landslides (a hundred or so feet and longer, as measured along the top of the sea cliff) have occurred along the sea cliff below Hope Ranch. In some locations, the Miocene Monterey Shale has inclined layers that are said to be daylighting, presenting a particular landslide hazard. When a layer along where a slip might happen is inclined down slope and is exposed in the sea cliff, we say the layer or plane daylight. The sea cliff, in areas where potential slip planes daylight, is naturally unstable; any activity at the top of the slide that increases the amount of water or loads the slope may significantly increase the hazard. Nevertheless, people plant large trees, such as eucalyptus, as well as sod (grass) that require additional water. The inevitable results are landslides.

Several years ago, a local contractor asked me to look at a particular property for potential landslide hazard on the sea cliff at Hope Ranch. I do this free of charge as part of University Public Service. On visiting the site, it was clear that new sod had recently been put on the property, right up to the edge of the sea cliff. I warned the contractor that the geology in the sea cliff below was unstable (potential slip planes were clearly daylighting, presenting a potential hazard), and that sod was a poor choice of vegetation because it requires water that, on infiltration into the soil and rock, adds weight to the slope (increasing the driving force) and lubricates potential slip planes. People often water new grass more than is necessary. The rise in groundwater due to watering raises fluid pressure in the rocks of the sea cliff and weakens the strength of the rock (decreasing the resisting forces). The changes due to the sod decrease the Factor of Safety (ratio of the resisting to driving forces),

increasing the probability of a landslide. I recommend planting native vegetation that requires no watering at the top of a sea cliff.

The Monterey Shale at the location where the house and new sod was located is composed in part of soft, light, porous fossil diatoms, which are very small, marine algae (plankton) with a beautiful silica shell (skeleton) - often called “jewels of the sea.” Most diatoms are smaller than a fine grain of sand (silt size), and you need a high-powered microscope to see them. Diatoms are at the base of the marine food chain, providing food for many organisms in the Santa Barbara Channel, including krill that are small, deepwater planktonic crustaceans that look like a small shrimp (about one inch long). The krill are eaten by small fish that are eaten by larger fish that are eaten by sea lions and dolphins. The food chain is much more complex than this simple example, and you could add in many other animals, such as squid, sharks, seabirds, and whales. The diatoms in the Monterey Shale of the Santa Barbara Channel 20 million years ago provided the carbon rich material that was transformed by heat and pressure into oil. That is, the Monterey Shale is the source rock for the oil and gas in the channel. Diatomite, a light colored, soft, earthy, very fine-grained, siliceous biogenic sedimentary rock, largely composed of diatoms and part of the Monterey Shale, is mined for diatomaceous earth near Lompoc. It is used for a variety of industrial purposes, especially in filters (swimming pools, beer etc.) as well as in cat litter, mechanical insecticide, mild abrasives, and as a component of dynamite.

Returning to the slope below Hope Ranch where the sod was planted at the top and near the edge of the sea cliff, the prediction that a landslide was likely to occur became a reality a few months later when a section of the cliff a hundred feet or so in length crashed onto the beach below, transporting slide material well out on the beach. Around



Fig. 2.15. Recent slide below Hope Ranch (early 21st century).

the time the moderate slide occurred, people were having a beach party only a few hundred feet from the landslide (Fig. 2.15). Had they chosen their party site to be where and when the slide occurred, a tragedy could have resulted.

While we're talking about small landslides along the top of the sea cliff, keep in mind that the top of the cliff is a very unstable area. The sediment on the top is often loose sand and is extremely prone to small failures (Fig. 2.16). This becomes apparent almost every year when someone along the sea cliff, often near Shoreline Park, the University, or Isla Vista, falls down the sea cliff. Several people have died from this experience. It seems that every year, following the rainy season, the sun comes out, and people venture outside to play in the sun, often much too close to the edge of the sea cliff. Some people also don't see the cliff at night and walk off it! Sometimes people sit at the top of the sea cliff, sunbathing with their legs dangling over the edge. Rest assured (poor pun), this is fairly risky behavior!

Similarly, next time you walk along the beach at the base of the sea cliff, look at all the boulders that are often present there. These boulders came from the sea cliff, and some of them may be very fresh, probably only having fallen in the last few days. Sometimes palm, eucalyptus, and other trees, along with shrubs and grass, are present on the beach. These have been moved to the beach by rockfall or other types of landslides. Rockfall is a common potential hazard on a steep sea cliff where unstable blocks of rock are common. Therefore, think twice about where you sunbathe at the base of the sea cliff. On one occasion, while walking along the base of the sea cliff near Shoreline Park, I warned some people who were sunbathing amidst a field of fallen boulders. They did not realize that where they had chosen to sunbathe was a place where, in the last few days, a number of large boulders had rolled or fallen down the sea cliff. They believed me and promptly moved to a safer location. You wouldn't think you'd have to warn people about not dangling their legs over the top of a 50-foot cliff or jumping up and down on it, or



Fig. 2.16. Small slide near Arroyo Burro Beach (2007)

sitting below it surrounded by rocks and soil with bits of vegetation that have fallen from above. Unless you really pay attention to your surroundings, you may not be conscious of the processes operating on the sea cliff, including the many small landslides we've been talking about.

As mentioned above, the top of the sea cliff is often wavy, and each small indentation (a few tens of feet long as measured along the top of the sea cliff) is a small landslide. A good place to see this is at Shoreline Park on the Mesa. Walk along the park and notice the fence near the edge of the sea cliff. The fence is not straight, and some parts of the fence are clearly older than other parts. Every few years, often during the winter, small landslides occur that carve a small arc from the sea cliff. As this happens over and over, the top of the cliff (bird's eye view) takes on a wavy shape. The wavelength at Shoreline Park is several tens of feet to more than 100 feet. Generally, in the past, as the landslides caused the sea cliff to retreat, the fence was moved back.

The Monterey Shale in the sea cliff at Shoreline Park has a variety of strong sedimentary beds and weaker ones as well. The rocks generally are inclined south but are folded and faulted. The age of the platform (ancient beach) that defines the marine terrace is 60,000 to 85,000 years old. The faults and folds in the sea cliff at the park are generally old geologically, and do not deform the wave-cut platform near the top of the sea cliff. However, the bedding planes (natural planes in the rock that separate different depositional events in the rocks, such as harder sandy beds from softer clay beds or deposition at different times) and fractures do produce a variety of potential slip planes that daylight in the sea cliff. Although the marine terrace at Shoreline Park is free of houses, it is far from being a natural landscape. The urban development north of Shoreline Drive, with the urban

runoff and watering of lawns and gardens, adds a lot of water to the land that, in a natural undeveloped state, would not be present. The park also adds water through watering of the grass. Some of the water infiltrates the surface to become shallow groundwater that emerges at various places in the sea cliff (mostly near the base of the cliff). The seeping water weakens the shale and accelerates sea cliff erosion, resulting in more landslides.

A small landslide (about 70 feet long) in the central part of the park was reported on January 25, 2008 (Fig. 2.17). The slide was near the restroom and stairs down to the beach. The head scarp, when first noticed, was delineated by arc-shaped cracks (concave to the ocean) and was about 3 feet high. A head scarp is one of the most prominent features of a landslide. It is usually a nearly vertical slope (cliff) without vegetation at the uppermost part of a slide. Over several days, the head scarp grew to about 10 feet high, and slide debris was moving to the beach. Frank J. Kenton, an Engineering Geologist from Simi Valley for the City of Santa Barbara, was studying the slide. According to Kenton, the small slide extended back nearly 40 feet from the former edge of the sea cliff. The sidewalk was broken into several large rectangular slabs that moved down the slide with the soil and broken rock. Most of the broken sidewalk is now on the beach. To some, it looked as if the park was falling apart and was the source of much anxiety. In reality, the slide was similar to others at the park in past years. It was a bit larger than some and smaller than others. Much larger slides along a sea cliff are possible. The landslide frequency at the park could be minimized by control of the water in and on the cliff, but landslides cannot be eliminated. Probably the most cost effective strategy is to do what has been done in the past, i.e., move the fence and rebuild the sidewalk. If the slide grows in the future and threatens the restroom, the restroom could be moved inland.



Fig. 2.17a. Small landslide on sea cliff above Shoreline Park that occurred in late January 2008. The curved headscarp is the landward limit of the slide. Another headscarp is present in the sea cliff. Similar older slides are common at the park, forming the wavy top of the cliff.

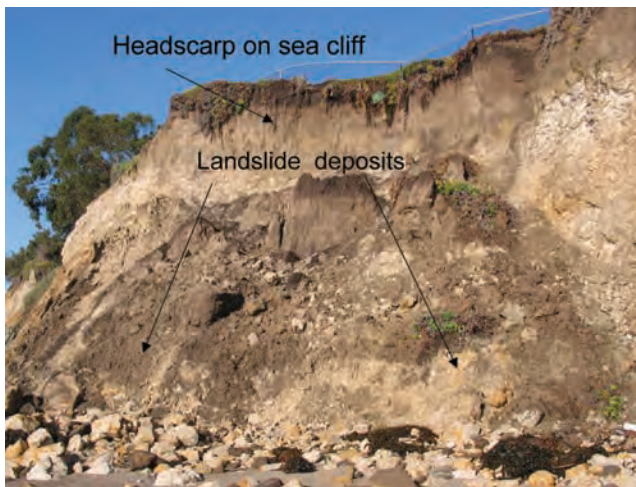


Fig. 2.17b. Landslide shown on Fig.2.6b from the beach. Slides such as this one at Shoreline Park form every few years. Watering of lawn probably contributes to the landsliding.



Fig. 2.17c. The landslide had grown much larger by May, 2008.

The stairs are built on an old landslide scar and will always be vulnerable to future earth movement and wave attack. The concrete slabs that were the sidewalk were on the beach as of early March, 2009. Eventually, the waves and other sediment will grind and pound them to small pieces, and they will end up on the sand spit at the harbor. For park management, I recommend building a small guard fence (the same fence that is present along the top of the sea cliff at the park) a few feet landward of the slide (as has been done in the past) and warn people that the sea cliff is unstable from top to bottom along the entire length of the cliff. The guard fence does not have to be placed as far back as the higher fence is now, as that would encourage people to hop over the fence to get closer to the edge (a dangerous activity, as the top of the sea cliff is sandy and unstable).

The best way to view the many landslides on the sea cliff of La Mesa Hills is to take a beach walk or two. Be sure to go at low tide. The wavy cliff top and small slides can be observed by walking west to east along the top of the sea cliff (stay behind the fence); then, at Santa Barbara Point, walk down to the beach and head west to One Thousand Steps staircase, just west of the park (do not climb the sea cliff). There are several small springs and landslides on the east side as you climb up the historic stairs.

Start at Arroyo Burro Beach and walk west toward UCSB to view several moderate and large slides. You will see pink burned shale, several large slides below Hope Ranch, and, if you walk several miles, the landslides associated with the tar seeps just west of More Mesa. The latter can also be accessed from Goleta Beach, if you can safely cross the slough inlet east of the pier. Take these walks and become familiar with some of our landslides. You will also become aware of the charming small pocket beaches, longer sandy beaches, and the ever-changing shape of the sea cliff produced by

the erosive action of waves on rocks with variable resistance to erosion. Hard rocks protrude further out on the beach, and softer rocks erode easier, producing wave-cut notches, small sea caves, and many small landslides - all together a geologic delight to behold.

Santa Barbara Flood Hazard

All streams flood! Whether we're talking about Rincon Creek to the east or Carpinteria Creek, Sycamore Creek, Mission Creek, and San Jose Creek in Goleta, they all have a potential flood hazard. All of them have flooded in the past, and flooding can be expected in the future. The common denominator is that flooding is a natural process. The south flank of the Santa Ynez Mountains receives a lot of precipitation in some years, and that precipitation may be intense. There is a cycle of wet and dry years in southern California which is related to the movement of air masses (storm tracks) that bring winter storms from the North Pacific. Some years, the storm track is further south, and we have more rain; when it stays north, we get less rain. The cycle of wet and dry conditions is about 10 to 20 years (a decadal cycle), explaining, in part, why we have drought for a series of years, followed by a series of wet years. Shorter events, called El Niño and La Niña, are related to water temperatures in the Pacific Ocean near the equator. El Nino in Spanish means "little boy," referring to the Christ Child because El Nino events begin off the west coast of South America near Christmas time. The precise origin of El Nino events is poorly understood. They result from natural processes that link the atmosphere and ocean in a dynamic system that periodically cause the waters of the eastern Pacific Ocean to warm, and the westward moving equatorial current to weaken or even reverse. Warm water can evaporate more water and feed energy into storms. As a result, rainfall intensity and volume,

along with flood hazard, may increase from Peru to California. El Nino events occur every few years, with strong events such as the El Ninos of 1982-1983 and 1997-1998 occurring less frequently. There is concern that the burning of vast amounts of fossil fuels is warming the atmosphere, and El Nino events may become more frequent and more intense. A typical El Nino event lasts 12 to 18 months. Flood damages to the Santa Barbara area resulted from three periods of storm activity in February of 1998. The first ten days of February alone brought about 12 inches of rain to Santa Barbara and 20 inches of rain in parts of the Santa Ynez Range to the north. Those amounts are about four times the average amount for February, and it occurred in a ten day period! Having said that, average precipitation doesn't mean much when the range of precipitation for a given year in southern California can be plus or minus several hundred percent of the average, and dry years can continue one after another, producing droughts. A severe drought of several years duration ended in March of 1991 with a late storm (called the March Miracle) that began a wet decade that produced the floods of 1995 and 1998. A strong El Niño in the decadal cycle of increased rainfall can produce an especially wet year. La Nina refers to the years between El Nino events, when waters in the western Pacific are cool and the equatorial currents take the rain to Australia rather than the Americas.

During wet years in the mountains above Santa Barbara, there is a lot of runoff. Streams, such as Mission Creek, have a short, steep path to the ocean. As a result, streams may overflow their banks onto adjacent areas, causing flood problems for people. If people were not here, there would be no flood hazard! Flooding is the most universally experienced natural hazard that we face. With this in mind, we will focus on Mission Creek, which flows through the heart of our city and has a no-

torious flood history. In the past 50 years, flooding of Mission Creek has occurred at least once each decade, often twice.

It is inspiring to read about coastal rivers by authors such as Steinbeck, who wrote some inspirational words about the Carmel River. The land definitely talked to Steinbeck. There are descriptions in Steinbeck's works that are applicable to Mission Creek. Mission Creek is everything a small mountain stream should be. It begins in the Santa Ynez Mountains, only a few miles above the city, and flows through a series of boulder rock pools that harbor trout to the piedmont area near Rocky Nook Park and the Santa Barbara Museum of Natural History. At this location, it emerges from the mountains with less regular flow, but potential for much higher flows. Along its banks, even amidst our homes, skunk, raccoon, coyote, mountain lions, and deer are not all that uncommon, and, in the winter, steelhead trout attempt to make their way to their mountain spawning grounds in its waters. In recent years, large adult steelhead trout and juvenile fish have been observed in lower Mission Creek. One resident near the creek close to Bath Street revealed that, when he first saw a 29 inch fish, he thought about catching it for a fish dinner. After a second thought, he called Fish and Game and protected the fish for others to see, especially children (Fig. 2.18). Upstream, in 2006, a 2 pound steelhead trout was observed in Rattlesnake Creek, the major tributary to Mission Creek. If you want to observe young trout, some of which will attempt to migrate to the ocean, visit the pools behind the Museum of Natural History, where you can learn more about these magnificent fish. There is water all year long there, in part because the creek flows along the Mission Ridge fault, which forces water to the surface. The city also adds water to the creek in especially dry years to protect the fish. This part of the creek is where Mission Creek makes a not-too-mysterious

bend to flow west (because it is diverted by the uplift of Mission Ridge), before it turns south again to the ocean. Some of the first signs of potential bank instability and flooding can be seen along the banks of Mission Creek near Oak Park. This park is one of the few places where there is anything approaching a floodplain along Mission Creek, and there is evidence (consisting of rock structures and crumbling concrete pads in the channel) of past attempts to control bank erosion and help speed the waters toward the ocean to reduce flooding. In wet years, Mission Creek at Oak Park is a magnificent creek with long and deep pools, perfect for fish to rest in on their journey upstream to their historic spawning grounds (Fig. 2.19).

Why isn't there a floodplain along Mission Creek? Probably, the main reason is that we are not dealing with a river valley with a flat-bottom floodplain, but a cone-shaped alluvial fan that heads near the Santa Barbara Mission. Most of the city of Santa Barbara is sited on the alluvial fan constructed by Mission Creek after it leaves the mountains near the Mission. Alluvial fans have a particular type of flooding that has been named, not surprisingly, "alluvial fan flooding". Alluvial fan flooding is characterized by uncertain flow paths in a variety of channels that may lead to rapid movement of channels through time and a lot of overland flow that can be relatively swift, but often fairly shallow. This type of flooding is a problem to people living on alluvial fans, and, so, they attempt to channel the stream. That has been the case with Mission Creek, where stream channelization has occurred near Highway 101. In some places, the channelization is a concrete-lined channel (Fig. 2.20), and, in others, it is a channel protected by various types of floodwalls, with channel straightening and other activity. In spite of all our attempts to control the flooding of Mission Creek, during storms when there is a lot of runoff, the water often spills out



Fig. 2.18a. Male steelhead 27 inches long in summer of 2004 in lower Mission Cr. Fish died before it could return to the ocean. Courtesy of Mark Capelli



Fig. 2.18b. Female steelhead (30 in.) in lower Mission Cr. 2008, note small male. Courtesy of Mark Capelli

and across parts of the alluvial fan. This process is particularly noticeable where the stream crosses Haley Street and further downstream, near the railroad station, as well as a little bit upstream near Cottage Hospital. The flood hazard along Mission Creek is particularly serious because development has taken place right up to the edge of the channel. Therefore, schemes to try to control the flooding have very little wiggle room (Fig. 2.21). A flood channel through a city should be designed to contain a 100 year flood (the level of flood water or discharge in cubic feet per second of water expected to be equaled or exceeded on average every 100 years). The probability of a 100 year flood occurring in a given year is 1%. If a 100 year flood



Fig. 2.19. Winter pool in Mission Cr, Oak Park (2005)

occurred last year, the probability of a 100 year flood this year remains at 1%. It's like throwing a die. If you want to throw a 6, there's one chance in six you'll get that number. You could also possibly throw three 6's in a row. Similarly, it's possible to have several 100 year floods in subsequent years. One of the problems in Santa Barbara is that the flood channel through the city only holds a flood flow with a return period of about 10 years (the 10 year flood has a probability of 10% of occurring in a given year). Therefore, flooding is a regular and recurring problem in Santa Barbara.

Some of the larger floods to occur recently in Santa Barbara are those of 1992, 1995, 1998, and 2005. Two floods, which occurred in January and March of 1995, are noteworthy (Fig. 2.22). The



Fig. 2.20. Channelized Mission Cr. near U.S. 101 (2007)

January event caused the most damage to the City of Santa Barbara. The storm that produced the flood had a low intensity of rainfall in the city, but had a long duration. For one eight-hour period, over 5 inches of rain fell. This was a storm with a return period of 125 years. That is, the storm exceeded the 100 year event for the eight-hour duration of rainfall. The flow in Mission Creek was not a 100-year event, but closer to a 30-50 year flood. Floodwaters backed up in many locations, especially in the old lagoon at Cesar Chavez Street (formerly Salsipuedes) near the railroad tracks. Floodwaters exceeded 4 feet in depth near the intersection of Yanonali and Cesar Chavez streets. Some of the water was overflow from Mission Creek near lower State Street that backed up into the old lagoon. Most of the floodwaters in the old lagoon were nearly clear water, that is, with little sediment (it is the sediment that makes storm water brown). The clear water suggests that the source of most of the floodwater in the old lagoon was from urban sources associated with the Laguna Drain, which drains part of Mission Ridge. Major flooding also occurred in Goleta from the January storm. Carneros and San Pedro Creeks flooded from Calle Real south through the Goleta Slough, and San Jose Creek caused flooding to parts of downtown Goleta. Santa Barbara Airport was inundated and remained closed for three days. Thousands of cu-



Fig. 2.21. Mission Cr. 1978. Courtesy of Santa Barbara Flood Control District



Fig. 2.22. Mission Cr. Flooding State Street buildings in 1998. Courtesy of Santa Barbara County Flood Control District

bic yards of mud and debris were deposited in peoples yards and on public roads.

The storm that produced the floods of March 1995 was very different from the January 1995 flood. The rainfall in March was of short duration, but very intense (1.6 inches in a 30-minute period, and 3 inches per hour in some locations). Such

intensity only occurs on the average of every 200 years. In one three-hour period, over three inches of rainfall occurred (an 85 year event). Goleta again experienced major flooding. San Jose Creek went over bank at Hollister Avenue, flooding much of downtown Goleta. At one used car dealership on Hollister, several cars floated off the ground and others were damaged by high water and sediment. Mission Creek caused less damage than during the January storm, but Sycamore Creek flooded parts of Santa Barbara damaging many homes, bridges, and a trailer park. One man in Sycamore Canyon was swept to his death as flood waters inundated his home on Sycamore Canyon Road.

The winter of 1997–1998 brought record rainfall to Santa Barbara. Nearly 47 inches of rain fell in Santa Barbara, which is 260% of normal average rainfall. It was an El Nino year, and, in the 1997–1998 winter, El Nino became a household word for storms and floods in California.

The flood hazard related to Mission Creek in the city of Santa Barbara is made worse because we have urbanized the land, and urbanization changes the hydrology of a drainage basin. This is certainly the case with lower Mission Creek. As houses are built and there are more roads and parking lots, the portion of the drainage that is impervious—or does not allow infiltration of water—increases. Because the water has to go someplace, it runs off quicker and enters storm drains that eventually go into Mission Creek. As a result, with urbanization, the lag time between when most of the precipitation falls and when the flood peak occurs gets shorter and shorter through the city portion of the creek. Most of the water is generated in the mountains and much of the water that results in the flooding comes from the upper, steeper reaches where there is more precipitation and the intensity is greater. However, the urbanization component can be considerable, particularly for lower Mission

Creek and what is known as the Laguna Drain.

Laguna Drain is a drainage system (canal) that allows water to flow through the old lagoon or salt marsh that was present during prehistoric times. I discovered some of these old channels through the city when we were involved with a lawsuit due to flooding in the old lagoon. In 1995, the water reached several feet, and a number of businesses were flooded. One of these was a moving and storage company, and they had an insurance policy that said that they were not covered for flooding unless the floodwaters resulted from the blocking of a drain. It is all but certain they were referring to flooding that would occur within a building, say, from a sink or toilet backing up, but it was a poorly written policy and, in fact, the flooding that occurred in their area was partly the result of the backing up of water from Laguna drain. When the floodwaters rose, a drain became plugged or closed. Water then backed up in parking lots and inundated buildings in the lower part of the old lagoon, particularly near where the railroad tracks cross Cesar Chavez Avenue. The lawsuit was settled and the company was paid damages, but we suspect the writing of the policies has since been changed to not include back up from drains outside the actual building. The lesson here for the insurance companies was to be careful how they write their policies with respect to flooding. The lesson to those in flood prone areas of the city along Mission Creek or in the old lagoon is to be prepared. Flood insurance is an option, but the best preparation is to flood-proof your property. The ways to flood proof buildings are well known and straightforward. Where floodwaters are only expected to be a few feet deep, buildings can be raised or flood proof doors can be installed. Several newer buildings in the old lagoon area are protected from floods (Fig. 2.23). Flood-proofing has been an option used near Mission Creek where it passes Haley Street. Some older homes were constructed several feet above ground. A really big flood

may still be a problem, but more common floods are less likely to cause damage. Bank erosion remains a potential hazard for some buildings right on the banks of the creek. They may become undermined during floods and collapse.

A final problem related to urbanization and flooding is ocean pollution. At first, these may not sound like they could be related, but, if you think a bit about the water flowing through and out the city, the implications are fairly straightforward. Our city streets harbor all sorts of trash, oil drippings from cars, organic material, and waste from dogs, cats, and other animals. Pollutants include pesticides; nutrients, such as nitrogen and phosphorus; and fine sediment from soil erosion and bacteria. Bacteria bring in threats of a variety of diseases, including stomach cramps, vomiting, diarrhea, and even hepatitis. When it rains, all of this material enters storm sewers and our creeks. From there, it's a very short journey to the ocean. As a result, during storm periods, a lot of water comes out of the creeks into the ocean, and that water is often polluted. The water from the mountains and floodwaters that enters the city is relatively clean (except for poison oak oil), but the water emerging from the city is very different in its composition. As a result, it's a good idea not to go swimming in the ocean shortly after floods.

The quality of water from the streams and the quality of water on the beaches is regularly monitored. Santa Barbara beaches that have periodic pollution problems include Goleta Beach, Arroyo Burro Beach, and East Beach. In 2005, there were about 650 beach warnings and closures due to bacterial pollution. The cautious person checks

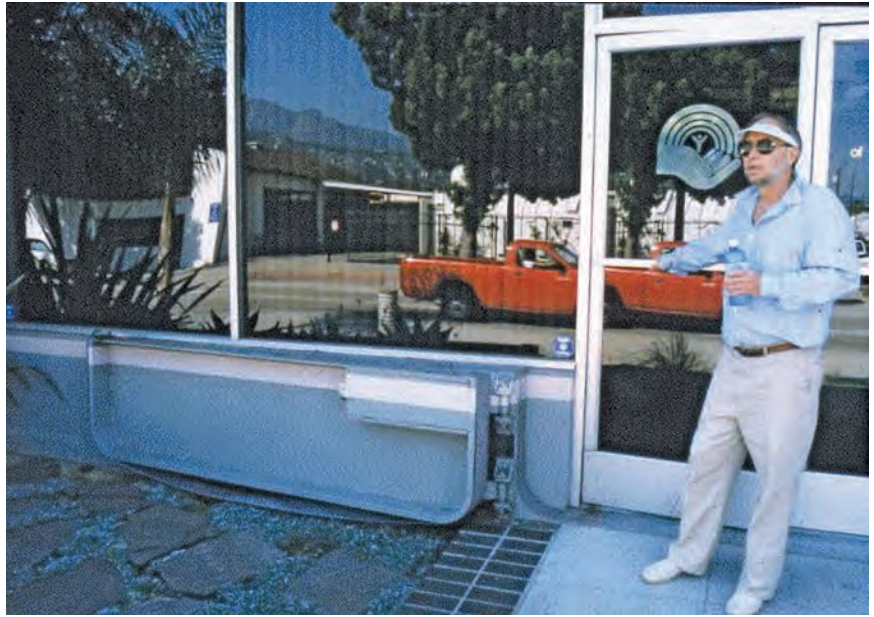


Fig. 2.23. Flood proofing a building in Santa Barbara. The gate closes, keeping water from building (1990s)

for beach closures as a result of pollution before swimming or surfing. Be careful and you can avoid what some locals call “surfer’s ear rot.” The solution to beach pollution is to identify sources of the pollution and to take aggressive action to eliminate pollutants before they reach our beaches. The city and county have clean stream programs and, hopefully, pollution levels will be reduced.

We are especially worried about flooding following wildfire. Runoff following wildfire can be much greater than for pre-fire conditions. Without chaparral vegetation, runoff from steep slopes is accelerated and may transport a lot of sand and small gravel that is deposited in stream channels, reducing the capacity of the channel to carry floodwaters. As a result, post fire flooding is a potential hazard, even from moderate rainstorms. Transport of coarse sediment, including large boulders (several feet in diameter), in debris flows is also possible. Large debris flows present a serious hazard. Fortunately, large debris flows do not occur nearly as often in a given drainage basin following wildfire as do increased runoff and transport of finer sedi-

ment that may cause flooding. We are fortunate to have in our area the Santa Barbara County Flood Control District, which works hard following fires to minimize potential flooding as a result of the fire.

Sea Cliff and Beach Erosion: No Place Is Excluded from Ellwood to La Conchita

Beach and sea cliff erosion is not just a Santa Barbara problem; it is a national and worldwide problem. The erosion occurs, in part, because sea levels are rising as a result of global warming, but also because there has been rapid development in the coastal zone. It seems everyone wants to live on the coast and, in some cases, poor land use choices have accelerated coastal erosion. In other places, people developed property that they thought was a reasonable distance from the beach, and, over a period of years as erosion slowly occurred, they have found themselves at a precarious point. This is particularly true in Isla Vista, where the rate of sea cliff erosion is about a half-foot a year, and a number of apartment buildings are on the brink of falling into the sea (Figs. 2.24 and 2.25). The actual rate of sea cliff erosion at a particular site is variable from a fraction of an inch to several inches per year. A number of years may pass with seemingly little erosion, followed by a particular year where the erosion rate may be a foot or more. This results because the driving forces of erosion, which include precipitation on the sea cliff itself, as well as wave erosion at the base, vary from year to year.

The rocks at a particular site on or at the base of a sea cliff in the Santa Barbara area vary in their resistance to erosion. Sometimes fine silt size sediment ($1/16$ th to $1/256$ of a millimeter in diameter, less than a tenth of the diameter of a human hair) is cemented with hard silica, and sometimes with softer calcium carbonate, iron oxide, or tar. In some parts of the Monterey Shale, the fine silt size grains are not cemented at all, but held together

by compaction. Compaction shale is the weakest of all. Compaction shale (Miocene Sisquoc Shale, a bit younger than Monterey Shale) is found in the sea cliff below Isla Vista. The Sisquoc Shale is so soft that you can crumble it in your hand (no wonder Isla Vista has an erosion problem). In other areas, generally east of the Santa Barbara Cemetery, the rocks of the sea cliff are Santa Barbara Sand or Casitas Formation (composed of sediment from sand size to boulders). These rocks are less than one million years old, much younger than the 6 to 18 million year old Monterey Shale. The environmental change from older Santa Barbara Sand (a marine rock deposited in shallow sea water) to younger Casitas sediments (mostly stream and debris flow deposits) is due to increased uplift of the Santa Ynez Mountains that initiated increased erosion on steep mountain slopes with shedding of sediment to the coastal area.

Take a walk at low tide from Arroyo Burro Beach east to Santa Barbara Point at the east end of Shoreline Park and observe the rock (Monterey Shale) near the base of the sea cliff and on the wave-cut platform. During the winter, when sand is stored a bit off shore, you will notice that hard layers (beds) of the Monterey Shale protrude out further and have more relief than do the softer beds. The patterns of erosion on the folded rock are beautiful. The smallest difference in rock resistance (often with different colors of rock for different beds) is amplified over time. The end result is a balance between erosion and rock resistance in a dynamic beach environment.

Isla Vista is one of the poster children of coastal erosion along the California coast. The erosion there has occurred over decades, to the point that some of the properties have had to be moved back and others are in a precarious position relative to the edge of the cliff. That wasn't the case decades ago when they were built, but coastal erosion has



Figs. 2.24 and 2.25. Coastal erosion in Isla Vista threatens apartment buildings (2007)

a way of continuing over time, regardless of what we would like. When the erosion has gotten to the point that is deemed a hazard, many people look for a technological fix. They say, “let us build a sea wall, and we can stop this erosion in its tracks.” They want to draw a line on the top of the sea cliff and say, “erosion shall go no further.” When a sea wall is constructed at the base of a sea cliff, it can slow down some of the erosion from that end of the system. This is often done at the expense of the beach, which will narrow over a period of decades (Figs. 2.26 to 2.28). Unfortunately, the top of the cliff is not protected (unless the sea cliff is low and a wall extends top to bottom), and, so, bluff-top erosion continues over a relatively long period of time, even after a wall is put in place. As a result, by the time the base of the sea cliff is protected, the top is in a precarious position, and the wall does little to help the situation at the bluff-top, where homes experience erosion problems as oceanside gardens narrow and patios may crumble into the sea. Furthermore, sea walls, whether rock, wood, or concrete, are unsightly and are frowned upon by the California Coastal Commission because of their known tendency to eventually result in loss of or restricted access to the beach, as well as decreased biological diversity of the beach ecosystem.

There are several processes of coastal erosion that occur on sea cliffs. The one that’s most apparent to people is the erosion at the base from the wave action. During years when there are particularly large waves attacking the sea cliff, the base of the cliff may become undermined, and a wave-cut notch may form. A particular well-developed wave-cut notch is located on the beach at the mouth of Arroyo Burro Creek (Fig. 2.29). Eventually, the rocks above the notch will fall, and the sea cliff will retreat. Also, during years when there are big waves, there is more rainfall - so more water strikes the sea cliff, and this causes erosion as well. The top of the sea cliff is a particularly vulnerable place because that is where surface water from irrigation and natural or urban runoff may flow over the lip of the sea cliff. If this occurs, a gully will form that will accentuate erosion. Because of development from houses, roads, parking lots, and so forth, the total amount of runoff has increased; if this water is allowed to flow over the face of the sea cliff, then erosion may be accelerated. That is why you see so many pipes and flexible plastic drainpipes draped over the sea cliff where there are houses or other development. The idea is to collect the storm water runoff and direct it to the base of the sea cliff rather than over the cliff where it can accelerate erosion.

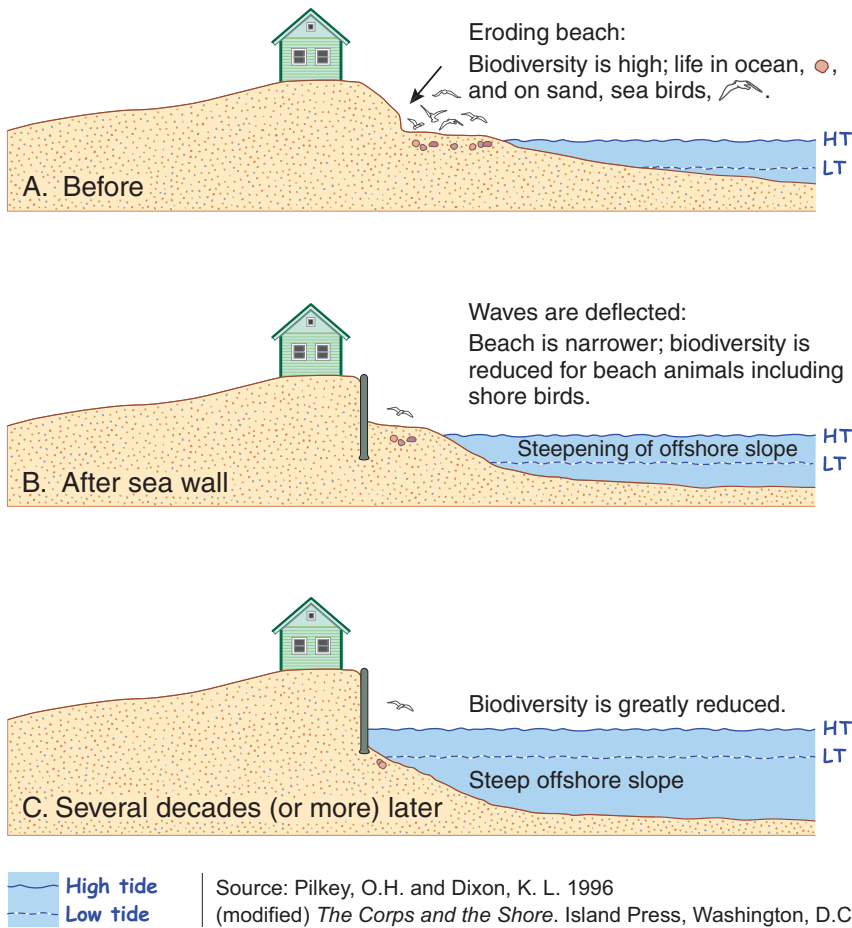


Fig. 2.26. Effects of a sea wall over time.



Fig. 2.27. Sea wall near Summerland (2007).

Walking along the beach below a sea cliff, many broken and corroded drainpipes are encountered. The ocean is a harsh environment, and, as boat owners know, frequent maintenance is necessary to maintain a boat. Drainpipes are no different than boats, but the dock (analogous to the sea cliff) is also eroding.

Near the base of the sea cliff, but as much as about half way up, other processes are operating that also cause erosion. Wetting and drying from the salt water splashing on the sea cliff is a process that can loosen rock, causing it to disintegrate and erode. Also, often near the base or partway up the cliff, water flowing through the rocks often emerges on the face of the sea cliff as seeps or springs, and seepage forces enhance erosion. The process is called “spring sapping” (Fig. 2.30) and is common along the sea cliffs of the Santa Barbara area.

The sea cliff environment is part of the coastal charm of Santa Barbara. Small, special places are encountered, especially at low tide when the bedrock wave-cut platform is exposed. The sea cliff and how it may be managed to minimize human caused and natural erosion requires a sound understanding of the ecological (physical and biological) processes that form, maintain, and change the cliff over time. Our responsibil-

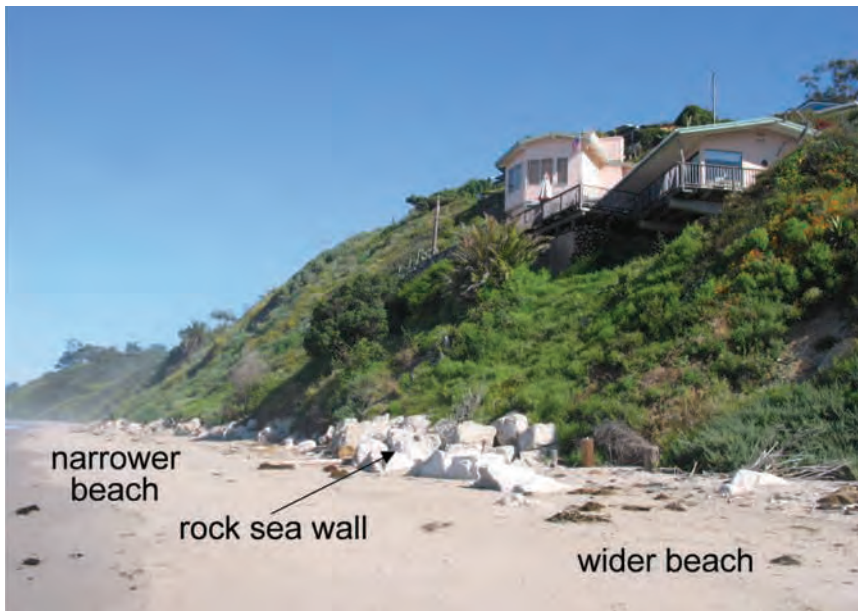


Fig. 2.28a. Rock revetment (sea wall) west of Arroyo Burro Beach (2007)



Fig. 2.28b. Wood piles and concrete sea wall at Isla Vista (2007)



Fig. 2.29. Wave-cut notch at Arroyo Burro Beach (2007)

ity is to implement land use decisions based on science and values. Application of our science and values will assist long term (intergenerational) management of our fragile coastal environment, while insuring public safety in the dynamic environment we call the coastal zone. This is the essence of sustainability with respect to our coast—doing what is right today, so we will have a quality coastal environment in the future.

Beach Erosion: Sand and Surf

Santa Barbara is a coastline



Fig. 2.30. Small seeps emerging from the sea cliff near Arroyo Burro Beach (2007)

of collision between the North American and the Pacific tectonic plates. The boundary, as a line on the map, is the San Andreas Fault, about 40 miles north, across the Transverse Ranges near the Cuyama Valley, but the faulting and uplift from the plate boundary is a zone stretching from a few miles north of the fault, south across the Transverse Ranges to the Channel Islands. Santa Barbara is on the leading edge of the zone, and our coastline is being folded, faulted, and uplifted a few feet per 1,000 years. Our shoreline is the battleground between the land and the sea. Some places, such as La Mesa, Hope Ranch, More Mesa, UCSB, I.V., and Elwood, are emerging from the sea. Other places, such as Carpinteria Slough, lower parts of Santa Barbara, and Goleta Slough, are still winning the battle to remain above sea level, but, with rising sea level over the next century, that could change.

Beach erosion is directly related to sea level change, the topography, and the type of waves arriving at our coastline. The waves that cause beach erosion at Santa Barbara are generated by offshore storms, sometimes thousands of miles away. When storms reach our coast, generally in winter, we are well aware of their power to erode the beach and sea cliff. But let's back up a bit and discuss types of waves.

The three common types of waves (breakers) we observe along our coast are: spilling, plunging, and surging. In addition, there are small edge waves (less than 1 foot high) whose crests travel at right angles to the shoreline and modify beach processes associated with the other waves. Looking toward the harbor from Santa Barbara Point, you can sometimes see edge waves as they run along the beach, helping produce the sinuous (meandering) pattern of the swash line as the other waves (the ones we see breaking in the surf zone) rush up and down the beach face.

Spilling and plunging breakers break in the surf zone. When these waves enter shallow water,

they rapidly increase in height, become unstable, and fail (collapse).

Spilling breakers are common between storms and in the summer. They are present on gently sloping beaches. Spilling breakers have relatively long wavelengths (measured distance from wave crest to wave crest between two successive waves) and relatively long periods (time in seconds between two successive waves breaking in the surf zone (generally 8 to 10 seconds). Spilling waves gently spill (roll over) to expend their energy with a line of cascading bubbles and white foam. They have effective uprush and can rapidly build a beach as sand is transported and deposited from offshore to form the beach berm (the flat part of the upper beach we like to stretch out on in warm weather). Walk the beach at mid-tide, and, if your bare feet sink in the sand an inch or so, the beach is building, probably from spilling waves.

Plunging breakers are generally associated with a steeper beach face than those with spilling breakers. In the surf zone, plunging breakers curl over, and the forward mass of water is thrown toward the beach. These waves are more common in storm conditions and have effective backwash. They tend to be a destructive type of wave that can quickly erode a beach, removing beach berms and sand to expose coarse gravel or bedrock on the wave-cut platform. During storms with large plunging breakers, the waves attack the bedrock wave-cut platform and tear up bits of rock that are transported onshore to the beach. After a storm, pieces of rock (from the offshore platform), often with a holdfast (part of the kelp that holds the plant to the rocky bottom) attached, are found on the beach (Fig. 2.31). This is one way rock from the nearshore environment is transported to the beach.

Plunging breakers peak up quickly when approaching the surf zone, and their break may trap

a lot of air and release it with explosive force (several thousand pounds per square foot). Plunging breakers from storms generally have relatively short periods (4 to 5 seconds), and, because they arrive in rapid succession, they can keep sand in motion along the beach as longshore transport, as well as offshore, where sand may be stored in submerged sandbars. As a result of their potentially great power, plunging breakers can cause significant beach erosion. When large plunging breakers peak up and break, they produce a large crashing noise that can be heard hundreds of feet from the beach. If a beach is eroding, you will walk on hard sand at the waters edge. Thus, you can tell if a beach is building or eroding just by walking and feeling with your toes. Sinking in an inch or so means fresh sand has been deposited; hard sand means the beach is eroding.

Surging breakers are most common on a beach with a very steep slope. They peak up as if to plunge, but then the base of the wave surges forward up the beach as the wave crest collapses (wave energy may be strongly reflected). You can see surging breakers in front of the breakwater at Santa Barbara Harbor. An actual beach is almost never present. At low tide, a very narrow beach may be present. Lots of sand moves along the coast in front of the breakwater but doesn't form a beach, as it does to the west at Ledbetter Beach (in front of the western end of City College). The breakwater is a type sea wall, reflecting wave energy and keeping sand in motion. A beach can only form if sand can be deposited and stored for a while.

Beach erosion is directly re-

lated to the flow of sand along the beach. If more sand is moving into a stretch of beach than leaving it, the beach will grow. Conversely, if more sand is leaving than coming in, erosion will occur. Waves arriving at a beach are seldom perfectly parallel to the beach. Dominant wave action along the Santa Barbara consists of waves approaching from the west and north. The angle the incoming waves make with the beach points west. This produces a component of wave power to the east, moving sand in the surf and on the beach eastward. Sometimes, storms bring waves from the south, and the direction of sand transport is temporarily reversed from the dominant eastern transport to the west. Most of the sand moves as a "river of sand," where one bank of the river is the upper beach face, and the other bank is the outer edge of the surf zone where waves peak up and break.

Waves coming from several different storms and striking a coast produce a rhythmic surf beat (I call it the rhythm of the beach). Take some time and sit on the shore and time waves striking a rocky



Fig. 2.31. Kelp with holdfast attached has been washed up on beach during a storm. This is one way rock eroded from the near off shore is transported to the beach.

point or breaking in the surf zone (measure the time between each arrival of a wave (in other words, the wave periods). Do this for 100 waves and record your results—you will record a regular repeating pattern or surf beat. Perhaps it will be 4 short period waves (periods of 6 seconds), followed by 7 long period waves (10 second period waves), then 3 waves with an intermediate period (8 seconds). Then the whole pattern is repeated again and again. A large number of patterns are possible. Use your imagination and put the surf beat to music, thus capturing an example of natural Earth music.

Surf beat produces the variability of wave height or wave sets we observe from the shore or on a surfboard. Actual wave height depends on shoreline and offshore topography. Rocky points cause waves to concentrate their energy and increase in height, compared to the coast between points. A delta where coarse sediment delivered from a stream or river accumulates in the nearshore also may cause wave height to increase (as, for example, Rincon Point, produced, in part, by Rincon Creek).

Beach conditions (erosion and deposition) change with the tide. High tide may erode the upper beach a bit, and, with falling tide, deposition may occur. Grunion (a small, sardine-size greenish–silver fish) take advantage of this and ride waves in at the highest tides during spring and summer months to spawn on the beach. Eggs are buried, only to be exposed at the next high tide. Observe grunion - but it's not kind to disturb a little fish trying to procreate on the beach in the moonlight!

The point where the land meets the sea is almost always dynamic and is an ever-changing environment. Linkages between waves a coastline receives and geologic, hydrologic, meteorological, and biologic processes determine the position of the shoreline at a specific place and time. Grunion (and other fish), sand crabs, seabirds, marine mammals, and people all use the beach. People can

make conscious choices about the future of the coastal zone that may determine the future of other living things we share the beach with. Aldo Leopold (a famous conservation biologist) summed it up in 1949 in writing “The Sand County Almanac.” Leopold argued that an action is right and ethical if it maintains the integrity, stability, and beauty of entire ecosystems that collectively represent the total environment; otherwise it is wrong. An ecosystem is an ecological community (a set of interacting species living in the same place) and its non-living environment (soil, rock, and water) where energy flows and chemical elements cycle. The coastal zone has several ecosystems. Some ecosystems are not much affected by human processes, others are made by humans, and most are a mixture (examples are beach, sea cliff, lagoon, sand dune, sand spit, harbor, and funk zone). Leopold's wise words serve as a guiding principle for planning, making decisions, and managing the dynamic, variable, and unique Santa Barbara coastal environment.

Santa Barbara: A Radon Hot Spot

Radon gas is a naturally occurring radioactive gas that is colorless, tasteless, and odorless. When present in our homes, radon gas can produce a health hazard and is the second-leading cause of lung cancer (Table 2.3). Uranium bearing rocks, such as granite and organic rich shale, are sources of radon gas. Uranium is a natural element found in some granite. Organic rich shale, as well as some sandstone, tends to trap and concentrate uranium as groundwater and other fluids (for example, oil and natural gas), and the fluids that contain uranium move through and chemically interact with rock. Radioactive decay is a natural process that results in the emission of radioactive particles or gamma radiation, similar to medical X rays. Each type of radiation has a particular set of characteristics and potential hazards. Uranium -238 is a

Radon Risk If You Smoke			
Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop smoking and...
20 pCi/L	About 260 people could get lung cancer	250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L	About 3 people could get lung cancer	(Average outdoor radon level)	
Note: If you are a former smoker, your risk may be lower.			
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).			
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.			

Radon Risk If You've Never Smoked			
Radon Level	If 1,000 people who never smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO:
20 pCi/L	About 36 people could get lung cancer	35 times the risk of drowning	Fix your home
10 pCi/L	About 18 people could get lung cancer	20 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 15 people could get lung cancer	4 times the risk of dying in a fall	Fix your home
4 pCi/L	About 7 people could get lung cancer	The risk of dying in a car crash	Fix your home
2 pCi/L	About 4 person could get lung cancer	The risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 2 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult.)
0.4 pCi/L		(Average outdoor radon level)	
Note: If you are a former smoker, your risk may be higher.			
* Lifetime risk of lung cancer deaths from EPA Assessment of Risks from Radon in Homes (EPA 402-R-03-003).			
** Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.			

Table 2.3. Risk from radon gas. After U.S. EPA

radioisotope of uranium that undergoes radioactive decay with a half-life of 4.5 billion years. The half-life is the time required for one-half of a given amount of a radioisotope to decay to another form. The 238 refers to the number of protons and neutrons in the nucleus of a Uranium-238 isotope, in this case 92 protons and 146 neutrons (all isotopes of uranium have 92 protons, but they can have a different number of neutrons). After several

decays, Uranium-238 decays to Radium 226 (half-life 1600 years) and then to Radon 222 (half-life 3.8 days), which is a gas that can move up through soil or rock to enter our homes. If you breathe in Radon 222, it may decay in your lungs to Polonium -218 (half-life 187 seconds). Marie and Pierre Curie discovered radium and Polonium in the late 1890s. Madam Currie died of radiation-induced cancer, and her laboratory remains sealed

to this day. Polonium -218 is a solid and may be attached to other particles in the air and be inhaled deep into the lungs where radioactivity may cause damage to DNA. What can happen is that Polonium-218 may be trapped in the lungs by sticky mucus on the surface of the bronchial airways of the lungs. Basal cells may be damaged by alpha radiation particles as Polonium -218 undergoes radioactive decay. The radiation can cause breakage of strands of DNA in basal cells. If both strands are broken, damage may be permanent, resulting in mutations. The mutations, by themselves, probably do not cause cancer, but they are linked to processes of initiation of the disease, which may later be promoted by exposure to chemicals, such as those found in cigarette smoke and other air pollution sources. The risk of contracting lung cancer from radon, if the EPA is correct, is about the same as the risk of dying in an automobile accident. Children are more susceptible to radon, and the risk increases significantly if you smoke.

The risk from exposure to radon gas varies with the dose. The concentration of radon is measured in terms of the number of radioactive decays per second. The main producer of radon gas in the Santa Barbara area is the Rincon Shale, which is Miocene, about 20 million years old. The rock is a dark shale, composed of small particles of silt and clay with organic material deposited in the marine environment. Organic material in the Rincon Shale tends to accumulate uranium, which eventually decays to radon gas.

Santa Barbara is one of the radon “hotspots” in the western USA, and the county is one of two in California recognized to have high radon potential. Uranium in the Rincon Shale and soil derived from the shale decays to radon gas that may rise and enter homes through cracks in the foundation.

The process that pushes radon gas into buildings is the stack or chimney effect. The effect is

similar to a fire in your fireplace. Hot air from burning wood or natural gas is lighter and rises up the chimney. The air is replaced by cooler air drawn in from the house and outside. Warm air in your home also rises because it is lighter. That is why the upper story of a home and the attic may be warmer and requires ventilation to avoid a build up of warm air. As the warm air moves up and out through the roof, cooler air from the soil and rock below may rise to replace the warm air. Radon gas, if present, will move up with the cooler air. Concentration of radon gas is generally lower in basements or lower floors, as well as in poorly vented closets or rooms. Those are the places to test for radon, in order to determine the worst possible case.

Radon gas is an environmental health hazard that can't be blamed on any company or group of people or anything we have done or not done to the environment. The gas enters our homes, schools, and other buildings from natural, site-specific, geologic processes.

Homes built on Rincon Shale, from Summerland to Goleta, may have elevated concentrations of radon gas. Testing suggests that over one-third of homes built on Rincon Shale may have a radon hazard. Some of the concentrations that have been measured in Santa Barbara are 10 to 25 times higher than what is deemed safe by the Environmental Protection Agency (Fig. 2.32). Areas where high radon has been measured in homes include parts of Mission Ridge, the Mesa Hills, and Summerland, where Rincon Shale is exposed at the surface. One home in the Mesa Hills that had high levels of radon was built on Santa Barbara Sand, where the sand is thin and overlies Rincon Shale. The radon from the shale below moved up through the porous sand to enter the well vented home, which had a central garden open to the air. Very high levels of radon were identified beneath the home. When these were vented with pipes to the air, the

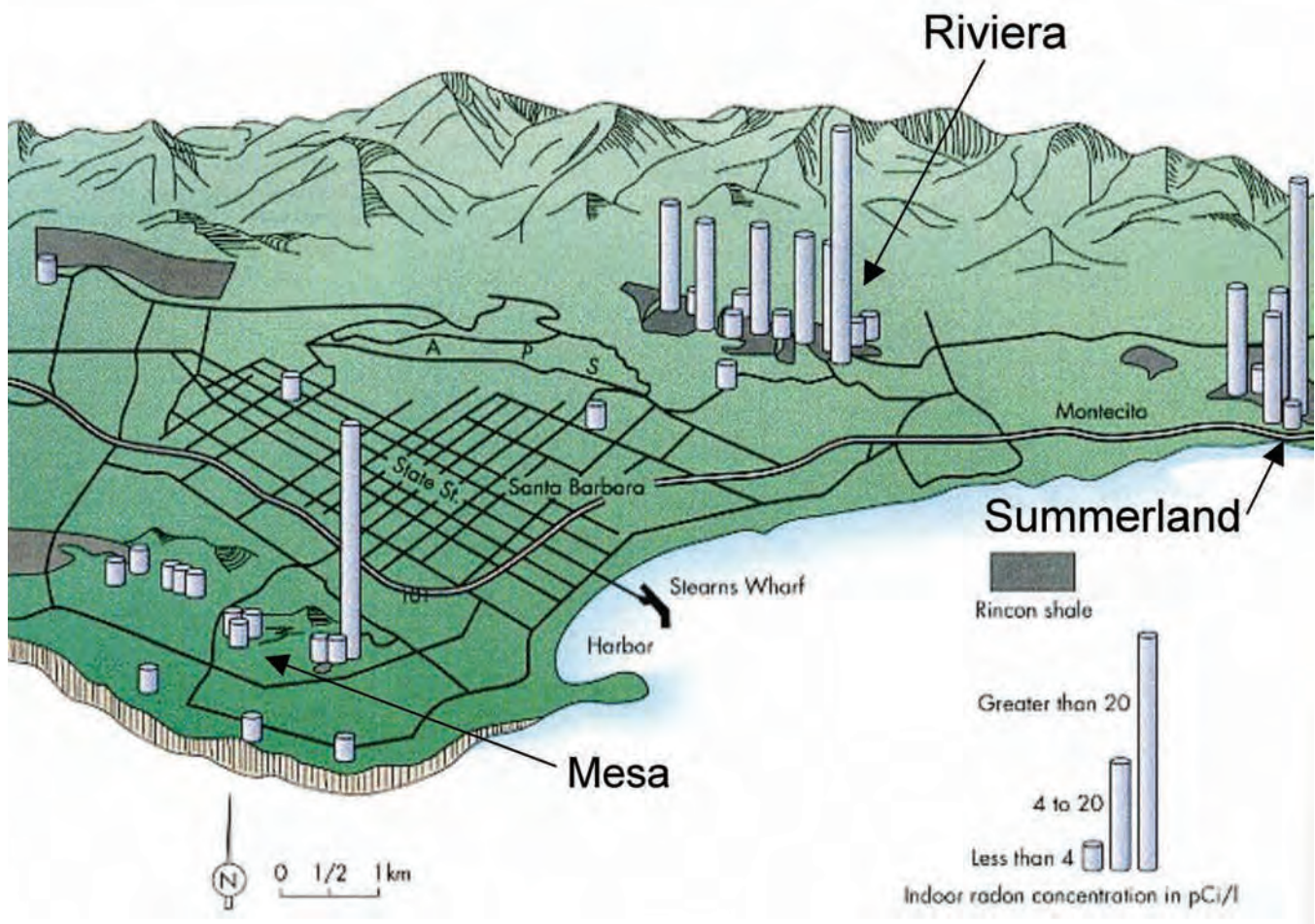


Fig. 2.32a. Radon in Santa Barbara. Most problems are near the Rincon shale. Radon is a problem easily fixed in homes.

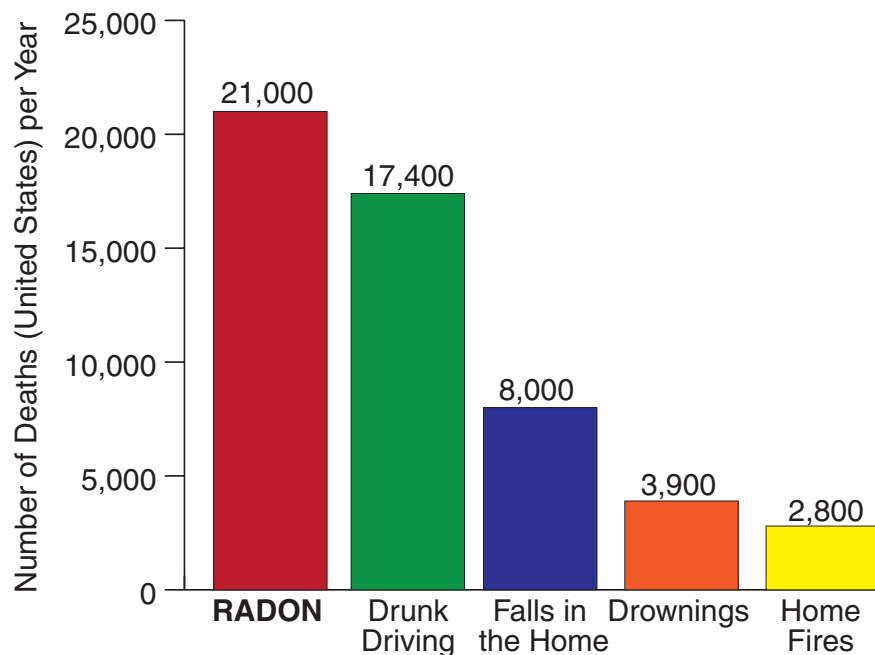


Fig. 2.32b. Source: U.S. EPA, 2007

radon concentration dropped to a safe level in the home. Some homes with moderately elevated concentrations of radon were found in Goleta, south of Cathedral Oaks Road, where earth flows may have delivered radon contaminated sediment from upslope Rincon Shale in the distant past.

There is concern that granite countertops, so popular in kitchens today, are contaminating homes with dangerous levels of radon gas. Granite does have uranium in some of the minerals that make up the rock. Granite rock with fracture zones that allow radon gas to migrate upward have been recognized in southern Virginia as a localized radon hazard. The important observation is that, in order to move up from soil and rock into our homes, radon gas needs pathways, such as fractures in the rock or open spaces between soil particles. Granite that is used in countertops is not very porous. If the rock has open fractures, it will break easily and can't be used for countertops. Therefore, even though granite has some uranium in the rock, it will generally yield very little radon gas. Radon entering homes from the soil beneath homes over weathered uranium bearing rocks (granite or sedimentary rock such as the Rincon Shale) is a significant public health risk. However, according to the U.S. Environmental Protection Agency, the risk from granite countertops or other building materials is not thought to be a serious problem. I would not be afraid to have granite countertops in my home, but I certainly would test any home I purchased for radon coming from any possible source before signing the dotted line.

In conclusion, there is good news and bad news regarding radon in Santa Barbara. The bad news is that we are in a hotspot for radon gas, and we need to be more conscious of the potential hazard. The good news is that radon gas is easy to detect and measure, and remedial measures for lowering the amount of gas in homes to a safe level are relatively inexpensive, at least compared to the price

of homes in Santa Barbara. When people ask for advice concerning radon, the most conservative approach is to assume that it's a possibility. For homes built on the Rincon Shale, approximately one-third or more will have elevated concentrations of radon. In other areas, it is much less clear. Therefore, it is recommended that you do an inexpensive test for radon in your home, or as part of your evaluation when purchasing a home.

Death Star: Extraterrestrial Impact

Earth being struck by a large extraterrestrial (ET) object, such as an asteroid (a metallic or rocky object) or a comet (a weak, porous mixture of frozen water and/or carbon dioxide plus small rock fragments that is sometimes called a dirty snowball) traveling at about 20 miles per second (about 150 times as fast as a jet airline) could be a death sentence for much of the life on Earth (Fig. 2.33). We believe that a large asteroid (about 6 miles in diameter) ended the domination of dinosaurs 65 million years ago, producing a mass extinction of life on Earth. Smaller objects are more common. On June 30, 1908, at about 7am, a small ET object about 120 ft. in diameter exploded above a remote spot in Siberia. Equivalent to 10 megatons of TNT, the event flattened and/or burned the forest over an area of more than 770 square miles. If the explosion had been over Paris, New York, or Los Angeles, the cities would have been destroyed. This is the ultimate natural hazard!

Santa Barbara, along with most of North America, Mexico, and part of South America may have experienced a catastrophic ET event 12,900 years ago. If it did, a fireball, violent winds, and wildfires rolled through our area to beyond the Channel Islands.

North America was ecologically different 13,000 years ago, when it was populated by Pleistocene megafauna that included mammoths (a type of elephant - a miniature version, called a pygmy mam-

moth, about the size of an American Bison lived on the Santa Barbara Channel Islands), dire wolves, American lions, short-faced bears (larger than modern grizzly bears), giant ground sloth, camels, and horses. Also present were Paleo American Indians, including the Clovis culture. Suddenly, and, perhaps, catastrophically, most of the megafauna disappeared, and the Clovis culture was no longer recognizable.

As a side story of local importance, the most complete skeleton of a pygmy mammoth ever discovered was on Santa Rosa Island in 1994 by Professor Tom Rockwell of San Diego State University. Tom was one of my first PhD students and is famous for his earthquake geology research in California. I am very proud of Tom's many accomplishments. Tom told me he discovered the pygmy mammoth skeleton when he saw part of the skeleton (including a tusk sticking out of the ground) exposed by erosion while heeding a call of nature. Great discoveries may be made by careful observa-

tion at such opportunistic times!

Returning to our story, the climate abruptly cooled about 13,000 years ago, and the ensuing cold period that lasted about 1,000 years is known as the Younger Dryas (YD), named after tundra fossil pollen of the dryas plant. The YD occurred suddenly during a period of warming when glaciers worldwide were melting, plunging Earth back into cold conditions. The possible causes of the extinction of the megafauna and the termination of the Clovis culture have been a long-standing, controversial subject. The two major competing hypotheses to explain the extinction of the megafauna are: 1) overkill by humans; and 2) abrupt cooling (very rapid climate change). Both of these hypotheses have shortcomings. Human overkill seems unlikely in light of the very large numbers of animals that went extinct, including many that the Paleo Americans evidently did not regularly hunt. The magnitude of the abrupt cooling at the onset of the Younger Dryas was little different than what often occurred over the previous 80,000 years, and none of these earlier events were associated with major extinctions. The conclusion is that the extinction of Pleistocene megafauna 12,900 years ago was too abrupt and widely distributed to have resulted from human overkill or climatic cooling.

At many Clovis sites, archeologists have identified what is known as a black mat, a thin layer of carbonaceous dark organic-rich clays. The base of the black mats coincide with the beginning of Younger Dryas cooling, after which there is no evidence for "in place" remains of the mega fauna or artifacts from the Clovis culture. Murray Springs in Arizona is a well-known and studied Clovis site where the youngest mammoth bones and Clovis tools are directly in contact with the base of the black mat. At that site, according to Professor C. Vance Haynes (University of Arizona), it is apparent that the death of Pleistocene megafauna and



Fig. 2.33. Idealized ET impact, from NASA

the Clovis culture was very sudden, occurring when the black mat was deposited. New evidence has emerged in the last several years that suggest that there may have been an extraterrestrial (cosmic) impact 12,900 years ago that contributed to the Pleistocene megafauna extinctions, as well as to the disappearance of the Clovis culture. Evaluation of 10 Clovis sites, selected because they were well documented and dated, supports the hypotheses that there may have been a major extraterrestrial collision over North America 12,900 years ago. That event is termed the YD event.

Hypothetically, the YD event, according to studies by Professor James Kennett (UCSB) and his son Professor Douglas Kennett (formerly a PhD student at UCSB and now a professor at the University of Oregon), along with numerous other scientists, consisted of one or more (perhaps many) low-density extraterrestrial objects (probably comets) that exploded widely in the atmosphere over North America. At that time, much of Canada was covered by the Laurentide Ice Sheet, which was partially destabilized by the proposed event. It is speculated that many objects exploded over the continent, including the ice sheet, setting off heat flashes and shock waves with intense winds (several hundred kilometers per hour) that traveled across North America. The event also would have spawned fireballs that moved across the landscape, destroying forest, grasslands, and animals, while producing an abundance of charcoal, ash, soot, and toxic fumes.

Physical evidence for the YD event includes the discovery of a variety of possible extraterrestrial markers, including magnetic grains with iridium, magnetic micro spherules, carbon spherules, iridium, charcoal and soot, and evidence of intense wildfires. Also, large numbers of very small nanometer diamonds (where $1\text{ nm} = 10^{-9}\text{ meter}$, 0.000000001 m , or 25 millionths of an inch) have been discovered at the YD boundary, but not above or below. The

type of nano diamonds discovered is normally interpreted to be formed only by cosmic impact. Two other types of very small diamonds, likely produced by cosmic impact, have also been discovered.

Evidence for wildfire, with a black mat interpreted to likely be associated with the ET event, was found in Arlington Canyon (called the Arlington Springs Site) on Santa Rosa Island. Dr. John R. Johnson, with the Santa Barbara Museum of Natural History, along with Douglas and Jim Kennett, are members of a team studying the site where skeletal remains (two thigh bones collected from a 13,000 year old person (previously believed to be bones from a Clovis Age woman, which are now thought to be from a man) were discovered almost 50 years ago. Arlington Canyon has two sites that have been studied. One has a charred pine log dated at 13,000 years. Evidently, there was a pine and cypress forest on Santa Rosa Island 13,000 years ago. The Arlington Springs Site is yielding evidence of catastrophic, island-wide wildfire and ecologic disruption along with carbonaceous material that date to the beginning of the YD.

Discovery of a very young 2.5 mi diameter crater in the Gulf of St. Lawrence was announced in 2011. The age of the impact is estimated to be about 12,900 years old.

As the hypotheses of the YD event continue to be tested, more data will be forthcoming, and we will learn more about the catastrophic event that brought about the demise of the Pleistocene megafauna and the Clovis culture and which caused the climate to change from warm to cold glacial conditions that lasted for about 1300 years.

We are learning that we remain more connected to the larger ET environment than we previously thought. We look to the stars with reverence, awe, and a sense of wonder of what might come.

Adjustments To Natural Hazards

The appropriate response to natural hazards involves the recognition of several principles. First, we need to recognize that natural hazards are predictable, due to scientific investigation. That is, we know where these hazards are likely to occur, and we can make maps that indicate relative hazards for processes such as earthquakes, landslides, and floods. Secondly, consequences of natural hazards can be predicted and minimized. We know enough about natural processes and what happens during hazardous events that we can recognize potential consequences and plan appropriately. What it comes down to is what is appropriate. Too often, the way we deal with hazardous events is primarily reactive. Following a disaster, we quickly go to the mode of search and rescue, firefighting, and providing emergency food, water, and shelter for people. While these are all worthwhile activities and need to be done to reduce loss of life and property, we need to move to a higher level of consciousness concerning natural hazards. This requires anticipating disasters and their effects. When we take this approach, we encourage proactive adjustments, such as land-use planning that would limit construction in areas where hazards occur or designing hazard-resistant construction. The choice of land-use planning is the environmentally sound adjustment to hazards. People can avoid building on active landslides, on floodplains, or along active faults. We can also make better use of flood-proof construction. With respect to sea cliff erosion, we can require adequate setbacks to ensure that a planned or desired amount of time will pass before erosion again becomes a problem. Other types of anticipatory reactions include insurance and disaster preparedness. Important aspects of disaster preparedness include plans for evacuation, stockpiling of materials needed following a disaster, and education of people concerning natural hazards.

Attempting a technological fix is another an-

ticipatory response to hazards. We have made many attempts to control natural processes, such as landslides, floods, and coastal erosion, with mixed results. Properly designed retaining walls can minimize a particular landslide hazard, and construction of rock revetments or sea walls can, in some cases, reduce coastal erosion. However, even the largest structures we build cannot be expected to adequately defend our property against extreme events. For example, we have painstakingly channeled rivers or built levees and dams to control flooding. All too often, these activities have tended to lure people into potentially hazardous areas, believing that the flood-control structures will protect them. These structures may well protect them for designed events, but there will eventually be bigger and less frequent events. As a result, over time, the financial losses from floods have continued to rise, even as we have made major attempts to control them. Another response to hazardous events is simply to bear the loss that may be caused by natural disasters. This is a position that many people take. We are generally optimistic about our chances to survive hazardous events. Many people believe it will be some other river that will flood or that landslides are very unlikely on the slope upon which their house is sited. Optimistic people often take little action in their own defense against natural processes. That is why, prior to purchasing real estate today, the banks often require a hazards assessment. Someone will come out to the property and evaluate it in terms of the landslide, flooding, and earthquake hazard, among others. If a home is found to be in an area of known flood hazard, then flood insurance may be required. Landslides are different because insurance policies usually do not cover them. Professional evaluation of hillside property is an important aspect of home inspection.

Santa Barbara: Life on an Alluvial Fan

The white to honey colored rocks of the Coldwater and Matilija sandstones, which form the beautiful, sandstone cliffs above Santa Barbara, are geologic gifts from the distant past, when sediment was deposited in the ocean near San Diego. Rocks in large blocks, such as the one that eventually became the Santa Ynez Mountains, were moved and rotated by plate tectonics to our area over millions of years (see Chapter 1). Fast-forwarding to today, when weathering breaks sandstone down into smaller rocks, which we call sediment, the particles are moved mostly by stream flow toward the sea, where they are eventually deposited. Along the way, from the mountains to the sea, all sizes of particles, from sand to boulders, are stored for variable periods of time in a variety of places along the path of streams and rivers, including gravel bars in the streams, valley fill, floodplains, and the beach.

When a stream emerges from a mountain front, it may migrate back and forth along variable, uncertain channels to form a depositional landform known as an alluvial fan. An alluvial fan has the shape of a segment of a cone or fan. It is the endpoint of an erosional-depositional system connected by a stream. In Santa Barbara, the drainage basin of Mission Creek (the area of that supplies runoff of precipitation to the creek) produces sediment from physical and chemical weathering of bedrock and down slope processes such as landslides. The

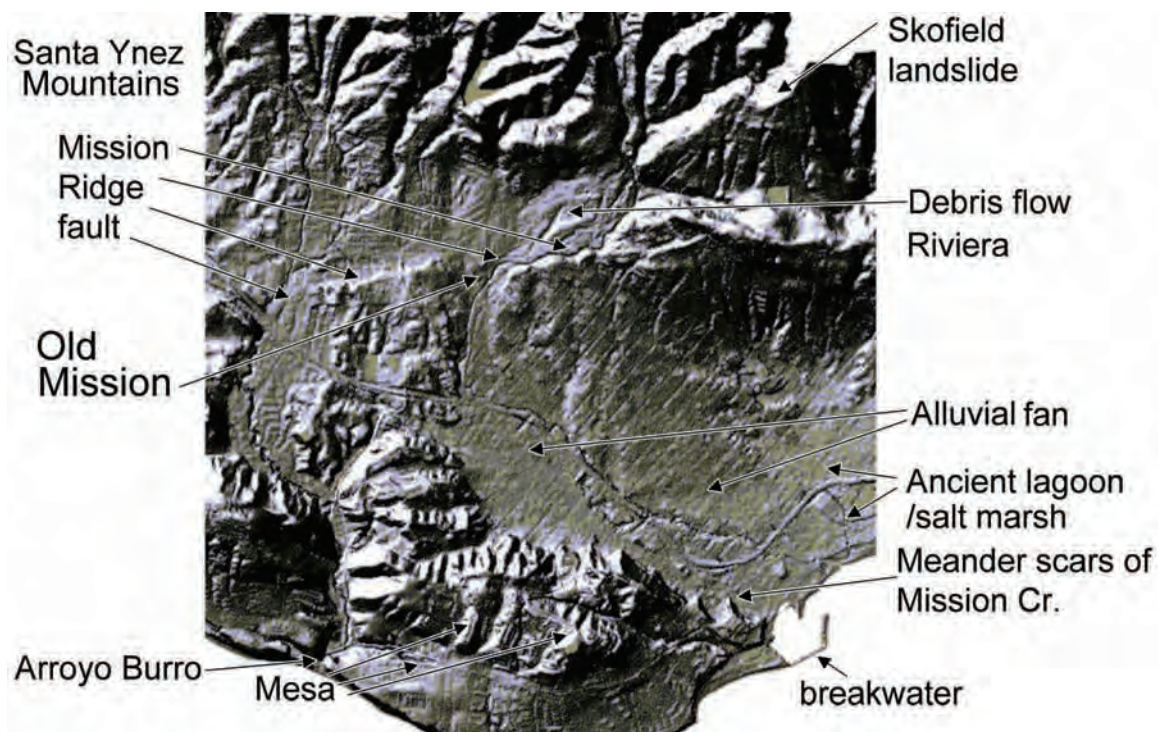


Fig. 3.1. Santa Barbara shaded relief view showing alluvial fan and other features

sediment ranging in size from sand grains to boulders is moved by the creek to be deposited on the alluvial fan, which the city of Santa Barbara is built on.

The head of the alluvial fan is near the historic Santa Barbara Mission (Fig. 3.1). Although Mission Creek no longer flows between the Mission and the small valley to the immediate east because it has been blocked by the uplift of Mission Ridge (American Riviera), the location is the head of the prehistoric fan, which is about 60,000 years old. We believe this because the fan merges near City College with a marine terrace we have dated at about 60,000 years. If you walk from the Mission down through the rose garden and then Laguna Street to the ocean across the fan, you can join the Santa Barbara Alluvial Fan Club. The club informally meets once each year at sunset during the Spring Equinox, near the tail end of the fan at Stearn's Wharf, to celebrate. On that date, it is possible to see the moon rise near the time the sun sets.

As Mission Creek emerges from the mountains, it changes. Before urbanization, it was probably wider and shallower, with more channels spreading over the fan surface. Some of the sediment that Mission Creek transports is temporarily deposited on its path to the ocean. Other sediment quickly is transported by the flowing water to the coast, where sand is deposited to nourish our beaches. In the case of Santa Barbara, these sediments may be anything from sand-sized or smaller to giant boulders. During large floods, boulders several feet in diameter may be transported out onto alluvial fans, but the truly gigantic boulders (5 to 20 feet or more in diameter) are delivered from more dynamic and energetic processes known as debris flows. The alluvial fan is constructed of alternating layers of stream deposits and debris flow deposits. Most of the fan deposits in Santa Barbara are from debris flows. A debris flow is a fast-moving mixture of everything from mud to large boulders. The steep snouts of

flows often contain some of the largest boulders, along with woody debris (trees, brush and poison oak), carried by the flow. Debris flows often occur following wildfire and can be extremely hazardous. Debris flows may be small events within a channel or cover much of an alluvial fan surface with large boulders. Large boulders are easily transported by a fluid debris flow because the flow contains fine sand, silt, clay, and water between the boulders, and the densities of the boulders and fine materials are about the same. The boulders bob and float along in the debris flow. Thanks to these larger boulders and rocks, we have many rock walls in Santa Barbara; some streets are named after the abundance of the boulders, such as Pedregosa Street. The closer you are to the foothills and the top of the fan, the more boulders there are and, so, the more rock walls you will see. However, you can see large boulders in the banks of Mission Creek all the way to the ocean.

As a result of the alluvial fan, we have a flood process called "alluvial fan floods." Alluvial fans are highly unstable in terms of the channels on them. The channels tend to move back and forth, and, when floods occur, there can be a wide-shallow flow that covers much of the fan. As a result, Santa Barbara doesn't have much of a "floodplain" (the flat area adjacent to a river where over-bank flows occur every few years), and water in channels breaks out and flows across the alluvial fan during floods. Mission Creek is a notorious stream in terms of its flood history, and we still struggle trying to find a solution to the flood hazard it creates.

Mission Ridge and Mission Creek: Our American Riviera Is Still Growing West

Several tens of thousands of years ago, there was an alluvial fan with its head upstream of Santa Barbara Mission. As a result of earthquakes and uplift, the ridge gradually grew up in front of Mission Creek near the Mission, forcing the creek to flow to

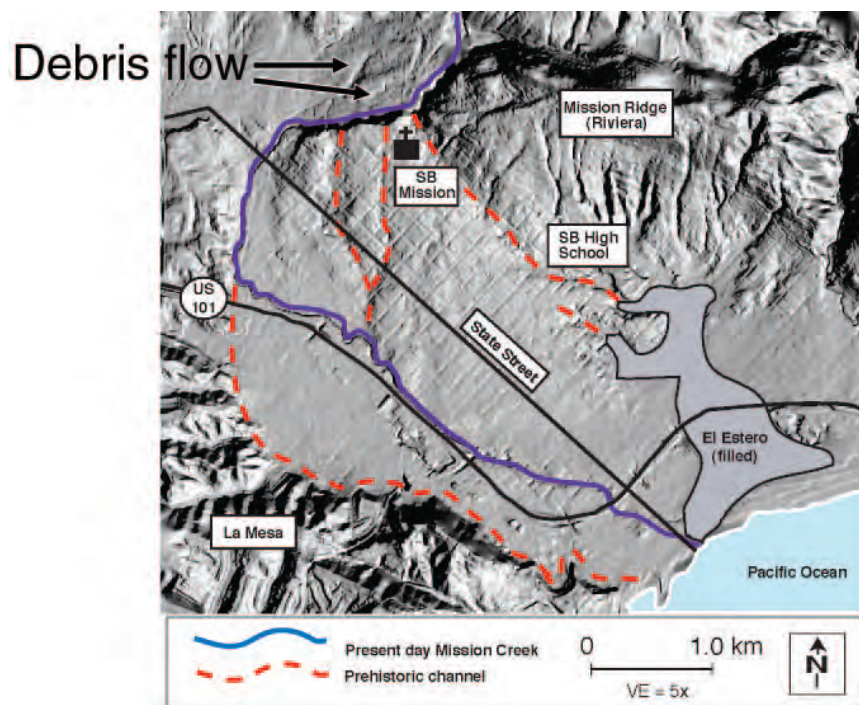


Fig. 3.2a. Shaded relief image of Santa Barbara showing several features of the landscape.

the west (Fig. 3.2). As a result, the creek today flows nearly east-west behind the Mission in front of the Santa Barbara Museum of Natural History. Take a walk behind the Museum and notice the hill to the south. That hill is near the western end of Mission Ridge. When Mission Creek reaches State Street, it turns south towards the ocean. The ridge, which to the east is called the “American Riviera,” or, as we know it, Mission Ridge, is still marching west at a rate of several meters per 1,000 years. Geologically, that is a fast rate. The ridge, in geologic terms, is an anticline, shaped like a banana cut lengthwise in half and placed flat-edge down on a table.

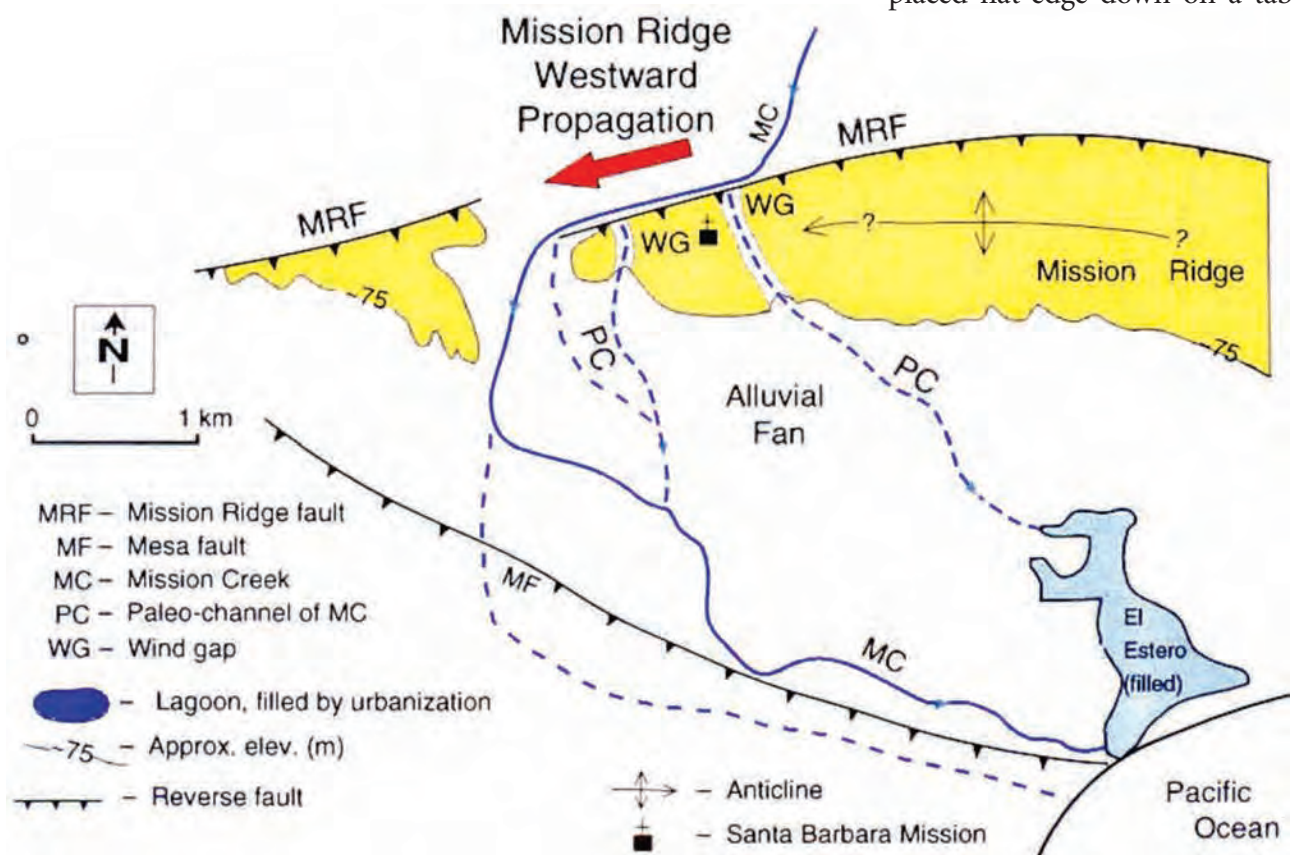


Fig. 3.2b. Ancient channels of Mission Cr. over last few tens of thousands of years



Fig. 3.3. Banks and channel of prehistoric Mission Creek just east of old Mission. Water flowed in this channel about 40,000 to 60,000 years ago through the site of what is now Santa Barbara High School into a large salt marsh and lagoon in lower Santa Barbara at the present site of the Rescue Mission, and waste water treatment plant.



Fig. 3.4. Santa Barbara High School football stadium. These visiting team bleachers are built on the bank of ancient Mission Creek. 2007

It is formed by folding, resulting from north-south shortening across our mountains and the Santa Barbara Channel. As Mission Creek has moved west due to the lateral growth of the ridge (anticline), it has left behind a series of channels on the alluvial fan that are present on our landscape today. The most

prominent of these is immediately east of the Mission. The old valley is clearly visible, and you can wander through it as it makes a right bend through the rose garden and then down through the city (Fig. 3.3). This old channel of Mission Creek flowed through Santa Barbara High School (Fig. 3.4). The stadium of the high school is built in the old canyon of Mission Creek. A good place to see one of these channels is at the corner of Laguna and Canon Perdido Streets. Look to the east and the west and you will see the banks of a broad ancient channel. The channel fed into what was an ancient salt marsh, known as El Estero, that was part of our landscape until at least the early 20th century. However, the main channel of Mission Creek that fed the marsh was diverted



Fig. 3.5. The Mesa is a complex anticline. Two anticlines with a faulted syncline in the center, 2007

from flowing into the marsh many thousands of years earlier. The water that flowed into the historic El Estero comes mainly from small streams draining Mission Ridge. In the 1850s, a canal still carried water from near the Mission south along what was then Canal Street, along what today is Laguna Street. If you try to walk along this ancient channel, you will soon run into houses and buildings; however, looking at old maps and present topography, you can follow it up through the high school, where it bends to the west and north through the park east of the Mission. There, the channel abruptly ends, and it no longer connects to modern Mission Creek. Due to uplift and folding of the ridge, the stream has been diverted to the west, and what is left behind is an ancient valley that we sometimes call an air gap (or wind gap) because it no longer contains an active stream. There are many air gaps along our folded landscape, and the one near the Mission is only one of the more recent of these. Another air gap can be found at Hope Ranch, and there are several along Mission Ridge east and west of the Mission.

As a result of the uplift and folding linked to erosion and deposition on the alluvial fan, Mission Creek has been all over the map of Santa Barbara (see Fig.3.2). It has flowed in channels that are present today in the landscape that are visible by driving through the city. Driving up State Street today, just north of Mission Street, you can see several of these channels as they obliquely cross State Street.

La Mesa Rising

The landscape gets complex in the lower part of Santa Barbara, particularly on the Mesa. Many people consider the Mesa, or “table” in Spanish, to be the relatively flat land adjacent to the sea; that’s one definition useful in describing the Mesa community, where many homes shops and restaurants are in a beach environment. The gently sloping parts of the Mesa are marine terraces that are several tens of thousands of years old. Based on the age of the marine terrace (wave-cut platform) at Santa Barbara Point and at sea level (relative to today), when the platform was eroded by waves, the



Fig. 3.6. Santa Barbara, artists view in 1877

rate of uplift of the Mesa is 4 to 5 feet per thousand years. We believe the uplift occurs by faulting during earthquakes on land and in the channel. The Mesa as a landform is a complex anticline, a double fold. It resembles the shape of a two-humped camel: two anticlines separated by a syncline, with a fault in between. If you don't believe this, just drive over Carrillo Hill—you go up to the top, over the first anticline, down in the syncline valley a little bit, up the next anticline, and down to the sea (Fig. 3.5). If you go along this fold (west to east), which we call the Mesa, on the back side (north side), at the eastern end, Mission Creek has eroded semi-circular meander bends in one of its past flow paths. This is particularly apparent near the tennis courts just below Santa Barbara City

College. The great scallops in the land there are easily visible in aerial photographs and can be seen from City College. The semi-circular forms cut into the backside of the Mesa are old abandoned meander bends of Mission Creek. So, next time you take up your racket and go down and play on those courts, or drive down Cliff Drive along City College (the road follows the meander bends of Mission Creek), take a look at the hills around you and their circular pattern and imagine Mission Creek flowing through them thousands of years ago (Fig. 3.6). While we are discussing the Mesa, let's discuss Shoreline Park and the beach rock there, Burton Mound, and the Harbor.



Fig. 3.7. Beach rock below Shoreline Park, 2006

What Is Beach Rock Doing at Shoreline Park?

Shoreline Park on the Mesa is one of the places along the Santa Barbara Coast that has everything a beach and coastal park should have. The marine terrace sands at Santa Barbara Point are about 60,000 years old, and we discovered a fossil shell locality on the east side of the point. From the point, there are views of the harbor, the coast to the east, and the Channel Islands. Along the beach, in the mostly white-rock sea cliff of Monterey Shale (6 to 18 Million years old), there are interesting geologic structures (folds and faults). Pocket beaches and tide pools below the park make for an interesting walk at low tide. From the park, you can see gray whales in the spring as they migrate north, dolphins and seals on most days, and the occasional sea otter. There is also something known as beach rock along the base of the sea cliff (Fig. 3.7). Beach rock consists of beach sands that are cemented together by calcium carbonate. That's the same mineral deposit that you see in the bottom of your pan if you boil Santa Barbara water. You wouldn't normally expect to find beach rock along the coast of Santa Barbara, but, strange as it seems, you can find small areas of beach rock attached to the sea



Fig. 3.8. Thousand Stairs just west of Shoreline Park, 2007

cliff on the beach below Shoreline Park. There is also a bit at the base of the sea cliff below the Douglas Family Preserve. The presence of beach rock is interesting because it faithfully records levels of sand along the beach. Sometimes, it's five or six feet above the present beach, suggesting that there is a lot of sand moving along this section of the coast. During the summer, the sand level is often five or six feet higher than it is in the winter, when the bedrock wave-cut platform (the rock platform cut by wave erosion that the beach sands are deposited on) is often exposed or covered with a very thin layer of boulders and sand.

The beach rock at Shoreline Park is probably the result of cultural activity. The watering of the park and private lawns, as well as the irrigation for the homes on the mesa, infiltrates into the ground to become a subsurface (groundwater) flow of water in the rock of the sea cliff. When this water emerges at the base of the sea cliff as springs



Fig. 3.9a. Santa Barbara harbor, 2007

or seeps, it is charged with the chemistry necessary to deposit calcium carbonate. The deposition is assisted by bacterial activity. Small seeps of water emerge from the sea cliff at the level of the beach sands, run along the sands, and cement them together (see Fig. 2.30). Thus, at Shoreline Park, we have a little bit of what you might find on the beaches of southern Greece, where beach rock is common, due, in part, to the abundance of limestone rock at the shore. Take a look at it next time you walk along the beach at Shoreline Park. The best place to see beach rock is to walk down the stairway in the center of the park and turn to the right, or the west, and look along the base of the sea cliff. Natural beach rock is found on San Miguel Island across the channel, and it is a geological wonder as it cements once living plants to sand and incorporates them into rock.

While you're walking along this section of coastline, you can also notice some of the coastal

erosion problems associated with Monterey Shale. At the top of the park, the edge of the sea cliff has a wavy form, and each indentation is a small landslide. Further to the west, where the park ends and there are homes, you can sometimes see bits of walls and trees and all sorts of human debris that have fallen down the sea cliff. Also, in that location, is the famous "1,000 Stairs" (Fig. 3.8). There are closer to a hundred stairs than a thousand, but it's an interesting old set of stairs of historical interest. The stairs occupy a small gully or channel that eroded into the sea cliff. Before the stairs were built, it was probably a trail down to the beach. In wet years, a lot of water moves out onto the stairway and they are slippery to walk on. Along with this, there are a number of small landslides that have occurred above the stairs, making walking down them somewhat of an adventure. If you use the stairs, keep a lookout for loose soil and rock above. We don't know of anyone who has been



Fig. 3.9b. Harbor, breakwater sand spit, and anticlines near Santa Barbara, 2007

injured by falling rocks there, but it's certainly a place where that could happen. The water comes out of the stairway about halfway up, where the contact between the white Monterey Shale and the overlying sediments of the marine terrace (about 85,000 years old) are exposed. That's also where some of the small landslides are present.

The Story of Santa Barbara Harbor

Santa Barbara harbor (Fig. 3.9), with Stearns Wharf and all the activities that range from commercial fishing to restaurants, shops, interesting people, and the Yacht Club, is one of the major tourist attractions of Santa Barbara. People of Santa Barbara began to talk about and promote the building of a harbor over 100 years ago. Between 1873 and 1921, the U.S. Army Corp of Engineers completed a number of reports concerning a possible harbor. All of these reports were unfavorable, due to the potential consequences of disturbing the flow of sand

along the coast. Nevertheless, in 1925, funds were raised to make the first breakwater. The first one was L-shaped and extended about 1,500 feet. At that time, a fair amount was known about coastal processes, but this was largely ignored; the first breakwater was not even tied to the shore on the west side of the harbor, which was the site of the old Castle Point near the Dibblee family home. The breakwater, which was completed in about 1929, blocked the longshore transport of sand moving east along the coast and, at first, made what looked like a good harbor for boats. Unfortunately, because it was not tied to the shore, the sand kept moving right on through and began to fill the new harbor. As a result, they had to add to the sea wall and attach it to the coast where it is today. Stearns Wharf is at the eastern end of the harbor, and, between the wharf and the breakwater, there is a narrow channel for boats to go in and out of the harbor. Once the transport of sand was stopped, it deposited a wide beach to the west of the

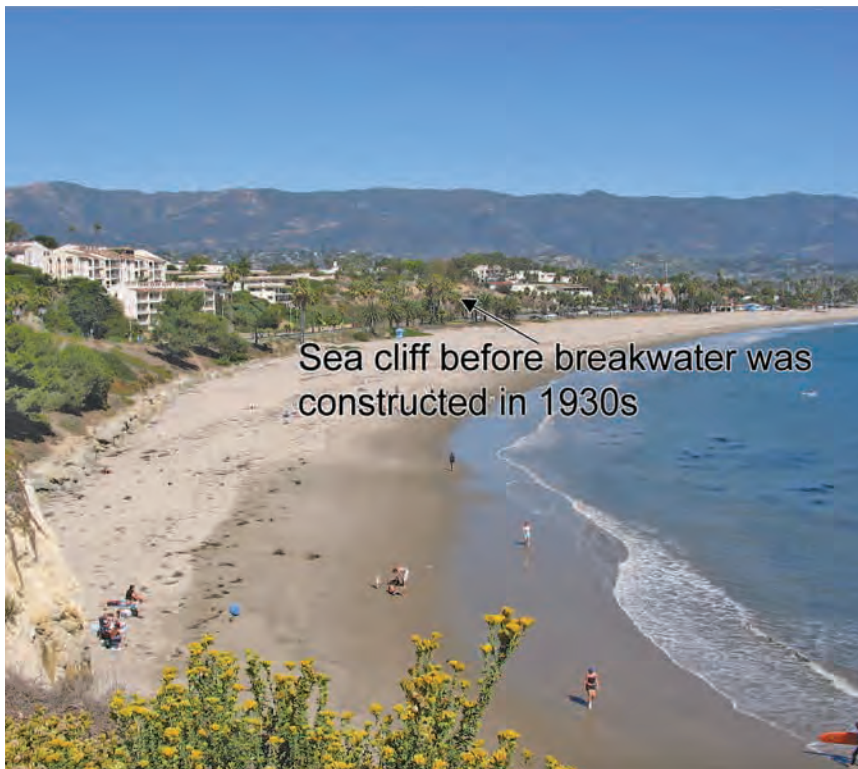


Fig. 3.10. View from Santa Barbara Point, 2007

breakwater. When sand filled out the beach to the breakwater, it moved along the outside of the breakwater to be transported into the harbor area, building the well-known sand spit. Given enough time, the sand spit would eventually close off the harbor and cause shoaling, or swallowing, of water under Stearns Wharf. Accumulation of sand began to be a problem, and, in order to keep the harbor open, we have to periodically dredge out that sand. It is pumped by a dredge mounted on a boat into a pipeline and transported to East Beach, where it is returned to the beach to continue its movement along the coast toward Ventura. An incredible amount of sand moves along that section of coast. Because we dredge the sand, it is one place where we know the rate of movement of sand along the coast. Every year, about 300,000 cubic yards of sand is dredged to keep the harbor open.

When the sand was first blocked by the harbor by piling up to the west, below what is now Santa

Barbara City College, as well as in the sand spit, there was much less sand available further to the east than there was prior to the breakwater. When more sand leaves an area than arrives, erosion occurs, and that's what happened at Miramar Beach a few miles east of the harbor and, later and even more disastrously, at Sandyland, about ten miles east. At Sandyland, there were a number of small beach cottages that had been constructed on the sandy beach. Seven years after completion of the harbor and breakwater, there had been substantial retreat, or erosion, of the coast. Houses eroded into the sea, and property damage, by today's standards, would be many millions of dollars, as the beach

cut back about 250 feet. According to Professor Robert Norris at UCSB, at first, the people managing the harbor decided to dredge a couple hundred thousand yards of sand and deposit it in about 20 feet of water to the east of the breakwater. They assumed that the sand would move toward and then down the beach, reducing the erosion. Much of that sand is still there today! This brings up an important point: The movement of sand along the coast is mostly in the surf zone, fairly close to the shoreline.

One positive aspect of building the breakwater, other than it being a great place for us to moor our boats, take a sunset walk, visit a museum, or have a meal, is the addition of the land west of the breakwater. At City College today, there's a track and football field whose bleachers are constructed on the old sea cliff that was there on the beach prior to the building the breakwater. All that land in

front of the old sea cliff, that includes parking lots, parks, and so on, is a result of the building of the breakwater that blocked the flow of sand from the west to the east. You can easily follow this old sea cliff all the way from the City College area to Santa Barbara Point at Shoreline Park (Fig. 3.10).

An obvious question is: Was building the breakwater the right thing to do? That really depends on the people you talk to. The harbor is a romantic place to go for a nice dinner or to get in a boat and sail out and observe whales in their natural environment. Speaking of which, don't follow whales closely or harass them – it's illegal and dangerous. A large whale swimming by Shoreline Park jumped into a small boat in the spring of 2006!

On balance, the harbor has been a great asset to the city of Santa Barbara. On the other hand, had we applied more of what we knew about coastal processes, the coastal erosion that occurred to the east could have been avoided. Today, at Sandyland, you'll find rock revetments or walls protecting the coast, even though the sand supply has been restored.

What Is Burton Mound? Life on a Fault Line

Burton Mound, located not far from Stearns Wharf and the mouth of Mission Creek at West Beach, is a historical landmark. On the sign that commemorates the site, there is an inscription describing the Chumash town of Syujutun that was on this site for thousands of years. When the Spanish arrived, the town on the mound was well established. People lived in comfortable houses, had a complex culture, and made a good living from the sea. Following permanent colonization by Europeans, the way of life of the coastal Chumash nearly came to an end. Burton Mound has yielded some of the most important archaeological evidence in California of Native American culture. Old maps show that Burton Mound was about 20 to 25 feet high and quite

broad. Of course, long habitation by people will lead to some raised relief, but, in this case, the mound is along the Mesa fault. It's not uncommon that, along faults, we find small squeeze-ups or pushups forming mounds, and we believe that's what Burton Mound is. Burton Mound is close to the beach and became the site of a famous hotel in Santa Barbara from 1902 to 1921. This hotel on West beach, known as the Potter Hotel, was a destination resort, and tourists traveled long distances to visit Santa Barbara and its beautiful hotel. Unfortunately, the hotel was destroyed by fire in 1921. Later, the site was excavated and was found to be a very rich archaeological location. Recent evaluation of the Mesa fault has shown that the fault is also beneath Stearns Wharf, goes right beside Burton Mound, and then through the infamous Carrillo underpass that is often wet (another geologic story that we will get to later).

More About Our Elongated Hills: Geologically They Are Anticlines

The Mesa and Mission Ridge are anticlinal ridges in which rocks from below are arched up by the folding. This can produce steep slopes with ocean views, such as the upper parts of the Mesa or Riviera, and it can also expose older rocks, such as the Rincon Shale, which is nothing but trouble for Santa Barbara. The Rincon Shale is dark, organic-rich shale of Miocene age, a bit older than the white Monterey Shale that composes the sea cliff at Shoreline Park. Rincon Shale is a very weak rock, contains organic material, is a source rock for oil, and is somewhat radiogenic and, so, has a radon gas problem. The shale tends to expand and contract when it wets and dries and is unstable on slopes. Many of the landslide problems of Santa Barbara, particularly those in the Sycamore Canyon area, are related to the notorious Rincon Shale. Some of those landslides are ancient landslides mapped decades ago by Tom Dibblee, the famous geologist who mapped

all of Santa Barbara and grew up on the Mesa in a house known as the “Castle.” The home was heavily damaged by the 1925 earthquake and subsequently demolished. City College is on the site today.

Landslides in Sycamore Canyon predate the mapping by Tom Dibblee by many thousands of years. Sycamore Canyon is one of the canyons that has maintained its path across Mission Ridge as it has been uplifted. That is, as the ridge was uplifted by earthquakes, Sycamore Creek was able to continue to flow through the ridge. Such a stream that crosses a structure and still flows through it is called a water gap and is said to be antecedent to the uplift. As a result of erosion that took place in lower Sycamore Canyon, the Rincon Shale was exposed. Because the slopes are steep and the rocks are weak, land sliding occurred and, probably, has been occurring for many thousands of years. People were seduced into building there because of the lovely creek side location, as well as views to the mountains and sea. Unfortunately, as we developed these areas, the landslides were reactivated. In recent years, several homes and roads have been lost, and landslides in Sycamore Canyon have damaged numerous homes. Some of the landslides remain active today.

Las Positas Canyon and Springs: Was Mission Creek Once There?

When we talk about Mission Creek and its alluvial fan, we are left with the impression that it has moved all over the place. It may have even flowed through what today is Las Positas Canyon (Fig. 3.11). The lower part of the canyon is occupied by Arroyo Burro Creek, which flows southward to the ocean at Arroyo Burro Beach, or, as the locals call it, Hendrys Beach. There is a small lagoon where Arroyo Burro Creek enters the ocean, and this is the site of the recent restoration of Mesa Creek, which flows west from the Mesa Community into the head of the lagoon. Mesa Creek was, until re-

cently, covered up and ran in a large pipe; following restoration in 2007, the creek is a creek again, open to the air and light, with native vegetation on the banks. Restoration includes a small fish ladder at Cliff Drive that makes it easier for the endangered southern steelhead trout to migrate up Arroyo Burro Creek to their spawning grounds in the mountains, as they did and do in many other coastal streams, including Mission Creek, Montecito Creek, and Carpinteria Creek, among others.

Let’s start near the Boat House Restaurant at Hendrys Beach (Arroyo Burro Beach), where people have visited and lived for thousands of years. The Chumash launched their plank canoes (tomolos) through the surf there and visited the Channel Islands. There is an authentic, modern tomolo behind the Water Resources Center at Hendry’s Beach that occasionally is used by the descendants of the seafaring Chumash to cruise the coast or cross the channel. If you walk upstream along the lagoon and turn north, you will enter a wide valley, parallel with Las Positas Road. Elings Park and tennis courts are on the east side of the valley, and condominiums are on the west. The slope above the condos is unstable (Rincon Shale is part of the problem), and landslides have occurred in wet years that partially blocked Arroyo Burro Creek (Fig. 3.12). Blocking of a creek is a potential hazard, because a small lake may form upstream of a landslide dam. If the lake fills with water and sediment and the dam “blows out” downstream, flooding can result. Santa Barbara Flood Control is well aware of the hazard, and landslide dams can be removed before they present a flood hazard.

On the east side of Las Positas Canyon, there are several springs along Las Positas Road, just north of the intersection with Veronica Springs Road (Las Positas means little wells or springs). Veronica Springs itself (hard to find) is located just to the south of these springs, a short dis-



Fig. 3.11a. Arroyo Burro Beach, lagoon, and Las Positas Canyon. Mission Creek once flowed here. Modified from photo by Calif. Coastal Project. ©2002-2007 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org



Fig. 3.11b. Restoration of Mesa Creek included opening the creek from a covered culvert, removal of introduced species of plants, and planting of native plants, 2007



Fig. 3.11c. Arroyo Burro Creek at head of lagoon, 2007



Fig. 3.12a. Shallow landslides. Las Positas Canyon, 1998



Fig. 3.12b. Shallow landslides block Arroyo Burro Creek in Las Positas Canyon. Courtesy of Santa Barbara County, 1998

tance up a small canyon along the west side of Arroyo Burro Creek, across from Elings Park. Veronica Springs has an interesting history. Professor Norris of UCSB writes that spring water, emerging from the Monterey shale, was commercially bottled from the turn of the 20th Century to about 1960. The bitter tasting water is rich in Epsom salt (hydrous magnesium sulfate) and was used as a laxative or to reduce inflammation.

As you walk, bike, or ride in a car northbound and get closer to US 101, Arroyo Burro Creek heads off on your left, flowing to the mountains - but you may notice that a valley continues! It's a broad, wide valley with a few homes in it, and you can see the old valley where Modoc Road crosses it. The fill of the freeway pretty much did the valley in, but, on the other side, you can follow it through Earl Warren Showground, where it makes a prominent right bend, going upstream and then crossing

Las Positas Road near Adams School. From there, it flows further up and, perhaps, to the east or north, where it may have once joined what is now Mission Creek to the east. It seems likely that Adams School was once on the banks of Mission Creek, albeit thousands of years ago.

Foam at Arroyo Burro Beach and the Guts of an Oil Reservoir

During the Christmas season of 2005 and into the new year of 2006, Arroyo Burro Beach looked something like a beach you might expect in Alaska, covered with snow. For as far up and down the beach as you could see, there were piles of foam up to a foot or more thick (Fig. 3.13a). The foam (suds) was left on the beach as the tide receded, and we all wondered what on earth was going on. We had high surf and waves on Arroyo Burro Beach during that period, and the tidal range was large. All of the churning up would naturally produce some foam in the ocean, and most of the suds and foam was from natural processes. Small, one-cell marine plants, known as diatoms (a plankton), live in the surf. They are surf diatoms, sharing the environment with surfers. When the diatoms bloom, they produce a white mucus that, with the churning surf of the winter, can produce the foam. However, we also know that suds on water can occur in streams where homes are served by septic systems and phosphorus ends up in the water. Phosphorus in cleaning solutions may also be found on our driveways and city streets, where it may wash into storm sewers and end up in the ocean. Finally, there is an unknown amount of phosphorus coming in from streams entering Goleta



Fig. 3.13a. Surf diatoms at Arroyo Burro Beach, 2006. Photo courtesy of Michael Iven



Fig. 3.13b. Exposed (uplifted and eroded) oil field, on beach about 400 yards east of Arroyo Burro Beach Park, 2007

Slough and, probably, out of the Hope Ranch area, where a lot of homes are on septic systems. When this phosphorus gets into the nearshore environment, it's something like a giant washing machine

(due to water churning in the surf), and, so, suds and foam are a natural result. We don't know the nature of the human footprint in relation to the foam on Arroyo Burro Beach, but it seems certain that some (probably small) portion of the foam on the beach resulted from human activity. Lets now consider the oil reservoir.

If you walk to the east (to the left facing the ocean) a few hundred yards from Arroyo Burro Beach, you will enter a fascinating rock environment of the Monterey Shale. The rock varies in age from approximately 6 to 18 million years, and, at numerous locations near Arroyo Burro Beach, the rocks are plugged with a variety of materials in the rock fractures. Included are black opal, the mineral calcite, and, very commonly, tar (Fig. 3.13b). In places, the rocks are completely broken up, and tar cements them together in what is known as a "tar breccia." The tar, which once was liquid petroleum, comprises an uplifted and eroded oil reservoir. Today, if you were to go deep in the earth into an oil reservoir that is being pumped to extract petroleum, it would look much like these rocks, except the tar would be in a liquid form we call petroleum. Along that stretch of beach, you also find numerous fossils in the shale. Most common are fish scales and bones as well as whale bones, sometimes impregnated with tar.

Next time you walk near Arroyo Burro Beach, think about what our oil resources look like at depth. The rocks along the beach give us a view of that environment.

Douglas Family Preserve

The Douglas Family Preserve (formally the Wilcox Property) is just above and east of Arroyo Burro Beach. The 70-acre preserve is located at the eastern end of the Mesa, on an ancient marine terrace (wave-cut platform), which is about 85,000 years old. That is, 85,000 years ago, what is now the preserve was a wave-cut platform and beach environ-



Fig. 3.14. View to the west from the Douglas Family Preserve.

ment, much like that directly below the bluffs at the southern border of the preserve today. A grass roots campaign to raise the funds to buy and preserve it, rather than let it be a major housing development, was initiated. Local fund drives and bake sales raised money from many small donors, and the purchase was completed when the Douglas family made a large donation in 1996.

Spectacular views of the coast and channel (Fig.3.14) are common from the bluff top that is about 150 feet above the Pacific Ocean. The sea cliff is composed of Monterey Shale with a thin surface layer of sediments that include beach sand, pebbles, and large boulders. Some of the pebbles and boulders have rock pholad borings (holes). Boring pholads are a type of mollusk, (clam) that lives in holes that it drills in rocks. It has a siphon,

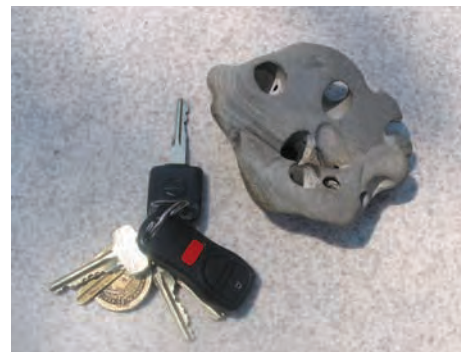


Fig. 3.15. Holes in this small rock found at Arroyo Burro Beach are made by rock boring pholads (a type of clam).

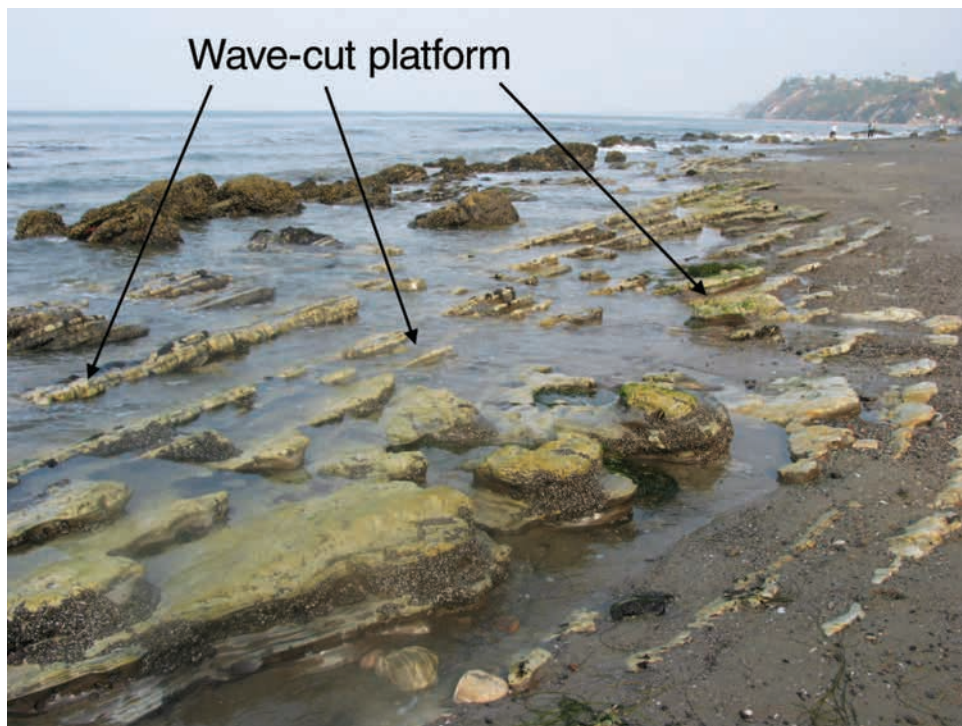


Fig. 3.16a. Wave-cut platform below the Douglas Family Preserve.



Fig 3.16b. Shoreline angle below Douglas Family Preserve.

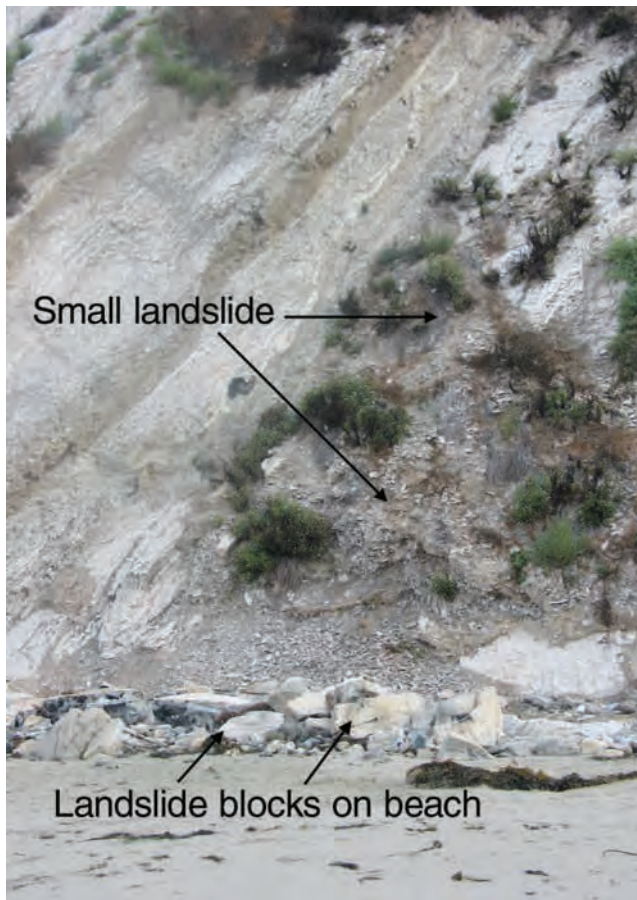


Fig. 3.17. Small landslide on sea cliff below the Douglas Family Preserve.



Fig. 3.18. Sea cliff below the Douglas Family Preserve. Eucalyptus trees that have fallen from the bluff top are imbedded in the beach. Black cormorants are perched on a limb.

or neck, as do clams, that extend up from its rock home into the water to filter feed. The rocks you see on the beach with interesting round holes in them are the product of pholad borings (Fig. 3.15) and are proof positive that you are on a wave-cut platform formed by the erosional power of the waves, water, and sediment.

The modern wave-cut platform below the preserve (Fig.3.16a) is cut on the Monterey Shale and slopes very gently offshore. The wave-cut platform joins the sea cliff to form a feature called the shoreline angle, which is about the elevation of mean high tide (Fig.3.16b).

The sea cliff below the preserve is unstable, with many small to larger landslides, because the inclination (dip of the strata) of the Monterey Shale is steep and, to the south, has potential slip planes exposed in the sea cliff. Small slides deliver rock blocks to the beach (Fig.3.17), and several large eucalyptus trees have fallen from the bluff top and become imbedded in the beach (Fig.3.18). The tree limbs make good perches for sea birds, such as black cormorants.

Near the east end of the preserve, there are two large slides that have prominent head scarps and lateral scarps with hummocky topography in the sea cliff (Fig.3.19). It was a wise decision not to develop the bluff top and to preserve the land for future generations.



Fig. 3.19. Large landslide near east end of the Douglas Family Preserve.



Fig. 3.20. Mission Ridge fault scarp along Modoc Road, 2007

Hope Ranch: A Beautiful and Interesting Landscape

What is happening at Hope Ranch is very interesting, if you consider the tectonic disruption, stream diversion, and burning shale. Hope Ranch is a desirable area that includes many estates and homes, from the ocean inland to about Modoc Road. At the north entry to Hope Ranch at Modoc Road, there is a steep slope of a long hill facing north that is produced by movement of the Mission Ridge fault, which produced Mission Ridge. The fault has produced fault or fold scarps, which appear as a steep slope up to the south (facing north) that is clearly visible east on Modoc Road on the north edge of Hope Ranch. You can also see the scarp (modified by excavation) behind the shopping center on the corner of State Street and Las Positas, where there are a number of stores and restaurants which we refer to, with tongue in cheek, as the “fault line cafes.”

At one time, a stream flowed north to south into and through Hope Ranch by what is now Laguna Blanca or “white lake” and out to the Pacific Ocean. That valley is still there today, but the stream that occupied it is mostly gone. The stream was abandoned because of the uplift on the Mission Ridge fault. What is left today is a mostly dry valley in the middle of Hope Ranch. A small stream flows into the ocean at the Hope Ranch Beach, but this is a small vestige of the stream that must have once flowed through the area. Laguna Blanca itself is a “sag pond” along the base of one of the faults that runs east-west through Hope Ranch.

A good location from which to observe how the Mission Ridge fault has uplifted Hope Ranch and molded the shape of the land is along Modoc Road, just north of the ranch (Fig. 3.20). From the entrance to the ranch at Las Palmas Drive, west to Hollister Road along Modoc Road, the land is higher to the south. The linear hill parallel to

Modoc is the topographic expression of fault displacement that uplifted Hope Ranch. Along the base of the hill, there are a series of fresh water wetlands that formed along the fault because the fault has blocked groundwater moving south toward the ocean from the north.

Why Did the Rocks in the Sea Cliff Below Hope Ranch Burn?

A strange thing occurred in the sea cliff below Hope Ranch on October 12, 2006. Flames leaping from a landslide deposit prompted the fire department to take action and extinguish the blaze before it set the vegetation on the sea cliff on fire (Fig. 3.21). Vegetation was cut back, water was sprinkled on the sea cliff for several months, and the fire eventually was extinguished or naturally burned out.

The location where the fire occurred is about a mile west of Arroyo Burro Beach, but the phenomena is natural and has been occurring for thousands of years. If you walk from Arroyo Burro Beach about half a mile to the west, you will see some beautiful pink shale. The rose-colored rock is reminiscent of some of the sandstones of the Southwestern United States, but the origin is entirely different. The Monterey Shale at some locations is impregnated with tar, and, if you visit the site, you will see a number of locations where bits of shale are cemented together with layers or veins of black, hard tar. When a landslide occurs, fresh tar may be exposed to the atmosphere, and a moving landslide can generate heat from friction. The oxygen in the atmosphere works on the tar and oxidizes it, and, in the process, the tar heats up. Sometimes, it gets so hot that it smokes and catches on fire (spontaneous combustion). That is what evidently happened in 2006. Such fires may last anywhere from a few days to a few months, years, or even perhaps a century. USCB geologist, Professor Jim Boles investigated the smoking shale at the landslide site in

2006, and found that the near surface temperature was about 700 degrees Fahrenheit. That’s about twice the temperature we cook pizza at! Burning shale has a long history in Santa Barbara because we are a major petroleum area and tar seeps are quite common. Fires and smoke were noticed in the 1800s by passing ships that, reportedly, even used the burning shale as a natural lighthouse to find safe harbor at Santa Barbara. A century earlier, the Spanish made comments about Santa Barbara’s “volcanoes,” because they thought the smoke and gases came from a volcanic source. Rest assured that Santa Barbara does not have a young volcano beneath it. We now know that these fires result from the spontaneous combustion of tar when it oxidizes. There are several potential problems related to the burning shale. The smoke and fumes may be toxic and annoying to people, and, when flames actually erupt at the surface, fires that burn the vegetation may also occur. One person told me that the fumes from the fire sent him to the emergency room for treatment. The Hope Ranch site is not the only place where burning shale has been reported; another location is to the east of Carpinteria near La Conchita, where pink rocks are present. Tar fires have also been reported on the Channel Islands, including Santa Cruz Island.

Burning shale is a natural process in our petroleum rich environment. More fires will occur in the future as landslides continue to uncover tar rich rocks. It is not “if” they will occur, but “when.” Walk along the beach west of Arroyo Burro Beach toward UCSB and you will see several places where the rocks have been baked to a beautiful orange color that reminds me of some of the rocks in Arizona and New Mexico (the orange color of the these rocks is a result of the oxidation of iron, not tar, so they do not burn). By the way, it is a great walk from Arroyo Burro Beach to UCSB. Go at a good low tide and plan to take several hours.



Fig. 3.21a. Fires in the rocks of sea cliffs have been fairly common in the past, 2006

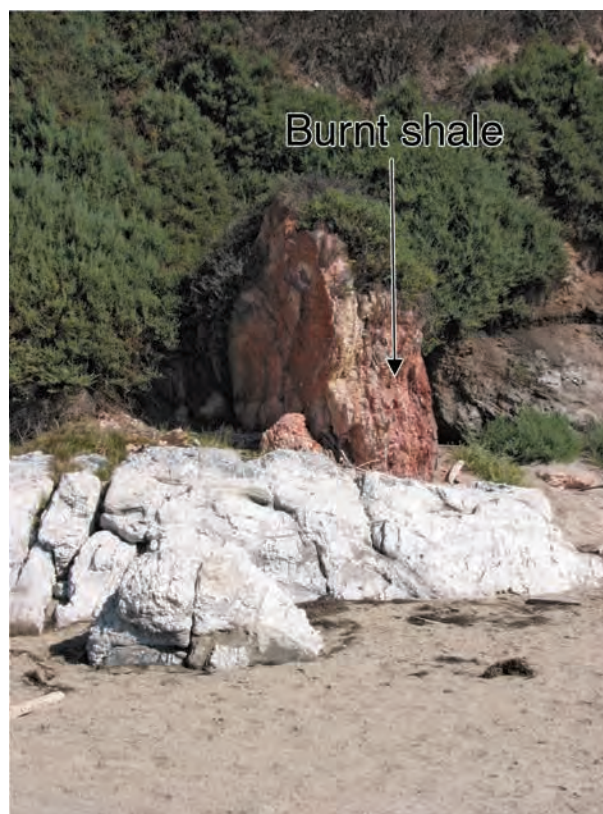


Fig. 3.21b. Burnt shale (orange, oxidized rock) from past fire in the rocks, just west of Arroyo Burro Beach, 2006

You will see large tar flows from the sea cliff right on to the beach west of Hope Ranch. The tar on the beach is several feet thick and sometimes, on hot days, sticky, but you will not sink in. Some of the UCSB faculty in the 1980s held a “turkey run” (near Thanksgiving Day) from Goleta Beach to Arroyo Burro Beach –it took about an hour or more, depending on your rate of trotting. I did the trot for several years, and it was great fun. By the way, running or walking along the beach will result in tar on your shoes or feet. A good way to remove tar from bare feet is to use baby oil.

Skofield and Rocky Nook: A Tale of Two Parks

Skofield Park and Rocky Nook Park, both in the Mission Creek drainage, were formed at almost precisely the same time, about 1,000 years ago, by a catastrophic event. That event started in Skofield Park in Rattlesnake Creek, the major tributary of Mission Creek, when a large landslide probably formed a dam and blocked much of the canyon. A lake may have formed behind the landslide dam. When the landslide lake filled and the dam washed out, a debris flow went roaring down the canyon to the present site of Rocky Nook Park, near the Museum of Natural History, all the way to State Street. If you wish to see the Skofield Park landslide, the view is especially fine from Gibraltar Road, high above Rattlesnake Canyon (Fig. 3.22). The flat playing fields in the park are slump blocks that resulted from the landslide. The debris that emerged from Skofield Park about a thousand years ago and roared down the canyon was probably 20 or 30 feet thick and moving up to 30 miles an hour, with the sound of a thousand thunders. Left behind, particularly well-preserved in Rocky Nook Park, are large boulders scattered like Easter eggs on the landscape, sometimes piled up into small linear hills and sometimes isolated

(Fig. 3.23). If we didn’t know about debris flows, we could never answer the question of how the boulders got there. The boulders had about the same density as the fine particles of the flow, and the boulders (even those over 15 feet in diameter) floated on the flow like bobbing bits of cork on water. The debris flow was large and deep, and, should another such event occur again, hundreds of homes, including the Museum of Natural History, would be instantaneously obliterated from the landscape. The chance of this happening in the near future is remote, as these events probably only happen in a given canyon every few thousand years. Even if a canyon were to become blocked by a landslide, we could use heavy equipment to breach the dam before it overtopped and initiated a flood or debris flow.

The debris flow occurred only a thousand years ago, and it was certain to have been observed by the Chumash people who lived in the area. That event may be recorded in their oral history, and a search of their stories reveals several interesting parallels. The Chumash have a story they tell about the Great Flood (see T. C. Blackburn, ed., 1975, *December’s Child*, University of California Press). A whole landscape was flooded, almost up to the

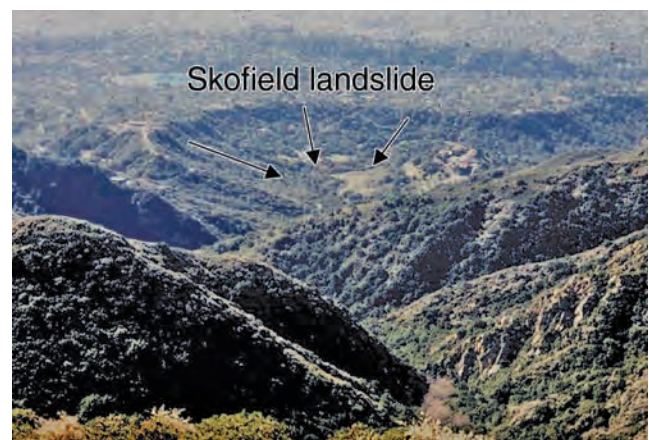


Fig. 3.22. Skofield Park landslide along Rattlesnake Creek (view to south). Note bowl shape of the slide. Arrows indicate direction of movement, 2004

levels of the tallest oak trees, and only woodpecker survived above the floodwaters on the tree he loved. When this occurred, many people drowned, and their bones are still present in the landscape today as giant boulders. Could this Chumash story have resulted from the debris flow in Mission Canyon? We really don't know, but, certainly, such an event would have gotten their attention, and there could be some Chumash structures buried beneath some parts of the debris flow.

Regarding landslides and debris flows, we conclude that two popular parks, Skofield and Rocky Nook, resulted from the same sequence of events that occurred about a thousand years ago. We can trace and map the landslide and the trail of boulders (debris flow) as it winds down Rattlesnake Canyon into Mission Canyon, spreads through Rocky Nook Park by the museum, and, eventually, ends near State Street and Constance Avenue. The debris flow, while large (about 10 million cubic yards), is certainly not unique to the Santa Barbara alluvial fan our city is built on. Numerous debris flows have come down the canyon onto the fan over the past 60 thousand years or so; that's why we have so many large boulders on and under our streets and homes, particularly in the Mission neighborhoods. If you go down some of the old channels, they may abruptly end in a steep slope, such as at Laguna Street, just south of Anacapa Street, which probably is the nose of an old debris flow frozen where it stopped, similar to the debris flow that came out of Mission Creek a thousand years ago.

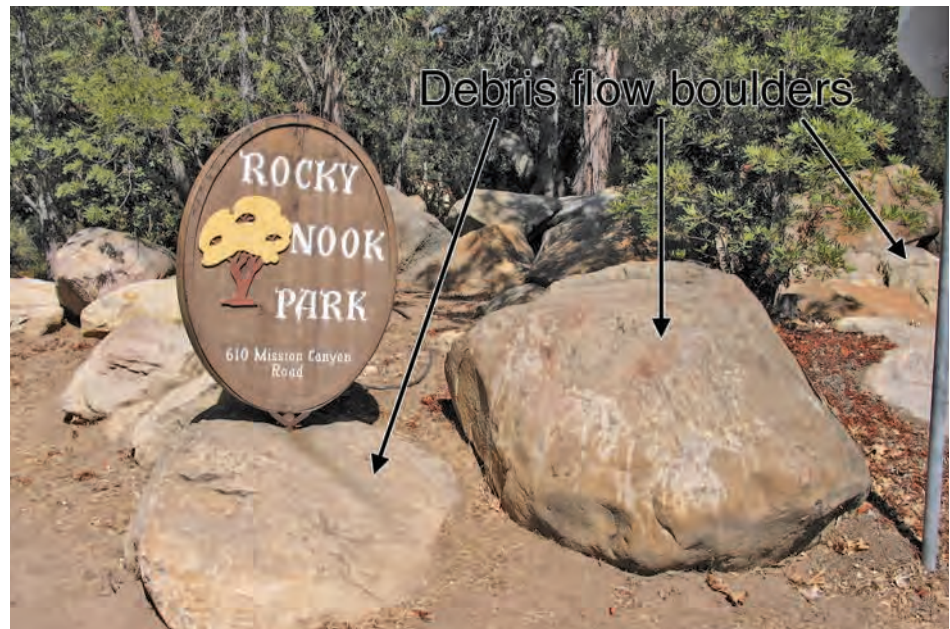


Fig. 3.23. Debris flow deposits, flow occurred about 1,000 years ago when a landslide dam burst at Skofield Park, 2007

What Produced the Landscape at the Zoo and Santa Barbara Cemetery?

Now let's turn our discussion to other popular areas of Santa Barbara, including the Santa Barbara Zoo, East Beach, Child's Estate, and Santa Barbara Cemetery. Mrs. Lillian Child donated the property for the zoo to the city. This is also the location of the Santa Barbara Cemetery and is "the story of two hills." If you visit the Bird Refuge just to the north of the zoo, that body of water is a remnant of a coastal lagoon, probably associated with Sycamore Canyon in the distant past. Today, the water passes between two small hills at the beach, with the zoo being on the west and the Child's Estate on the east. These hills are elongated, growing anticlines that are clearly visible in the landscape (Fig. 3.24). If you walk from East Beach a bit more to the east along the beach, you can see the internal structure of one of these anticlines in the sea cliff below the cemetery. The zoo is a wonderful place to visit and look at penguins and bears, but keep in mind that the hill there is the re-

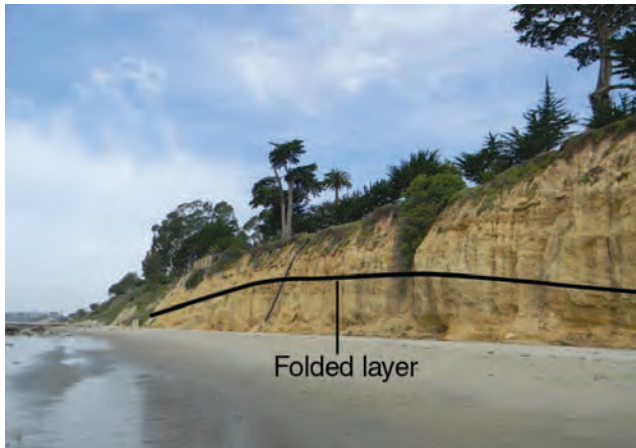


Fig. 3.24a. Cemetery anticline, 2011.

sult of earthquake processes that have uplifted and changed the landscape. Stop a moment in the zoo and let the land speak to you. As you walk along the quiet paths of the zoo, think about the environment that is there and how it came to be that way. The forces that shortened the land and rocks between the Santa Ynez Mountains and the Channel Islands have formed a small fold. There is a gap eroded between the hills, forming a passage which allows water from the Bird Refuge or the old lagoon to flow into the sea. The passage through the hills is called a water gap.

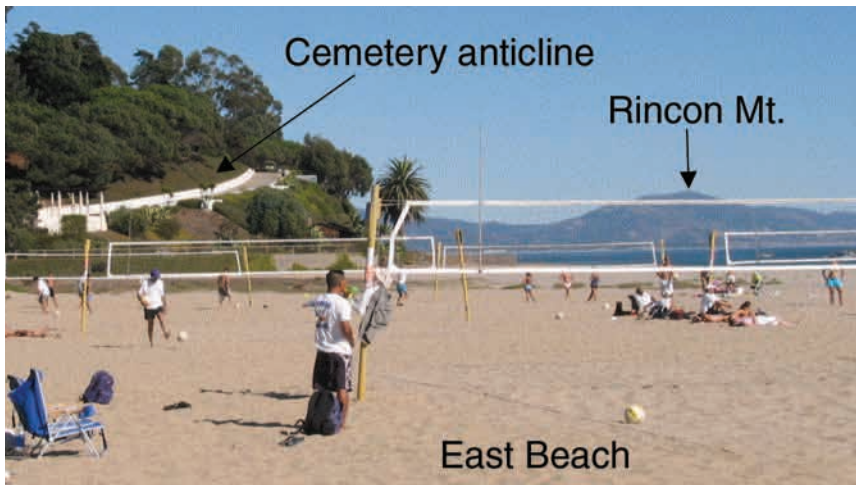


Fig. 3.24b. Cemetery anticline at East beach, 2007. Just to the south is the Zoo anticline. The Bird Refuge is a synclinal basin located to the immediate north.

El Estero: Prehistoric Lagoon of Mission Creek

Leaving the Bird Refuge and the salt marsh, let's move a bit to the west and talk about the large, now filled in, El Estero or salt marsh that covers much of the downtown Santa Barbara area. One of the main streets in the area is Salsipuedes. Salsipuedes in Spanish means, "get out if you can" (see Fig. 3.1 and 3.2). In the early 20th century, it was difficult to move along this street because of muddy conditions. Tom Dibblee told me that wagons were often stuck in the mud. It was, after all, a salt marsh until recently. The salt marsh was still partly present until modern times, at least as recent as the last 80 years. Some "old-timers" have told me stories of people taking a canoe trip from Santa Barbara High School to the ocean! What was left of the old salt marsh was filled in following the 1925 earthquake. Following



Fig. 3.24c. Cemetery anticline, 2007

an earthquake, the rubble from buildings is a large volume of trash, and we look for a close place to dump it. All too often, the place chosen to fill in is a salt marsh or other wetland. We are only now realizing what is lost. Think about the water gardens we might have downtown, if the old lagoon were not filled.

Most of the old El Estero (prehistoric lagoon of Mission Creek), however, did not fill in because of human activities. It was starved of water when Mission Creek was diverted to the west tens of thousands of years ago. As a result of being starved of water and sediment, the salt marsh would have naturally disappeared from the landscape, even if we hadn't administered the coup de grace following the earthquake. Although the old lagoon isn't there anymore and is covered with pavement, houses, factories, and all sorts of buildings (and even, perhaps, time-share condos in the future), it still presents a flood hazard. During floods in the last several decades, water overflowed from Mission Creek and entered the old lagoon. Runoff from the Riviera also flows south along city streets and drains (Laguna Drain) into the old lagoon. Thus, if you are down in the "funk zone," where artists of all kinds hang out, you will see signs that say "flood hazard," and you might wonder why, since Mission Creek is quite a ways away. Wouldn't it be great if the funk zone was preserved and became an even more prominent place for locals and tourists to visit? Take a look at Granville Island in Vancouver Canada to see an example of the power of land use transformation, from industrial eye sore to a valued area for art galleries, art studios, farmers markets, and restaurants.

When Mission Creek overflows, it may fill its old lagoon with water. When it rains hard or long, the old salt marsh may fill with two to three feet of water. Flooding has occurred several times in recent years, especially 1995 and 1998, and con-

tinues to present a hazard to Santa Barbara. The old lagoon also contains a lot of sand and silt, fine-grained soils with a high water table. As a result, the area is prone to liquefaction during seismic shaking. Liquefaction occurs when shaking of saturated, fine-grained soil particles during earthquakes disrupts the soil structure by increasing the water pressure, turning the soil into a liquid. If this happens, some of the buildings may sink into the soil.

When the old lagoon fills, it looks like an inviting place to take a swim by jumping off one of the freeway overpasses or other bridges. Don't do it! That is, unless you want to get a bad case of poison oak. From the mountains, the oils of poison oak end up in the water and float on top of the floodwaters. Even wading in it can give you a very bad case of the itch. We wonder about this every time we see the flooding and young people boating, swimming, playing, or frolicking in what was the old lagoon. This behavior is risky, unless you want to get the Santa Barbara itch. Also, you might drown or be exposed to all sorts of pathogens and toxins from our polluted urban waters that tend to pool in these areas during times of flooding.

Why Is It Often Wet Where Castillo Street Passes Below the Freeway?

For years, it's nearly always been wet at the Castillo underpass. Of course, it's a low area, and the groundwater table is high, so you might expect some seepage of groundwater. However, it is also the site where the Mesa fault crosses through. We mentioned earlier that, where faults cross the landscape, they often dam groundwater. The Mesa fault is south-side-up and blocks groundwater moving from the mountains to the sea. The fault is a barrier to groundwater, forcing it to the surface, where groundwater levels near the sea are already high! Water seeping onto the road has been a common problem at the Castillo Street underpass for



Fig. 3.25. Castillo Street underpass is often wet. The mesa fault crosses here and dams groundwater, forcing water to the surface, 2007.

decades. Engineers have given a lot of attention to this, and we have tried one solution after another. The newest idea is some sort of soil electrode process to move the water, but the water is likely to be a continuing problem. It was still wet in 2011 (Fig. 3.25), and it is still occasionally wet today. It's difficult to fight Mother Nature. If sufficient funds are spent and the groundwater is kept low by pumping or electrolysis, then the underpass could probably be kept dry. A simple solution might be to elevate the road a few inches, collect the groundwater, and pump it to nearby Mission Creek. Fixing the water problem would make the street safer to drive on.

Mission Canyon: Retreat to Old Santa Barbara

Mission Canyon, along with its main tributary Rattlesnake Canyon, is only a few square miles in area, but what a difference a little distance, altitude, and water can make. Before discussing the natural history of Mission Canyon, it is important to acknowledge that it was not Juan Cabrillo (an explorer who sailed through the area in 1542 during the period of Spanish exploration) who discovered the area called home by the Chumash People. The first Native Americans arrived at least 13 thousand years ago, and they were the people

who discovered this land and populated it long before the arrival of Europeans. When the Spanish arrived, there were many Chumash villages along the coast and on the Channel Islands. The total population may have been at least 18,000 persons. Two of the larger villages were in the Santa Barbara to Goleta area. Particularly well known was the Chumash Village, known as Syuxtum, at Burton Mound, close to Stearns Wharf today. Many descendants of those people, and those they intermarried with, live in Santa Barbara today.

There is a Chumash oral history handed down generation to generation. A collection of these oral narratives is presented in the book "December's Child," which is based on the work of John P. Harrington and is edited by Thomas C. Blackburn. The first oral narrative in the book speaks of the three worlds defined by the Chumash as the world in which we live, as well as the one above and the one below. To the Chumash, the world in which we live was the center and biggest island. They believed that two giant serpents held up the world,

and, when they moved, they caused earthquakes. The world above was sustained by a giant eagle who, when its wings were spread, caused the phases of the moon and flow of water in the streams and in springs of the earth.

Three sacred parts of the environment to the Chumash were earth, air, and water, with sun as the principle god. The Chumash listened to their elders and passed on their stories and wisdom. They passed on the idea that the earth is on top of the waters of the ocean and that there are three elements that must be treated with caution. Those elements are wind, rain, and fire, with the rainbow being the shadow of these elements that compose the world.

Chumash art (painting on rock) is preserved in Painted Cave in the south slope of the Santa Ynez Mountains on the east side of San Marcos Pass, along a tributary of Maria Ygnacio Creek (Fig. 3.26). According to research by the Santa Barbara Museum of Natural History, the paintings are thought to have been completed in the past 1,000 years. One round figure (a black circle outlined in white) could be a solar eclipse of the sun that occurred in 1677 (consistent with the age estimate). A numerical date of the paint, using Carbon -14 in the organic component of the paint (radiocarbon dating), has not been done. Therefore, the age is an educated opinion (guess). The paintings were done over a period of time, and some earlier images are partly covered by more recent ones. The dominant colors of the art are black, white, and red. Red and black paint can be made from iron oxide minerals (ochre or hematite), and white paint can be made from the mineral gypsum (calcium sulfate) or diatomaceous earth (mostly silica from diatoms, a form of plankton) from the

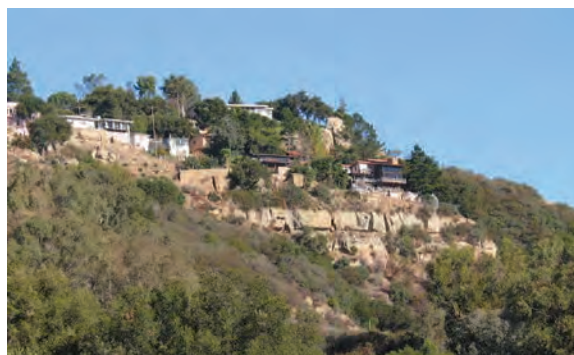


Fig. 3.26a. Community of Painted Cave sited on nearly flat lying Coldwater Sandstone Cliff, 2007. The cave (Painted Cave) is located below the cliff, and not shown on this photograph.

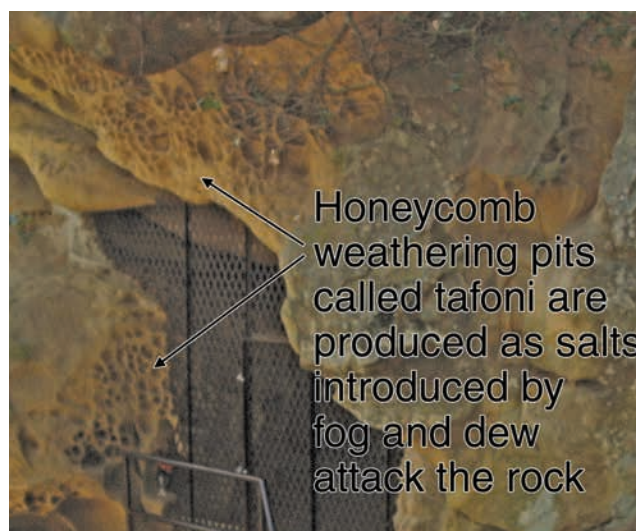


Fig. 3.26b. Entrance to Painted Cave. Gate protects paintings. The cave is in Coldwater Sandstone, and is a large opening produced by chemical weathering as are the other smaller holes.



Fig. 3.26c. Paintings on the left ceiling of Painted Cave, 2007

Monterey Shale. Organic binders, such as animal oil and charcoal, were evidently also used, along with crushed plants and water.

The cave itself has formed in gently inclined (to the north) Coldwater Sandstone, below the sandstone cliffs where the community of Painted cave is sited. There are at least two hypotheses (educated guesses, with limited evidence) to explain the origin of the cave. Hypotheses in science are put forth to explain a phenomena. They are assumed without proof, but the best hypotheses have evidence to support them. A hypothesis is possible to test (for example, through experiments in a laboratory or collection of field data with analysis and interpretation). The best hypotheses can lead to predictions. An educated guess that can't be tested is not a hypothesis and is not science. One hypothesis for the origin of Painted Cave is that the cave results from the process of rock fall, where several large blocks of sandstone ended up in the right position to produce a cave. I have seen caves in Yosemite Valley near Mirror Lake that were formed from large rock falls. In Yosemite, two or three blocks, with an opening in between, form the cave walls, and another block forms the roof. Rock falls have occurred below the Painted Cave Community, and a cave produced in a manner similar to some of those in Yosemite seems possible. However, examination of the rock at and around the cave does not support a rock fall origin. Although there are rock fall blocks on the slope near the cave, the main blocks of rock forming the cave are in place (that is they appear to be part of the rock mass of the Santa Ynez Mountains, not blocks of rock that moved down slope in a landslide). You can observe the rock along the road in front of the cave. One thin sandstone bed has fossil oyster shells, typical of the Coldwater Sandstone. Different masses of the rock (outcrops), including the one the cave is in, suggest a common tilting ("dipping" to a geolo-

gist) of the sedimentary rock layers (beds) into the mountain. They are part of the syncline (elongated bowl-shaped fold) mapped many years ago by legendary Santa Barbara geologist (and my friend) Thomas Dibblee Jr., who lived on Mission Street until his death at age 93 in 2004.

A second hypothesis is that the cave was formed by rock weathering (physical and chemical processes that break down rocks near the surface of the Earth). The honeycomb shaped pits on the outside of the cave are known as tafoni (Fig. 3.26b) and are produced by weathering of the rock. The weathering process that forms tafoni starts with water and salts delivered by fog and dew from the ocean. The water and salt infiltrates the rock about an inch, and, when the water evaporates, the salt forms mineral crystals near the surface of the rock. As the crystals grow between and around the grains of the rock or in small fractures, they expand (increase in volume) and force small bits of the rock to flake off, forming holes that eventually look like the inside of an egg carton. The outer surface of the rock may harden due to mineral precipitation, forming a crust.

The process that forms tafoni is known to produce caves (it is called cavernous weathering). Hemispheric pits and small caves on the undersides of overhanging blocks of rocks in exposed cliffs have been reported in semiarid areas in California and other semiarid regions in the world. As tafoni develops, it often grows larger, both upward and inward, producing openings in rock (caves) of various size.

Examination of Painted Cave suggests that one or two of the sandstone layers are particularly susceptible to weathering that produces the tafoni. Some of the larger pits appear to have formed from the coalescence of smaller tafoni pits, forming alcoves several feet across and deep. In other words, they are smaller versions of the main cave. Similar alcoves are on the inside of the cave where the paintings are located. Thus, it appears that ta-

toni weathering is the process that best explains the origin of Painted Cave.

You can drive to Painted Cave State Historic Park by turning left on Painted Cave Road, about 5 miles north up San Marcos Pass Road (Highway 154) from Foothill Road in Santa Barbara. Drive about 2 miles (seems like 10) up the sometimes very steep, winding, narrow road until you enter a shaded canyon just below the Painted Cave Community. Parking is very limited, so be mindful of other cars, pedestrians, bikers, and wildlife. You will find the cave a few steps up the western slope of the canyon. There is a locked iron gate in front of the cave, but the paintings are clearly visible (a flashlight helps see them more clearly on a cloudy day, but no flash photographs, please). You can do an Internet search for tafoni weathering and read more about the process of cavernous weathering and tafoni. Painted Cave reminds us of the people who were here for thousands of years before the Spanish arrived. Chumash heritage and history is to be celebrated; just as

we celebrate those who followed the Chumash to this land we call Santa Barbara.

Having discussed the Chumash heritage of Santa Barbara, we will move on to a discussion of Mission Canyon. Today, the gateway to Mission Canyon is the Santa Barbara Mission (Fig. 3.27). The mission, with its commanding view of the city, channel, and islands, is on the uplifted plate of the Mission Ridge fault. The east-to-west linear hill across the creek behind the Santa Barbara Museum of National History is the topographic expression of the fault and fold that produced Mission Ridge. We begin our journey of exploring Mission Canyon at the Mission and work our way to the Santa Barbara Botanic Garden and the Rattlesnake Creek Wilderness Area.

Historic Old Santa Barbara Mission was the tenth of a series of missions and was established in 1784, on the Feast of St. Barbara, by a Spanish Franciscan Priest. The Mission started humbly with a group of small adobe and thatch buildings that,

through the years, grew larger, as a series of churches, each larger than the previous, was constructed. An earthquake in 1812 destroyed the adobe structures that, with reconstruction, led to the present church and buildings. Adobe (a mixture of clay and straw) is one of the building materials most vulnerable to earthquake shaking. Adobe is no match for even modest earthquakes, and thousands of lives have been lost in areas where un-reinforced construction with adobe has taken place.

The present church was dedicated in 1820, and residences for the Mission community were built thereafter until about 1870.



Fig. 3.27. Old Santa Barbara Mission, located at the head of the alluvial fan the city is sited on. The lion head was the laundry facility. Water came from Mission and Rattlesnake creeks to the north via an aqueduct, 2007.

The magnitude 6.8 earthquake of 1925 damaged the building, which was restored in 1927 and reinforced in 1953.

Two major challenges in establishing a successful mission included the availability of building materials and a reliable water supply. There was no shortage of sandstone to be cut into blocks. Many millions of tons of sandstone were supplied by prehistoric debris flows that delivered boulders at their doorstep. When it came to their water supply, the padres had some good engineers who were sent from Mexico to study the canyons and water resources above the Mission.

Santa Barbara, with its semi-arid, Mediterranean climate, has highly variable precipitation. Average annual rain fall in the city is about 18 inches, but it can vary from as low as 5 inches to as much as 48 inches. When it rains 18 inches in the city, the rainfall in the mountains may be double that or more. Several years of above average rainfall are often followed by several years below average, in a decadal cycle based on the movement of air masses and ocean circulation pattern. A system of high pressure and the jet stream migrates north and south in the Pacific Ocean and on land. When the jet stream is south of Santa Barbara in the winter, storms from the North Pacific can reach us. When the jet stream remains to our north, we will receive fewer storms and less rainfall. Superposed on this is the periodic warming of the equatorial Pacific Ocean that drives El Niño events. During periodic El Niño years, we often have increased, intense rain, while, across the Pacific in Australia, there is drought. During El Niño years, we also have higher storm waves that attack the shoreline. Goleta Beach still has not recovered from the strong El Niño of 1983.

Of primary importance to the Mission was a system of water storage and distribution from the mountains above the Mission, where water was more abundant. The water was needed for agri-

culture, cattle, and sheep, as well as for the local growing population. There was the necessity to be self-sufficient because Santa Barbara, then as now, was relatively isolated, and the Mission couldn't depend upon assistance from far away locations.

Changing land stewardship occurred over many years, first from the Chumash to the Spanish, and then from Spain to Mexico in 1822. In 1848, Santa Barbara, with the rest of California, became a part of the United States. Because Santa Barbara was difficult to get to and had many Spanish speaking people, it retained much of its Spanish heritage and language longer than most of California.

The water system that the Franciscans constructed included two small dams about 2 miles up Mission Canyon. They then constructed a system of small aqueducts that delivered the water to the Mission. The Spanish word for the aqueducts that they built was canoas, which translates to flumes that funnel the water to the mission. Thus the name of Las Canoas Road in Rattlesnake Creek is a result of the water system.

The largest dam on Mission Creek is about 150 feet wide and 25 feet high. It was constructed in 1807, with the help of the Chumash. A smaller dam on Rattlesnake Creek was built shortly thereafter. Both dams are now completely filled with sediment that was transported down the canyon by the power of the streams and is trapped behind the dams. The dams remain as part of our Mission Period heritage.

The water moved down canyons in aqueducts (canoas) and was stored in a holding basin near the Mission. From there, the water was distributed to the fields and Mission to be used in its outdoor laundry facility, which has a carving of a mountain lion in the front of the rock trough. Water also fed the Moorish fountain that was completed in 1808. The aqueduct, although on a smaller scale, is

reminiscent of aqueducts in southern Spain that, after hundreds of years, still deliver water from the Sierra Nevada to the famous Alhambra Palace in Granada. By 1809, a variety of crops and thousands of cattle and sheep nourished by the water from Mission Canyon helped make the Mission self-sufficient and economically viable. With this short history behind us, we will now move our discussion to Mission and Rattlesnake Canyons, which remain much as they were hundreds, if not thousands, of years ago.

Entering Mission Canyon above Rocky Nook Park, you encounter an enchanted forest. Giant oaks, hundreds of years old, greet visitors and hang over the road, providing shade on hot days. Sounds of wild birds, ranging from quail to turkey and songbirds, mixed with the sounds of wind and running water, create a canyon environment that is a quiet retreat from city life below.

Mission Creek and its major tributary, Rattlesnake Creek, both flow over bedrock that varies from soft shale to hard sandstone. Pools are eroded by water flowing around and between large boulders, delivered to the channel in the past from debris flows and floods. Other pools are at the base of rock ledges that create waterfalls. I call one pool in Rattlesnake Creek above Skofield Park in the Rattlesnake Canyon Wilderness Area *Ojo Frio* or Cold Eye (Fig. 3.28). The round, deep pool at the base of a small waterfall is excavated in the bed of the channel and surrounded by boulders of Matilija and Coldwater Sandstone. The Coldwater lives up to its name, delivering cool water from springs and seeps that maintain habitat for the endangered southern steelhead trout in Rattlesnake Creek. Where the stream flows through the Coldwater Sandstone, the valley is relatively narrow, with steep sandstone cliffs or slopes. Sandstone forms narrows that I call steelhead narrows, where water persists even in dry years when most of the

stream channel has little or no summer water. You won't easily find the pools in steelhead narrows because they are not visible from the trail that winds its way up the canyon. Do a bit of rock hopping above the second trail crossing, and you will find the pools. Be very careful walking on rocks near the stream, as they can be slippery. I wear shoes, such as sneakers or river sandals, and wade up the channel (in the water) using my hands and sometimes crawling over rocks to increase safety. Take a swim on a summer day or meditate on the silence of the canyon, but don't go fishing! The trout are endangered and protected.

The name *Rattlesnake Canyon*, according to Karen Telleen-Lawton (who wrote the wonderful book *Canyon Voices*, 2006), is derived from the sinuous pattern of the canyon as it winds its way south, looking like a rattlesnake lying along a trail. In all my hikes in the canyon, I have not seen a rattlesnake, although others have.

The canyon looks ancient and eternal, but, geologically, it is very young. Deposits of past debris flows are common, and, if you look closely, you can find debris flow levees a few feet above and parallel to the channel. The levees consist of open framework boulders (linear piles of boulders with large open spaces, a few inches to a foot or more, between them). The levees form as a debris flow pushes the boulders to the side and top of the flow. The fine sediment (gravel, sand, silt, and clay) in the flow drained away from the levees during the depositional process.

Along the eastern crest of the canyon, above Skofield Park, there is a remnant of a 125,000 year-old alluvial fan that is similar to the fan that the city of Santa Barbara is located upon today. We know the age of the fan because we have several numerical dates of boulders at the top of the fan above Skofield Park. These boulders were delivered from debris flows from the Santa Ynez Mountains



Fig. 3.28a. Boulder defended pool (*ojo frio*) in steelhead narrows of Rattlesnake Creek, 2005

to the north during the last major warm interval, about 125,000 years ago (known as the Emian). At that time, sparse vegetation and intense winter precipitation produced voluminous amounts of sediment that constructed alluvial fans in many locations in California. Boulder deposits and fans extended south from an ancient mountain front and over what is now Mission Ridge. This explains the many boulders found on Mission Ridge today and provides a minimum age for the ridge. During the past 125,000 years, the fan has been uplifted and folded, forming Mission Ridge. Further north, the alluvial fan was incised (stream channels eroded), forming, with slope processes that widened canyons, south flowing steep canyons, including Mission and Rattlesnake Canyons. If you hike to the top of the fan above the east side of the canyon above and a bit north of Skofield Park, you can see the Santa Ynez Mountains and the Santa Barbara landscape all the way to the Channel Islands. This is where the Tea Fire recently claimed the beloved Mt. Calvary Monastery.

What a different place it must have been 125,000 years ago, when the alluvial fans merged to the south with the Pacific Ocean. Another period of fan building occurred about 60 thousand years ago, transporting the gravel and boulders to parts of the alluvial fan that the city of Santa Barbara is built on. Remnants of the upper parts of the fan form the flat surface above Mission Canyon at the Santa Barbara Botanical Garden. The 60,000 year old fans haven't been dated. The ages are inferred from their connection with marine terraces at Shoreline Park, which have been dated. Also,

it is thought that a time of major deposition of sediment occurred in southern California about 60,000 years ago, during a minor warm period.

An obvious question is, how do we know that the alluvial fan at the top of Rattlesnake Canyon, which is folded over Mission Ridge, is 125,000 years old, or that the debris flow at Skofield and Rocky Nook parks (see Tale of Two Parks) is 1,000 years old? The date of the debris flow and Skofield Park resulted from Carbon-14 dating. Carbon-14 dating is the most widely used method for dating organic materials as old as about 50,000 years. Carbon-14 is a natural radioactive isotope of carbon that is produced in the upper atmosphere when neutrons from cosmic rays interact with Nitrogen-14. Carbon-14 is an isotope of carbon. An isotope refers to atoms of the same element (in this case carbon) that have the same numbers of protons in their nucleus, but a different number of neutrons. The three naturally occurring isotopes of carbon are Carbon-12, Carbon-13 (both of which are stable), and Carbon-14 (which is unstable and radioactive).

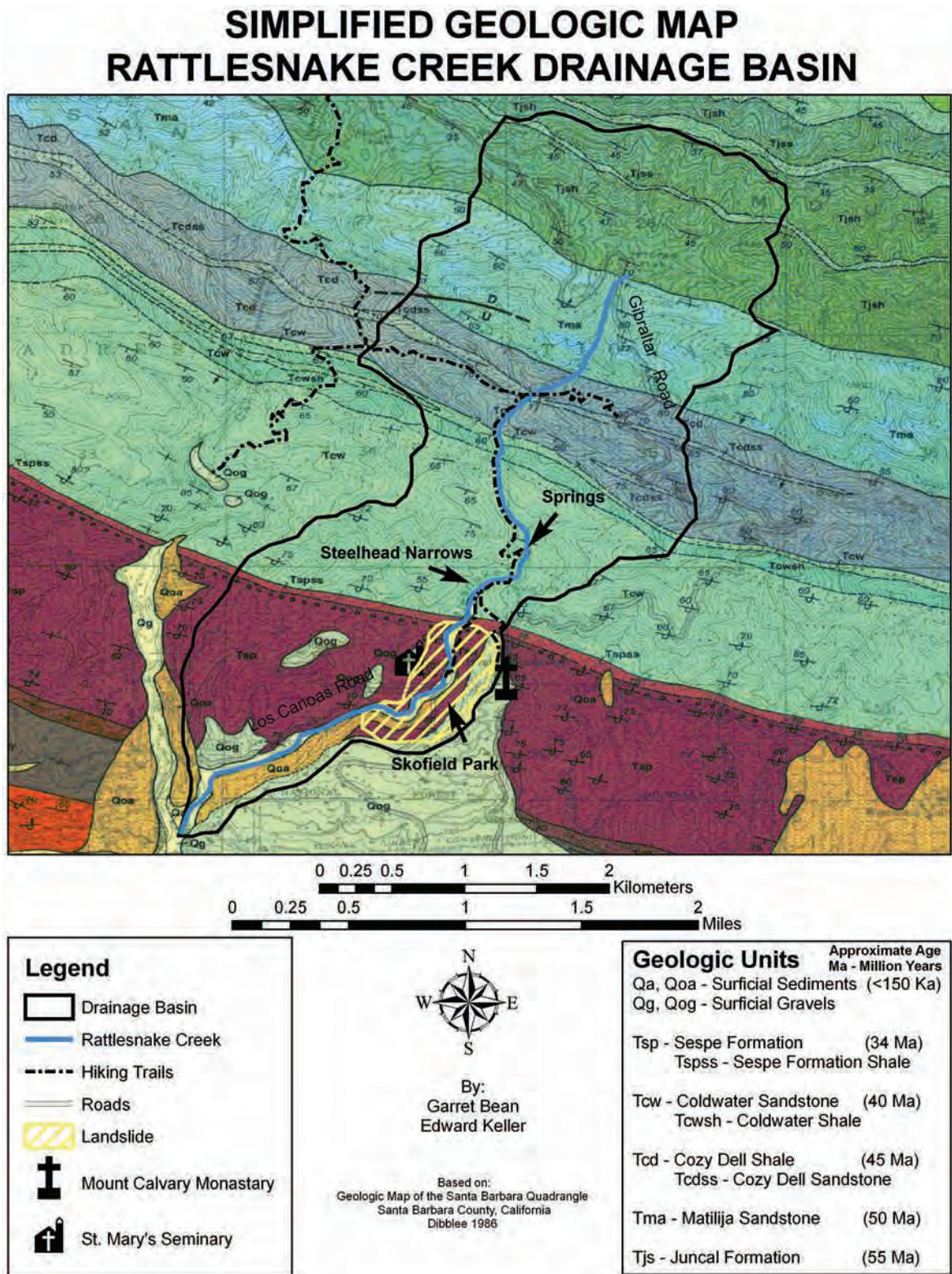


Fig. 3.28b. Map produced by Garret Bean.

Although Carbon-14 is a very tiny portion of the total carbon, it enters all living things while they are alive in a relatively constant amount, proportional to other stable carbon isotopes. When an organism dies, it stops taking in Carbon-14, and the Carbon-14 starts decaying to Nitrogen-14. Using sophisticated scientific instruments, we can count the numbers of atoms of Carbon-14 and Nitrogen-14, which are related to the amount of time the decay has been going on. For carbon-14, we know that the half-life is approximately 5,568 years, which means that, after that time period, the amount of Carbon-14 left in a sample is one-half the original. The amount of Carbon-14 is reduced by half after every subsequent half-life.

The measurement of Carbon-14 is an established method for dating organic materials, but how do we date the boulders on the tops of alluvial fans and arrive at the age of 125,000 years? The method we use in dating alluvial fans is known as exposure dating. Exposure dating works because Earth is being bombarded constantly by galactic cosmic radiation. The radiation consists of high-energy protons and other particles that have a source within our galaxy. Interactions between the cosmic radiation and other particles produce nuclides (a type of isotope) that include, among others, Beryllium-10, Neon-21, Aluminum-26, and Chlorine-36. These nuclides strike Earth and enter into minerals and rocks (and, thus, the boulders) at the surface of the earth. Different nuclides are appropriate for dating particular minerals. In order to date how long a boulder has been at the surface of earth on an alluvial fan, we need to know two things. First, we need to know the rate of production of a particular nuclide, and, second, we have to know how much of that nuclide has accumulated in the sample. Knowing those two things, it takes simple arithmetic to obtain an exposure date, i.e., the amount accumulated divided by the rate of production (the rate the

nuclide is accumulating in the boulder). In practice, a boulder is sampled by drilling it and taking a core or closely spaced samples to a depth of a few inches in the boulder. A simple analogy to exposure dating is measuring the degree of sunburn on a person by how red he or she is.

Scientists with the US Geological Survey, working in cooperation with some of us at UCSB, collected samples from boulders on the alluvial fan above Rattlesnake Creek. Using Neon-21, an age close to 125,000 years was obtained. The date is only an approximation. The numerical dates we received from the U.S. Geological Survey are within a few thousand years of 125,000 years. We believe that 125,000 years, which was the last major warming when a lot of rock debris was produced in many places in California, is the best estimate of the age. Although there are a lot of uncertainties with exposure dating, and because it is a relatively new technique, the dates obtained seem reasonable, given the geologic environment and what we know from other areas. Having digressed to introduce the topic of how we know the geologic timing of our natural history, we return to our discussion of Mission Canyon.

When you visit the Botanic Garden, you can partake of the mountain views of the crest of the Santa Ynez Mountains to the north that include Cathedral Peak on the left (Fig. 3.29). The peak is a rock spire, with an elevation of 3,323 feet, and is often confused with Arlington Peak, which is more visible (Arlington peak is sometimes called Cathedral Peak on maps). La Cumbre Peak (elevation 3,985 feet) is to the right when viewed from the gardens. The white sandstone cliffs that hold up the two peaks are the Coldwater and Matilija Sandstones, respectively. These hard sandstones are the main sources of large boulders (3 ft to over 20 ft in diameter) found in the canyons below. As you descend into Mission Creek from the entrance



Fig. 3.29. Santa Barbara Botanic Garden. Large boulder is part of a debris flow deposit, 2007

of the Botanical Garden, you will drop through the alluvial fan with its debris flow deposits to the site of the Mission Dam constructed 200 years ago (Figs. 3.30 and 3.31). That it has survived to this day is a testimony to the skills of the people who constructed it. Parts of the garden, including some plants, outbuildings, and equipment, were burned during the Jesusita Fire in 2009. The native vegetation will recover, and other parts of the garden will be restored.

Mission Canyon is different from Rattlesnake Canyon in a major way. Rattlesnake Creek has summer low flow that supports fish, while Mission Creek above the confluence with Rattlesnake Creek generally does not. Mission Canyon is eroded through the same Coldwater Sandstone as Rattlesnake Canyon, so why doesn't it have springs and seeps that provide summer low flow and fish habitat? The reason may be that Mission Tunnel, which was constructed from 1904 to 1912 to provide water to the city of Santa Barbara from Gibraltar Dam on the Santa Ynez River, takes water that otherwise would seep into Mission Creek.

In other words, the 4 mile long tunnel through the mountains, which is directly over Mission Creek, is a drain that collects water that would otherwise seep into Mission Creek.

A study by UCSB Geologist Dr. Laura Radamacher and Professors Jordan Clark and James Boles (UCSB) on the hydrology of the tunnel found that water that seeps into the tunnel is a mixture of water that is older than 50 years, along with modern water. Water younger than 50 years is recognizable due to the presence of tritium from radioactive fallout from testing nuclear weapons. When it rains, water seeps into the rocks, moves downward along fractures, and enters

the tunnel. A lot of groundwater enters the tunnel. The amount of water that flows into the tunnel from the rocks averages about 1,300 acre-feet per year. This is about 20% of the total water delivered from the reservoir. If the tunnel were not present, more groundwater would seep into Mission Creek to help provide summer low flow that might support trout, as in Rattlesnake Creek. Water is occasionally released by the city into lower Mission Creek to maintain steelhead trout in the creek. Near the Santa Barbara Museum of Natural History, the stream flows parallel to the Mission Ridge fault through Rocky Nook and behind the museum. Take a walk behind the museum and ponder the steep hill that is the fold (fault) scarp. There is almost always perennial flow here, and the area is one of the refuges for the endangered southern steelhead trout.

In 2005-2006 (a wet year), steelhead were found in surprising numbers along Mission Creek, including large pools in the city near Haley, Ortega, and Bath Streets. In the spring of 2006, we observed about 30 juvenile steelhead (approx-



Fig. 3.30. Debris flow deposits east side of Mission Creek at the Botanic Garden. Note mixed sizes of boulders, characteristic of debris flows, 2007



Fig. 3.31. Old Mission Dam, 2007

mately 6 inches long) that had schooled into one of the pools. We know they moved to that pool from upstream, perhaps Rattlesnake Canyon, because they appeared in a pool where no fish were observed two weeks earlier. Some of the pools also contained adult fish, as well as young of the year. Two weeks later, most fish were gone; we assume that they swam to the ocean because swimming upstream in the late spring is not likely. The presence of the steelhead is encouraging for the restoration of the fish in Mission Creek. The major physical barrier that remains is the section of concrete lined channel, parallel to US 101 near Carrillo Street and near the railroad station. Plans are underway to modify the concrete channel to allow for fish passage.

Our history of Mission Canyon started with the Chumash people and moved from the mountains to the sea, as the creek does. The future of Mission Canyon and Mission Creek, including everything from the trees along the banks to the fish and other wildlife, is in our hands. It is encouraging to note the many friends of Mission Creek and the effort that is going into restoring lower Mission Creek, linked by water and sediment to the mountain canyons upstream.

Recapping Santa Barbara Natural History

Our discussion about the Santa Barbara landscape upon which our city is built has concluded that we live in a dynamic place. The alluvial fan that connects the mountains to the sea, along with all its deposition of boulders and rocks, has greatly shaped our landscape. The historic Mission is lo-

cated at the head of the alluvial fan, looking out over the channel and Channel Islands. It has been uplifted along the Mission Ridge fault and kept dry because the stream that flowed by it has been diverted behind it and to the west. The padres picked a good place to build a mission! It is out of the fog, with spectacular views, and in a place that

is not subject to a flood hazard.

Catastrophic events have shaped our Santa Barbara landscape, producing some of our most popular parks and landscapes. If it was not for these processes of uplift and erosion, and for boulders thundering down canyons, our landscape would be safer, but not nearly so interesting.

BEACH LOVERS CREED

Born of this earth, nurtured by knowledge, science and values:

- *I believe in reverence of and respect for beaches; will teach my children and others that they might also revere beaches.*
- *I will celebrate beaches as places of constant change, not to be tamed, but to be respected.*
- *I recognize the centrality of water to life, and will not litter, pollute, or degrade beaches.*
- *I recognize and celebrate each individual beach for its diversity of geology, hydrology, and form.*
- *I will value ecological processes on beaches and pledge to help conserve biodiversity of hydrologic and biologic environments of beaches.*
- *I will experience beaches either as an individual or in small groups, whether it be for walking, hiking, picnicking, meditating, surfing, boating, swimming, painting and photographing, wildlife and bird watching, or catch and release fishing for personal reasons as it enriches my life. I will keep only my memories and leave only my footprints.*
- *I will defend beaches from human manipulation that changes their dynamics and reduces their biodiversity.*
- *I will support sustainable coastal management and restoration so that my and other people's children will inherit quality beaches to enjoy.*
- *I will support coastal landuse planning and zoning as the only reasonable way to both reduce societal loss to beach erosion and to preserve natural beach function.*
- *I believe in and will support the right of scenic, wild, free beaches in today's hectic world to exist.*
- *I believe that beaches have community value far exceeding commercial value and support urban beach parks.*

m⁴ontecito to Carpinteria and La Conchita

Charming Little Hills and Hot Springs of Montecito

Montecito owes much of its charming landscape to the presence of Montecito Creek, San Ysidro Creek, and the Mission Ridge fault system that runs through the area from west to east (see Fig. 2.1). The land is younger and lower between Montecito and San Ysidro Creeks than it is to the west at Mission Ridge. As you wander through Montecito, you'll see a series of small linear hills and aligned drainages that are suggestive of recent uplift caused by earthquakes. This is particularly evident in the vicinity of the Montecito Union Elementary School and adjacent Manning Park. As you drive up San Ysidro Road, you will notice a small hill just beyond the school. The hill is part of an actively growing anticline produced by the Mission Ridge fault system. Oak Creek, just east of the San Ysidro Road where the creek flows through Manning Park by the YMCA, is a water gap (a stream that is present before uplift of a fold and is able to maintain channel position across the fold by erosion as the uplift grows in width and elevation). Across the road to the west, the tennis courts in Manning Park are located on the south flank of the small anticline, and there is speculative evidence that the tennis courts have been tilted to the south. Twenty years ago, when playing tennis with my family there, the balls tended to roll to the south end of the court, and I often collected them there. The foundation of the tennis court, at that time, had been resurfaced several times, and the surfacing was thicker on the south end, perhaps in an at-

tempt to keep the court level. The important geologic observation for the area is that active faulting and folding is apparently producing the linear hills running east to west through Montecito. The faulting and folding has produced a small hill just south of East Valley Road, from San Ysidro Road east to Valley Club Golf Course. The Mission Ridge fault in Montecito has been trenched (excavated with a backhoe or bulldozed) in order to more precisely locate the position of the fault. When the position is known, the information is input to land use planning with the objective of reducing the ground rupture hazard by avoiding building homes and other structures across the fault.

Montecito Creek is the major stream in Montecito. Just upstream from East Valley Road, the stream divides to become Cold Springs Creek and Hot Springs Creek. Hot Springs Creek is the more famous tributary of Montecito Creek. The junction of Cold Springs and Hot Springs Creeks has a long and interesting history that has been chronicled by the famous Santa Barbara historian, Walker Tompkins. The stream junction is the western boundary of what was once known as "Old Spanish Town," where retired Spanish soldiers lived after serving the Santa Barbara Mission and Presidio. Some of the old family names in Montecito reflect that heritage. But let's go back a little further in time and talk about the springs of Montecito.

An interesting geologic question is, why do springs occur at all along the south front of the Santa Ynez Mountains? The reason is mostly due to the sequence of steeply inclined sedimentary

rocks that include sandstones and finer grained rocks called shale and siltstone. When it rains, water infiltrates the soil and fractures in the rocks. Some of the water may migrate down deep into the earth where the natural geothermal gradient heats the water. The average geothermal gradient is about 75 degrees Fahrenheit per mile. The deep groundwater returns to the surface along fractures and faults (conduits for flow) because the hot water is lighter and more buoyant than cooler water and naturally flows to the surface. This is analogous to a hot air balloon that rises in the atmosphere because the air in the balloon is lighter than the surrounding air. At the surface, the hot water is discharged in hot springs, generally at the low places along the bottom of a stream valley.

Where groundwater flows deep beneath the Santa Ynez Mountains (about 1.5 miles), the water is heated by the geothermal gradient to exceed 100 degrees Fahrenheit. Professor Norris (UCSB) reports in his book on the geology of Santa Barbara that the springs in Hot Springs Canyon near Montecito are about 116 degrees Fahrenheit. The springs emerge from the lower part of the Eocene Cozy Dell Formation (marine shales, siltstones, and sandstone beds). Water of about the same temperature was encountered in 1953, during the construction of the Tecolote Tunnel that delivers water from Lake Cachuma through the Santa Ynez Mountains to Goleta and the South Coast.

Water moving through the earth that does not circulate so deeply or moves up slowly emerges at the surface much cooler (about 60 degrees Fahrenheit). Cold springs are much more common than hot springs. The cool springs that are found along streams, such as Cold Springs Creek and Rattlesnake Creek, among others, provide important habitat for endangered southern steelhead trout. The springs in Rattlesnake Creek are almost all in the Coldwater Sandstone, a predictable name, giv-

en the cold springs that emerge from the rocks. The springs are a source of cool water (at least several thousand cubic feet per day) that is critical during drought or summer low-flow periods when water temperatures in creeks may become too warm for trout. The springs, during drought years, may provide almost all the flow needed that maintains the fish. Montecito Creek and its tributary, Cold Springs Creek, are important habitats for steelhead trout, and several adult fish, which presumably migrated upstream from the ocean to spawn, have been observed in recent years. A number of years ago, there was an article in the Santa Barbara News Press showing fishermen proudly holding several small trout they caught in Montecito Creek. The young fish had not yet migrated to the ocean to become steelhead. The instinct that drives a young rainbow trout to swim downstream to the ocean to become a steelhead is a mystery. After going to the ocean, many cannot return upstream to the best spawning grounds, due to barriers such as roads and culverts that block their migration. Nevertheless, resident adult trout evidently continue to reproduce young steelhead, helping to sustain the species. On the other hand, if adult steelhead do not return, natural selection may eventually lessen the urge for young fish in mountain streams to migrate to the ocean. Protecting our natural resources, including the steelhead, will require removing barriers to migration and maintaining water quality in streams such as Montecito Creek. Pumping water from the creek, as has been done historically, should not be allowed.

The Chumash people in prehistoric times discovered hot springs in Hot Springs Canyon (not a surprising name). To them, as well as to many people today, the waters of hot springs were believed to have special powers. The term *power* has great significance to Native American people and goes far beyond implying the ability to heal the sick by using

warm water. According to Walter Tompkins, one of the first American settlers to Montecito was Wilbur Curtiss who arrived in Santa Barbara in 1855. He was sick and expected to die within a few months. However, as it turned out, he lived a long life. The story goes that a 100-year-old Chumash led him to the springs. Curtiss attributed his remarkable recovery to the healing waters of the hot springs. He acquired the land and built a hotel at the site.

The Montecito area above and adjacent to the oak woodlands is subject to periodic wildfires, which naturally occur every few decades at a particular location in the chaparral environment of southern California. The Tea Fire is a recent reminder. People building wood buildings did not know the fire history of previous years, and a series of wooden hotels at the springs were destroyed by successive wildfires. The Montecito Hot Springs Resort Hotel was destroyed in the Coyote Fire of 1964. Today, the springs, with their perceived therapeutic value, are no longer accessible to the general public.

Montecito is a special place with giant oaks hanging over winding, narrow roads. It features a gentle landscape of small hills and hidden treasures, with the opportunity for views of the mountains and sea; it is a slower and more relaxed California. May it always be so.

Lookout Park and Ortega Hill

Just west of Lookout Park in Summerland is Ortega Hill (the hill you drive over approaching Summerland on the south bound US 101). The fold is one of the few places in the Santa Barbara Fold Belt where it is easy to see a young anticline and put your hand on the folded rock. You can do this on the beach at the base of the sea cliff (at low tide), and at the crest of the fold above US 101.

Most of our faults are buried deeply, and what you see at the surface is an anticline fold that is usually eroded by surface water. Erosion of gul-

lies and streams can mask the basic pure form of a fold. Not so at Ortega Hill. The anticline is young. We know this because the folded sedimentary rocks are young. The form of the fold at the sea cliff is not significantly eroded. In addition, the beach at Lookout Park is one of the treasures of Santa Barbara. With its abundance of white sand and clean water, it is a great place for a swim, walking, or sun bathing.

Carpinteria: It's All about Earthquake Faults

My friend Tom Dibblee once told us that the geology of southern California had a very simple relationship to the topography. Where the topography is high, earthquakes and other movements have uplifted it; and, where it's low, it's been down-dropped. Over the years, this has proven to be a good explanation for the big picture of the topography of southern California, including the Santa Barbara area. A good place to see the relationship between topography and uplift is the Carpinteria area. The backdrop of Carpinteria, as with Santa Barbara and Goleta, is the Santa Ynez Mountains. The mountains have been uplifted along earthquake faults for a million years or so and folded to produce the mountain range we see today. To the south, just in front of the main range, is a smaller ridge, uplifted along the Arroyo Parida branch of the Mission Ridge fault. The ridge is an older, large fold and fault that the Arroyo Parida fault produced, but it is similar in structure to the Loon Point fault. Further out from the mountains and just to the east of Carpinteria is the Rincon Creek anticline that has an interesting history involving the City of Carpinteria, the Carpinteria Salt Marsh, and Rincon Point. The smaller Carpinteria fault is also important and plays a role in some of the smaller-scale topography and stream processes of the Carpinteria area.



Fig. 4.1. Inlet of Carpinteria slough and salt marsh, modified after California Coastal Project. ©2002-2007 Kenneth & Gabrielle Adelman, California Coastal Records Project.

Carpinteria Salt Marsh: A Fault-Bounded Basin

The Carpinteria Salt Marsh (Fig. 4.1), part of which is a natural reserve managed by the University of California Santa Barbara, is a remarkable place. Santa Monica and Franklin Creeks flow in and through the slough, which provides important habitats for plants, animals, and fish. In recent historic times, the salt marsh was considerably deeper than it is today, but it still forms a place of tranquility in the midst of our modern, hectic world. The salt marsh itself owes its existence to Carpinteria fault, Rincon Creek fault, and, to a lesser extent, Arroyo Parida fault, which down dropped the basin in which the salt marsh is located by over one-half mile. You won't see a deep hole because the basin is nearly filled with sedi-

ment from the mountains. Because the faults are south side up, they have blocked the intrusion of salty groundwater and ponded fresh groundwater to the north, helping form and maintain the water resources of the slough.

The Magic of Carpinteria Beach

The long sandy beach at Carpinteria has a gentle slope offshore, which is ideal for swimming. Some people say it is the World's safest beach.

In the summer, grunion (a small fish) emerge from the sea at high tide during a full or new moon and spawn on the beach (usually late at night). The eggs are buried in the sand and remain above high water during incubation (about 10 days) until the next high tide, when wave erosion releases hatchlings to the sea.



Fig. 4.2. Carpinteria Creek Lagoon 2004, modified after California Coastal Project. ©2002-2007 Kenneth & Gabrielle Adelman, California Coastal Records Project.

When grunion run in large numbers, the swash zone (where waves rush up and back on the beach face) is alive with the motion of fish coming and going in a spawning frenzy. Seeing a grunion run in the first hours of a new day is one of the special pleasures of life. I do not bother them, but I observe their dance with life, shining in the night with silver, iridescent green color.

The best months to observe grunion (grunion hunting, but not taking) at local beaches are May to July; that is when I most likely will venture out on sandy beaches during full moon at high tide.

The Carpinteria Harbor Seal Preserve at the east end of the beach below the bluffs is often home to 200 or more adult seals. The preserve is

where they haul-out (come out of the ocean) to rest and give birth to their pups. On one night in the fall of 2006, Peter Howorth counted 482 animals. The beach is closed on both sides of the rookery from December to May to give pups time to develop the thick layer of fat necessary to withstand cold ocean water. The population of seals is, apparently, slowly increasing.

Carpinteria Beach is a gift to us from our planet. Geological, hydrological, chemical, and biological processes, acting in harmony over many thousands of years, produced the beach and the life. We enjoy the beach now, but our ultimate responsibility is to observe and protect it for future generations.

Carpinteria Creek

Carpinteria Creek south of US Highway 101 has perennial flow. That is, it flows all year. The stream flows into Carpinteria State Beach and there is a lovely little lagoon at the ocean (Fig. 4.2). The perennial flow in Carpinteria Creek is due to the Carpinteria fault, which is a south side up fault, that blocks groundwater flowing from the mountains toward the sea. As the water dams behind the fault, it comes to the surface at the lowest point, which is along the creek, and, so, provides stream flow. That water also provides important habitats for plants, animals, and fish. The headwaters of Carpinteria Creek are in the Santa Ynez Mountains, and the creek is one of the important local habitats for endangered southern steelhead trout. Plans to restore these magnificent fish from the present small run to something resembling their former abundance are underway. This will involve removal of barriers to migration, such as road crossings, and education (since many people do not even know these fish exist). Several years ago, a picture in the Santa Barbara News Press showed a game warden holding a very large “salmon-sized” steelhead trout that had been plucked from the creek by a worker who simply didn’t know any better.

The group spearheading the creek restoration is the Carpinteria Creek Watershed Coalition (a partnership of local landowners, interested individuals, community groups, and government agencies). Restoration projects to replace several concrete slab road

crossings, that restrict fish migration, with bridges began in summer 2008, after several years of planning. People like you and me can volunteer and participate in restoration activities, such as planting native vegetation along the creek banks. It will be local interest and activity that will bring back the steelhead to Carpinteria Creek.

Tar Seeps

Although it may not be commonly known, the name “Carpinteria” probably owes itself, in part, to the oil and tar seeps that occur along the base of the sea cliff at the east end of Carpinteria Beach State Park (Fig. 4.3). The tar comes up as natural seepage along fractures and faults, which are produced by earthquakes in the rocks that underlie the area.

The Chumash people who inhabited the Carpinteria area for thousands of years prior to the arrival of Europeans knew well the value of the tar. They used the tar for a variety of purposes,



Fig. 4.3. Tar seeps at Tar Pit Beach, Carpinteria State Beach, 2011.

including attaching stone objects to tools (points to arrows and spears), to seal their baskets, and to caulk the wood planks of their canoes (tomolos). Their famous canoes were seaworthy and allowed the Chumash to reach the Santa Barbara Channel Islands and, even, places further afield.

Soldiers with the Gaspar de Portola expedition in 1769 named the Chumash village *La Carpinteria*, or *the carpenter shop*, because they observed Chumash people in the area splitting driftwood and shaping redwood planks to form the tomolos. The redwood was gathered from local beaches, where they had been transported by the currents from northern California where they grow naturally. The name *Carpinteria* is still with us, as a result of the activities of the Chumash people.

As oil and tar moves to the surface at the beach, it initially forms bulging black, small flows, or mounds of oil and asphalt. The asphalt deposits contain fossils of animals, such as elephants, saber tooth cats, and plants, similar to those found at the well-known La Brea Tar Pits in Los Angeles. As in Los Angeles, the asphalt at Carpinteria was mined and was used for the first paved roads in Santa Barbara County. If you visit Carpinteria Beach State Park, you can still see what it known as Tar Pit Beach, near the east end of the park. Some small oil and tar pits are also present in some housing areas of Carpinteria. Holes excavated for utilities where these natural tar deposits are located will fill in with flowing tar.

Carpinteria Bluffs: Thunder Bowl of the past, Playing Fields and a good Hotdog

Carpinteria Bluff is an uplifted marine terrace. The age of the terrace (dated near La Conchita) is about 45,000 years, and the vertical rate of uplift from folding and earthquakes is several feet per thousand years. It is a highly deformed terrace that, from east to west, drops in elevation from

about 600 feet near La Conchita to dive below sea level at Carpinteria. In other words, the terrace is strongly tilted down to the west.

The bluffs, located just east of the city, are a positive story of preservation of land for the common good. Not too many years ago, a project on the bluffs was suggested that called for 300 units of housing, as well as a shopping mall, gas stations, and fast food stores. The people (in a grassroots movement) objected, and, today, the bluffs are a place that expresses the community's cultural values in a variety of ways.

The people who helped preserve the Carpinteria Bluffs for future generations placed more value on natural habitat and recreation than on urban development. The site is crossed by several active faults, including the south-side-up Carpinteria fault and a smaller related north-side-up fault a few 100 feet further to the south, but still on the bluffs. Driving along US 101 east of the city, or, better yet, along Carpinteria Avenue, it's easy to miss the gentle hill that slopes up to the south before the topography becomes flatter at the top of the bluffs' area (Fig. 4.4). Along the base of that small hill or scarp, which is due to the Carpinteria fault, the soil is often wet. It is wet because the south-side-up fault tends to block groundwater and forces it to the surface. The presence of water at or near the surface due to a fault is a common phenomenon.

Visit the soccer playing field near the east end of the bluffs. The land was graded to make a level playing field. Because some soil was removed, the northern edge of the soccer field, parallel to Carpinteria Avenue (where the fault is located), is lower and wetter than it was prior to grading. Observe young players enjoying soccer on a Saturday afternoon. At times you will see that the north side of the field (where parents watch their children play games) often is muddy. Some of the players look like mud balls moving up and down

the field. That area will be wet frequently as a result of the Carpinteria fault, but it will not detract from enthusiastic soccer play. The fault also passes directly below the Hotdog Man's Surf Dog stand. Conversation with its owner is lively, and we have discussed the fault several times when I've taken UCSB students to map the fault as a learning exercise. By the way, the hotdogs with homemade sauces are not to be missed - people drive for miles to get them!

Thunder Bowl

As you go further to the east along Carpinteria Avenue, you will come to the site of the Thunder Bowl, mentioned by Professor Robert Norris (UCSB) in his informative book on the geology of Santa Barbara County. The bowl was a racetrack, located on the Carpinteria Bluffs near the intersection of Highways 101 and 150, close to the famous

Rincon Point surfing area. The track held jalopy and other races between about 1947 and 1956. The location of the racetrack was along the south-side-up Carpinteria fault. Small depressions, called sag ponds, are common on the downside of a fault. Such a depression must have looked like a good place for a racetrack. The quarter-mile dirt oval track produced a lot of noise and acquired the name "Thunder Bowl."

Fault Deforms US 101

If you go further to the east to the "big cut" of US 101 near Rincon Point, you may observe that the south-side-up Carpinteria fault is warping 101 where it crosses the interstate. As you drive through the cut towards La Conchita, carefully observe the car in front of you, and you may see it abruptly rise up a few inches as it goes over a small bump. You may also feel the slight bump in the



Fig. 4.4. Carpinteria fault scarp near Ballard Road, 2007

road as you cross the fault. This would suggest that there is a component of very slow movement, or fault creep, on the structure. Of course, it could also result from compaction on the north side of the fault, as a result of softer earth materials being present along a depression before the road was constructed.

Our discussion of Carpinteria leads us to the conclusion that our recent geologic history is interpreted, in part, by looking closely at the land. It reminds me of what I teach my students: Observe the landscape carefully, and it will reveal the history. I call this process listening to the Earth.

Much of the geologic history may be covered with vegetation or have been removed by erosion, so I define listening to the Earth as using observational skills, as well as imagination, along with geologic data to interpret Earth history. Studying geology is sometimes analogous to doing a jigsaw puzzle where about half or more of the pieces are missing--like the TV Game show *Wheel Of Fortune* where letters of a phrase are concealed and the contestant tries to figure it out, using limited information. Earth Scientists, when interpreting the landscape, attempt to fill in the concealed or missing information and determine the message.



Fig. 4.5. Rincon Point, view to the east of this famous surfing spot, 2009.

Surf's Up Dude: Rincon Creek and Origin of a Famous Surfing Spot

Rincon Point (Fig. 4.5) is a prominent headland where Rincon Creek now flows into the ocean, forming what is known as a headland delta, which is composed of boulder deposits carried to the shore by Rincon Creek, as well as along the shore by wave processes. Rincon Point is a cusped delta because of its triangular shape and effect on the shoreline. The point projects to form a very favorable location, relative to incoming waves, to produce a long, continuous break. The point is one of the famous surfing sites in southern California, and surfers say you can catch a wave at the point and ride it perhaps as far as one mile to the east during the big breaks.

Rincon Creek drainage basin (the area contributing water to the creek) is a large one along the coast, and, in the past, a large number of boulders have been delivered by way of stream processes during floods and debris flows. The boulders protect the point, helping it to be preserved. Another reason the point is at this location is that a major change in geology occurs there. The structure is a cross-fault, as Dr. Larry Gurrola at UCSB discovered, trending south to north that terminates at east to west structures. Large folds to the east terminate and new ones start to the west of the point. For example, the Rincon Creek fault and anticline begins just west of Rincon Creek and is growing west into Carpinteria.

If you go up Rincon Creek toward its headwaters, you will notice no particular topographic break in the streambed or anything to suggest that the stream hasn't always been in the position it is today. However, if you look more closely at the topography, and, in particular, at the Rincon Creek anticline, a segment of which starts near the western side of Rincon Creek and can be followed to the west, you may get a slightly different view

of the history of the creek. In the prehistoric past, near the present intersection of Highways 150 and 192, Rincon Creek made a sharp bend to the west, eventually joining Carpinteria Creek to the west. How do we know this? There is a paleo-valley that is a prehistoric valley running east-west along the base of the Rincon Creek anticline. That ancient valley intersects the present Rincon Creek valley near the intersection mentioned above. The Rincon Creek anticline forms a prominent fold scarp that faces north and can be seen for a mile or so along Highway 192 (Fig. 4.6). There is also a well-developed sag pond (a depression along a fault, produced by faulting), which still has some water at the base of the ancient valley. One interesting question is, why can't you see this anticline from Highway 101, looking to the north? The reason is that the fold rises up so slowly that the topography looks gentle and almost flat. Yet, when you cross the crest, you encounter a steep fold scarp of significant height. Just to the north and forming the north side of the old paleo-valley of Rincon Creek is the housing community of Shepherd Mesa. The mesa is a high point that was constructed on alluvial deposits that were previously thought to be uplifted by a north-side-up fault. If my interpretation is correct, then no fault is there and Shepherd Mesa is higher because the stream valley of the ancient Rincon Creek has eroded back to produce a steep, high slope and valley wall. So, if Rincon Creek flowed east west into Carpinteria Creek at one time, how did the creek get to its present position at the point? What happened was that a smaller coastal stream that was eroding its channel upstream from the beach eroded headward into Rincon Creek, capturing the stream and drainage in a well-known geomorphic process called "stream capture." That is, one stream, flowing more directly to the ocean with a steeper gradient, intersects another one further up

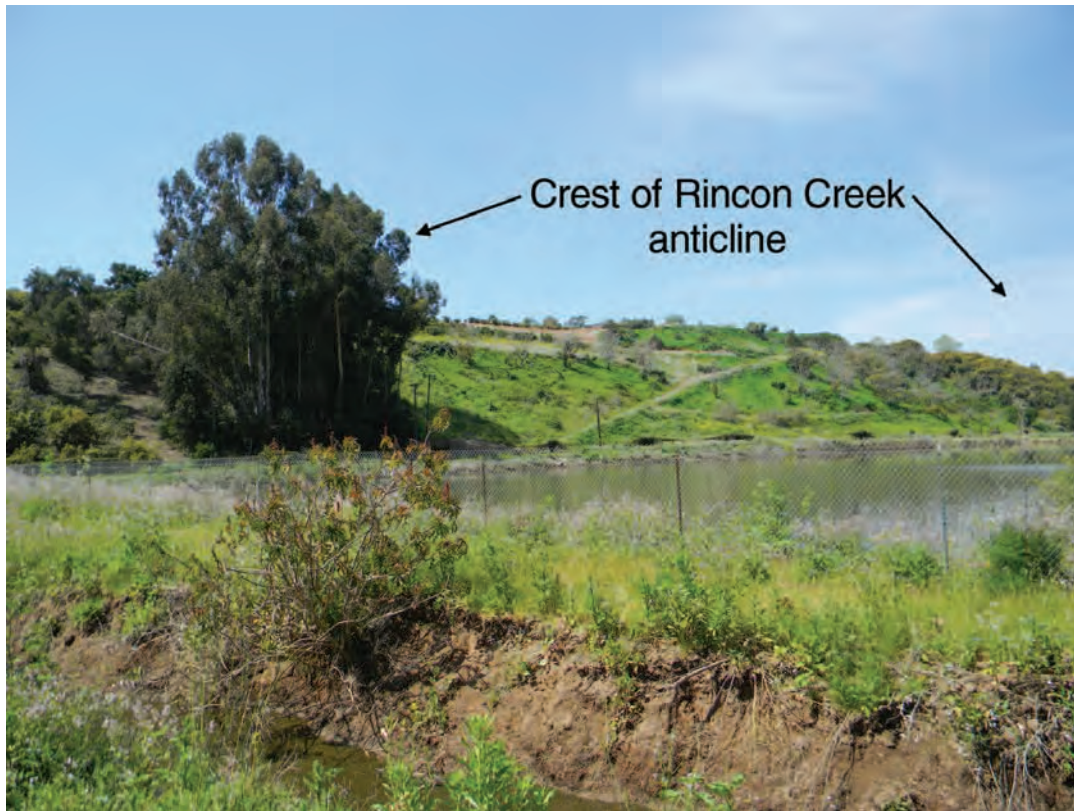


Fig.4.6. Rincon Creek Anticline. View to the south along the crest, 2011.

and captures its upstream drainage. At that time, the valley of Rincon Creek that was flowing to the west was abandoned. Since that time, the creek has eroded its channel to the level of the present valley floor that feeds the boulders to the point and helps produce the famous surfing site. So, all you surfers out there, you owe one of your favorite places to a variety of processes related to uplift, folding, and faulting of the landscape. This is another example of the natural service function of our geologic history and processes that produced the landscape of the Santa Barbara area.

La Conchita: 1995 and 2005 Landslides

Steep, high slopes and weak rocks, along with intense or prolonged precipitation, are a recipe for landslides. This is the case at La Conchita (Little Shell), where landslides have been a problem for

over a century. Recent problems became apparent again in 1995, when a fast-moving slide originated on the high steep slope above La Conchita and several homes along the base of the slope were destroyed (Fig. 4.7). One man said that the slide came in the back of his house as he went out the front—several of his valuable antique cars were buried, but he escaped unharmed. The slide occurred following periods of unusually long and intense rainfall. Following the 1995 slide, work was done by geologists to try to better understand what was going on to produce the numerous landslides that were known to have occurred at and near La Conchita in the past. The studies were mostly confined to the immediate area of the high, steep slope above the community. All of the geologists agreed that it was not if, but when, another landslide would occur.

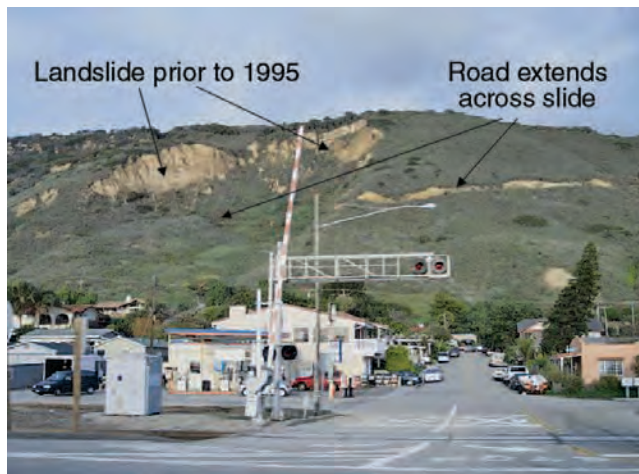


Fig. 4.7a. La Conchita in the late 1980s, before the slide of 1995

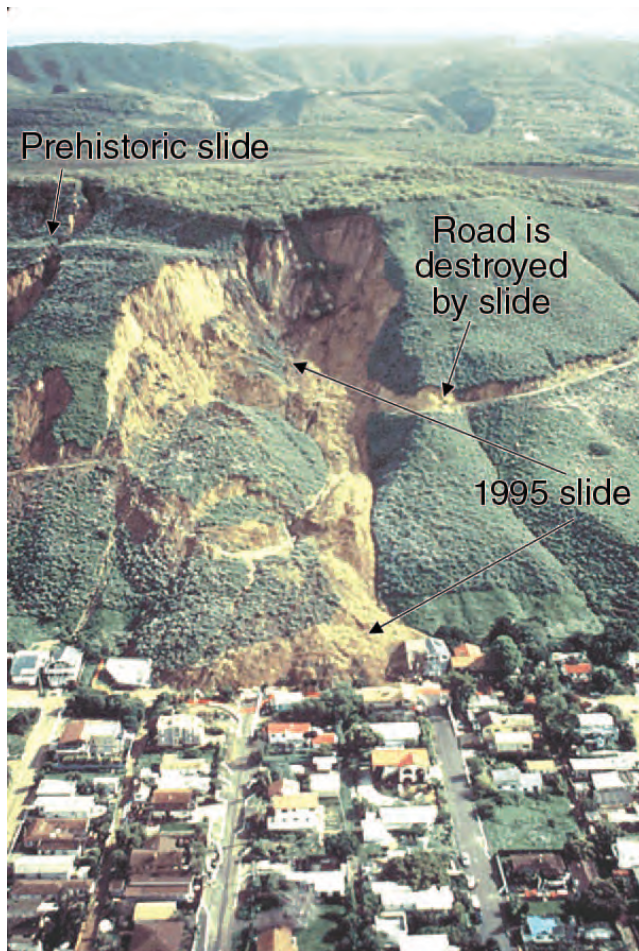


Fig. 4.7b. La Conchita slide of 1995, Modified after U.S. Geological Survey

Following the 1995 slide, the County of Ventura constructed a small wall at the lower end, or toe, of the slope. The purpose of the wall was not to stop future large landslides, but to stop small amounts of debris, such as mud, from moving out onto roads. Some people perceived that the wall would protect the community from future landslides.

People are often optimistic about where they live, and many people evidently believed that, following the 1995 event and the construction of the wall, it was safe to remain in La Conchita. The mistake of believing this was tragically shown in 2005, when, during intense rainfall, another, even faster-moving slide (earth flow), occurred that claimed 10 lives and about 30 homes (Fig. 4.8). To view a video of the 2005 landslide, do an Internet search on La Conchita Landslide (find the YouTube presentation). As it turned out, the 2005 slide was a reactivation of part of the 1995 slide mass. Both of these are part of an even older, prehistoric slide that is clearly visible in the landscape near the top of the slope.

The steep slope behind the community is a high sea cliff, less than about 6,000 years old. That is also the age of the low wave-cut platform near the Cliff House Inn at Muscle Shoals, located across US 101, a few hundred yards southeast of La Conchita. The platform is likely due to an earthquake that uplifted Muscle Shoals and the surrounding area.

The marine terrace present east and west of La Conchita at the top of the 6,000 year old sea cliff has been dated at about 45,000 years. You can see the bedrock sea cliff, wave-cut platform, and terrace deposits near the top of the slope across US 101 from the Cliff House Inn.

Directly above La Conchita (where the 1995 and 2005 landslides occurred), we conclude, from fieldwork and holes drilled by geologic consultants, that the wave-cut platform is not present near the top of the slope (as it is further to the east



Fig. 4.8a. La Conchita slide of 2005. Modified after U.S. Geological Survey



Fig. 4.8b. Homes buried by 2005 landslide, 2005

and west). Rather, the slope is largely composed of debris flow deposits from an even older, larger prehistoric landslide that extends to near the crest of Rincon Mountain (Fig. 4.9). The older slide (several tens of thousands of years old) is no longer active as a unit, but several active landslides are within its boundary, especially in the western portion.

The main reasons why the coastline at La Conchita is one of the landslide capitals of southern California are: 1) presence of steep, high slopes (about 600 feet high) behind the community that produce high driving forces for landslides; 2) presence of weak sedimentary rocks prone to landslides; 3) presence of moderate volumes of water discharging from springs and seeps where the Red Mountain fault passes through the slope; 4) presence of numerous historic and prehistoric landslides, both at La Conchita and in the immediate vicinity (debris flows and mudflows periodically close US 101 following and during large rainstorms, and numerous other landslides are present along the steep slopes that characterize the

coast); and 5) periodic, prolonged, intense rainfall, typical of southern California winters, that infiltrates slopes, reducing slope stability.

One of the primary objectives of identifying geologic hazards is to minimize loss of human life; if people continue to live in La Conchita, more lives might be lost. A secondary objective is protection of property. The choices the people at La Conchita make will reflect their values. Science can suggest solutions to problems, but which solution is chosen will reflect our values. We sympathize with the right of people to live where they want and to take a risk that they determine to be acceptable. How-

ever, when children are involved, it becomes less clear. We require children to be in safety seats, when riding in a car, for their safety. There are some places in the United States on floodplains and at the base of steep slopes where landslides are likely and where people shouldn't live.

La Conchita is a close-knit community with a vibrant identity. The beach environment is enjoyed by people living there much of the year. However, when it rains, some of the people get nervous (and they should)

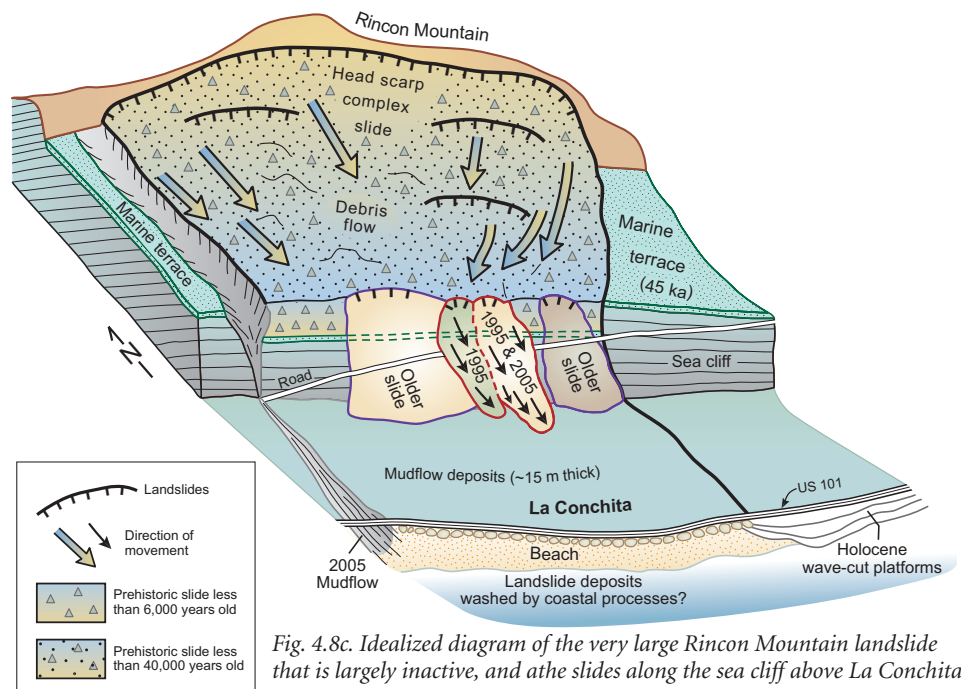


Fig. 4.8c. Idealized diagram of the very large Rincon Mountain landslide that is largely inactive, and the slides along the sea cliff above La Conchita.

because the occurrence of future landslides is not a matter of if, but of when.

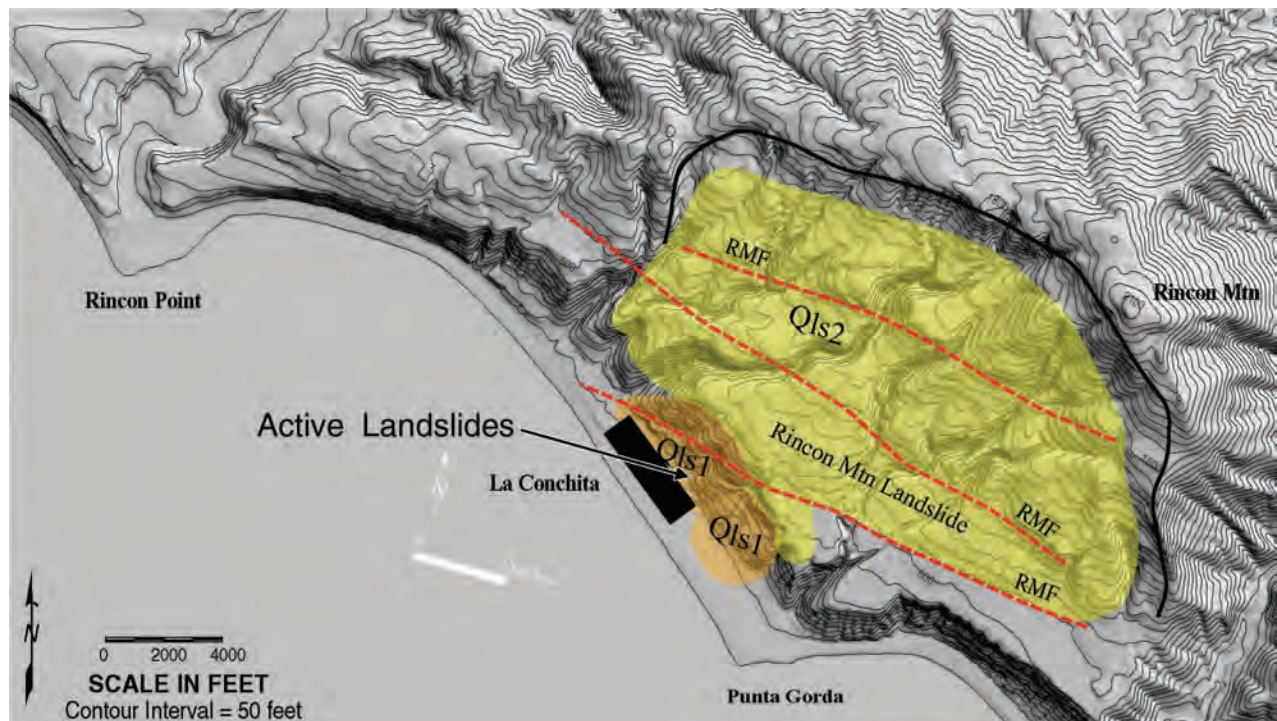


Fig. 4.9. Large prehistoric landslide (green) above and including smaller slides at La Conchita (orange). Courtesy of Larry Gurrola

more Mesa to Ellwood Mesa by Way of Goleta Beach

More Mesa: A High Sea Cliff: More and Less

More Mesa extends from the western end of Hope Ranch to near the mouth of Goleta Slough at the Beachside restaurant (Fig. 5.1). The sea cliff along the highest part of the mesa is nearly 100 feet above the beach and is very steep. The rate of uplift is about 6 feet per 1,000 years, which is a high rate anywhere in the world. Presumably, the mesa is uplifted several feet at a time during large earthquakes. Near the top of the sea cliff, you can observe where the sedimentary rocks that form most of the cliff have been beveled by wave erosion. Where the rocks end and the overlying sediments (usually sand and some beach deposit) begin is the prehistoric wave-cut platform that dates back about 45,000 years. We have dated the terrace deposits and shells just above the platform by Carbon-14, which depends upon the time-dependent

radioactive decay of Carbon-14 (that is found in all living things) to Nitrogen-14, and the radioactive decay of uranium in a solitary coral from what we believe is the same terrace in Isla Vista. We also used optically stimulated luminescence (OSL) dating, which measures the time dependent accumulation (absorption) of ionizing (radioactive) radiation in mineral grains of quartz and feldspar (both of which are common in our beach sand).

At one location near the top of More Mesa, there is a fossil locality that contains beach shells and shells of a mollusk (a rock boring clam) that bores into the rock, wave-cut platform. These boring pholads make a hole in the rock where they live. This explains the rocks found on the beach with perfect round holes through them. The clams have an organ that can be extended into the water to filter feed. We call them boring mollusks (although, to us, they are not boring!), and they communicate to us through their carbon. It is these shells and their surrounding sediment that we date.

Most of the sedimentary rocks that comprise More Mesa are older Monterey Shale (6 to 18 million years old), and others are relatively young sediments that are stream gravels inset into the older shale of the sea cliff. These sediments are part of an ancient stream channel that flowed into the Pacific. Perhaps it was a prehistoric channel of Atascadero Creek.

If you cross the outlet of the Goleta Slough and walk about one mile east, you will come to a marvelous locality. Look



Fig. 5.1. Inlet of Goleta Slough, modified after Kenneth & Gabrielle Adelman, California Coastal Project ©2002-2007



Fig. 5.2. Tar flows on sea cliff and beach at More Mesa. Modified after Kenneth & Gabrielle Adelman, *California Coastal Project* ©2002.

for black rocks along the beach that form large bulbous masses of, usually, hard tar (I say usually, because, on hot days, it is sticky). The tar comes out of the sea cliff as a slow moving flow down the sea cliff and out onto the beach (Fig. 5.2). Occasionally, small birds and other animals get stuck in it, reminding us of the large mammals that became stuck in the La Brea tar pits in Los Angeles and the tar pits at Carpinteria Beach.

We live in a petroleum area, and it is informative to see this asphalt or very thick tar oozing from the ground. It reminds us that there are millions of barrels of oil below us. Ever since the Spanish explorers first arrived, there has been mention of tar on our beaches. The tar that sticks to our shoes, bathing suits, and hair is mostly natural and not due to human processes. We observe tar in the 45,000-year-old marine terrace deposits. Individual tar events may be related to past earthquakes. Prior to the main shock, micro fracturing may allow oil (a precursor of tar) to seep up to the surface. Several hours before the 1925 magnitude 6.8 Santa Barbara earthquake occurred, oil was

observed seeping up on local beaches and in the channel.

From More Mesa Beach towards Goleta Slough, the 45,000 year-old marine terrace remains at a relatively high elevation. Along this section, the More Mesa anticline has grown to the west, diverting Atascadero Creek in that direction (Fig. 5.3). If you walk or bike along Atascadero Creek, you can see the rise in topography to the south, which is the fold scarp of the More Mesa anticline (Fig. 5.4). The buried fault that is producing the fold is part of the Mission Ridge Fault System. The uplift rate from the fault is about 1 foot per 1,000 years.

More Mesa Beach is isolated and frequented by people who enjoy nature. This reminds me of a humorous story I heard years ago. It seems that a lady who lived on top of the mesa called the sheriff to report illegal nude sunbathers on the beach below. When the sheriff arrived, he asked her how she knew nude people were there. She told the sheriff to go into her bathroom, stand on the toilet, look out the small window, and see for himself. Thus, at More Mesa Beach, there is more and less.

Goleta Slough Is Part of a Larger Wetland System of the Past

Goleta Slough today is a wetland that was part of a series of larger wetlands that extended from the present Goleta Slough west to Devereux Slough. That is, in the recent past, there was a series of wetlands that would transform what today is UCSB and Isla Vista into an island surrounded by marshlands and the ocean.

Goleta Slough is a down-dropped basin, or a synclinal basin bounded by faults. The primary fault is the More Ranch segment of the Mission Creek fault, which extends east west across the en-



Fig. 5.3. Goleta Slough, 2011.

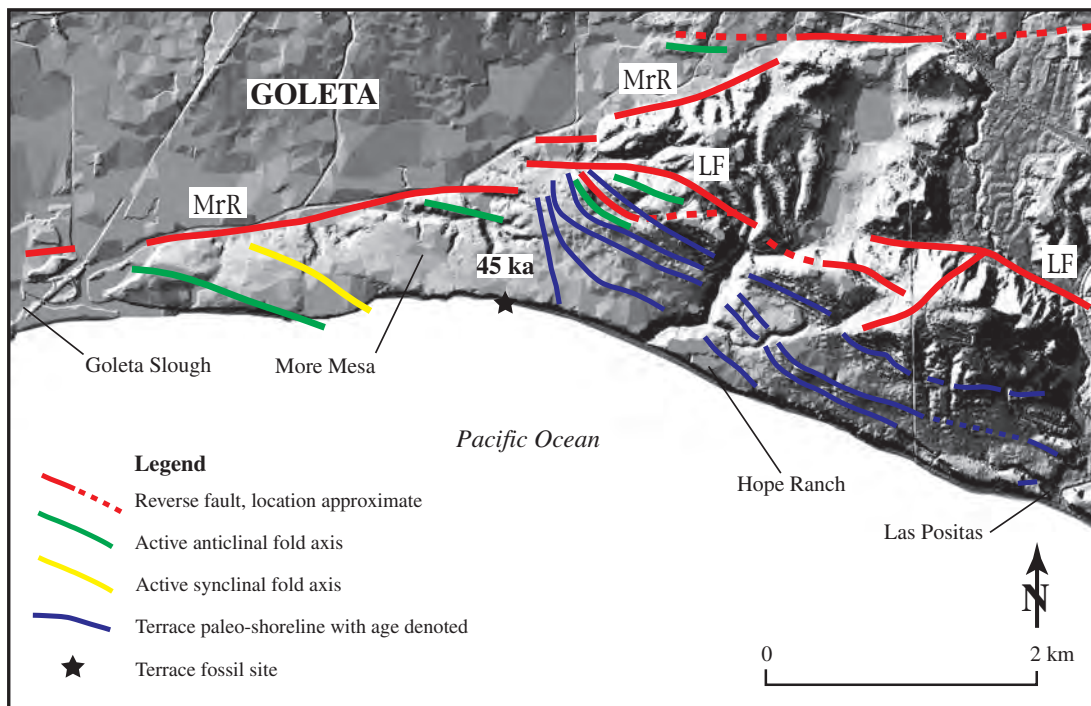


Fig. 5.4. Hope Ranch to Goleta Slough. MrR is Mission Ridge fault, and LF is Lajavia fault. Gurrola, 2000.

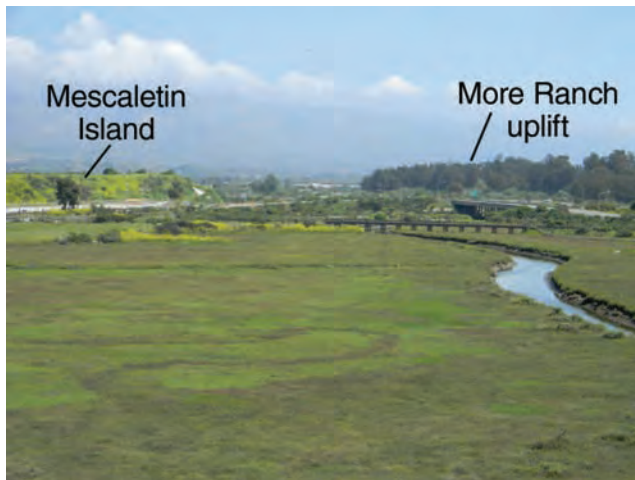


Fig. 5.5. Lower part of Goleta Slough showing what is left of Mescalatin Island and the More Ranch uplift, 2011.

tire Santa Barbara area. Goleta Slough empties into the Pacific Ocean at Goleta Beach County Park. Several major creeks flow into Goleta Slough. These creeks merge together south of the Santa Barbara Airport and exit the slough at the eastern end of Goleta Beach, near the Beachside Restaurant.

Goleta Slough was not always the shallow salt marsh that we see today. For several thousand years, there was a large Chumash village near the present mouth of the slough, known as Mescalitan Island (Fig. 5.5). About half of the island is still present and can be seen just south of the wastewater treatment plant adjacent to the airport. The More Ranch fault (part of the Mission Ridge Fault System) cuts across the island and is clearly visible on old aerial photographs.

Native people inhabited the area before the arrival of Spanish explorers in 1542 and again in 1769. Those explorers were impressed with the island that was located in the middle of a “lagoon.” Goleta Bay and its lagoon were sufficiently deep for ships to anchor in, at least until the early part of the 1800s.

During the California gold rush, the 1949ers (miners) needed lots of supplies and food, especially meat. This led to a locally large cattle ranching venture in the Goleta area. The land transfor-



Fig. 5.6. Devereux Slough. Modified after Kenneth & Gabrielle Adelman, California Coastal Project ©2002-2007

mation to grazing rendered soil more vulnerable to erosion, in part, setting the stage for the demise of the lagoon.

The filling-in of the Goleta Slough and its loss as a lagoon and anchoring spot for boats began in the mid-1800s, when floods following wildfire carried huge amounts of sediments into the lagoon in 1861 and 1862. The sediment turned the lagoon into a salt marsh. In the latter part of the 19th century, there was construction of roads and dikes into the Goleta Slough, further fragmenting the environment. In 1928, a landing strip was established, and this was expanded in 1942-1943 for the Marine Corps Air Station, which is now the site of the Santa Barbara Airport. Much of Mesalitan Island was removed as part of the fill for the landing strip and Marine Corps air station. A lot of soil was also removed from the mesa that is now UCSB for the same purpose.

Today, the system of wetlands that extended from the Goleta Slough to Devereux Slough has been greatly impacted by urbanization (Fig. 5.6). The wetlands/sloughs have been infringed upon and fragmented by urban development for a long time. The largest intrusion is the Santa Barbara Municipal Airport, which covers much of the eastern part of what is left of the slough. Of the land in the Goleta Slough that is part of the City of Santa Barbara, about 100 acres is salt marsh, with nearly 200 acres of vernal wetlands (seasonal wetlands). These wetlands are periodically inundated by fresh water and are also close to the ocean, and, thus, salty water. A much smaller part of the land is actually in salt flats, mud flats, or streamside environments.

In summary, the Goleta Slough is but a remnant of its former self, having been filled by natural and human processes over a period of 150 years. The basin itself results from geologic processes of down warping or folding adjacent to the major faults, which transect the area from east to west.

Pollution In Goleta Slough

Water enters Goleta Slough from four main watersheds (from east to west, they are Atascadero Creek, San Jose Creek, San Pedro Creek, and Tecolotito Creek). Atascadero, San Jose, and San Pedro join each other upstream and provide most of the water in the lower part of the slough. Tecolotito Creek flows into the heart of the slough from the west, just south of the airport. The runway is being relocated somewhat, and a portion of Tecolotito Creek will also be relocated. Santa Barbara Channel Keepers have monitored the water quality of the slough for several years; they found that a number of chemicals from fertilizers, pesticides, and nutrients from human activity are entering the creeks that feed into the slough. For example, the concentrations of phosphate and nitrate commonly exceed the limits that have been set by the Environmental Protection Agency for water quality. Just where do these chemicals come from? You don't have to look very far upstream to find housing areas, agricultural lands, golf courses, and horse stables. All of these are potential sources of the chemicals that are observed in high concentrations in the waters of Goleta Slough. Pesticides are poisons, and, where they occur in waters in high concentration, they can cause problems for wildlife because they tend to be hormonal blockers and imitators that trick organisms into accepting them into their cells. This can result in abnormalities to animals, especially amphibians. The nutrients nitrogen and phosphorus can cause algal blooms and a process known as cultural eutrophication, in which blooms of algae can cover the water surface, reducing the light that reaches deeper water. Lacking light, some algae die, and, as it decomposes, it reduces the oxygen in the water. Reduced oxygen stresses fish and other organisms in the water and, in some cases, may kill them. Since these pollutants originate from human processes and subse-

quent runoff from storms, it seems prudent that we should try to better manage our storm water runoff in order to reduce these pollutants before they enter streams and, ultimately, Goleta Slough. Surface runoff can be collected in basins and treated using ultraviolet light. Artificial wetlands can be constructed, with plants taking up the nutrients

If we don't develop plans to control surface runoff from expanding urban areas in Goleta, then the amount of pollution will increase. We can expect higher concentrations of bacteria, as well as heavy metals, pesticides, and herbicides. Continued monitoring of water quality in the slough is certainly important, but we must be more proactive and develop water quality treatment plans if we hope to improve the waters of the slough.

Goleta Valley

Goleta Valley is a low lying area located between several faults and uplifts, including the More Ranch branch of the Missions Ridge Fault to the south, which uplifts Hope Ranch and More Ranch, and a series of more northwest to southeast faults, including the Carneros and San Pedro Faults to the north.

The name "Goleta" is Spanish for "small ship" or "schooner," and the subsurface shape of the valley is similar to that of the hull of a schooner (the shape of the basin is not why it is called Goleta, but is an interesting coincidence). The valley extends north from the Goleta Slough that is a remnant of a much larger wetland that existed as recently as 400 years ago. The Goleta Valley and slough are parts of the Goleta Basin that formed between several strands of the More Ranch fault that extends westward through UCSB and on to Elwood Mesa, where it displaces the Marine terrace at The Sandpiper Golf Course.

The Goleta Basin is several hundred to over 1,000 feet deep. The basin is filled with Santa Barba-

ra Sand (shallow marine sediments that are several hundred thousands of years old), consisting of fine clay at deeper levels and sand closer to the surface, and younger sands and gravels (probably less than about 100, 000 years old) deposited from streams flowing into and through the Goleta Valley.

The origin of Goleta Valley is the result of earth movements on the faults along the southern and northern margin of the valley over at least several hundred thousand years. A number of streams flow into and through Goleta Valley. Some of the larger ones, from the east to the west, include Atascadero Creek, Maria Ignacio Creek, and San Jose Creek. These streams have had their channels disrupted by active forces of uplift and folding.

Groundwater in the Goleta Basin is an important resource for urban supply and agriculture. In many coastal areas, the groundwater near the coast is degraded as salty groundwater moves inland, due to pumping from water wells along the coast. The groundwater in Goleta Basin is protected from saltwater intrusion by the south-side-up More Ranch fault. How the protection occurs is, as a fault moves and produces earthquakes, the displacement across the fault grinds up and crushes rock, producing, in conjunction with weathering, a clay layer along the fault (called a fault gauge) that is a barrier to salty groundwater that might otherwise migrate inland from the coastal zone.

Atascadero Creek heads north of Hope Ranch near the eastern end of Goleta Valley. Atascadero Creek probably once flowed through the ranch by way of Laguna Blanca Lake to the Pacific Ocean where the Hope Ranch Beach is today. The creek was diverted and defeated by uplift along the More Ranch branch of the Mission Ridge Fault System near the intersection of Modoc Road and Las Palmas Drive. Imagine Atascadero Creek flowing through the central valley of the ranch in the distant geologic past (probably about 100,000 years ago).

As the anticline that formed much of the Hope Ranch landscape grew to the west, a ridge up to 370 feet high was produced that diverted the Atascadero Creek west. Today, the creek is diverted approximately four miles to the west to enter Goleta Slough near the east end of Goleta Beach. You can observe the fold scarp produced by uplift just south of Modoc Road from the intersection of Las Palmas Drive west to the intersection with Encore Drive and Modoc Road.

Take Puente Drive south from Hollister Avenue to Via Huerto (across the street from a private tennis court) to observe the topographic expression of folding at the eastern end of More Mesa. Park and walk up the path on the right (there is a white square pillar at the trail head), south to More Mesa. You will walk up a steep path on the north flank of a young anticline (arch shape fold that is about 130 feet high). About half way up the slope, there is often a wet spot where, I believe, the More Ranch fault has dammed ground water. At the top, there is a good view of More Mesa and the fold scarp to the west.

Much of the western portion of Atascadero creek flows along the bike path that can be visited by exiting US 101 on Patterson Avenue and going south until you see the rise of More Mesa. That small rise is the fold and fault scarp of the More Ranch fault. In that area of More Mesa, there are a number of greenhouses and nurseries. The land is about 70 feet above the creek to the south (the ocean side of the bike path). The linear hill, parallel to Atascadero Creek, continues west to Goleta Slough because the land has been uplifted by the More Ranch fault.

The marine terrace that is being folded at More Mesa is 45,000 years old. It is the same terrace that UCSB and I.V. are located on. We dated this terrace by several numerical means, and it is probably one of the best-dated marine terraces in the world.

Examination of the geology clearly suggests the western propagation (lateral growth) of the folding by the More Ranch fault. For a more detailed view of the geology, you can do an Internet search for "Santa Barbara geology map" and find the geologic map of the Santa Barbara and Goleta areas. That map was produced by the U.S. Geological Survey, and a number of UCSB students participated with me in the mapping project.

Returning to Goleta Valley, if you travel along US 101 from El Sueno Drive to Turnpike Road, you will see a low, linear (east to west) hill off to your right to the north. At the waste management facility behind the recycling area, you can observe the Santa Barbara Sand (formal name of a Pleistocene geologic unit, called a formation, composed of marine sand less than 700, 000 years old) inclined to the south. There are some beautiful fossil shells there, but the area is generally closed to collection. We have named that structure the Goleta Valley Anticline, and it is produced by movement of the Carneros and San Pedro Faults that cross the valley northwest to southeast. The anticline, from east to west, jumps from the San Pedro Fault to the Carneros Fault at Patterson Avenue. The fold appears to be older to the east (where it is more eroded) and younger to the west (where it is less eroded). From US 101, you can see two water gaps through the structure. The youngest part of the Goleta Valley Anticline can be viewed if you drive north from US 101 on Patterson Avenue north towards Cathedral Oaks Road. North of the freeway, just south of Agana Drive, you cross a small, broad rise in the road that extends north almost to Cathedral Oaks Road. The slightly folded gap the road passes through may be a former channel of San Jose Creek. To the left (west) of Patterson Avenue, just south of Agana Drive, is a low hill (about 50 feet high) that marks the topographic termination, or nose, of the Goleta Valley Anticline (at this location, produced by

the Carneros Fault). An older house is on top of the fold (hill), surrounded by avocado and other trees. A higher linear hill (about 110 feet high), that is part of the Goleta Valley Anticline System (in this case produced by the San Pedro Fault), is located east of Patterson Avenue. Turn east (right going north) from Patterson on Franelita Road (directly across Agana Drive) and proceed to the top of the anticline (hill) for a grand view of Goleta Valley. There you can also see coarse gravel from the Santa Ynez Mountains to the north. Consider the process of uplift from earthquakes that lifted the stream gravels from the valley floor to the top of the fold (hill).

In summary, Goleta Valley has an interesting geologic history that is related to geologically young faulting and folding. Driving or biking on Patterson Avenue from Cathedral Oaks Road south across the US 101 to More Mesa, you will cross two prominent geologic structures, both of which can be easily viewed and appreciated for their part in producing the topography and landscape of the Goleta Valley.

University Of California, Santa Barbara: Campus Point and Lagoon

The University of California, Santa Barbara must have one of the most spectacular settings of any university in the world. We like to say we have a beautiful location, with beautiful minds – after all, UCSB is also a leading research and teaching institution that is world famous.

With two miles of beach, mostly at the base of an uplifted marine terrace, as well as pocket beaches, there are spectacular views in all directions at UCSB (Fig. 5.7). Before it opened in 1954,

the campus was a Marine Corps air base, and some of the early buildings from that base are still present on campus.

The mesa or marine terrace that the university is constructed on is 45,000 years old, equivalent in age to More Mesa, Isla Vista, and Ellwood Mesas. The vertical rate of uplift is about 6 feet per 1,000 years and, generally, occurs a few feet at a time during large earthquakes. The More Ranch fault diverted Atascadero Creek to the west (east



Fig. 5.7. Campus Beach at low tide, 2007

of UCSB) and uplifted the land to the south of the fault. The More Ranch fault trends from the east to the west, through the campus near its northern boundary, and the vertical rate of uplift (due to the fault) is about 1 foot per thousand years. Most of the uplift of the area is due to movement on faults offshore in the channel.

The arrival of the University of California led to many changes of the mesa area from Campus Point (also called Goleta Point) east to Goleta Beach. Campus Point is particularly interesting, because there is a small, uplifted wave-cut platform at the point that makes a particularly good wave break for surfers, boogie boarders, and kayakers (Fig. 5.8). That is also where Campus Beach is located. I believe that the small wave-cut plat-



Fig. 5.8. Campus Point, 2004. Modified after Kenneth & Gabrielle Adelman, California Coastal Project ©2002-2007

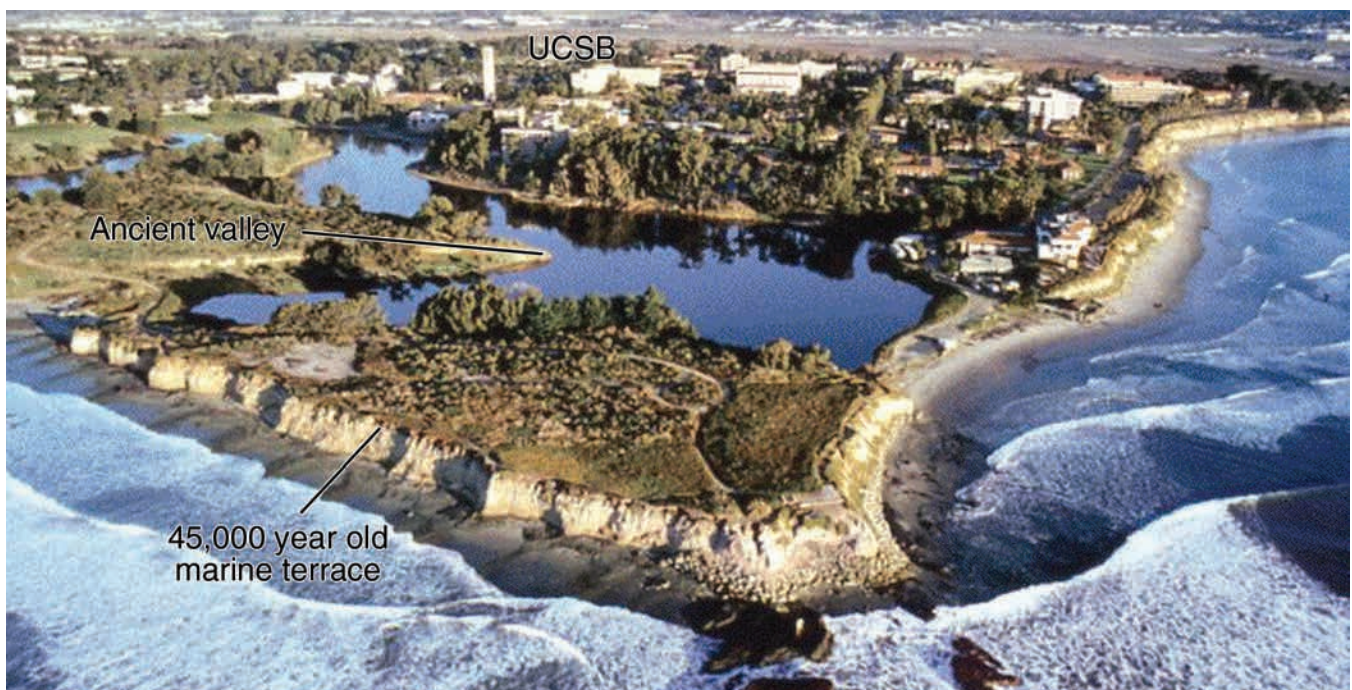


Fig. 5.9. UCSB Campus Lagoon. The lagoon is part of an ancient stream valley that flowed north to Goleta Slough. UCSB Photo Services.

form at the point, which is about 6 feet above the presently forming wave-cut platform, is the result of an earthquake that occurred in the past few thousand years, but this is speculative. The setting of the point and the numerous large faults, both onshore and in the Santa Barbara Channel, argues that an earthquake uplifted the nearshore sea bed and wave-cut platform. Nevertheless, the origin of the platform remains in the hypothesis stage (an educated guess). Some of my former graduate students argue that the wave-cut platform at Campus Point is the result of coastal erosion processes related to rock resistance, rather than uplift from an earthquake. I can't eliminate their hypothesis any more than I can verify that it was an earthquake that uplifted the platform. If it was an earthquake, it was a big one, with a magnitude of about 7. An earthquake of about that magnitude is necessary to produce instant uplift of 6 feet.

Another interesting feature found on the UCSB campus is Campus Lagoon (Fig. 5.9). Its long, sinuous shape suggests that it was a stream valley that has eroded into the marine platform during the past 45,000 years, and it appears that the stream that formed this valley was flowing north into the Goleta Slough. The shape of Campus Lagoon, with its three outlets, looks like the branches of a channel system that flowed northward. Thus, the most seaward parts of these channels have been eroded away by coastal erosion in the last 45,000 years.

Campus Lagoon is also the site of an asphalt (tar) mine that was located just east of the Faculty Club, at the north end of the lagoon. Today, there is a small fence around the pit to keep people from falling into it. The mine operated for about 5 years near the end of the 19th Century. The tar was easily removed, at first near the surface because it was hard, but, as the pit was deepened, the tar was soft and became difficult to mine. Nevertheless, ac-

cording to Professor Robert Norris (UCSB), the mine employed about 50 miners and supplied tar to many places in California, including the streets of San Francisco.

Campus Lagoon and Ecological Restoration

Campus Lagoon is kept full of water by barriers at the ocean that control overflow and release of water from the Marine Science facility after it has been used for biological research. Thus, the lagoon is "artificial", but, nevertheless, it provides valuable habitats for plants and animals.

Because the university has a fair amount of urban runoff containing nutrients, such as nitrogen, the waters that enter the lagoon from the campus have caused some pollution problems. In the summer, algae blooms have formed in the lagoon. Dead algae on the water surface and shoreline are sometimes present, which is unsightly and can smell bad.

More recently, ecological restoration projects have begun in and around the lagoon to enhance the habitat and naturalize the environment. Islands have been constructed in the lagoon near the University Center to provide bird habitat. The lagoon is used by an interesting variety of water birds and is a good place for bird watching.

A number of habitats adjacent to and on the mesa above the lagoon have been established, including coastal shrub, oak woodlands, coastal dunes, vernal pools (shallow seasonal wetland ponds), and vernal marsh land (Fig. 5.10). The runoff from the student housing project, known as Manzanita Village, utilizes a number of vegetated channels, or bioswales, where runoff from the complex lingers a bit, feeding the vegetation and removing pollutants from the water before it enters Campus Lagoon (Fig. 5.11). This is reducing summer algae blooms in the lagoon. Vernal pools have been constructed on the bluffs near the housing and are designed to be physically and hydro-



Fig. 5.10a, b. Campus Lagoon restoration. Small islands were constructed for bird habitat, 2003

logically similar to those that were found on the mesa in prehistoric times. The vernal pools provide habitats for a variety of plants and animals, such as fairy shrimp (Fig. 5.12). Today, restoration is ongoing at Campus Lagoon and the surrounding area. Projects that enhance habitats for birds and other living things, while producing a more natural landscape, are steps in the right direction.

Punting On the Lagoon?

The lagoon is both an artificial environment and a shallow lake, and part of it could be utilized as a place for students, staff, faculty, and visitors to enjoy some water recreation. Some major universities around the world have taken advantage of their nearby waterways. For example, Cambridge University in England has the River Cam, and the university community has a long history of people interacting with the environment, including the sport of punting on the river. Punting involves standing (balancing) with a long pole on a small platform at the back of a flat-bottom boat and propelling the boat forward by planting the pole in the bottom of the river and pushing. If the pole gets stuck in the bottom and you hang on to the pole, you may be left with the pole but no boat! This (sometimes humorous situation) nearly happened to me



Fig. 5.11a. Bioswales that use vegetation to remove nutrients running into Campus Lagoon from Manzanita Village student housing at UCSB were designed to reduce the growth of algae shown here in 2003.



Fig. 5.11b. Manzanita Village student housing, 2003. Bioswales had just been constructed.



Fig. 5.11c. By 2005 bioswales were well vegetated with wetland plants.



Fig. 5.11d. Below Manzanita Village runoff from bioswales after treatment by wetland plants to remove nutrients enters Campus Lagoon, 2005.

on the River Cam at Cambridge University in the year 2000 while on sabbatical and a Fellow of Emmanuel College (part of Cambridge University). At the last possible moment, I let go of the pole and used my hands, with directions from my wife, to back up and reach the pole that was stuck in the mud. I am not saying that we should have punting on the campus lagoon, although it could provide interesting access to the lagoon environment for a variety of activities. Imagine naturalizing the lagoon a bit on its north end near the Faculty Green. It's always wet there because of water seeping to

the surface. We could extend that area of the lagoon with a narrow channel, build a small arched bridge, and make a place to dock boats for punting on part of the lagoon. As at Cambridge, UCSB students could be employed to give tours of the lagoon while singing romantic songs (this may be going too far). Such activities would not interfere with the lagoon environment, as most of the birds and other wild life there are used to people and are not generally shy of being around visitors. A small outdoor coffee and eating area would add to the atmosphere. A little imagination can go a long way.



Fig. 5.12a. Vernal pool construction at UCSB, 2003



Fig. 5.12b. Vernal pools at UCSB two years after construction, 2005



Fig. 5.12c. Vernal marsh (deeper water than vernal pool) construction at UCSB, 2003



Fig. 5.12d. Vernal marsh at UCSB, 2005

Isla Vista: Densely Populated Student Community by the Sea

Isla Vista, along with UCSB and More Mesa, is located on an ancient marine terrace that is about 45,000 years old. We dated the terrace near the stairs down to the beach at the end of El Embarcadero Road. When we first received funding from the U.S. Geological Survey to study the local earthquake hazard over 10 years ago, I asked Larry Gurrola, my new PhD student, to go there to look for a solitary coral. One afternoon he went to look for corals (*Balanophyllia elegans*, orange cup coral) that could be dated by a U-series technique. We had read that people looking through

shell-rich marine terrace deposits that are thousands of years old might find parts of the small corals, about the size of a human molar. The coral are found living today from Oregon to Southern California. They have bright orange to yellow colored polyps with cuplike, calcareous, external skeletons. Solitary coral are found on and under rock ledges, attaching to the rocky bottom. They may be found with the more abundant encrusting tubeworms at shallow intertidal water depths on a wave-cut platform. Larry came back in an hour or so later from I.V. with two small white corals (they are off-white color when found as fossils), and we thought the search was going to be a piece of cake.

Little did we know. The first corals had a uranium content too high to date, so back out we went. We looked for another two years before finding another solitary coral. I would faithfully take student volunteers to help look for the corals almost every Friday afternoon, and, finally, a student said he had something interesting. I looked but couldn't see the structure and almost dismissed the small sample which was about a quarter of an inch on a side. The student persisted and took the sample to the beach and washed it. What emerged was a beautiful coral that we dated. We published the date, and I received a phone call from a paleontologist in San Diego who was not happy and said we let the cat out of the bag about the young date. Scientists thought the Isla Vista terrace might be young, but it had not been dated. The young date is important, because it means that the rate of earthquake activity in the area is much higher than previously believed. He said he collected a coral at the same spot years earlier but never dated it because he couldn't bear to crush the sample in preparation of dating. I responded that I wished he had dated it so I could have avoided 2 years of work looking for a sample. If the truth be known, it was fun to be on the beach on Friday afternoons in I.V., but I'm happy we finally found the coral. I also said that, if he would send me his coral, I would crush it in a nanosecond and do a second dating. I never did receive it. Just last year, the student who found the coral asked for a recommendation for graduate studies and reminded me: "I am the guy who found the coral." I will never forget that memorable day.

The community of Isla Vista is one of the most densely populated areas in the United States. If UCSB alumni remember one thing about their university experience, it is likely associated with I.V. A former student I know visited I.V. with me one day a few years ago, and, as soon as the now

high-powered economist entered the community, off came the shoes and shirt and he marched through I.V. like the student of yesteryear. He said he used to go see a particular movie called *The Rocky Horror Picture Show* almost every weekend for a late showing where participants dressed in costume and recited memorized lines in unison.

The I.V. Community is integrated with the university with lecture halls, bookstores, and beach living. It is also one of the capitals of coastal erosion on the West Coast. Some of the most desirable houses are located along the famous Del Playa Drive, which is on the oceanfront. Unfortunately, the oceanfront is becoming closer to Del Playa Drive by a few inches every year, and some of the buildings are threatened by coastal erosion. When the apartment buildings were originally constructed, they were further from the edge of the bluffs than they are today, and, due to erosion over the years, there has been a lot of concern that some of them may have to be abandoned. In the past, the owners of the apartment buildings requested protection to reduce coastal erosion by building a sea wall barrier along the base of the sea cliff. Unfortunately, this would not greatly reduce the rate of erosion, as much of it (at least one-half or more) occurs at the top. Therefore, before the slope could become stabilized, it would erode back a considerable distance. Furthermore, sea walls and rock revetments (a sea wall made of boulders) are unsightly, and, if we wish future generations to enjoy the beaches along I.V., we need to find a more workable solution to the erosion problem.

Probably the best solution for I.V. is a plan for managed retreat. For example, the houses and apartment buildings could be moved back toward Del Playa Drive where the present parking lots are. Some buildings have been moved back in recent years. Small parks are found at several places in stark contrast to the cliff top buildings (Fig. 5.13).



Fig. 5.13. Cliff top park contrasts with apartment building at Isla Vista, 2007

Much of Isla Vista could be closed to car traffic, with the development of parking structures on exterior areas. People could then bike, walk, or be transported into the “people area” of Isla Vista, which would have walking and bike paths. This would allow the buildings to be set back a considerable distance, and they could enjoy another few decades of life before erosion would begin to cause problems again. Given the very high density of people in Isla Vista, it doesn’t make much sense to have open roads with automobiles, bicycles, and pedestrians all trying to occupy the same place at the same time.

Devereux Slough , Coal Oil Point Oil Seeps and Ellwood Mesa

Devereux Slough is bounded to the north by the Ocean Meadows Golf Club, to the east by Isla Vista, and to the south by Coal Oil Point. The slough is a seasonally flooded tidal lagoon or blind estuary with a sand beach barrier. It may dry out in the summer or be reduced to salt flats and ponds of saline water connected by channels. Several strands of the More Ranch fault cross the area, influencing the hydrology and form of the

slough, but the details of the geologic history of Devereux Slough are poorly understood.

Devereux slough is part of the University of California Coal Oil Point Natural Reserve and has important habitats for many plants, birds, and fish. The slough and adjacent areas are sites of several monitoring, restoration, and research projects, including the monitoring of the snowy plover, a small tan and white shorebird that nests on the beach adjacent to the slough. Snowy plovers were listed

as a threatened species under the Endangered Species Act in 1993. The UCSB plover management plan has successfully protected critical plover habitat without excluding people from the entire beach. Public education (information sheets, signs, and a docent program) and symbolic fences (post and rope around plover roost) are allowing the plover population to recover. The birds use part of the beach, and people give them the space they require.

Santa Barbara Channel: Life and Oil

The Santa Barbara Channel inshore and offshore is a region with a high number of species including blue, humpback, and gray whales; several species of dolphins; sea otter, elephant seals, sea lions and harbor seals; many species birds; and a wide variety of fish. High productivity of krill, a small shrimp-like animal in the deep waters of the channel, and other plankton form the base of the food chain.

The beaches and nearshore reefs (rock outcrops on folds and uplifted by earthquakes) of the Santa Barbara and Goleta area are rich in life. In addition to gray whales sea otter, fish, seals, and

birds, many species are found in the kelp forest that prospers on the reefs (for example abalone and sea urchin). Beaches are rich in sand crabs, clams, sand fleas, shore birds and grunion (when they run on our beaches to spawn). I enjoy watching corbina (a relatively large fish in the croaker family that can weigh over 6 lbs and exceed 2 feet in length) in the summer feeding in the swash zone on sand crabs washed out by wave action. Sometimes you can see them from Goleta Beach, where some fishermen successfully snag them with large hooks from the pier. This is not a sporting way to catch these magnificent fish! It is great fishing sport to catch (and release) corbina on a fly rod using an imitation sand crab fly. This is the closest we have in our local waters to catching bone fish on a fly. It requires careful study of the fish and stalking them along the beach, looking for their tails in the swash as they feed. Do everything right and they still are difficult to fool and catch. Try any local sandy beach from Goleta to Carpinteria.

Santa Barbara Channel is a region with significant oil and gas resources that have been exploited by people for thousands of years. The first people to use the oil were Native Americans who lived along the shoreline and collected tar from oil seeps to seal baskets and the planks of their sea-going canoes. During the last century, oil wells on land and from platforms anchored on the seabed have been extracting oil and gas resources. The oil and gas are hydrocarbons, and, as such, are part of the global carbon cycle that involves physical, geological, biological, and chemical processes.

The story of oil and gas in the Santa Barbara Channel goes back 6 to 18 million years ago with deposition of a voluminous amount of fine sediment, enriched with planktonic microorganisms whose bodies sank to the floor of the seabed and were buried. Over geologic time, the sediment was transformed into sedimentary rock, and the organ-

ic material was transformed by heat and pressure to oil and gas. About a million or so years ago, tectonic forces had produced uplift and fracturing that facilitated the oil and gas to move towards the surface. The seeps at Coal Oil Point have been studied for years by the Seep Team, consisting of a group of professors and graduate students at UCSB. Geologic evidence suggests that leakage or seepage of oil and gas has occurred for at least 120 thousand years and perhaps more than one half million years. Some of the largest seeps of natural gas (methane) and oil are found off shore of the University of California, Santa Barbara, at Coal Oil Point. Shallow water seeps there emit approximately 57,000 cubic meters (2 million cubic feet) of gas per day, along with about 100 barrels of oil. To put the amount of oil in perspective, the Exxon Valdez tanker accident in the Prince William Sound in 1989 released about 250,000 barrel of oil. Thus, the seepage of oil from the Coal Oil Point area alone produces an equivalent of one Exxon Valdez accident once every 7 years. This is a tremendous amount of oil to be added to the marine environment. The oil seeps at Coal Oil Point are some of the largest in the world, but seeps are found in many locations in the marine environment. The methane gas is a strong greenhouse gas, and there are concerns that its emission will contribute to global climate change. The methane, along with other gases that are also hydrocarbons, contributes to air pollution in the Santa Barbara and Goleta area. As the hydrocarbons are released to the atmosphere, they interact with sunlight to produce smog, much like that produced from emissions of hydrocarbons from automobiles in Los Angeles and other areas. If all the methane ended up in the atmosphere as hydrocarbons, the contribution to air pollution in Santa Barbara County would be more than the emissions from the on-road vehicles in the county. The fate of these hydrocarbons emitted from the seeps

turns out to be a complex story, involving the hydrocarbons, the biological processes, and chemical processes. As the gas and oil is driven to the surface, the gas arises as clouds of bubbles, clearly visible at the surface (Fig. 5.14). As the oil and gas forms slicks at the surface, it is transported by marine currents and wind. Rates of emission are also slightly affected by tides that are about 2m. At the highest tides, emissions decrease slightly, due to increased pressure on the seafloor seeps from the deeper water. Finally, emissions of the tar and gas can change the topography of the seafloor. Accumulation of the tar can form tar mounds several meters or more in diameter, and larger, sudden amounts of methane are occasionally emitted from the seeps. Sudden emissions can also create small pits (crater-like depressions) on the seafloor.

During transport, some of the volatiles (gases from the seeps) are lost from the oil, and it soon forms a thicker tar that washes up on local beaches. Sometimes the tar covers enough of the water and beach to stick to the bare feet and skin of beach walkers and swimmers. Tar on the beaches may be found for several kilometers to the east, as it moves with beach processes that transport sand along the beach. However, the story that emerges with the seeps is much more complex. Much of the methane is dissolved in the seawater, and there is a large gas and oil plume that may



Fig. 5.14a. Methane seep at on seabed at Coal Oil Point (bubble is about one-half inch across). Photo courtesy of David Valentine



Fig. 5.14b. Methane bubbles in surface water over a seep at Coal Oil Point. Photo courtesy of David Valentine

spread out over 25 square miles from the seeps. The fate of the methane, as it moves with surface currents and wind, is a subject of ongoing research by Professor David Valentine and his graduate students at UCSB. Results suggest that the ma-

rine water has a tremendous capacity to take up methane that is released as the gas plume dissolves and moves away from Coal Oil Point. Most of the methane is transported below the ocean's surface, away from the seep area, where it feeds bacteria that degrade the methane. Approximately one half of the methane moving up from the seeps is dissolved into the ocean and consumed by bacteria as a natural process. As a result of microbial decomposition of the methane, only about 1% of the methane that is dissolved in the seawater is emitted into the atmosphere. The chemical process by microbial (bacterial) activity is one of oxidation. The currents that move the dissolved methane supply it to the bacteria, and they do the destructive process.

Two areas of prolific emission of gases were covered by what are known as “seep tents” by Arco in 1982. These tents are steel pyramids that cover about 20,000 square feet of the floor of the sea. Collection of gas from the seep tents following their installation resulted in as much as a million cubic feet of gas per day. Those rates continued until a decline in the rates of collection began in about 1989. By the mid-1990s, emission rates had declined to about half their peak when the tents were first installed. Some of the reduction in the emissions of gas that were captured by the tents could be due to natural changes in the geologic environment that supplies the gas. However, a preponderance of evidence suggests that the decrease is most likely due to the pumping of oil from Platform Holly, which is in the vicinity of the seep tents. The process that allows this is most likely a decrease in the underground pressures in the oil reservoirs as a result of pumping. Continued monitoring of gas emissions is an important task for environmental scientists.

Sand Dunes at Campus Lagoon and Coal Oil Point

We often associate sand dunes with places like Saudi Arabia or Death Valley. However, sand dunes are also found along our coast, and they provide interesting scenery and habitats for a variety of plants and animals not found in other coastal environments. Along our coast, sand dunes are found at several locations, including Campus Lagoon and Coal Oil Point.

Small dunes are present at two pocket beaches at Campus Lagoon. The dunes, once covered by an invasive species of ice plant, are being restored (Fig. 5.15).

Coastal dunes generally form where some of the sand that is moving along the beaches in the long shore transport system moves inland and accumulates in linear hills that we term sand dunes. The beach at Coal Oil Point is favorably oriented for sand to blow inland from the beach. Sand is very gregarious; once sand starts moving across the beach and hits other sand particles, the grains will stop and accumulate. As they accumulate, they develop the waveform that we recognize as sand dunes. Sand dunes are asymmetric, with a gentle slope on the side of the dune from which the wind is blowing and a steep slip face on the downwind slope that is usually about 30 degrees. That's about as steep as you can pile sand in a small hill before it will slip off. If the wind is steady and the sand supply sufficient, the dunes will continue to move inland. In some places, like near Santa Maria, California, they have marched inland several miles. At Coal Oil Point, the sand dunes are not extensive, but the steady supply of sand blowing inland has formed a series of dunes located just west of the inlet to Devereux Lagoon.

You have to be a special type of plant to survive in the coastal sand dune environment, because the



Fig. 5.15a. Sand dunes during restoration at UCSB. Notice the dead ice plant after being covered with black plastic, 2003.



Fig. 5.15b. Sand dunes following restoration that removed ice plant followed by planting of native dune plants, 2005.

dunes are ever shifting, moving back and forth and up and down. Some of the most beautiful and exotic wildflowers found on the coast can be viewed in the spring on our coastal sand dune environments.

Ellwood Mesa: Butterfly Reserve and More

Moving to the west of Coal Oil Point, we arrive at Ellwood Mesa, which extends from Devereux Slough west to Sandpiper Golf Course. Devereux Creek runs roughly east to west along the More Ranch segment of the Mission Ridge fault system. The fault goes offshore at the Sandpiper Golf

Course. At that location, the 45,000 year-old wave-cut platform and associated marine terrace is displaced about 20 feet south-side up by displacement along the fault. The fault and displaced terrace can be seen in the sea cliff below the golf course.

Ellwood Mesa, with its monarch butterfly reserve, is a young, actively forming anticline. The total vertical rate of uplift from faulting and folding is about 6 ft. per 1000 years, which, geologically, is very fast. The fold scarp is clearly visible to the south of Devereux Creek. The topographic relief, or distance in elevation from base to top of the fold scarp, is anywhere from a few feet to about 50 feet. Near Ellwood School along Hollister Avenue, you can look to the south and clearly see the rising fold scarp. But gazing at it from far away is not the most appropriate way to appreciate Ellwood Mesa. Find one of the many accesses and walk along the mesa bluff top with its views of the Pacific Ocean. During the winter, as many as 50,000 golden-orange-winged monarch butterflies, from as far away as Canada, inhabit the eucalyptus forest, roosting together in large clumps and offering a chance to observe a wonder of nature. Lie on your back and ponder what drives the monarchs to make the long journey to return to the eucalyptus forest on Ellwood Mesa.

Erosion at Goleta Beach Park: It's All about Science and Values

Goleta Beach County Park is one of the most popular locations for locals and tourists alike. Visitors go to the park to undertake a variety of activities, including beach cookouts, playing horseshoes, visiting the restaurant, fishing, swimming, surfing, walking on the beach, and parking for UCSB (which may result in a parking ticket). In addition, a lot of people just like to drive out to the Goleta Beach parking lot and have lunch while viewing the ocean. Whatever their reasons for go-



Fig. 5.16a. Sea arch at west end of Goleta Beach, 2003

ing to Goleta Beach, many people have strong feelings about the park and what it means to them.

An important part of understanding environmental problems is related to the concept that, while science can provide solutions to problems, which solution we ultimately choose depends upon our values. For example, Hurricane Katrina struck the Gulf Coast in 2005, delivering a near deathblow to much of the city of New Orleans. Science can provide solutions that will help protect the city from future flooding when it's rebuilt, but how and when we rebuild will reflect our values, not only of New Orleans, but of the surrounding land as well. We can choose to build ever-higher sea walls and levies to surround the city. We might also choose to restore salt marshes that provide a buffer from hurricanes and storm waves. We might decide to build new housing on piles, with homes above flood level and garages below, all designed to withstand hurricane strength winds. First, though, we needed to decide if, in fact, New Orleans is worth rebuilding. The answer to that was a resounding yes, and, therefore, we needed to move on to considering what ways to rebuild, while also protecting the city from future flood events. These are all questions of science and val-



Fig. 5.16b. Sea arch present in 2003 collapsed by 2006. Photograph from 2007.

ues and are similar to some of the questions asked about Goleta Beach County Park. Let's start with a little history of Goleta Beach.

Goleta Beach is a sand spit, or barrier beach, at the mouth of Goleta Slough. That is the origin of Sandspit Road. The beach has been there for thousands of years. However, in the past, overwash of the beach into the slough from storm waves was probably frequent, and the stream exiting the lagoon migrated along the entire barrier beach from Fish Rock at the west end near UCSB east to the present inlet. Some of the time, the channel hugged the rocks at the western end, and a sea arch was there for a few years until it finally collapsed (Fig. 5.16). People still fish there regularly, and students have told me it is a good place to fly fish for halibut and other fish. Due to the eastward drift of beach sand (toward Santa Barbara), the inlet would naturally migrate east with the sand. However, when the lagoon was present with much more water, the inlet could have been near Fish Rock more frequently than after the lagoon nearly filled with sediment from floods in the early to mid 1800s. Inlets commonly are located just down coast (direction of sand transport) of a rocky headland. The presence of the high stream-



Fig. 5.17a. Erosion hot zone, west end Goleta beach. A rock sea wall protects the parking lot, 2005.

cut banks adjacent to the west side of the slough near UCSB suggests that vigorous stream erosion formed the bank and helped form a western inlet.

The west end of Goleta Beach is known as an erosion hotspot, and, if left unprotected by rock revetments, it might become an inlet again. High waves from a distant, strong Pacific storm in early December of 2007 attacked this area, eroding artificial fill below the parking lot. Sand and other debris from the ocean was deposited in the first row of the lot, as well as along the ocean side of the park toward the restaurant (Fig. 5.17).

Part of the sand spit, prior to 1925, was a dump-site for all sorts of rubbish, including bottles and cans. I found part of a Coca-Cola bottle there that dates to that period. Occasionally, some of these old soil deposits have been exposed by coastal erosion. The layers in the soil at the site are deformed. The soil and artificial fill has vertical to concave-shaped layers or intrusions that appear as if they behaved like a liquid in the past (after the trash was deposited). These structures are probably the result of liquefaction during an earthquake, which would suggest that some of the trash was dumped before 1925, when an earthquake large enough to cause liquefaction occurred. Nevertheless, most of



Fig. 5.17b. High waves in early December of 2007 caused erosion of the hot spot, exposing the rock wall.

the top few feet of material at the park today is the result of artificial fill material dumped on top of the sand dunes and sand spit (beach) in the 1940s to help support the road across the barrier to what was then the Marine air base.

Up until the early 1980s, Goleta Beach was a wide, sandy beach with no serious erosion problems. However, serious erosion was evident as a result of storms during the El Niño season of 1983 (Fig. 5.18). Between 1983 and 1997, the beach slowly recovered. However, following the 1997-98 El Niño, erosion was renewed, and that erosion further impacted the park, resulting in the consideration of several alternatives to protect it. Goleta Beach has not yet fully recovered from that erosion.

One question that is sometimes asked is why would a beach so wide in the past become narrower today? Beach erosion reflects a balance between sediment supply and transport. If more sediment comes into a beach by long shore transport than is removed, then the beach will grow. Conversely, if more sediment leaves than comes in, then erosion results. For a period of years, the same amount of, or more, sand was coming in than going out, and, so, the beaches below the University of California, Santa Barbara, as well as Goleta Beach, be-

came wider or stayed the same. In the last 20 years, however, they have begun to narrow because more sand is leaving compared to that being added. Sand flow is also related to the Pacific Decadal Oscillation and storm tracks that affect wave direction into or out of the Santa Barbara Channel and coastal environment.

An important question is, what controls the volume of sand that arrives at the coast and that moves along the shoreline? The origin of the sand is from the streams and rivers flowing to the coastal environment. During a particularly wet year, there is often a lot of sediment delivered to the coastal environment from flooding streams. Following wildfire and flood, the amount of sediment deliv-

ered to the coast may increase several times for a year or so. In subsequent years, following the delivery of a pulse of sand from streams, it is moved along the shore to nourish the beaches. If the supply of sediment is cut off for a few years during droughts, then the beaches may become starved of sediment and erosion occurs. During one period of beach erosion, a cannon from a Spanish ship was found off Goleta Beach.

It is believed that much of the natural sand that nourishes our beaches comes from small mountain streams located between Point Conception and the Santa Barbara area. Some sand probably also moves around Point Conception, but the amount of that sand in relation to our total supply of sand is not well known. Some geologists believe that little if any sand actually goes around Point Conception, while others believe that a fair amount has been supplied from rivers, such as the Santa Ynez and Santa Maria Rivers to the north. Large dams have been constructed on the Santa Ynez River, as well as on the Santa Maria River. These dams block sediment that otherwise would have reached the coastal environment. The dams were built several decades ago, and there has probably been a lag time between when the dams were built and when the sediment below the dams would have reached the coast. Therefore, one reason why there may be less sand on our beaches is that it is trapped in other locations, such as reservoirs. Once the sand reaches the coast, it is moved from west to east, primarily by waves.

There also appears to be long term natural cycles of sand moving along our coast, such that, for a period of years, a beach may be flush with sand, followed by a period of years when the sand supply is less. Dr. David Revell (PhD at UCSC) and Professor Garry Griggs (UCSC) are both UCSB alumni who have worked on the sand flow along our coast. Dr. Revell believes that natural cycles, which influ-



Fig. 5.18a. Beach below UCSB in 1975 was wide. Goleta Beach is to the far right. Photo courtesy of Art Sylvester



Fig. 5.18b. Beach below UCSB in 1983 El Niño year at high tide. These storm waves eroded Goleta Beach. Photo courtesy of Art Sylvester

ence the storm track and affect the wave direction relative to the beach face, are significant factors influencing beach sediment supply and erosion potential. During years when waves are higher, sand transport is greater. During years with calm waves, such as 2008-2009, sand transport was low and beaches tended to build out. In contrast, 2007 had several large storm events which moved a lot of sand along the coast.

Erosion of Goleta Beach during the last 25 years has resulted in partial loss of some facilities and infrastructure at the beach park. The parking lot and lawn with part of the irrigation system at the west end of the beach has experienced overwash (waves carrying sand, wood, and other debris onto the parking lot or grass) and erosion that formed a steep slope (small sea cliff) a few feet high, exposing the fill that was artificially placed on the sandspit decades ago. Overwash and erosion also occurred in the central portion of the park, east to near the restaurant. In addition, there is concern that buried utilities and the outhouse at the western end of the park might be exposed and damaged, should coastal erosion continue.

As a result of concern about the erosion, in 2000 the county built a 1,000 foot-long rock revetment (a type of sea wall) as an emergency measure. The revetment was later removed. Then, in 2002, because of continued erosion, a 600 foot-long rock revetment (with permits) was constructed at the west end of the beach. From 2003 into 2004, sand was artificially brought to the beach as a beach nourishment experiment (Fig. 5.19). Altogether, about 60,000 cubic yards of sand was placed on the beach. The purpose of beach nourishment is to replenish beach sand lost by erosion to enhance a recreational beach and provide protection from erosion to backshore land (in this case the park). Beach nourishment is expensive, often has to be repeated, and has had mixed success where it has been used



Fig. 5.19a. Rock sea wall, constructed in 2003 following erosion at Goleta Beach.



Fig. 5.19b. Goleta Beach following beach nourishment, summer 2005. Rock sea wall is buried below the sand.

at other beaches. The sand size needs to match the natural sand for nourishment to be successful. If the size that is artificially added to the beach has a small grain size relative to the native sand, it may be quickly eroded from the beach. Such sand is considered to be sacrificial sand because it stays on the beach a shorter time than more appropriately sized (courser) sand would. The beach nourishment experiment at Goleta Beach produced a nice wide beach. A 350 foot long emergency rock revetment with permits was put in place in 2005.

A working group, consisting of citizens, park people, consultants, scientists, and others with an

interest in Goleta Beach, was organized in 2003 to work on a master plan for the beach park. The working group, or panel, was given the task of coming up with a solution to the chronic erosion of Goleta Beach County Park. There was hope that consensus could be reached on a way to stop the coastal erosion and that a common front could be presented to the California Coastal Commission, so that approval of erosion control remedies would be forthcoming. After a year and a half of meetings and talking, the panel was deeply divided. The division resulted from different values, all of which are valid and important. In beach management as in life, we need to validate each other's values in order to move on or make progress in solving a problem. One group clearly values the park, over the beach itself, as the top priority. Their view has been that they don't want to lose another blade of grass to erosion. The other group has taken a different perspective and is willing to lose, or at least live with, some erosion for the sake of a more natural beach environment. Many people want to save the park and save the beach. Maximizing for both is probably not possible. You can't save every blade of grass and have a wide natural beach with no consequences to other parts of the coast at the same time. However, with good science, creative planning, and the willingness of people to be flexible, long-term management objectives can be achieved.

Science can offer a number of solutions to the erosion problem at Goleta Beach. However, the solution that is chosen will reflect the values of the people. In recent winters, when erosion has occurred, the county has put up a small, plastic, temporary fence where wave erosion formed a small sea cliff about 6 to 10 feet high. The purpose of this little fence is to keep people who are trying to access the beach from being injured by falling to the beach below. Every year, many children from schools visit Goleta Beach, and I am sure

their teachers tell them that they will play "on the beach." Once, while walking along that barrier several years ago, I noticed that a group of very young children had no way to access the beach. They had brought with them their little buckets and shovels in order to make sand castles and were determined to do so. I observed one child putting his little shovel through the fence and bringing back small amounts of sand on his side of the fence in a wonderfully optimistic, but futile, attempt to make a castle. This epitomizes one of the problems of the Goleta Beach management. Without access to the beach, much is lost. If cooking or playing horseshoes is the most important beach activity to you, then whether or not you can actually walk on the beach has less value. If you value the sand between your toes and the waves on your feet, then, perhaps, the beach will have a greater value than the grass or the park. At Goleta Beach, an inordinate amount of money has been spent to protect a parking lot and an outhouse. Speaking of parking lots, the one at the west end of Goleta Beach uses some of the most valuable coastal land in southern California. Some would say that is a poor choice for the location of a parking lot (see Fig. 5.17). When it rains, oil that has leaked from cars can quickly be washed into the ocean. A more natural area with barbecues and tables and access to the beach could be there instead of the parking lot. The outhouse, at the west end of the park could be moved, but not unless erosion makes it absolutely necessary.

There are many parks in southern California and Goleta, but few are on the beach. To some, the real value of Goleta Beach Park is the beach experience and all it entails, including the sand, grunion runs, sand crabs, clams, kelp, and birds. I was criticized at one of the meetings and advised that I was there to provide scientific advice, not to make value judgments. I disagreed, stating that, as scientists, we also have the right to express our values.

At the same time, we need to respect the values of others and look for win-win solutions to environmental problems.

Let's step back a moment and think about what would happen in the future if nothing were done and erosion continued at the beach. Beaches form in one of Earth's most dynamic places --where the sea meets the land. A hundred years from now, there would still be a Goleta Beach. However, the beach might be more to the north by a few feet, a few tens of feet, or even more than where it is today.

Wherever the land meets the sea, a beach composed of whatever sediment is available will form. So, it's not really about losing Goleta Beach if nothing is done, as much as it is about losing some of park as it exists today. To some people, that loss may be natural, but it is unacceptable. To others, what is important is to maintain a quality beach environment for people and the other life we share the beach with.

With an expected rise in sea level of at least 1.5 feet by the end of this century, due to global warming, beach erosion will become an ever-growing problem, particularly along coasts where there is little wiggle room between the sea and human development. The rise in sea level will be due, in part, to thermal expansion of seawater as the ocean warms. The volume of water on the ocean (330 million cubic miles today) will increase as the water warms, causing sea levels to rise worldwide. As the Earth warms, glaciers are melting, and the return of water stored on land in glaciers to the sea will also cause sea levels to rise.

A number of solutions have been suggested to minimize erosion at Goleta Beach Park. I will summarize the three that are most talked about:

1) Permeable piles (a field of piles spaced closer together than the piles for the existing pier) adjacent and east of the pier (20 feet wide by 500 feet long from the present shoreline).

2) Managed retreat, where some hard defense (rock revetment) and the reconfiguration of utility pipes, restrooms, and parking lots are included.

3) Park reconfiguration (the most recent suggestion and not in the original Environmental Impact Report [EIR]) has some aspects of the managed retreat option. It is based on the study of the history of the coastline since about 1943, including the pattern and process of sediment flow and changes in beach width.

Permeable Piles: This option has support from the County and from many people who use the park. The basic idea is to drive piles into the sand on the east (Santa Barbara) side of the pier. The piles will be arranged with a footprint of about 20 feet wide by 500 feet long, and be placed closer together than the piles for the present pier. Initially they would look something like a long inverted hairbrush with plastic bristles up (imagine a long, narrow brush with rows of 1 inch plastic bristles spaced about one-fourth inch apart and scaled up to the size of the pier). The field of pilings would be designed to slow down sand transport to the east toward Santa Barbara and, as a result, produce a wider beach. A large accumulation of sand (salient) convex to the ocean will widen the beach by several hundred feet. The width of the beach will gradually decrease to the west, widening most of Goleta Beach. In order to avoid erosion to the east of the pier, the salient will be pre-filled with about 500,000 cubic yards of sand dredged from about one-mile offshore and pumped through a pipe to the beach. When the beach reaches a stable configuration, the piles will receive a wooden top and become part of the pier. Thus, the first 500 feet of the pier will be about twice as wide as it is today. The major concern regarding this plan is whether it can work over the long term without causing erosion problems to the east. Recent research using aerial photographs

taken over the past 75 years suggests that Goleta Beach has not steadily decreased in width, but has oscillated from narrower to wider than it is today. With the changes in beach width, the flow of sand has changed with changing cycles of storms and waves at time periods ranging from a decade to a few decades. Thus, we may never see a stable width for Goleta Beach. If the beach narrows, due to natural change in coming years due to change in the wave environment and sand supply, as it has in the past, the sand stored by the permeable piles may reduce sand transport, causing beach erosion to the east of the pier. Change occurs whenever we place a structure that affects the sand flow on a beach. Interference with natural beach processes produces secondary and tertiary changes that may have unanticipated adverse consequences (usually unwanted erosion at another location). This is generally true, no matter how carefully the engineering is done (a lot of good engineering went into this project), how carefully potential changes are considered (state of the art models are used), and how carefully the construction is done. Nature is complex, and a seemingly simple solution may not work in the long run. Professor Norris at UCSB, an expert on coastal processes, once told me (paraphrasing H.L. Mencken) that, for every complex problem there is a seemingly simple answer—and it is almost always wrong. The initial cost of this option is estimated at about \$8.7 million and \$9.6 million over 20 years.

Managed Retreat: This option sounds a bit like we are accepting the unacceptable (beach erosion will continue into the distant future). Erosion will not be a problem for those years when the natural supply of sand delivered to the beach is high. With the managed retreat plan, utility lines and restrooms would be moved back (landward) from present locations, rock revetments would be removed in the central and western portion of

the park, and the western end parking lot would be transformed into new parkland. A higher and longer rock revetment would be constructed at the eastern end of the park (where the restaurant is). A buffer zone to erosion is created, and the position of the shoreline is allowed to change naturally within limits. Most controversial is the construction of a 1,900 ft. long “last defense” or backstop rock revetment (to protect relocated utilities, parking lots, and restrooms). The area between the landward position of the buffer zone and the present beach line is defined in the EIR to approximate the coastal erosion hazard zone. The backstop revetment (to be located at the landward edge of the coastal erosion hazard zone) would be constructed when utilities and other structures are relocated. About 97,000 cubic yards of new beach sand brought on from an offshore location would be required to restore the beach to the width of 2005, prior to erosion in 2007. A problem with rock revetments is that they are constructed to protect development, not save the beach. After a few decades or longer, revetments, as is the case with sea walls, cause the beach to narrow as wave energy is reflected. Eventually, the beach will be drowned, especially at high tide. Thus, the lateral beach access will be reduced, and there will be less beach area for other living things we share the beach with. The initial cost of this option is estimated at about \$7.5 million and \$11.1 million over 20 years.

Park Reconfiguration: This suggestion for long-term management of Goleta Beach is backed by research that considered the position of the beach during the past 75 years and future changes that may occur. The coastal process zone from about 1943 to present is identified as a 450 feet wide zone the beach will likely move through over a period of years. Today, the beach near the western end of the park is within 100 feet of the inland bound-

ary of the zone, which extends several hundred feet offshore of the present beach. The plan (prepared by David Revell of the consulting firm Philip Williams and Associates in late 2008) is based on:

- 1) Recognizing that the position of Goleta Beach in the past 70 years has fluctuated in width about 450 feet, with a maximum landward extent in 1943. This fluctuation defines the coastal process zone.

- 2) With the exception of the restaurant, park elements can be relocated outside of the coastal process zone.

- 3) Future erosion damage is minimized, natural fluctuation of the beach environment occurs, natural beach width is optimized, and potential down coast erosion is avoided.

Specifically, the reconfiguration option protects the restaurant and pier as they are today. The plan is to relocate threatened park infrastructure (parking lots, utilities, restrooms) that is now on the seaward side of the coastal process zone to the landward side of the zone. The plan utilizes no new rock or backstop revetment, while (compared to 2008) maintaining the same number of parking spots, the same total area of lawn, the same number of restrooms, and a similar total area of beach. Funds for occasional emergency beach nourishment are banked. The initial cost of the option is about \$4.7 million and \$8.4 million over 20 years.

A consequence of the park reconfiguration option is that we would need to learn to live with predicted change. During some years, the beach will be narrower, and, during others, it will be wider. With future erosion events that we know will occur within the coastal process zone, relatively low, steep scarps (a few feet high) will form during some storms. These scarps will be lowered and smoothed, and some beach nourishment may be necessary. Thus, park reconfiguration does require some periodic maintenance on an as-needed

basis (all three plans will require various types of maintenance). Park reconfiguration is a phased plan. All proposed changes in the conceptual design need not occur initially.

The coastal zone is an active place where change is expected. In the past decade or so, just a few feet west of Goleta Beach, a sea cave formed that led to a sea arch that collapsed a few years ago. It was a pleasure and a gift to see those changes in the few decades of my lifetime.

Which path we take to manage Goleta Beach will reflect our science and our values. It will reflect how we value the future for our children and theirs. Recently, I discussed Goleta Beach with several people on retirement row near the end of the pier at the restaurant. They were clearly for rock protection that doesn't give up a blade of grass. They said that, in their remaining years, they wanted no change in the park. One asked me if I was for managed retreat, and I replied no, not as generally envisioned, with a last ditch line in the sand. Flexibility is the key to living in the coastal process zone at Goleta Beach—protecting some park elements, such as the restaurant and pier, while allowing for natural beach processes to operate. With this option, your children can play in the surf, build sandcastles, and take their children to the beach.

This is the only Goleta Beach we will ever have. What the future will bring is difficult to predict. Which path we take to protect and/or manage Goleta Beach is uncertain. Nature teaches us to be cognizant of the fact that, in the long term, we don't have much control. Support for the permeable piles was very strong from the people of Goleta. However, the California Coastal Commission in July of 2009 denied the permeable pile option. This was a disappointment to many people in Goleta that supported the pile approach. The solution that is finally adopted and approved should incorporate adaptive management that uses science

and research as an integral part of management. For Goleta Beach this requires that the best available coastal science be applied and tested. Adaptive management will also require monitoring of physical and biological resources (beach, sandspit, slough mouth, grunion, shore birds, kelp, and life below the sand in the swash zone) before the project, during construction, and after the project is completed. If environmental problems are discovered at any point, such as unacceptable loss of biodiversity or unacceptable beach erosion, management practices can be modified to reduce or eliminate the problem. In other words the management can theoretically adapt to uncertainty and change. We could also add a component of education to the project with a learning center where we can teach and research coastal processes linked to Goleta Slough. What is certain is there will continue to be uncertainties, changes and surprises at Goleta Beach in coming years.

LISTEN TO THE EARTH

Listen to the Earth it speaks to us and we connect with nature

Sit on a riverbank Take in images sounds and smells of the river

*Trout from beneath rocks emerge as if by magic
Circling feeding being*

*Listen to the movement of the water and pebbles
during a high flow on their journey to the sea*

We become one with the river

Listen to the beach it speaks to us

*Focus on the sounds, and smells Feel energy move
through you as waves travel up and down the
beach face to softly spill or loudly plunge*

*The sand is alive with motion and sound as it
swishes back and forth always along the coast
to nourishing beaches*

Listen to the mountains as they grow

*Imagine the mountains as they change with each
earthquake*

*Rocks humming from below Rumbling from
earthquake Forced up to the surface Fracturing and
weathering Moving with water to the sea*

*Listen to the Earth it speaks to us All we must do is
ask and listen*

– Ed Keller

Sustainable Santa Barbara

People and Environment

The environmental problem is human population increase, and the preferred environmental solution is sustainability. The famous human ecologist Garrett Hardin, who was a professor at the University of California, Santa Barbara, once stated very eloquently that the total environmental impact of people on Earth is the product of the impact per person times the number of people. However, the impact per person varies widely from place to place, with some of the highest impacts occurring in places like Santa Barbara with its affluent society. In fact, the United States, with 5% of Earth's population, uses 20% of the world's energy resources, as well as a disproportionate share of other resources. Another major concept and a fundamental truth is that the Earth is our only suitable habitat, and its resources are limited. Finally, the environmental effects of human use of the environment are cumulative, and we have an ethical and moral obligation to future generations. It is also important to remember that we evolved on Earth. It is our home, and we have a right to be here. This is well stated in the "Desiderata" that was written by Max Ehrmann in 1927. He stated that "you are a child of the universe, no less than the trees and the stars; you have a right to be here. And whether or not it is clear to you, no doubt the universe is unfolding as it should." Environmentalists have argued that, while we have a right to be here and use resources, this comes with responsibility. One of the early conservationists and environmentalists was Aldo Leopold, who wrote about

the lack of ethics regarding the environment. In a famous essay published in 1949, Leopold outlined what he called "the land ethic." Leopold recognized that ecological ethics involved limitations on social as well as individual freedom of action in the struggle for existence in the environment. The ethic proposed by Leopold affirmed the rights of all resources, including plants, animals, and rocks, to continued existence. Accepting a land ethic as proposed by Leopold assumes that we are ethically responsible not only for other individuals in our own society and to people of Earth, but also to the total environment and to the larger community that we call ecosystems, composed of plants, animals, soil, atmosphere, and other materials. Acceptance of a land ethic changes our role from that of master and conqueror of the land to that of protector of the environment.

The resounding message of consideration of the "Desiderata" and the idea of environmental ethics is that humanity is an integral part of the environment. One person is no more than any other, and we have a moral obligation to those that follow us. This obligation is to ensure that our children and all people who follow us will also have the opportunity to experience a quality environment.

Uses of Resources: Some Generalizations, Concerns and Successes

Santa Barbara is a diverse community with an economy based to a significant extent on tourism. As such, it is similar to other destination tourist

locations, such as the Hawaiian Island of Maui and Taos in New Mexico. As with these other top tourist locations, we have growing environmental concerns related to basic use of resources, such as scenery (yes, scenery is a resource), water, energy, and food, as well as waste management. Santa Barbara extends a welcome to the world to visit and partake in many activities, such as bike and foot races, festivals for music and film, ethnic celebrations, and, of course, Summer Solstice and Fiesta. All these activities that are important and help define our community require resources of all types, including waste management. When we visit other popular tourist locations, people often mention Santa Barbara. Either they have been here or want to visit. A community such as Santa Barbara, where the number of people present at any given time ebbs and flows, uses a different mix of resources over time than one in which the population is more stable week to week. Planning the management of natural resources in order to maintain a high quality environment is paramount to the future of our community. We need to become a leader and role model in finding ways use our resources sustainably. With this in mind, we explore resource use in a more general discussion.

It is becoming apparent that untrammelled growth of use of all resources in the U.S. is an environmental march of folly. Growth in resource use is using the resources future generations will need, while degrading our air, water, and land today. It is a march of folly because we have recognized for decades that our present path is not sustainable and is damaging the environment we depend on for our existence. In other words, we have long recognized that our ever-increasing demand for growth, based on a finite resource base, is counter-productive. A main characteristic of folly is rejection of reason and the compulsive pursuit of the counter-productive after it has been recognized as

counter-productive. To have a march of folly implies that there must also be feasible alternatives to the counter-productive practices. In this case, the alternative is sustainable development.

Garrett Hardin, who was a professor at UCSB, introduced the “Tragedy of the Commons.” He argued, in one of the most cited science papers ever, that resources held in common by people (air, water, and space, for examples) would eventually be overused and degraded.

Hardin’s tragedy is based on the idea of the “commons” that were and still are located near villages in England. The commons were grazing grounds for their animals. Today, most of England’s commons are parks. When Hardin talks about tragedy, he is talking about a “Greek tragedy,” in which events unfold that are difficult to stop and are relentless in their development. Hardin emphasized that a tragedy can result from each person making logical decisions for their own benefit.

His argument goes something like this: A commons can support a given number of animals before over grazing causes damage and collapse. Each herdsman logically concludes that if he increases his herd by one animal, he increases his wealth by that addition. If he has ten animals and adds one more, his herd increases by ten percent. The cost of the additional animal is born by the entire commons and would, in the herdsman’s mind, cause a small negative change by the additional grazing. As a result, each rational herdsman decides to add more animals. Adding new animals works as long as the commons can support additional grazing. Eventually though, the commons may reach its carrying capacity, and additional animals beyond this will degrade the ability to support grazing animals.

The tragedy results from the cumulative effect of using the commons. Our wider commons include the air we breathe, the water we drink, the

minerals we use, the soil we grow our food on, and the living resources we depend on. We are attempting to find ways to manage our common resources so that we can sustain our environment. We often manage the commons through laws and regulations that control resource use and protect the environment. At another level, small groups of people in particular environments, such as coral reefs, may band together to manage the commons at a local level.

The point is that an industry that is given unrestricted and uncontrolled access to resources also exploits the commons. Therefore, exploitation of resources by individuals or groups without appropriate environmental oversight often results in environmental degradation. As Hardin argued, our pattern of resource use and the growth of human population are counter-productive and could lead to ruin.

Reducing rapid resource depletion and environmental degradation of resource exploitation, along with stabilization of population, are important environmental challenges of the 21st century. These challenges need to be solved if we are to enjoy a quality environment shared with other living creatures. Continuing business as usual will most likely make the existence for more people less pleasant. Environmental deterioration that accompanies rapid mineral and fuel resource use will make business as usual less possible. Over the past three decades, there have been several resource wars. In any case, Earth will survive and move on in “deep time,” regardless of what we do. As Professor Stephen Gould (Harvard University) has stated concerning our need of an ethical relation with our planet, “If we treat her nicely, she will keep us going for a while. If we scratch her, she will bleed, kick us out, bandage up, and go about her business at her own time scale.” To allow environmental policies of untrammelled growth to de-

termine our future is classic folly. To end the folly, we must move away from growth and hyper-consumerism to a sustainable path. This will require leadership.

There are many good examples of positive environmental policy (and these need to be continued and expanded). For example, during the past forty years, the US government has enacted legislation including the National Environmental Policy Act (NEPA) in 1969, the 1972 Clean Water Act, the 1976 Resource Conservation Recovery Act (for hazardous waste), and the Water Quality Standards and Pollution Act of 1996. At the international level, the Montreal Protocol in 1987 resulted in reduction of global emissions of chlorofluorocarbons (CFCs) that were shown to cause stratospheric ozone depletion. As another example, the United Nations International Environmental Conference in 1992, known as the “Earth Summit,” brought to the surface conflicts between environmental concern, economic issues, and emissions of carbon dioxide which are known to be contributing to global warming. This was followed by a conference in 1997 in Kyoto, Japan, which had the purpose of negotiating to reduce emissions of carbon dioxide to levels below those of 1990 by the year 2010. The United States emits about 20% of the atmospheric carbon dioxide, and many people in the United States are reluctant (for financial and other reasons) to support reductions of emission of carbon dioxide. The reluctance of the U.S. was damaging to international cooperation, as we are considered to be a world leader. The United States, from 1970 to about 2000, was a leader in developing environmental policy with the objective of reducing environmental impacts resulting from human activity. Our position of leadership was weakened and eroded from 2000-2008, as environmental concerns too often took second place behind economic growth.

As industrial lobbyists push to delay environmental regulations and demand additional scientific study before taking action to reduce potential environmental problems, the torch of environmental protection is being passed to the European Union. It is the EU, which is recommending the application of the Precautionary Principle (implementing cost-effective environmental protection when evidence exists, but scientific proof is lacking, that an activity is damaging the environment). The EU is aggressively developing new environmental protection policy. Fear of economic isolation (for example, the EU may not buy our products if they do not meet their environmental standards) may force the United States to follow the EU lead. China experienced this with the toxic toy (lead) scare of 2007. In this case, world trade and globalization may lead to improved environmental regulations. This is a change with potentially far-reaching consequences. In the past, globalization has too often resulted in environmental neglect. With the Obama Presidency, environmental policies will hopefully again be based on science, as well as on economics and politics. The Environmental Protection Agency in early December of 2009 concluded that greenhouse gases, such as carbon dioxide and methane, that cause climate change endanger public health. The conclusion paves the way to regulate emissions of carbon dioxide. The U.S. attempted to gather support to aggressively address this issue at the Copenhagen Climate Change Conference in December of 2009.

The Need of People for Nature in Our Urban Environment

Genetically, we are people of the Pleistocene. Although we are evolving rapidly, we cannot escape some basic instincts from our past. Do you ever wonder why we like campfires, even though smoke burns our eyes and stains our clothes? We sing songs and dance around the fire while burning marshmallows. We love telling stories about large predators and rattlesnakes around the fire. Nothing gets our attention like a story of a big bear near a camp. Our distant ancestors felt safe around the fire and so do we! Take a hike with 20 people in the day and we all spread out along the trail; take a night hike and we bunch up. Fire protected us from the beast of the night; today we use the flashlight. I have often wondered why women like large purses, similar to a basket. Could it be a throwback to our hunting and gathering times?

Our Pleistocene heritage of only a few thousands years ago required us to use all of our senses in order to survive. We needed to be able to smell where fruits and berries were located and be able to see them clearly. We had to be able to hear the movement in the grass of game or the scratch of the claws of predators. We used our senses in order to survive, and people who were more successful were more likely to pass on their genes to future generations. Fast forward thousands of years and we find ourselves in large urban complexes surrounded by concrete and asphalt, often with few trees or vegetation. The sounds we hear are traffic, loud talking, construction work, and other sounds that are foreign to our Pleistocene heritage. It's little wonder that we often feel stressed in our urban environment and yearn to return to what is more common to our basic nature.



Fig. 6.1. Shoreline Park is one of many parks in Santa Barbara. This park was established by community action to avoid development and provide a place for people to enjoy their coastal environment, 2007.

Children and people that are not connected to nature may suffer more from attention deficit and depression. Those who exercise outside in a natural setting, such as a forest, along a stream or lake, in the mountains or desert, on a beach, or in a city park, are more relaxed and less anxious or angry than people who exercise only inside. In hospital, we tend to heal faster and spend a shorter time there when we can look out upon a natural setting. Children regularly exposed to nature (local parks or even a group of trees) may be more self confident, less anxious, do better in science, and interact (cooperate) with others in play or work in more positive ways.

Our need for nature in our urban environment is now being much more appreciated since so many more of us live in urban areas. Of course, there have always been city parks like that in New York, Paris, and other large cities, but recent research has carefully documented the need for many more parks and green belts, as well as for trees and other vegetation in our urban environment.

Recent studies have verified our need for nature in cities. When parks, gardens, and green spaces surround buildings, crime tends to go down, people are less stressed, and there is a stronger sense of community (Fig. 6.1). As a result, people feel safer when surrounded by green belts and trees than concrete and asphalt. The value of city parks is exemplified by the famous central park on Manhattan Island in the city of New York. One of the large cities of the world that takes parks very seriously is Paris, which has about 450 parks and gardens

that cover nearly a third of the city's surface. As a result, Paris is one of Europe's greenest cities. The very presence of trees can help protect us from air pollution. A single large tree has an effect on the surrounding air—studies have determined that each large tree may remove over 200 tons of particulates, nearly 100 tons of nitrogen dioxide, about 90 tons of sulfur dioxide, and about 17 tons of carbon monoxide. Trees also pull carbon dioxide from the atmosphere in photosynthesis. Trees have another function in cooling the surrounding area. Trees with their leaves provide shade that can make the air near them cooler than the surrounding area. The temperature over the blacktop might be something like 38 degrees C (100 Fahrenheit), but, in a nearby wooded area, the temperature could be 20 degrees Celsius (70 degrees Fahrenheit). Thus, we are able to stay in our comfort zone much easier if trees are present, and the air we breathe will be cleaner. Beyond this, the green area supports our heritage and our need to be in the presence of a more natural environment. We will now discuss the environmental movement and sustainability.

Emergence of the Environmental Movement

The 1960s were a time of emergence for environmentalism. During this time, people began to recognize environmental problems and the effect of the human footprint on Earth, as seen, for example, in the work of Rachael Carson which warned us of the dangers of the extensive use of insecticides, including DDT. People in New York started the environmental movement on the East Coast with the Hudson River. Scenic Hudson was the organization that started a movement to protect the river. It was joined in 1969 by Clearwater, which included the folksinger, activist, and environmentalist, Pete Seeger, best known for songs including “Where Have All the Flowers Gone,” and Lee Hays, best known for “If I Had a Hammer.” Clearwater built a sloop (an historic working boat) on the Hudson that toured up and down the river, taking people on the river and educating them about environmental concerns, such as fighting to control and eliminate pollution and encouraging river restoration. Both Scenic Hudson and Clearwater remain active today.

The oil spill in offshore Santa Barbara in 1969 served as a catalyst for the emerging environmental movement. People in Santa Barbara, and from Sacramento to Washington D.C., were outraged that, as a result of oil extraction, the coastal environment had been spoiled and degraded. As the spill continued for days, oil covered the water and washed up on beaches from Rincon Point to Goleta and Isla Vista. The oil slick reached the beaches of the Channel Islands. Thousands of birds exposed to the oil died, as did numerous seals, dolphins, and other marine mammals. The spill was an environmental nightmare for all involved, from the oil company responsible for the blowout and spill to the government at all levels and, particularly, for the people of Santa Barbara. Local people, including students,

merchants, surfers, parents with their children, retired people, and rich and famous people all joined in the cleanup efforts. The oil spill was broader than Santa Barbara, and it raised environmental consciousness across the country. It is no surprise that, in 1969, the National Environmental Policy Act (NEPA) was passed by congress. The next year, we celebrated the first Earth Day. The environmental movement was now coast to coast.

The idea behind NEPA was to encourage harmony with our environment and to promote efforts to prevent or reduce environmental degradation. The Act had the purpose of improving our understanding of relationships between ecosystems and important natural resources, as well as promoting environmental research. Perhaps the most significant part of the National Environmental Policy Act was the requirement of an Environmental Impact Statement before major federal projects, such as the construction of dams and highways, could begin and that could significantly affect the quality of the environment.

Environmental impact analysis led to a better understanding of how we were affecting our environment and of some of the damage that was being done. In subsequent years, we moved from activism concerning degradation of the environment to finding solutions to environmental problems. This naturally led to the concept of sustainability.

What Is Sustainability?

The concept of sustainability means different things to different people, and it is something that we continue to struggle to define. Probably the simplest definition of sustainability is development that ensures that future generations will have equal access to what our planet offers. Sustainable development is economically viable, does not harm the environment, and is socially just. The idea that development needs to be economi-

cally viable is a no-brainer. Sometimes ecologists define sustainability a bit more narrowly - as the use of a renewable (biologic) resource at a rate that can be maintained indefinitely without decreasing the ability of the resources to provide that rate of use and without damaging ecosystems. In other words, The Earth has a finite capacity to produce living resources that maintain ecosystems, and we have the moral and ethical responsibility not to use them to such an extent that the environment is degraded. This statement is applied to the global environment, recognizing there are land uses in specific areas or regions, such as urban, agricultural, forestry, and mining areas, where some biologic resources are changed and removed. I believe what we do to the environment as a people and species is similar to what other species do to maintain their ecosystem (we are a natural part of the biosphere). For example, elephants tear down trees to feed, termites build towers, and birds build nests. Too many elephants or birds can damage other parts of the environment. However, we have the capacity to do much more damage than elephants or birds, and, as a result, have the responsibility and obligation to apply the concept of sustainability in our use of the environment.

The challenge in regard to sustainability has been to find methods of development that are both economically viable and do not harm the environment. New programs that include environmental protection are often resisted as being too expensive and liable to cause the loss of jobs and are termed economic disasters. However, in general, as new ideas that could improve the environment emerge, just the opposite is the case. Jobs are produced with new activities, and people learn not only to accept new ideas and more environmental-friendly development but also to appreciate it. The progression from ideas to development is similar to that of new scientific discoveries that suddenly

emerge. It's probably human nature to be skeptical and resistant to change. At first, often in spite of strong evidence, many people may reject the new discovery, saying that there are too many problems for it to be right. But, given time to study and verify the evidence, the discovery may be accepted as a new paradigm, and former skeptics often claim that they believed it all along.

The third part of sustainable development involves finding ways to develop land and resources that are environmentally just. When discussing environmental justice, we are talking about ways of dealing with environmental problems and solutions in such a manner that we do not discriminate against people based on socio-economic status, race, or ethnic grouping. The concept of environmental justice is most apparent when we consider locating a major facility, such as a landfill, a chemical plant, or other activities that may be objectionable to people who live near those facilities. These facilities may add risk to nearby people, due to the possibility of spills, fires, explosions, or the illegal discharge of waste or chemicals. A study of waste facilities in Los Angeles County revealed that, for the most part, people living near hazardous waste facilities are members of racial and ethnic minorities who are below the county average in terms of income, employment, education, and voting participation. The point of bringing up the concept of environmental justice is that we cannot continue to site hazardous facilities in areas that have people who are least able to object to them. Rather, we must find ways to solve our environmental problems in ways that are not hazardous to people of any economic status.

The reason we are discussing sustainability is that most of the evidence today points to the fact that what we are doing with respect to our environment is not sustainable. The idea of sustainability is a long-term concept, something that happens over

decades or even hundreds of years. Sustainability of renewable resources, such as water, air, and soil, is fairly straightforward, but the picture becomes muddled when we consider non-renewable resources, such as fossil fuels and minerals. We need to focus on how these resources can be extended through a variety of activities, such as conservation or recycling, rather than focusing on when a particular non-renewable resource will be depleted. That is, focus on how the mineral resource is used and develop substitutes for those uses. As stated above, we are not using our resources and environment in a way that is sustainable today. We are using some living resources, such as forests and fish, at rates faster than natural processes can replenish them. We have watched as fish population after fish population crashed. Similarly, we are using more and more mineral resources, oil, and groundwater without sufficient concern for the consequences of future shortages. We are now facing a time when about one-half of the total conventional oil resources (petroleum) now available with known technology will have been used, and, as a result, supplies in coming decades will likely become scarcer and more expensive. Another resource we are worried about is water. In many parts of the planet, we are using a large, disproportionate amount of the water that natural processes provide, and shortages are becoming more common. As a result of shortages, it is apparent that we need to learn how to sustain our environment and its resources, so that they will continue to provide what we and the other living things we share this planet with will need in the foreseeable future. This is the heart of sustainability; it strives to ensure that future generations will have fair access to the resources our planet provides.

How Can We Achieve Sustainability?

We began our discussion of sustainability by defining it as types of development that are economically viable and do not harm the environment. We also recognize that sustainability is a long-term, intergenerational process. That is, the objective is to meet our needs today while ensuring that future generations will have fair access to the resources of our planet. In reality, sustainability is as much a social concept as an environmental concept. The big question that needs to be asked is how can we organize our society and civilization, as well as human activity, in such a way as to provide for our present needs while maintaining a quality environment indefinitely into the future? In other words, how can we develop a sustainable future? Merely asking the question suggests that our actions today may not be sustainable. That is, our present path of overpopulation linked to resource consumption and pollution is not a sustainable future. A 2005 study, contributed to by over 1,000 scientists known as the Millennium Ecosystem Assessment, concluded that, of the 24 major ecosystems evaluated, about 60% were being degraded or used unsustainably. Natural service functions of ecosystems that produce clean water, air, and living resources are being strained to the tipping point where their ability to sustain future generations of people and other living things can no longer be taken for granted. What will be required to reverse human-induced environmental degradation is a transformation to a new path that is clearly different than the present way we run society. We need to move from a society in which the creation of wealth is the main goal to one that integrates social, economic, industrial, and agriculture interests with environmental interests to form a more harmonious system that is sustainable. In order to obtain sustainability, three things must be accomplished simultaneously. First, the trans-

formation to a sustainable system will involve the evolution of values and lifestyles that moves us toward sustainability. Today, in the United States and many other parts of the world, the value systems are changing, and vast majorities of the people state that protecting the environment should be a top priority. Nearly one-half of the people also believe that protection of the environment does not need to conflict with economic growth. Secondly, we need to recognize that sustainable development in any form needs to include all people on Earth, rich and poor alike. We need to bring about a higher standard of living for all without compromising the environment. To achieve this, we need to assist the disadvantaged peoples of the world and not take advantage of them. Working people deserve and need a living wage with which they can support their families. Continued exploitation of other countries' resources and labor in order to reduce costs of resources, such as food or manufactured goods, undermines everyone. Finally, the third thing we need to do is to become proactive rather than reactive to change that occurs. This is particularly true with regards to future increases in human population, use of resources, and occurrences of natural hazards. In the past, we have generally waited for an event to occur, are shocked by it when it does, and then react to it. We have sufficient knowledge of change now to take a much more proactive position.

What is needed to change our present path that is unsustainable to one that is sustainable is to recognize that the transformation does not involve a revolution but an evolution through education and continued consciousness-raising. The evolution will attract people to sustainability because it is the right thing to do, and it is just. Past activism that involved attacking what we do not agree with should be abandoned in favor of applying sound scientific argument and appropriate values to attain sustain-

ability. Another way of saying this is that we need to develop a new paradigm or a new pattern as an alternative to the present way we run society and create wealth. We are apparently headed in that direction, and the transformation is underway, but much more needs to be done. Doing more to obtain sustainability is the obligation of this generation and the next generation as well. In the next few sections we will discuss sustainability with respect to water, energy, waste management, agriculture, ecotourism, and selected ecosystems. The chapter will end with a discussion of global change.

Sustainable Water in Santa Barbara

Water is essential to sustain life. We understand that water is necessary to maintain ecological systems needed for our own survival, as well as the survival of other living things we share the planet with. Santa Barbara is a semi-arid environment with extremely varied rainfall. There is no such thing as average rainfall in Santa Barbara. Rainfall can be plus or minus several hundred percent over a period of years. We say that, in some places, the average precipitation might be something like 17 to 20 inches per year, but we recognize that, in some years, there may be several times that amount, and we may go a number of years where it is substantially less. Even in a given storm, the variability is incredible. A single storm may dump about an inch or so on the coastal areas of Santa Barbara, but up to about 8 inches at San Marcos Pass. In some years, we have an abundance of rainfall that causes local flooding and erosion. At other times, we may go for years with deficits of rainfall and, thus, experience drought. Droughts in the mid-1800s were significant in the Santa Barbara area and resulted in the loss of the local cattle-raising industry. We often think that, following a year or so of drought, we're bound to get more rainfall, and, eventually, of course, that is

true. However, after several years of low amounts of rainfall there is actually a greater probability of another year of low rainfall than a higher one. You just need to look at the native vegetation to know that we are in an area that has potential water shortages. The scrub brush on our hills, known as the chaparral, is typical of semi-arid environments. Oak woodlands and grasslands can survive with relatively low rainfall. We say in Santa Barbara that we have two seasons: the wet, or mud, season and the dry and hot season.

Santa Barbara and Goleta have what is commonly referred to as a variable-source water resource base. We receive contributions to our city water supply from the Santa Ynez River, over the mountains in the Santa Ynez Valley, via tunnels to storage facilities, such as Sheffield Reservoir, which is covered by a park. The Sheffield site, just north of the Mission Ridge fault/fold scarp that produced the ridge, retains the filtration plant, but the 25-acre site is now a park with large buried water tanks. The water storage facilities are disguised as a natural area with lots of large rocks and trails for walking or jogging (Fig. 6.2). The Sheffield project was controversial, but it is much preferred to an open reservoir with the potential for water pollution from birds and other sources, such as ash from wildfire. Runoff from the site is routed through artificial wetland channels (bioswales) to join Sycamore Creek. We also use water stream runoff from the south side of the Santa Ynez Mountains and groundwater. More recently, we have begun to import state water from northern California. We have a desalination plant which has been



Fig. 6.2. Sheffield Reservoir. Once an open reservoir to store water is now a park designed as a natural area. Huge tanks now store the water. Filtered water is delivered to city users, 2007.

mothballed but which could be brought online at considerable expense if the need is great enough. In recognition of our semi-arid status and limited water resources, we have made considerable strides in water conservation and the use of reclaimed water from our sewage treatment plants, both in Santa Barbara and Goleta.

Reclaimed water is a water resource that has its origin at a wastewater treatment plant. The El Estero plant in Santa Barbara treats about 8 million gallons of wastewater from our homes and businesses per day. Following secondary treatment, which includes both physical and biological processes, most of the water is sent to the ocean. About 10% or 700,000 gallons per day is filtered further and may be used to water lawns and plants in about 40 Santa Barbara locations (Fig. 6.3). In Goleta, reclaimed water is also used in many locations, including UCSB and Goleta Beach. All this is well and good, but it is a drop in the bucket (poor pun) of opportunity. Each person in Santa Barbara produces about 100 gallons per day of wastewater, and, of this, probably 50% could be

reclaimed. Thus, we are wasting a lot of water. The major benefits of using reclaimed water include:

1. Water used for private lawns and golf courses saves money because reclaimed water is generally less expensive;
2. Reclaimed water that is used on golf courses and lawns and parks has traces of nitrogen and phosphorous which are types of fertilizer;
3. The use of reclaimed water increases the amount of fresh drinking water that is available to the rest of the community.

The distribution system for the reclaimed water extends along the ocean but also makes a couple of inroads to the north, including to Santa Barbara High School and the municipal golf course along Los Positas Road. There are about forty or so sites where the wastewater is used today, but there are thousands of homes that could use it.

Palm Beach, Florida (as with Santa Barbara) is a beach community faced with periodic drought and water shortages. Palm Beach distributes approximately 9 million gallons of reclaimed waste-

water a day to parks, golf courses, and homes. Santa Barbara has the beach and palm trees—now let's extend the use of reclaimed water to our homes. As in Palm Beach, we could use color-coded pipes to ensure that reclaimed water is used for appropriate purposes, such as the irrigation of lawns and gardens.

The variable sources of the water supply model in Santa Barbara, which constitute our master water plan, have the objective of sustainability. Some of the components of sustainable water management include: the development of water resources in sufficient volume to ensure human health and well-being; a plan for sufficient water resources to maintain health and maintenance of ecosystems; providing the appropriate water quality for desired uses; ensuring that our actions concerning water use do not damage or reduce the long-term sustainability of the resource; and developing and promoting the use of water-efficient technology, practice, and pricing.

Santa Barbara is making the right decisions concerning sustainable water management. Our fresh-



Fig. 6.3. City of Santa Barbara Recycled Water Project (UCSB Artworks / Instructional Development, 2009).

water resources are limited, although variable and subject to change in the future. The Pacific Ocean is unlimited with respect to our needs, but use of that water resource will remain expensive. We have come a long way in Santa Barbara with respect to water conservation through the pricing of water, as well as through the use of reclaimed water. As we move forward, we should do more with these policies and also be prepared for future droughts that are inevitable in the long-term history of our area.

Sustainable Energy

Two thousand years ago, affluent Roman citizens lived in homes that had central heating that consumed huge amounts of wood - as much as 275 lb every hour. Wood was the fuel of choice and necessity, much as oil is today in the United States. Unfortunately the supply of wood was finite and shortages occurred, sending an energy shock to the Romans. The Romans then decided to import wood from as far as 1000 miles away. Eventually, those distant supplies became scarce, and the Romans faced a second energy shock (sound familiar?). They then turned to solar energy with much success. The ancient Romans became very efficient in the use of solar energy and established laws to protect a person's right to his or her share of the solar energy. In some cases, it was illegal to construct a building that shaded another building because the shade would deny neighbors their fair share of solar energy.

During the summer of 2008, we were shocked by the rapid price increase of gasoline. The sharp increase followed years of lower prices (particularly in the 1990s), due to a glut of oil and gasoline. The reasons for the price increase included: 1) oil-producing countries reduced production rates, 2) there was political unrest and war in the Middle East, and 3) the U.S. government instituted new regulations that required oil producers to

reformulate gasoline to produce a cleaner burning fuel. These factors, and others, resulted in shortages, and, by August 2008, crude oil was over \$120/barrel. By late 2008, the price had dropped significantly from the high in the summer, and, by April 2009, the price was about \$40/barrel, which was the same price as 2004. In Mid December of 2009 it was back up to about \$70/barrel. As dramatic as the price shifts were, they were not the first. There have been several oil shocks in the past 40 years.

In 2001, California experienced “rolling blackouts,” resulting from electrical power outages that caused disruption to industries and homes. The blackouts were an energy shock. The basic problem in California was that economic growth in the 1990s brought prosperity that resulted in an increase in population, accompanied by an increase in demand for energy. However, few new sources of energy came online to meet the growing demand, and utility companies were forced to buy emergency power at very high (even extortionate) prices. The California energy crisis was a shock to the entire country and resulted in a serious discussion concerning national energy policy for the first time in over 30 years. Lawmakers at the national level recognized that the entire country could face a similar crisis in coming years. Some of the lawmakers supported the so-called “hard path,” which is business as usual to build more large power plants that utilize fossil fuels or to build nuclear power plants. Other lawmakers recognized that we need to place more emphasis on energy conservation and the use of alternative energy, such as solar and wind power. Finally, in the summer of 2005, the Energy Policy Act of 2005 was passed by congress and signed by the President. The major provisions of the act are:

- Promotion of conventional energy sources, such as coal, natural gas, and nuclear power, with the objective of reducing our reliance on energy from foreign sources.

- Encouragement of the use of alternative energy by authorizing support or subsidies for wind and solar energy. Also promoted are the uses of geothermal energy, biofuels (ethanol and biodiesel), and hydrogen.
- Promotion of energy conservation measures through setting higher efficiency standards for federal buildings and household products, such as appliances, lighting, and insulation of buildings.
- Promotion of research into finding new and innovative ways to improve coal plants, which produce much of our electricity, to help develop cleaner coal technology. Other research is ongoing to determine how to utilize vast amounts of oil trapped in oil shale of the western USA.
- Provision for energy infrastructure so that oil refineries may expand their capacity. Other improvements and infrastructure would help insure that electricity is distributed over more dependable modern facilities.

The Energy Policy Act was criticized for making the most significant incentives and subsidies to fossil fuels and nuclear energy at the expense of energy conservation and alternative energy. Nevertheless, the act was a step in the right direction with respect to its incentives for encouraging alternative energy and conservation. The 2005 Act was just the beginning of thinking about energy policy in the 21st century. A number of topics related to energy came to the table in mid 2009, including the American Clean Energy and Security Act of 2009 that took a serious step towards energy self sufficiency in the United States. The 2009 Act includes four parts: *clean energy*, which involves renewable energy, development of clean fuels and vehicles, and a better electricity transmission grid; *energy efficiency*, which has components for buildings, homes, transportation, and utilities; *reduc-*

tion of carbon dioxide and other greenhouse gases associated with global warming, that includes programs to reduce global warming by reducing emissions of carbon dioxide in coming years; and *making the transition to a clean energy economy*, which involves economic incentives for development of green energy jobs, exporting clean technology, increasing domestic competitiveness, and finding ways to adapt to global warming.

We have grown prosperous and have lived longer during the past century as a result of abundant, low cost energy, particularly crude oil. However, the amount of conventional oil available to us from Earth is a finite quantity. While the benefits of oil are undeniable and well-documented, so are the potential problems, including air and water pollution, as well as global warming. Unconventional oil sources such as tarsand and oil shale are abundant but are difficult and expensive to extract. We will not run out of oil, but there are good environmental and security reasons to reduce our dependency on the fuel.

Regardless of the benefits and liabilities of using fossil fuels, we are about to learn what life will be like with more expensive oil. Prices of crude oil in 2008 were at an all time high, and high prices are likely to be with us from now on (Fig. 6.4). The problem is that we are reaching the time when one half of Earth's oil has been discovered, exploited, and used. The term for this is sometimes called "peak oil." In 1940, five times as much oil was discovered as was consumed. By 1980, the amount discovered equaled the amount consumed, and, by the year 2000, the consumption of oil on a global basis was 3 times what was being discovered. It seems obvious that the trend in the relationship between the amount of oil discovered and consumed is not sustainable. The known oil is being rapidly developed and consumed, and new sources are not sufficient. As peak production oc-

curs, there will be an increase in the gap between production and consumption that will continue to drive up prices. If we don't prepare for the peak, then disruption to society is all but certain. Some believe that the peak has already arrived, but most analyses suggest it will occur sometime between 2020 and 2050. Therefore, we still have a decade or two, or perhaps a little longer, to prepare for the peak and to make transitions to other energy sources. Fortunately, this transition is beginning, and cost-competitive alternatives to oil are coming online. The rate of increase in alternative energy sources, such as solar, wind, and bio-fuels, is dramatic, at about 30 percent per year. However, alternative energy is still a very small portion of the total energy that we produce, and much more needs to be done. We need a national energy program on the scale of our goal to reach the moon in the 1960s to provide the clean energy we will need in the future.

A basic goal of energy management is to move towards sustainable energy development that would provide reliable sources of energy while not causing harm to our environment. As such, sustainable energy development establishes and maintains linkages between energy production, energy consumption, human health and well-being, and the quality of our environment. Sustainable energy is a reasonable goal that could be reached in a few decades. The average global potential of solar and wind energy (at a given moment) that can be developed today at known locations with known technology is about 650 trillion watts (of which 580 is solar). This amount of energy is about 50 times the maxi-

mum energy consumed (at a given moment) by all the people on Earth (about 12.5 trillion watts). To help put these numbers in perspective, a large coal burning power plant produces about 1 billion watts, a large solar plant 300 million watts, a large wind turbine 5 million watts, and the photovoltaic cells on top of a building 3000 watts. At the global scale, the sum of several million small to larger steps (wind turbines, rooftop photovoltaic systems, hydro power stations from waves in the ocean, and concentrated solar power plants) could do the job. This sounds like a big change –it is, but it can be done. A global energy system based on wind and solar power can reliably supply the energy we desire to run society. The sticking points of developing a new energy system independent of fossil fuels are political, not technical.

Santa Barbara is blessed with abundant sunshine, and solar energy has a bright future here. To date, we have exploited only a tiny fraction of the available resource, but that is changing. Many



Fig. 6.4. Gasoline prices were near a record high in the spring of 2008.

buildings in Santa Barbara have solar panels to produce hot water or electricity. Recently, UCSB's Cheadle Center for Biodiversity and Ecological Restoration installed solar panels on top of Harder Stadium annex that will provide about 30 % of the electricity needed for the center. This is another small step toward sustainable energy.

Sustainable energy for Santa Barbara will remain linked to developing sustainable energy in California, the western states, and the entire United States. The buzzword phrase going around with sustainable energy is integrated, sustainable energy management. Such management recognizes that no single source of energy can provide all the necessary energy for the various countries in the world. There is a range of options that vary from region to region, and a mix of technologies and sources of energy will be necessary. These will include both fossil fuels and alternative energy sources.

Energy policy today is at a crossroads. One road leads to technologies, which involves finding ever-greater amounts of fossil fuels and building larger, centralized power plants. Following this road (the hard path) means continuing "business as usual." This is the comfortable approach we have taken for decades; it requires no new thinking or realignment of political, economic, and social conditions. However, the business as usual path does not adequately anticipate the inevitable depletion of oil. Those who advocate the hard path have argued that environmental degradation occurs in some countries because people have been driven to utilize local energy resources, such as wood, resulting in deforestation and erosion of the land. They believe that the best way to solve these environmental problems is to provide people with cheap energy (oil, natural gas, or coal) that fuels industry and technology. Furthermore, countries with sizable resources of coal or petroleum should, in their opinion, exploit these

resources to prevent environmental degradation. Proponents of this view maintain that allowing the energy industry the freedom to develop available resources ensures a steady supply of energy with less total environmental damage than if government regulates the energy industry. The business as usual path continues to dominate most energy planning in the United States, but there are signs that energy policy is changing.

One of the champions for change in energy policy (the soft path) is Amory Lovins (Chief Scientist of the Rocky Mountain Institute, among other things, a think tank for energy conservation and efficiency) who argues for energy alternatives that are renewable, flexible, decentralized, and environmentally benign. The soft path also attempts to match the end use of energy (what the energy is used for, say recharging a digital camera) with the energy source (say solar). Lovins points out we do not need the temperature of the sun in a nuclear reactor or high temperature combustion of coal to power an electric toothbrush. It is like starting a campfire with a giant blowtorch rather than a match. Energy conservation occurs when we match energy end uses with appropriate sources. Of particular importance are energy uses below 212 degrees Fahrenheit (the boiling point of water at sea level) where a large share of end uses for energy are space heating for buildings and heating water for a shower or bath. For these end uses, solar and wind energy, as well as low temperature geothermal energy, will do the job. As Lovins says, we are not interested in kilowatt-hours of electricity as much as the services the electricity provides.

We now appear to be moving slowly from the hard path approach to energy policy in the U.S. to the soft path that: 1) increases energy conservation and efficiency; 2) uses sources of alternative energy, such as solar and wind; and 3) reduces our dependency on foreign oil. A big question is, what

will be the sources for the anticipated growth in energy consumption? What seems certain is that our energy sources will be more diversified in the future than they are today.

During the next 30 years, the demand for electricity in the U.S. will likely increase at least 25- 35% (especially peak demand on hot days when people want air conditioning). The needed power could come from building more large power plants that burn oil or natural gas; new nuclear power plants; or, preferably, alternative sources such as solar, wind, hydro (waves), or geothermal energy. A total of about 4,000 new, large 1 billion watt power plants or a much larger number (millions) of smaller plants (wind turbines or solar) will be needed by 2030. Thinking outside the box, much of the needed new power could come from energy conservation by building so-called “smart electric grids” and “smart houses” where computers more efficiently control the use of electricity in homes and through the grid, the system of electric wires strung on poles or, less often, underground that delivers electricity to our homes. Smart grids and smart homes would allow a better two-way flow of electricity. For example, electricity from rooftop solar units, battery packs in homes, or batteries in plug-in hybrid cars could supply more supplementary energy to the general grid at times of peak demand. Although the wide scale use of the plug-in hybrid is at least 20 years away, due to the high cost of the new lithium ion battery, it could have a significant impact in the future. The U.S. is projected to sell about 2 million plug-in hybrid cars in 2030 (out of a total of 19 million cars sold). Assuming that battery storage is about 50 million watts per car with a peak output of 20,000 watts, the total peak output is 40 billion watts - equivalent to 40 large fossil fuel or nuclear electric power plants. Since cars are idle about 95 % of the time, the cars are a potential supplementary

power source to the general electric grid. They also can function as a backup generator for a home during a power outage.

Energy planning for the future is complicated; we are well aware that burning fossil fuels is degrading our global environment and changing the climate. We seek a new energy path because: 1) Cheap oil is coming to an end, whether it comes this year or 20 years from now; 2) technology and economic opportunities are becoming more favorable for the development and use of more alternative, renewable energy; and 3) using less fossil fuel will reduce emissions of carbon dioxide and air pollutants and also increase security, insofar as we will not be so dependent on importing oil. There is enough coal in the U.S. to last hundreds of years, but it may be preferable to use coal as a short term, transitional energy source rather than as a long-term energy source. Perhaps a better transition to renewable energy is natural gas, which is abundant and relatively inexpensive.

At any rate, development of a sustainable energy policy requires finding useful sources of energy that can be maintained and that do not pollute the atmosphere; cause climatic perturbations, such as global warming; or present an unacceptable risk to our security. The change to sustainable energy would probably involve continued utilization of fossil fuels in some form for transportation (perhaps natural gas). Electrical power, essential for many purposes in our society, could come more and more from alternative energy (including nuclear power) and, perhaps, from developing clean ways to use coal. The energy path we take must be one capable of supplying the energy we need for human activities without endangering the planet. This is the heart of the concept of a sustainable energy policy. We will now turn to sustainable waste management.

Sustainable Management of Our Waste

One of the major environmental problems that any urban area faces is what to do with its liquid and solid waste. Waste management is one of the most costly environmental expenditures we have, but the waste situation goes far beyond the large amount of money spent. How serious we are about environmental protection is linked to how we choose to manage our waste.

Homes, restaurants, businesses, parks, and agriculture generate wastewater. The amount of wastewater generated by the Santa Barbara community, including Goleta, is surprisingly large, at approximately 14 million gallons per day.

Wastewater from our homes is managed in two ways. Most of it enters a sewer system and is routed to treatment plants in Santa Barbara or Goleta where it is treated. Something like 20-30% of the wastewater is sufficiently treated so that it may be used again as reclaimed water for parks, golf courses, and institutions, such as the University of California, Santa Barbara. Most treated wastewater is discharged into the ocean offshore at locations known as outfalls. The second method is the use of a septic system located near the home site.

The Goleta wastewater treatment plant is located across the street from the airport, and treated wastewater flows through a pipe along the west side of Goleta pier. The pipe is on a bed of rocks, and a line of kelp delineates the location. The outfall is in about 92 feet of water, approximately one mile from shore. The Goleta wastewater facility is completing a 10-year plan for renovation and updating that will allow treatment of all wastewater at the secondary level. Treatment includes both screening of heavy solids and removal of grease and so forth (primary treatment), as well as treating it with microbes to further reduce organic material (secondary treatment). The wastewater is then chlorinated and dechlorinated before being discharged into the ocean.

The story is similar at the El Estero plant in Santa Barbara, except all of the waste is currently treated at the secondary level. The outfall is in shallower water than at Goleta, approximately 1.5 miles off shore.

Municipal sewers and sewage-treatment facilities are the most effective and environmentally preferred method of sewage disposal. However, in some areas, the construction of an adequate sewage system has often not kept pace with growth, and some people prefer not to be connected with sewer lines that transport waste to a treatment plant. Some people believe that, if their area is connected, than unwanted growth will result. This is unfortunate, as the environment is held hostage. For whatever reasons, the individual septic-tank disposal system continues to be an important method of sewage disposal in several areas of the Santa Barbara urban corridor and the wildland-urban interface in our foothills.

Septic systems were probably invented in France about 150 years ago, and they arrived in the U.S. by the early 1880s. There are millions of septic systems in the U.S., and several hundred thousand new systems are added each year. Many septic systems are several decades old. However, not all land is suitable for the installation of a septic-tank disposal system, and careful evaluation of the soils, hydrology, and geology at a specific site is necessary and required by law before a permit can be issued.

The basic parts of a **septic tank disposal system include** the sewer line from the house or small business that leads to an underground septic tank in the yard. Solid organic matter settles to the bottom of the tank, where it is digested and liquefied by bacterial action. The liquid wastewater discharges into either a drain field, also called an absorption field, which is a system of shallowly buried perforated piping, or into a large-diameter (a few feet), deep (often 20 to 40 feet), gravel-filled

“dry well” through which the wastewater seeps into the surrounding soil. As the wastewater moves through the soil, it is further treated and purified by natural processes of filtering and oxidation. The term soil here refers to unconsolidated sediment that, in some areas, may be very large boulders deposited from prehistoric debris flows. Some older systems in the Santa Barbara have dry wells that are open, deep holes with a lid on top. These can be dangerous if they collapse. Falling into a septic tank or drywell can kill you quickly by asphyxiation. Gases generated in septic systems are highly toxic and can result in death within just minutes of exposure. Filling an old, hollow dry well with gravel will eliminate the possibility of someone falling into a deep toxic pit. Septic systems need to be periodically safely checked to ensure that the lid and tank have not been compromised by rust. Older systems may be constructed of brick. Tanks may also be constructed from concrete or strong plastic.

Geologic factors that affect the suitability of a septic-tank disposal system in a particular location include type of soil, depth to the water table, depth to bedrock, and topography. These variables are generally included in the soil descriptions found in the soil survey of an area. Soil surveys published by the U.S. Department of Agriculture are valuable when evaluating potential land use, such as suitability for a septic system. However, the reliability of a soils map for predicting the limitations of soils is confined to an area no larger than a few thousand square feet, and soil types can change within a few feet — so it is often necessary to have an on-site evaluation by a soil scientist or soils engineer. To calculate the size of the drain field or dry well needed, one must know the rate at which water infiltrates into the soil, which is best determined by testing the soil.

Sewage drain fields or dry wells may fail for several reasons. The most common cause is poor soil

drainage, which allows the wastewater to rise to the surface in wet weather. Poor drainage can be expected to be present in areas with clay-rich soils or rock, such as shale, with low hydraulic conductivity, in areas with a water table that is near the surface, or in areas of frequent flooding. Several foothill locations, such as Rattlesnake Canyon in the Mission Creek drainage, are characterized by an abundance of large boulders from prehistoric landslides and debris flows that can be 20 or more feet thick. The surface is littered with boulders, and the subsurface is like a pile of large marbles of various sizes, from one foot to more than 10 feet in diameter. A good place to see this is at Rocky Nook Park near the Mission. The boulders were delivered about 1,000 years ago as a large, fast moving debris flow that originated at the site of a large landslide that formed Skofield Park along Rattlesnake Creek. You can visit this site by driving up Las Canoas Road from Mission Canyon Road. The Rattle Snake trail starts there as well. The bowl shape of the Skofield Park landslide is clearly visible from near the crest of the range along Gibraltar Road.

Drilling a dry well through the boulders can be difficult, and there may be seasonal groundwater problems because the boulder soil rests on bedrock, often Sespe Formation of Oligocene age (23-35 million years old) that contains beds of sand and gravel, as well as silt and clay. The Sespe often is red-colored and consists of sedimentary layers deposited on land originally near San Diego and northern Baja Mexico. During past millions of years, the deposits of the Sespe were moved to our area by large-scale tectonic processes of translation. These processes formed the Santa Barbara Basin by spreading and rotating. Later (a few hundred thousand years ago), as the land shortened north to south by convergence caused by ruptures along the Big Bend of the San Andreas fault, the Santa Ynez Mountains were folded and uplifted.

Returning to septic systems, infiltration of water from rainfall is generally much faster for the boulder-rich soil than the finer grained beds of the Sespe. As a result, water during rain events may be ponded on the Sespe, and this can create problems for septic systems that depend on groundwater flowing out and down to naturally disperse and cleanse wastewater. The younger gravels also may have a local body of groundwater perched on a layer of fine deposits within the gravel. During a rain storm, groundwater above this perched water may come to the surface. If your dry well crosses one of these, the water in the well may suddenly rise, making disposal of wastewater more difficult. Following the rain in warm weather, the perched water disappears until the next big storm.

When septic systems fail, waste materials often surface above the drain field or dry well, producing a potential health hazard. This sort of failure is often easy to see in the form of suds (foam, organic material, and bad smells on the surface, Fig.6.5). Unfortunately, what is happening beneath the ground is not so easy to see, and, if extensive leaching of waste occurs at the water table, then groundwater resources may be polluted. Often, after the first rain of the season, local creeks in the foothills may look like they are covered with white foam, probably released from washing machines that use phosphorus-rich soaps. Sometimes I have seen foam running on the streets as well. Prosperous is a nutrient that, in streams, lagoons, or the ocean, may cause unwanted algae blooms in warm weather, resulting in unsightly, smelly mats of algae that consume oxygen in the water.

This problem is called cultural eutrophication (from the Greek for “well fed”). I have seen this phenomenon in the small lagoon at the mouth of Mission Creek upstream and downstream of the Cabrillo Boulevard bridge at State Street.

One way to hold nutrients upstream is to use greywater systems where water from toilets and kitchen sinks is sent to the septic system, and other water is sent to a collection site, such as a tank, where the nutrient-rich water can be used for irrigation. Where it is not needed for irrigation (some homes plant native species that do not require watering), it may be disposed of directly in a separate dry well (separate from that used for the water from the septic tank). Greywater can also be used for homes connected to a community sewer line.

The California Building Standards Commission on August 4, 2009 recognized what began in Santa Barbara and other areas 20 years ago during a serious drought. Earlier, the County of Santa Barbara became one of the first agencies to change its building codes to legalize the use of greywater



Fig. 6.5. Foam and suds on a tributary channel of Rattlesnake Creek, in 2009 probably due in part to failure of septic systems that allowed nutrients (from soaps) to enter the stream.

(wastewater from washing machines, showers, bathtubs, and bathroom sinks) to water plants and trees. It is estimated that an average family of four, by diverting just laundry water, can save about 20,000 gallons of water per year. It is now legal and in accord with the new state standards for people in California to install simple greywater systems and to use that water for irrigation without a permit. However, it is recommended that homeowners do get a permit and contract licensed professionals to install greywater systems rather than do it themselves. This will help ensure that the system works properly. I encourage city officials to do what they can to encourage greywater systems in order to save more water.

The preferable long-term solution to wastewater from septic systems is to put in sewer lines and route the water to a wastewater treatment plant. Relying on septic systems with dry wells invites water pollution in the long term.

Santa Barbara is generally an environmentally conscious community, and it would behoove us to ensure that our wastewater is treated properly. This is particularly true for communities close to the coastline or areas along creeks that are particularly susceptible to pollution from leaking septic systems. Home owners at Rincon Point in 2007 voted to eliminate their septic systems in favor of sewer lines linked to a treatment plant. If Hope Ranch, Rattlesnake Canyon, and other areas on septic systems would make the same decision, water quality would improve for our streams, lagoons, and the ocean. Speaking of leaking systems, we must also ensure that the sewer lines that we utilize in the city are carefully monitored from time to time in order to be sure that leaks are not occurring. As cities age, so do their sewer lines, and how we treat our wastewater is a measure of our environmental consciousness.

We are facing serious solid waste problems in Santa Barbara. We produce a lot of solid waste,

and acceptable areas for its disposal are becoming more and more difficult to find as present facilities are becoming filled. That is not to say we are running out of space for landfills, but it is becoming more difficult and expensive to find places. The common attitude is known as NIMBY, or “Not In My Backyard.” No one wants to live next to a waste disposal facility, with its well-known or perceived sights and smells. There has been controversy concerning our landfill for several years. People living near the facility have complained of pollution of the land as well as of the beach.

Tajiguas Landfill is located about 26 miles west of Santa Barbara and occupies both sides of Canada de la Pila, a small, narrow ephemeral canyon stream (flowing in response to precipitation) that drains into the ocean about 0.4mi. south of the landfill. The landfill is sited in the central part of the canyon whose total drainage area is 468 acres (about $\frac{3}{4}$ of a square mile). Approximately 40 percent of the canyon area is upstream of the landfill. Waste was initially disposed of along both banks of Canada de la Pila and eventually in and over the streambed itself. The drainage is now piped around the landfill. The lower canyon near the sea is eroded through an uplifted Pleistocene marine terrace about 100 feet in elevation and is about 100,000 years old. The highest elevations near the top of the watershed exceed 1,000 feet.

The landfill (since 1967) has been owned and operated by Santa Barbara County as a sanitary landfill (also called a municipal solid waste landfill). As defined by the American Society of Civil Engineering, a sanitary landfill is a method of solid waste disposal that functions without creating a nuisance or public health hazard. The landfill is designed to confine the waste to the smallest practical area, reduce it to the smallest practical volume, and to be covered with a layer of compacted soil or specially designed tarps at the end of each

day of operation. Covering of the waste and collecting landfill gas and leachate is what makes the sanitary landfill sanitary. The cover denies continued access to the waste by insects, rodents, and other animals and isolates the refuse from the air. The compacted cover also serves the function of minimizing the amount of surface water entering into the waste and the amount of gas escaping from it. In reality, it does neither completely. All landfills leak fluids and produce gases (commonly methane). The idea is to minimize: 1) the formation and off site migration of highly contaminated water called leachate that is produced when clean water (rain, surface runoff, and groundwater) infiltrates and moves through the buried waste and interacts with it; and 2) landfill gas, mostly methane, that forms as the waste decomposes. At Tajiguas there are several features designed to minimize the environmental impact. These include: leachate collection systems, a methane recovery system that collects and burns the methane to make electricity, and lining of the newer parts of the landfill. The performance of these systems is measured by a network of monitoring wells, and the information thus collected is provided to the regulatory agencies at least twice per year.

The geology of the landfill site is relatively simple. Most of the site is on Miocene (6 to 18 million years) Rincon Shale consisting of marine siltstone and claystone that is inclined to the south on the south flank of the Santa Ynez Mountains which is a large, faulted anticline. The shale has low permeability (a measure of the ability of groundwater to move through the rock), and the potential for groundwater pollution from the landfill as designed and operated is relatively low as landfills go.

Tajiguas Landfill has sufficient capacity to accept waste at present rates of disposal until about 2023. At present, the landfill accepts about 650 tons of municipal solid waste per day and is permit-

ted to accept up to 1,500 tons per day. The south coast community contributes about 200,000 tons of waste per year to the landfill. Of this, the lion's share (about 70 %) is solid waste from our homes. Just over 65 % of the waste generated by the south coast community is diverted from the landfill by the 3 Rs of waste management: reduce, reuse, and recycle. Increased diversion may eventually be increased to about 85% through improved waste management. In other words, the life of the landfill can be extended by waste management practices that divert more waste from the landfill through conservation, recycling, or conversion of waste to an energy source. The objective is to turn more of our waste that is presently buried at Tajiguas into clean energy. The plan is to use what is termed conversion technology that involves linking non-combustion thermal or biochemical processes with the solid waste, following removal of materials that can be recycled, to produce a variety of products, including electricity and alternative fuels (for example, biodiesel). The net result of the conversion technology is that less material is disposed of in the landfill, there is reduced potential for adverse environmental impacts of waste disposal (pollution of ground and surface water), and clean (green) energy is produced. A part of the landfill (a few acres) has been set aside for the development and testing of the new technology (waste conversion). This might start as soon as 2015.

One of the more interesting aspects of the Tajiguas landfill involves dealing with the large number of seagulls that visit the site to feed on our garbage. After feasting on the refuse, they then fly from the waste facility to the local beach where they defecate (poop) on the beach and cause, in some people's minds, a water quality problem. An innovative approach to this problem was tried after more conventional means to scare the birds failed. A professional falconer who had peregrine

falcons was hired. The birds are sent up to scare the gulls away, and the program has been remarkably successful. It's interesting that the flight of one falcon can scare hundreds of seagulls away—every seagull must think that the falcon is after him alone.

The use of the falcons is an example of the “ecology of fear.” Another interesting example of the ecology of fear recently played out in Yellowstone National Park. A few years ago, wolves were reintroduced after not being in the ecosystem for about 35 years, and this resulted in dramatic environmental improvement to some small streams. When the wolves were absent in Yellowstone, elk (a favorite food of wolves) grazed heavily along stream banks, denuding streamside vegetation and trampling (eroding) stream banks. When the wolves were reintroduced to the park in the mid 1990s, the elk quickly abandoned most grazing along streams where the tricky terrain rendered them more vulnerable to attack by wolves. When the elk retreated to higher slopes, the stream environment improved. Water temperature decreased due to increased shading by stream bank vegetation as it recovered, and water quality increased as bank erosion decreased and water became less turbid (muddy). Both of these factors increased the quality of the fish habitat.

Returning to our discussion of the Tajiguas Landfill, the site is not the greatest location for a landfill. It is close to the sea, and it seems inevitable that some pollution of the coastal environment, now or in the future, is possible as water leaks through the waste and migrates towards the coast. The good news is that the landfill will have funds set aside for maintenance for 30 years after the site is closed.

All landfills can leak polluted water known as leachate (as described above), and most do. The trick is to control the leaks and to avoid pollution

outside of the site. Potential pollution aside, we're going to have a problem because there's only limited space at Tajiguas, even when the existing facility is expanded. Finding another site further inland is a possibility, but transporting large amounts of trash over an extended distance will greatly increase the cost of disposal, which is high already.

Santa Barbara has been a center for the study of urban waste disposal for decades, thanks to the Community Environmental Council. That organization was one of the leaders in developing integrated waste management which includes a variety of processes for re-use, source reduction, recycling, composting, landfill, and incineration. The people of Santa Barbara currently divert more than 65% of the waste that formerly ended up at the landfill.

Recycling has been successful for the most part, but ensuring markets for recycled materials remains problematic in some areas. We haven't done as much with re-use and source reduction as we could. We're still, basically, a throwaway society, and much of our waste results from packaging that could be greatly reduced or even eliminated in many cases. Producers and manufacturers of television and computer screens (part of e-waste) may be required to take a greater responsibility for the cost of disposal in the future. Recently, a surcharge was added to help fund e-waste disposal costs. People can now drop off such waste at the transfer station.

Self-delivered waste (the solid waste you take in your car, trailer, or truck) starts its journey to the landfill from the transfer station just north of Calle Real on the County Dump Road between El Sueno and Turnpike Roads (Fig. 6.6). The transfer station was the former site of the Foothill Landfill that closed when Tajiguas was opened. An impressive recycling center is located at the transfer station which is in the heart of the Goleta Valley anticline (an elongated, low fold/ridge that is eas-



Fig. 6.6. Transfer station on County Dump Road north of Calle Real between El Sueno and Turnpike Roads. The hill is the Goleta Valley anticline, 2011.

ily viewed from US 101). Some interesting fossils (including a variety of seashells that look like the Shell Oil Company logo) can be found in the Santa Barbara Sands (about 700,000 years old) above the transfer station. Waste picked up curbside at our homes goes straight to Tajigas, and recyclables go a company in Ventura.

For decades, many people have recognized that another way to look at our waste is to view it as a resource that is out of place. This has led to the development of several new ideas, including industrial ecology, which is the study of relationships in industrial and urban systems and their links to natural systems. The basic idea is that, in ecosystems, the concept of waste does not exist. What is waste in one part of the system is a resource in another

part. For example, elephants excrete huge amounts of dung which would pile up all over the place in Africa if it weren't for dung beetles that process the waste. What the dung beetles leave after their processing is a resource for something else, and so on. Recycling programs, green waste mulch programs, and conversion technology programs are examples of this "zero waste" concept. The idea is for our industrial and urban areas to try to emulate ecosystems. The concept of zero waste is catching on, and some communities have begun to make commitments and to propose plans to reach a zero waste position sometime in the coming decades. Hopefully, Santa Barbara will continue to be a leader in the waste management arena, and new and innovative programs will be forthcoming.

Sustainable Agriculture and Horticulture

Philosopher George Santayana in 1905 said, “Those who cannot remember the past are condemned to repeat it.” Scholars continue to debate the age-old question of whether cycles in human history repeat themselves, but the repetitive nature of soil erosion and the collapse of past civilizations is undisputed.

The lessons in land use from the Old World are explicit. Where sound conservation practices were used, there were successful adjustments of population; but, where wasteful exploitation of resources was practiced, the results varied from gullied fields and alluvial plains in rocky hills and steep slopes to silted-up irrigation reservoirs and canals and ruins of once-prosperous cities. Three examples from Lowdermilk’s (1943) study will emphasize this point.

About 5,300 years ago, the Phoenicians migrated from the desert to settle along the eastern coast of the Mediterranean Sea and establish the coastal towns of Tyre, Sidon, Beyrouth, and Byblos. The land is mountainous, with a relief of about 3,000 meters and, at that time, was heavily forested with the famous cedars of Lebanon. These trees became the timber supply for the alluvial plains of the Nile and Mesopotamia. As the limited, flat land along the coast was populated to its carrying capacity, the people moved to the slopes, and, as the slopes were cleared and cultivated, they were subject to soil erosion. Today, a large number of terrace walls, in various states of repair, indicate that the ancient Phoenician farmers attempted to control erosion with rock walls across the slope as many as 40 to 50 centuries ago.

The cedars of Lebanon retreated under the axe, until, today, very little of the original forest of approximately 1,000 square miles is left. Evidence suggests that, given present climatic conditions, the forests would grow where soil has escaped the process of erosion. Today, the bare limestone

slopes strewn with remnants of former terrace walls are testimony to the results of erosion and the decline and loss of the resources of a country.

In northern Syria are a number of formerly prosperous cities that are now practically dead. Before the invasion of the Persians and Arabs, cities such as El Bare prospered from the conversion of forest to farmland, which resulted in exports of olive oil and wine to Rome. After the invasion, which destroyed their agriculture, as much as six feet of soil eroded from the slopes, and, today, the 13 centuries of neglect can be seen in the nearly complete destruction of the land. What is left of the formerly productive land is an artificial desert, generally lacking vegetation, water, and soil.

The Promised Land described by Moses on Mount Nebo approximately 3,000 years ago was a land of streams and springs; a land of wheat, barley, and vines; a land of abundant resources. But the Promised Land at the time of Lowdermilk’s investigation was a sad commentary on human use of the land. Soil erosion and accelerated runoff from barren slopes has caused many of the hills to become greatly depopulated. For example, consider the Wadi Musrara watershed which drains the western slope from Jerusalem to Tel-Aviv. Reduction in population of ancient village sites, along with topography, has occurred since the seventh century. The breakdown of old terrace walls on steeper slopes and subsequent erosion of the soil are probably sufficient to explain the greater frequency of abandoned sites in the steeper, higher hills than on adjacent plains.

The history of areas long populated suggests that soil erosion is a serious problem that has destroyed land and retarded the progress of civilization. Therefore, conservation of our soils must remain a priority, for, as stated by Lowdermilk, “One generation of people replaces another, but productive soils destroyed by erosion are seldom restorable and never replaceable.”

Flashing forward to today, feeding about 10 billion people projected to be living on Earth (our home) by the year 2050 in a way that sustains agricultural productivity for future generations is a daunting task. The combination of potential water shortages and high-energy costs may drive food costs beyond the level of affordability for many people on Earth. Some urban areas are making deals to purchase water from agriculture areas. This is water that could be used to for crops to feed people. For example, the rapidly growing, water-poor city of San Diego has arranged to purchase about 200,000 acre-feet of water from farmers in the Imperial Valley annually over the next 75 years. For comparison, Lake Cachuma, when it is full, holds about 188,000 acre-feet of water, and one acre-foot (325,851 gallons) is approximately the amount of water consumed annually by about 10 people in Santa Barbara. The price paid to farmers to ship water to San Diego is far more than they could make from irrigating crops to sell on the food markets. The transfer of water from crops to urban use for San Diego is the largest such transfer in U.S. history. More such water deals are likely because most large cities, including Los Angeles, California and Cairo, Egypt, can only increase their growing demand for water by taking water now used by agriculture.

As Earth warms, deserts are expanding at unprecedented rates in Asia, Africa, and other areas where food is produced. Thousands of villages have been abandoned in former agricultural lands in Africa and China, covered by sand and silt. Countries that formerly were able to raise much of the food they require, such as Haiti, Nigeria, and Rwanda, are now importing large amounts of food. Saudi Arabia has been mining its groundwater resources (using it much faster than it is replaced by nature) to the point that most wheat production will end in a few years. Many other countries are

on the same unsustainable path with respect to agriculture production. Suggestions to counter and reverse the bleak global scenario mentioned above with respect to people, water, food, and energy are discussed by Lester Brown (2009). Solutions involve stabilizing human population growth and climate, eradicating poverty, using non-renewable resources wisely, and restoring Earth's living resources. The specifics of Brown's plan are beyond our discussion here, but are recommended food for thought (poor pun) and action. We will now move on to sustainable agriculture at the local level, beginning with a discussion of slow food.

The Slow Food movement began in the 1980s in the Piedmont region of Italy. It seems that a McDonalds Restaurant was planned near the Piazza di Spagna in Rome. Demonstrations were organized against the fast food restaurant, and an alternative emerged which became the Slow Food movement and which has grown tremendously in recent years to become an important part of the environmental movement. You might ask, "How could the enjoyment of food and eating slow have something to do with the environment?" The answer is that the goals of the Slow Food movement are not only the enjoyment of food, but also the consumption of food grown locally by local farmers and people, with the objective of maintaining the biodiversity of food plants and seeds, as well as domestic animals that we raise on our farms. It is an alternative to large agriculture, which produces food that may be transported thousands of miles before it is consumed, and giant factory farms that raise animals, such as chickens and pigs, on a mass production scale. Education is an important component of the Slow Food movement, with the objective of teaching our children about the origin of our food, as well as about the taste and pleasures of its consumption. Children learn to develop their senses and appreciation of food, as well

as understanding the importance of maintaining the biodiversity of the foods, including plants and animals that we use. The Slow Food movement is worldwide and is challenging the alternative of fast food and, in fact, everything fast that warps our sense of time and space. You can visit slow food Santa Barbara at www.slowfoodsantabarbara.org. Having discussed the Slow Food movement, let us now consider sustainable agriculture.

Agriculture is, generally, the large-scale (relative to vegetable gardens and small orchards and farms) production of crops, livestock, or poultry, whereas horticulture is defined as the use, study, and science of plants. Horticulture can also include small-scale agriculture. Horticulturists are people interested in plant growth, plant cultivation, crop production, and plant breeding, as well as biogeochemistry, physiology, and the genetic engineering of plants.

Three main goals are integrated into sustainable agriculture: environmental health, economic success, and social equality. The concept of sustainability is based on the principle that we meet the needs of the present people on Earth without compromising the ability of future generations to meet their needs. With respect to agriculture, this implies careful management of natural and human resources involved in our food chain.

The emergence of sustainable agriculture involves the use of science and systems to understand linkages between farming and our use of the environment. It has been pointed out that sustainable agriculture is a process of transition to an improved agricultural system.

Important components of sustainable agriculture and horticulture include the management of soil, water, energy, air, and wildlife. One of the most serious threats to sustainable agriculture is soil erosion, which is a serious problem in many parts of the United States and the world today. A major problem is that soils form very slowly, generally

much slower than the removal of soil by erosion processes. Erosion of soil resources has increased as the result of traditional agricultural practices that tear up the land by plowing it, exposing soil to the erosion processes of wind and water. The key to managing soil erosion and minimizing it is to minimize the plowing that increases erosion and surface runoff and to keep soils covered with plants or mulch. Other objectives are to enhance the quality of the soil through applications of organic materials that increase the water holding capacity of soils, maintain higher levels of nutrients and minimize the use of industrially produced fertilizers.

An important issue related to water resources and agriculture is that of water quality. Surface and ground waters may be contaminated by pesticides, nitrates, and heavy metals, such as selenium, or may become salty as the result of applying irrigated waters from distant places. Even if the irrigation waters have a very low salt content, over years, salts may accumulate in the soil and damage the ability of the plants to be sustained. Other problems are related to mining of groundwater and transport of water for irrigation from locations far away. Water resources are protected by using systems of water delivery that provide just the right amount of water at the right time to appropriate plants for a particular area.

Air resources are affected by agriculture, and sustainable agriculture has an objective to conserve air quality. Most impacts from agriculture that can reduce air quality, include burning of agricultural plants that produces air pollution, dust from plowing and traffic and harvesting, and the drift of pesticides from areas where they are sprayed to other areas where people may live. There are many good options that can improve air quality in agricultural areas, and principles of sustainable agriculture are playing a significant role in their development and use.

Sustainable agriculture has a component of wildlife conservation. Conventional agricultural practices have resulted in the destruction of habitat for many animals and plants. Conversion of wildlands to traditional agricultural practices generally reduces the biodiversity of an area. Sustainable agriculture, on the other hand, has the objective of supporting the diversity of wildlife and enhancing natural ecosystems through the use of particular plants along riparian areas and providing for buffer zones that encourage wildlife. A positive aspect of this is that wildlife can help eliminate agricultural pests and, thus, lead to better management of agricultural lands, as well as providing the diversity of life necessary for other ecosystems to survive.

Energy is another important factor in agriculture. Our present, large scale, industrial agriculture is heavily dependent on (some would say addicted to) the use of non-renewable energy sources, especially petroleum. It is used to make fertilizers and to run tractors and other equipment, and it is used in almost every aspect of large-scale agriculture. As we make a transition to other energy sources, sustainable agriculture practice is determining how and where energy may be produced from the farms themselves. Crop residue can be used to make liquid fuels, such as gasoline, and manure may be used to produce energy gasses. Thus, we see that sustainable agriculture works with energy systems to derive the energy it needs for crop production on site, importing as little outside energy as is possible.

With all the above aspects of sustainable agriculture, there are also social and cultural issues related to the labor force of those raising, growing, and harvesting our food. Ensuring that social justice is applied to the workforce so its members can make a decent living and raise their families is of concern.

The emergence of sustainable agriculture involves the use of science to understand linkages between agriculture and our use of the environment. Important components of sustainable agriculture and horticulture include the management of soil, water, energy, air, and wildlife as a social, economic, and scientific endeavor.

Sustainable agriculture and horticulture can be found in Santa Barbara, and a number of farms and gardens have been established that apply principles of sustainable agriculture, as well as providing places to experience our living planet. These farms and gardens often have a component of research, as well as educational programs where children and adults can learn more about plants and where their food comes from. Some have self-guided tours, and others offer guided tours by docents.

Sustainable agriculture, which includes farms in cities, is linked to the Slow Food movement that has the dual objectives of: 1) providing and consuming foods that are locally grown and eaten at their peak of flavor and 2) preserving the biodiversity of the crops and animals we raise. Two local examples are Fairview Gardens and John Givens Farms in Goleta. Both are Community Supported Agriculture (CSA) members. CSA provides a way (with growing popularity) for people to purchase local, seasonal food at peak flavor directly from farmers. A participating farmer offers boxes of vegetables (and sometimes other farm products) to people in the community. People that purchase a share subscription receive a box of produce each week throughout the farming season. Sometimes the boxes are delivered and left for people at designated places, such as is the case at UCSB, or they may be picked up at a farm.

Givens Farms (with 180 acres in 12 locations) started in Goleta Valley on one acre in 1980. The farms have a strong commitment to food production and maintaining food crop diversity with the

use of principles of sustainable agriculture. The farm plants many varieties of vegetables, and organic, seasonal crops (grown to specific standards) are sold at peak flavor and nutrition. The farm has production programs with the objective to extend the availability of crops longer in cooler months and to provide for timely delivery of seasonal crops.

Fairview Gardens (Fig. 6.7) is a model for small-scale urban food production, preservation of agricultural land, and sustainable agriculture. The mission of the gardens is to help demonstrate connections between land, food, and human well-being. The gardens produce a large variety of organic fruits and vegetables on their 12.5 acres. They sell their crops at two farmers markets and from a small (on site) produce stand. They help sponsor or provide a variety of activities, including guided tours of the gardens, lectures, internships, school education programs, cooking and gardening classes, and special farm festivals.

Local Santa Barbara area botanic gardens apply a variety of sustainable techniques, including production of mulches and other materials that assist plant growth and reduces the need for irrigation, while providing measures of erosion control. Botanic gardens are places that help maintain biological diversity through the collection of plants in living museums.

Lotusland (Figs. 6.8 & 6.9) is a 37-acre botanic



Fig. 6.7a. Fairview Gardens is one of the oldest organic farms in California, 2009.



Fig. 6.7b. Crops at Fairview Gardens, 2009.

garden and estate, established through the creativity of Ganna Walska in Montecito on an older alluvial fan constructed by Montecito Creek. The age of the fan, based on the relation of the fan to dated marine terraces to the south, is estimated to be 60,000 to 100,000 years. The garden is about one-



Fig. 6.8. Lotus pond at Lotusland, 2009.



Fig. 6.9. Lotusland's rose garden, where compost tea is applied to help control pests, 2009.

half mile north of the small east–west hills produced by folding and faulting along the Mission Ridge Fault System. Madame Walska purchased the property in 1941 and named it “Lotusland” in honor of the iconic, sacred Indian lotus that was growing in a pond on the estate. The lotus is a

beautiful aquatic plant with pink (reddish) or white blossoms of overlapping petals that stand well above the surface of the water. Lotus flowers in India symbolize many important things, including fertility, wealth, knowledge, divinity, and enlightenment. The socialite who became a designer of gardens and a collector of rare and unusual plants died in 1984. She left the gardens for future generations to enjoy under the name of the Ganna Walska Lotusland Foundation.

Lotusland applies a number of best management options to maintain soil fertility and pest control. According to the horticulturists at Lotusland, they use garden practices that are certified as organically based and that are the least harmful to the environment. This is done in recognition of the fact that garden procedures based on chemical fertilizers and chemical pest controls that were widely used in the past harmed the environment.

Lotusland has developed the use of compost tea that greatly reduces or eliminates the application of traditional fungicides to

roses (Fig. 6.10). The “tea” provides a film of living organisms that are beneficial to rosebushes and other plants by preventing fungal disease spores and bacteria from infecting the plants. Plant pests or diseases are not killed by the tea but are effectively controlled. Thus, the tea is an environmen-



Fig. 6.10. Tank shown here by Michael Iven, Director of Grounds and Facilities at Lotusland, is brewing compost tea that is applied to the gardens, 2009.

tally friendly alternative to the use of commercial chemical fertilizers and pesticides. The tea (there are many recipes used in many places) is produced by soaking (steeping) compost in water. The compost naturally contains nutrients and microorganisms beneficial to plants, and, when applied as a tea to the soil or leaves of plants, increases soil fertility and plant growth, while also protecting plants from pests.

The Santa Barbara Botanic Garden (founded in 1926) is located in the foothills of Mission Canyon on about 65 acres (Fig. 6.11). The meadow that greets visitors with vibrant wild flowers when they enter the garden in the spring and look north to the mountains appears to be the head of the alluvial fan the city of Santa Barbara is built on. The surface of the fan slopes south and is fairly smooth, with the occasional large boulder poking through. The age of the fan surface is estimated to be about 60,000 years.

Fan deposits at the garden include boulders from a series of debris flows that built the fan. Mis-

sion Creek has cut down through the fan, providing a good place for the Spanish priests and their engineers from Mexico to build a dam on Sespe Sandstone exposed in the lower canyon along the creek. The Sespe Sandstone is a generally red sandstone of Oligocene age (about 30 million years old) that is inclined (dipping) south along most of the Santa Ynez Mountains. The red color is due to iron in the sand that has oxidized. The sands were deposited on land (probably in wide river valleys near the coast), in contrast to the marine sedimentary rock the Sespe is sandwiched between. Sespe Sandstone

is part of the southern limb of the large anticline that is the Santa Ynez Mountains. The dam was constructed over 200 years ago to provide water to Old Santa Barbara Mission via an aqueduct. The structure is largely intact, and it is a great place to soak up some early California history.

The garden has the objectives of research, conservation education, and maintaining botanic collections. It is a living museum. Important to the broader community is the garden's scientific study and management of endangered plants of the California Central Coast. With more than 1,000 examples of California native plants, the garden is a living example of the plant diversity of California. The garden has an expansion plan approved by the Santa Barbara Planning Commission to construct a significant number of new buildings and facilities as well as pave the main trails (some of the trails have been recently paved with small concrete blocks that look like stone, and more may be paved). The approval of the Planning Commission was appealed by Friends of the Mission Can-

yon with support of other citizens and interested groups. A difference in values apparently exists between the position of the garden, which is pushing for the expansion, and others who want to maintain the physical site of the garden more or less as it has been in the recent past. They argue that the garden has an outdoor research and educational mission, and new facilities would encourage indoor activities at the expense of the environment. They further argue that research based on fieldwork on the site can be best accomplished in and with academic institutions, rather than in laboratories on the site of the garden. One of the most revered locations in the garden is the meadow terrace, which is a relatively young (geologically speaking) debris flow terrace with brilliant wild flowers in the spring and spectacular views to the mountains. The terrace will evidently be protected from future development.

Wildfire is a common process in the chaparral environment of Southern California, and fire frequency and intensity are predicted to increase in coming decades, as a result of global warming. Wildfire is a natural process, but, as more human structures are placed in the wildland-urban interface (such as where the garden is), damages are sure to increase. The possibility of this became a fact in May of 2009 when the Jesusita Fire roared through much of Mission Canyon and adjacent Rattlesnake Canyon (a major branch of Mission Creek). Several garden buildings (along with 78 homes) were significantly damaged or destroyed by flames. The historic, century-old Gane House in the garden was consumed by the flames, as were garden equipment and several other buildings (including the director's home and offices for staff). The

portion of the garden within the canyon of Mission Creek burned, and one-footbridge across the creek on one of the major trails was destroyed.

Heavy rains came in January of 2010. Storms produced the most significant rain since the damaging storms of 2005. Several inches of rain produced bank-full-plus discharge in Mission and Rattlesnake Creeks, mobilizing sediment on bare burned slopes, some of which had been treated with hydromulch. The hydromulch, applied by aircraft, following the Jesusita Fire is an all-organic mixture of paper and wood fiber, along with water and a binding material. It is certified to be plastic free. Organic green dye helps pilots see where the mulch has been applied so adjacent areas may be treated. The purpose of the hydromulch is to help retard erosion, hold soil moisture, and encourage new growth and the sprouting of native plants following the fire. University and government scientists are evaluating the effectiveness of the hydromulch in retarding erosion and encouraging the recovery of vegetation.

I visited the garden and canyon in early February of 2010 and observed that a pulse of sediment ranging from gravel to sand and silt flushed off the



Fig. 6.11. The Santa Barbara Botanic Garden, 2007.

burned slopes had entered the creek. In some places, 2 feet or more of sediment was deposited, often in pools. This is a common occurrence following wild fire, documented following the Painted Cave Fire in 1990. In Rattlesnake Canyon, one large, deep pool (just upstream of Skofield Park) that was prime habitat for endangered southern steelhead trout before the fire was nearly completely filled with sediment following the January storms. It will be interesting to see the pool reform after subsequent storms, once the fire-released sediment is flushed through the system. The upside of the fire and sediment is that a large amount of gravel will be distributed along the stream channel. The gravel is important for fish-spawning habitat, and erosion (including landslides) following fire is a major source of gravel to the stream.

The understory vegetation (those native plants that grow beneath the oaks) in Mission Canyon burned during the Jesusita Fire, and most oak trees were partially burned. Six months after the fire, there were many new leaves on the oaks, and most will fully recover. Many of the understory plants are also sprouting and will recover. Wildfire in the oak woodland of the garden is a natural and recurring process (the natural return period of fire is about 40-60 years). Oak trees that live several hundred years will experience a number of fires during their lives. The oak woodland and the riparian and adjacent chaparral ecosystems are fire adapted and need fire to flourish. That certainly is not the case for people and our structures. We are struggling to adjust to periodic fire which is our most serious frequently occurring natural hazard.

The previous fire in Mission Canyon was the Coyote Fire of 1964 which burned about eight times as much area as Jesusita. In the past 100 years, the entire south front of the Santa Ynez Range has burned. Major earthquakes are less frequent than fire, and high magnitude floods are restricted to relatively narrow corridors. An exception would

be a flood and debris flow on the alluvial fan the City of Santa Barbara is built on. Such an event is even rarer than a major earthquake. The last catastrophic debris flow was about 1,000 years ago. It came from Rattlesnake Canyon, roared through the present site of the Museum of Natural History, and extended into the city to near the intersection of State Street and Alamar Avenue.

In summary, the benefit of having local farms and gardens that are using sustainable methods to grow crops and plants and to preserve our environment is that they provide valuable examples of sustainable land use. Visiting these farms and gardens allows us to see what we might do in our own homes to conserve water, reduce soil erosion, and, generally, apply principles of sustainability to our lives and property. We have illusions that we own the land because we have purchased it. The reality is we are on the land a very short period of time (a few hundreds of years for long surviving families) compared to land that has been here largely the same for over 100,000 years. As a result, we have custodial obligations to the land that include the passing of land to future generations, along with all the beauty and resources the land offers. This is the essence of sustainable land management.

Sustainable Tourism (Ecotourism)

Tourism is one of the largest components of the global economy, producing over 230 million jobs and accounting for over 10 percent of the worldwide gross domestic product. Growth in tourism has been rapid, at about 7 percent per year (more in some developing countries), which means it doubles every decade. Tourism is not all a positive for the environment. For example, people visiting islands with coral reefs can contribute to damage to reefs if boats (including cruise ships) break off coral when dropping anchor, and reef materials may be collected to be sold to tourists. Tourists

from cruise ships visiting the Caribbean produce thousands of tons of waste per year, some of which stays on the ships and some of which ends up polluting the local environment. When golf courses are constructed, they use large amounts of water and nutrients that might be better used for agriculture or other purposes. This is especially true on islands and in coastal areas where the quantity and quality of water is often problematic due to poor drainage and the proximity of salt water. Nutrients, such as nitrogen and phosphorous, when they runoff from agriculture fields, golf courses, or urban lands to enter local waters (streams, ponds, lagoons, the ocean, etc.), can cause smelly and unsightly algae blooms (a process known as cultural eutrophication). It is clear that tourism can cause a wide range of environmental problems.

Ecotourism is experiencing (by visitors) the natural and cultural environment of an area in ways that conserve the environment and improves the well being of local people. By improving the well being of local people, I mean that ecotourism provides employment for people, while focusing on ways to preserve and enhance our environment. In some locations (for example, people viewing mountain gorilla or lions in Africa, snorkeling coral reefs on some Caribbean Islands, or whale watching in Mexican lagoons), ecotourism is a dominant economic activity, generating funds that preserve biodiversity and ecosystems. Ecotourism has the objectives of providing meaningful experiences to visitors, as well as to those living in that area; providing financial benefits to the local community; raising environmental sensitivity through direct contact with the environment; and enhancing sustainability of the region in both natural and urban areas.

Ecotourism or ecologically sound tourism integrates tourists into our community and establishes harmonious relationships between tourists,

local people, and the environment. People aspects include music, dance, food, culture, and architecture, whereas the environmental aspects include plants, animals, wildlife, and the land (geology and hydrology). An objective of sustainable ecotourism is to produce a vacation experience that enriches the lives of visitors (tourists) while not harming the environment and, ideally, improving it for future generations. Sustainable ecotourism encourages finding ways of welcoming tourists that preserves, maintains, enhances, and restores ecosystems; wisely uses and conserves natural resources, such as air, water, soil, plants, and animals; wisely manages materials and waste through the principles of the three Rs of reduce, reuse, and recycle; and uses energy in ways that emphasize, wherever possible, alternative energy sources, such as solar power that matches the energy source with appropriate end uses.

Ecotourism is growing at about three times the rate of traditional tourism (about 30 percent per year). Sunny places with great beaches provide mature markets, and experiential tourism, which includes nature (whale watching, for example), culture (wine tours and visiting small villages, for example), history (archeology, for example), and soft adventure (river rafting and hiking, for example) are types of ecotourism that are growing rapidly.

Santa Barbara is a destination tourist area that rivals any place on Earth. The combination of the ocean and mountains with an agreeable climate is one of the prime reasons. Santa Barbara is and always has been a bit difficult to get to, relative to other popular areas in California. One major highway leads in and out, and floods and mudslides periodically close that road. Similar problems plague the rail line that extends along the California coast, and the airport is relatively small and vulnerable to fog and flooding. Nevertheless, for over 100

years, people have flocked to Santa Barbara to enjoy the physical, biological, and cultural environment. Visitors to the Santa Barbara area do more than just sit on the beach, walk in the hills, shop in stores, and eat in restaurants. Tourists interact with our natural and urban environments in many ways at a variety of levels from economical to physical and social.

Santa Barbara is a gateway to the Santa Barbara Channel Islands (Fig. 6.12), and the channel provides many opportunities for traditional tourism and ecotourism (Fig. 6.13). Two of the most common activities are whale watching and island excursions (Figs. 6.14 & 6.15). Whale watching is actually much broader than simply watching a gray whale swim along the coast or watching blue whales in the channel. Whale watching involves observation of a variety of marine life, ranging from sea lions and dolphins to feeding fish and birds. Whale watching trips have a component of education, insofar as people learn about the ecosystems of the Santa Barbara Channel and their integration into the wider marine system. Santa Barbara has many tours and activities for tourists, including adventure tours (kayaking, surfing, hiking, paragliding, and rock climbing); walking tours in the city (history, art, architecture, and culture); segway tours (to the Mission, beach, and around town); the land shark (a vehicle that travels on land and in the water); sailing tours (the channel and Channel Islands); sport fishing (Sea Landing, Wave Walker, Stardust, and others); and bicycle and horseback tours. Tourists also visit our numerous gardens and museums, including the Santa Barbara Museum of Natural History (Fig. 6.16) the Martine Museum, the Sea Center, the Santa Barbara Museum of Art, the Carriage and Western Art Museum, the Historical Museum, Casa de la Guerra, Stow House, the UCSB Art Museum, the UCSB Coal Oil Point Reserve, the UCSB



Fig. 6.12. Anacapa and Santa Cruz Islands along with Santa Rosa and San Miguel Islands to the west and not shown here are part of Channel Islands National Park, visited by many people. Santa Cruz island has a research center administered by the University of California Santa Barbara.



Fig. 6.13. East end of Santa Barbara Harbor has the Santa Barbara Sail Center (shown here) and Sea Landing where ecotourism activities in the channel often depart from.

Carpinteria Salt Marsh Reserve, the Santa Barbara Botanic Garden, Lotusland, and the Santa Barbara Zoological Gardens. All these places and organizations, along with others, provide environmental education, often on a regular basis. Some have docent programs where you can volunteer and teach others – this is a high calling: to learn and to teach others.

Excursions to the Channel Islands have increased since the creation of the Channel Islands



Fig. 6.14. Humpback whale in the channel, observed aboard the Condor Express. Photograph courtesy of Eric Zimmerman.



Fig. 6.15. Common dolphin in the channel, observed aboard the Condor Express. Photograph courtesy of Eric Zimmerman.

National Park, and numerous people make day trips and overnight camping excursions to several of the islands. These excursions may include activities such as diving, fishing, and sea kayaking. To better preserve marine resources in the Santa Barbara Channel, a series of marine preserves and marine conservation areas have been established at various places around the Channel Islands (especially Anacapa, Santa Cruz, Santa Rosa, and San Miguel). The island fox (the world's second smallest fox and an iconic species on the Channel Islands) is making a remarkable comeback—a success story in ecological restoration.



Fig. 6.16. The Santa Barbara Museum of Natural History located along Mission Creek is a place for young and old alike to begin exploring our natural history.

Urbanization and Ecotourism

Tourism draws large numbers of people to Santa Barbara, and there must be sufficient housing, water, infrastructure, and other facilities to make their visits both enjoyable to the individual and beneficial to the community. Large resort hotels, as well as smaller hotels, motels, and vacation homes are utilized, and this use has an impact on the local environment. Tourists, like the rest of us, use water resources, produce waste, and impact our beaches and hiking trails. Therefore, management of ecotourism activities in a meaningful way to achieve sustainability is an important part of our long-term planning. Important questions include how many hotels, motels, and so forth can the Santa Barbara area sustain? How can we preserve a balance between maintaining cultural and natural resources and the need to provide for tourists? Do we want to go the way of other tourist areas in developing timeshare condominiums in the coastal areas, or do we prefer to preserve local, coastal cultural areas, such as the Funk Zone near the Harbor with its artists and craftsmen and inter-

esting shops (Fig. 6.17). We need to be mindful of what produces a quality tourist experience for our visitors. Of importance is finding ways to maintain ecotourism activities while sustaining environmental quality. For example, one of the threats to ecotourism is beach pollution. No one wants to be exposed to potential disease and harmful chemicals while swimming or surfing. Our beaches are a golden egg to ecotourism, and we want to insure we don't damage the goose that laid the egg.



Fig. 6.17. The Funk Zone near Sterns Wharf is a place to visit art studios, a surfing museum and interesting shops, 2007.

Sustainable Ecosystems

Part of the charm of Santa Barbara is its mixture and juxtaposition of wild lands with urban lands. The two are separated by an urban fringe where housing density is less than in the more urban areas. That Santa Barbara has not gone the way of much of Southern California, with rapid sprawl and urbanization, is a reflection of the values of the local people. We have generally tried to hold the line on development in terms of what is developed, how big it is, what the architecture is, and how it fits into the general community. If our

land is to be sustained, then these principles must be carried on, as there is ever-more pressure to loosen restrictions on future development. If you want to see some of this process firsthand, you can go to the Architectural Review Board meetings where people hoping to remodel or build and develop new areas must start. These hearings are also televised on the public access station and provide insight into our development process. Part of land sustainability has to do with sustaining our

architecture, as well as the size and amount of development at a specific location. Although those hoping to develop property do not always appreciate the amount of review required before construction starts, most of us, when not on the hot seat at the review board, appreciate the results of careful planning.

Management of ecosystems requires a thorough understanding of ecosystem structure, process, function, and change. We define an ecosystem as a community of organisms, including its local, non-living environment. A species is a group of individuals ca-

pable of interbreeding. When we speak of species, we also use terms that are related to whether or not a particular species has been introduced into a new area. Such species are sometimes called exotic or introduced species. When an introduced species causes environmental problems (most do not), such as driving out native species, it may be called an invasive species. Other species are termed endemic or native species. Still other species have a very broad distribution around the world and may be present if the environment is appropriate; these are known as “cosmopolitan” species.

For example, monarch butterflies may be found in the landscape over very large areas of thousands of miles in length during their migrations. Finally, species that are found practically everywhere on the surface of the solid Earth may be known as a ubiquitous species. We humans are an example of such a species.

A community of organisms is a group of different species that are living in the same local area and are interacting with one another. Thus, the community is the living part of the ecosystem. The non-living part of the ecosystem includes the rocks, soil, and water that, together with the community of organisms, define the entire system. Thus, basic ecosystem structure includes two parts: 1) the living part and 2) the non-living part. Study of ecosystems is as much a part of geology and hydrology as biology.

Two important processes operate in ecosystems. These are the cycling of chemical elements necessary for the ecosystem, and the flow of energy through various parts of the ecosystem (Fig. 6.18). Ecosystem function is the rate of energy flow and the rate of the chemical cycling of chemicals. Change in ecosystems is called succession, and it involves a generally orderly change in the ecological community, along with a change in ecosystem function. Succession often occurs following disturbance. For example, after wildfire, the recovery of vegetation is natural secondary succession. It is secondary because some of the pre-disturbance ecosystem remains. If a new island is produced in the ocean by volcanic eruption, new land is produced and primary succession occurs.

We have learned through the study of ecosystems that the persistence of life on Earth is a characteristic of ecosystems and not of individual organisms. Sustaining ecosystems

requires ensuring that the right amount of necessary elements that the system requires are present at the right times in the right amounts. Thus, we need to maintain the biogeochemical cycles that cycle necessary elements and nutrients (such as oxygen, nitrogen, phosphorus, sulfur, and carbon) through ecosystems (air, water, soil, rock, and life). Too high of a concentration of these chemicals or not enough will limit life. Human processes are altering biogeochemical cycles like never before. For example, we produce nitrogen fertilizers (fix nitrogen) in comparable amounts to all other non-human processes of nitrogen fixation. Our lower atmosphere is about 80 percent nitrogen, but it is inert and not available to life. Nitrogen fixation refers to the process of converting inorganic nitrogen in the atmosphere to nitrates and ammonia. In nature, it is carried out by a few species of

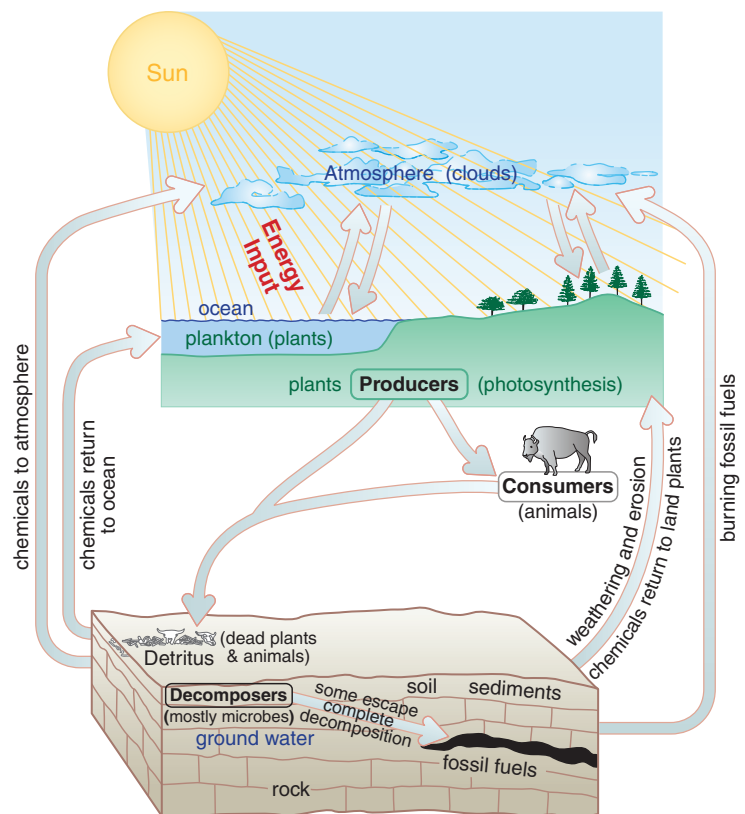


Fig. 6.18. How an ecosystem works: Energy flows through the system and is transformed; chemicals cycle and can be reused.

bacteria that all species of life on Earth depend on. Lightning strike fixes a small amount of nitrogen through oxidation (sometimes you can smell it). We fix nitrogen through applying lots of energy from burning fossil fuels. When nitrogen fertilizers are applied to agricultural lands, runoff and percolation transfers nitrogen to groundwater and surface waters and, eventually, to the ocean. High concentrations of nitrogen in water area serious water pollutant that can cause health problems to people.

In ponds and lakes, as in the ocean, excessive nitrogen can cause the explosive growth of algae that can cover ponds (smelling bad and reducing oxygen in the water as the algae dies and decays). As mentioned earlier, I have observed this at the mouth of Mission Creek in the summer where it crosses State Street toward the ocean, sometimes blocked by a barrier beach, producing a small lagoon. The process of the explosive growth of algae is called cultural eutrophication. It is all too often a problem in Campus lagoon at UCSB. In the Gulf of Mexico, excessive nitrogen from runoff from midwestern farms often produces a dead zone (up to about 7,000 square miles) of depleted oxygen in the gulf during the summer where non-mobile or slow moving life forms. such shellfish, crabs, and snails, are killed from lack of sufficient oxygen.

If we strive to manage ecosystems effectively, we have to know a lot about the individual organisms that make up the communities, as well as how they are linked with the non-living environment. Methods of ecosystem management being practiced in the Santa Barbara area include the establishment of natural areas, reserves, and marine sanctuaries, such as Goleta Slough, Devereux Slough, Carpinteria Salt Marsh, Ellwood Mesa, and the Douglas Family Preserve. These areas have been set-aside as places where the natural environment is preserved for future generations.

One of the basic concepts related to all ecosystems is that of biological diversity. Often the term “biological diversity” is wrapped up with people’s concern for endangered species. More commonly, though, when we talk about biological diversity with respect to ecology, we are often concerned with the total number of species and their interaction in a particular ecosystem, area, or region.

Biological diversity generally involves three components. First, we may speak of genetic diversity, which refers to the total number of genetic characteristics. Genetic diversity may be applied to specific species, subspecies, or groups of species. Secondly, we are concerned with habitat diversity in a given area or with respect to a particular ecosystem. Where a species lives or could live is the habitat. Associated with habitat is the concept of the ecological niche that defines what a species does to make a living. For example, consider an analogy. If surfers were a species (some people mistakenly think so), waves are their habitat, and their niche is riding the waves on a wood or fiberglass board while remaining in a standing position. For mountain lions, the habitat is the mountains and the niche is eating deer.

Returning to biodiversity, the third way we may view biological diversity is species diversity. Species richness or the total number of species; species evenness, the relative abundance of species; or species dominance, the most abundant species are terms used when discussing species diversity. But why do we care about biodiversity?

There are several fundamental reasons or justifications why we may wish to manage and maintain species and biodiversity: 1) *moral justification* - species and ecosystems have the basic right to exist; *aesthetic justification* - appreciation of the beauty of nature. Many of us want to live in a word with more nature not less; *ecological justification* - the species or ecosystem is necessary for

other species to thrive or survive; and *utilitarian justification* – a species or ecosystem has economic or medical value that we desire. For examples, we may choose to maintain an estuary because it provides valuable shellfish or they provide a buffer from storm waves or tsunami waves that protects our property from damage.

Factors that Increase or Decrease Biological Diversity

Those factors that may tend to decrease biological diversity include: environmental stress, such as pollution; extreme disturbance that disrupts the entire ecosystem, such as timber harvesting or hydraulic mining in a drainage basin; or the introduction of exotic, invasive species that cause the extinction of other species. For example, in many rivers in the western USA, native populations of cutthroat trout have been displaced by the introduction of rainbow and brown trout.

One of our significant concerns is environmental pollution that places great stress on our river systems. Pollutants that have routinely damaged river ecosystems include oxygen-demanding waste (organic matter from processes, such as spillage of sewage into a river), toxic substances, and hazardous chemicals from our agricultural and urban industries; acid mine drainage from present and previous mining activities; sediment from soil erosion from agricultural lands, overgrazing, mining, and deforestation; and thermal pollution – the introduction of warm water from industrial operations and power plants.

Let's now consider some of the factors that may increase biodiversity. Of utmost importance is diverse physical habitat. This follows from our premise that the form and process of ecosystems evolve in harmony, but that function, from a biological viewpoint, clearly follows form. Therefore, an ecosystem with diverse physical and hydro-

logical habitat supports a greater biodiversity than does an ecosystem with less diverse habitat. Therefore, processes that increase habitat diversity will increase the biodiversity of an ecosystem. Moderate amounts of disturbance are beneficial and can increase biodiversity. Moderate disturbances, such as smaller landslides and floods of less than catastrophic proportion, are important in delivering sediment and nutrients to river systems. For example, a limiting factor in many streams for the production of salmon and trout is the amount and availability of stream gravels for spawning. These gravels are probably introduced as a result of moderate disturbance events in the head-ward reaches of river systems where sediment and water is produced. Were these disturbances not to occur, the stream system would become impoverished of gravels necessary for the spawning of fish. The introduction of exotic species that are not invasive (do not push out other species) increases biodiversity. A final factor important to the increase of biological diversity of ecosystems is a high degree of modification of the system by life. Our urban environment is a human example; all sorts of introduced plants and animals (including parrots) mingle and live with us, sometimes under our homes, decks, hot tubs, or in a woodpile kept to feed our fireplaces. The Mesa is a haven for skunks and shoe-stealing raccoons. I have had one shoe from each of three pairs stolen by raccoons and never to be seen again. Perhaps they like the salt, or perhaps I just smell good to them. Sometimes I think there are more skunks, raccoons, and coyotes within the city than outside it because of a more dependable food supply - and smelly shoes.

Plants living on the banks of a river in the riparian zone, as well as plants and animals living in the river, contribute greatly to the diversity and even to the maintenance of the stream ecosystems. Consider the impact of beaver on stream biodiver-

sity. Prior to the arrival of Europeans, many American streams from coast to coast resembled a series of ponds, due to the industrious activities of the numerous beavers, which, at 50 pounds or so, are North America's largest rodent. As with gorillas, there are mountain beaver (in California they are the Point Arena mountain beaver, a bit of a misnomer as they can be found near sea level) and the lowland beaver. The density of beaver dams may have run as high as two or three colonies (each with a dam) per half-mile. The series of beaver ponds on these early streams had a tremendous impact on the landscape. They stored water and sediment, eventually filling with sediment to become meadow lands that would later support trees, such as cottonwood, alder, and willow. As the dams were filled with sediment, the beavers would abandon them and find other sites on which to build new dams, thus continuing the cycle. Unfortunately for the beaver and streams, beaver pelts became valuable, and the mountain men who arrived in the early 19th century began harvesting the animals whose skins were used to adorn fashionable hats in Europe. Although the beavers did not become extinct, their numbers were greatly reduced, and their effects on the rivers were greatly diminished. As the beaver ponds were eliminated, they broke up, and the character of the streams began to change, as did the aquatic ecology. The trapping of the beaver in the streams caused the dams to be prematurely destroyed as they were abandoned, causing many changes in the stream, including higher loads of sediment and wider, faster, and deeper water in the river channels. As a result, the rivers could transport sediment more readily, but the hydrology and biology of the river ecosystem changed. Beaver hats are no longer the rage, and beavers are recovering, in some areas, to populations as large as before trapping. In some cases, landowners are not happy if beavers build dams that flood their property (dam beavers, they

said). Beaver dams and ponds produce wetlands, and wetlands are protected. As a result, beavers may not be removed without a permit.

With approval (an exception to policy), the California Department of Fish and Game recommended that beaver could be relocated from Alhambra Creek in downtown Martinez, California in the Bay Area (ironically, once the home of naturalist John Muir). The beaver had shown up in 2006, found the area to their liking, and built a dam. In 2007, the city cried foul (in this case, beaver) and determined that the large beaver dam (30 feet long by 6 feet high) was creating a flood hazard. The potential removal or relocation of the beaver raised a lot of media attention and controversy. Some said the city should never have developed the floodplain, and that the beaver should remain. Some people and teachers took children to see the beavers, using their presence as a teaching opportunity on their backdoor step. The beaver dam changed stream hydrology and produced habitat for other fish and animals, including river otter, spotted mink, steelhead trout, and many birds that moved in.

Native Americans evidently recognized early on the importance of beaver to water resources, fishing, and the hunting of birds and other animals that used beaver ponds. Many chose not to hunt the beaver much or to remove their dams.

In the end, the solution for Martinez is to construct an outlet structure (a pipe through the dam) to control the water depth and size of the pond. The beaver will instinctively try to plug up any perceived leaks in their dam. The trick is to install a device that controls the pond level without creating suction that the beaver will notice. If they do not associate a drop in water level with their dam, they will ignore it. The city evidently will try this. We shall wait and see.

Without the input of nutrients from life to the river, it would become an impoverished and less



Fig. 6.19. The chaparral brush lands just west of Rattlesnake Canyon before the 2009 wildfire.



Fig. 6.20. Oak Woodlands of Rattlesnake Canyon the major tributary of Mission Canyon (my home).



Fig. 6.21. Riparian (stream) corridor of Mission Creek at Rocky Nook Park. Typical trees are sycamore, alder and big leaf maple.



Fig. 6.22. Wetlands near family housing at UCSB. These were once part of a much larger system of wetlands from Goleta Slough to Devereux Slough.

productive system. Only recently have we understood the importance of returning salmon to the streams and rivers of the Pacific Northwest. The salmon life cycle is completed when adults die following spawning. While feeding in the ocean, the large fish store nutrients in their bodies that are released to the river system upon their death. The nutrients are used by a variety of life forms, including eagles and bears that distribute the nutrients in the watershed through their own life processes. Rivers and streams highly modified by life in all its forms and processes increase biological diversity.

The major ecosystems of the Santa Barbara area include: 1) chaparral (Fig.6.19), consisting of brush lands on upper slopes above the city for the most part; 2) oak woodlands that occupy some of the valley bottoms and mesas (Fig. 6.20); 3) stream and riparian areas, which consist of the stream and near-stream environments (Fig. 6.21); 4) grasslands, which usually are associated with rocks poor in nutrients, such as the Rincon Shale; 5) coastal sage, consisting of low shrubs in some of our near-coastal areas; 6) coastal wetlands that include lagoons, sloughs, salt marshes, and vernal pools (Fig.

6.22); 7) various other coastal ecosystems, including the beaches, sea cliffs, and sand dunes; 8) the Santa Barbara Channel; and 9) the Channel Islands. A particular suite of animals and plants characterizes each of these ecosystems. In addition, we have our urban ecosystem, which has been highly modified by human activity, as well as nearshore ecosystems, including rock reefs and kelp forests.

An important aspect of Santa Barbara ecosystems is the introduction of exotic species (introduced above). A large number of plants, as well as some animals and birds, have been deliberately or accidentally introduced into Santa Barbara. Examples of exotic plants include eucalyptus trees (Australia), ice plant (South Africa), and arundo (Mediterranean Europe and India). Most exotic plants have a small impact on our total biodiversity. What would the look of Santa Barbara homes be without the ever-present red bougainvillea? Exotic species that do cause problems are sometimes called invasive species. These species adversely affect the ecosystems they invade, becoming naturalized and self-sustaining. For example, large eucalyptus trees increase our fire hazard because they burn fast and hot. Ice plants have pretty flowers, but increase the slide hazard when they grow on steep slopes. Ice plants have shallow roots and heavy leaves that increase the incidence of shallow landslides. Each leaf is like a small canteen of water. Ice plant usually forms thick mats that drive out native plants and animals. Following a rainstorm, I have observed ice plant slips on slopes adjacent Cliff Drive that, during a rain storm, moved down a slope as a unit, looking like a crumpled rug at the base of a slope, sometimes ending up on the street.

Arundo (a giant reed), which grows along our creeks, is perhaps the most significant threat to our native creek (riparian) ecosystems. Arundo looks like bamboo with hollow stems about 1 inch in diameter and long leaves (up to about 2 feet long and an inch or so wide) (Fig. 6.23). It grows very fast, at several inches per week to a height exceeding 20 feet. Arundo spreads easily from a near-surface, coarse root system of rhizomes that forms a nearly continuous root mat about 2 to 3 feet thick that resembles very large bulbs of ginger. Below the root mat, smaller, pencil-size-diameter roots extend down several feet. The whole root structure (you have to dig it up to see it) reminds me of jellyfish with long tentacles hanging down. Arundo can take over and dominate a streamside and floodplain environment. The plant chokes out native riparian plants and provides poor habitat for birds we associate with the stream environment. In small streams, arundo can fill the channel and increase the flood hazard by displacing floodwaters. In large streams or rivers, the plant can change the form of the channel by diverting flow from one bank to



Fig. 6.23. Arundo, an invasive species that looks like bamboo in lower Mission Creek.

another, causing bank erosion. It can also narrow the channel, changing a braided channel with mid-channel islands into a single thread channel lacking islands. In other cases, arundo may armor part of the channel, helping to maintain mid-channel islands by protecting them from erosion. After a flood, which can remove large amounts of arundo from creek banks and floodplains, it is not uncommon to see piles of arundo stalks and roots on our beaches. People like to make all sorts of structures, such as shacks, on the beach from the stalks of the plant. Arundo, originally introduced to California about 1820 and used as thatching for the roofs of buildings, is used today to make the reeds for wind instruments. Research is ongoing to find more uses for arundo, for example, as a biofuel.

Through studying and observing ecosystems, we've learned that all species are not of equal importance to an ecosystem. Some are known as keystone species, which have a large community effect. That is, a keystone species has a large effect on its community, and its removal or addition leads to large changes in many or all other species in the community. Recall our discussion above of the return of beaver to Alhambra Creek. Beaver are a keystone species. When they are present, so are many other species, and when they are gone, biodiversity diminishes (other species go with them).

Kelp Beds and Sea Otters

The kelp forests off the coast of Santa Barbara are a remarkable ecosystem. They are one of the most dynamic and productive ecosystems on Earth. Our kelp forest offers a large variety of fish habitat, ranging from rock hiding places to kelp-covered surfaces. Abalone (a much prized gastropod, classed as a low-spiral snail) and sea urchins (another commercial species), along with starfish, other snails, moray eels, and solitary coral (small colorful, orange coral growing upright and resem-

bling the tip of a pencil—less than an inch high), live below the kelp canopy on and in small openings in the rock substrata. Sea mammals, such as California Grey Whales, frequent the kelp beds. When a female whale migrates north with a young calf, she often keeps close to shore near kelp to become less visible to her main predators, killer whales, which are present in the Santa Barbara Channel. I have often seen grey whales with calves (from Campus Point and Shoreline Park) swimming west, just outside the kelp. The best viewing time for me is near Easter (that is when I remember to go to the bluff tops to look for them, not necessarily when they are the most abundant).

Kelp forests form areas of variable size; the abundant kelp visible at the surface is tied to the ocean bottom on exposed rock. These areas are called kelp beds. The existence of kelp beds offshore of Santa Barbara is dependent to a significant degree on the local geology, especially folds and faults. Some of the rocky environments to which kelp is attached are wave-cut platforms found offshore, in fairly shallow water and rock reefs, which may have water depths of up to several tens of feet. The wave-cut platform that extends off shore from the sea cliff at a number of our beaches is cut directly on bedrock by waves. The platform has variable relief, depending upon the local resistance of the particular rock shelf, and slopes gently offshore. After a winter storm, large waves attack the platform and the beach, and sand is moved off shore a bit and the platform is often exposed in all its glory. I say this is glorious because, when the platform is laid bare, it is possible to see the tremendous variability in the 6 to 18 million year old Miocene shale. Small faults and folds are everywhere, and each individual bed with variable thickness and color (black, white, orange, banded or spotted, sometimes impregnated with tar from an ancient oil deposit), is there to see. Winter in the late afternoon at low tide is a great

time to visit the platform after a storm. Tide pools abound, full of rounded beach rocks of every color and size. There are shells thrown up by the waves, and colorful beach glass can be found. Driftwood with shells and rock make for a great photo shoot. Sit for a bit and become one with the environment—hear the waves rush up and spill back, listen to the sound of shore birds, see the brilliant colors of the sun setting on the ocean and beach, and feel the last light of the day (perhaps you will see the green flash). Such an experience is one of nature's tranquilizers.

Returning to our discussion of kelp beds, rock reefs offshore from a few hundred feet to several miles often result from geologic uplift from faulting or the presence of more resistant (hard) rock. Geologic structures are parallel to shore - roughly east to west. Nearly all the offshore reefs that support kelp forests owe their existence to an active geologic environment. We know these as One Mile Reef, Two Mile Reef, Camby's Reef, and Naples Reef (a bit to the west), among others. These are favorite spots for fishermen to pursue calico bass, barracuda, bonito, white seabass, and, occasionally, yellowtail. I encourage fishermen to keep only what they wish to eat on the day of their catch and to let the rest go free. For calico bass, a local, beautiful fish that has declined (in my opinion) in recent years, catch and release at all times (as fresh water bass fishermen have done for years) is a good policy which will help to ensure that our grand children will see these fish in their natural abundance.

What exactly is kelp? The simplest explanation is that kelp is a type of large marine alga that grows incredibly fast. The giant kelp of southern California can grow up to more than 10 inches per day, reaching a height of over 30 feet above the sea floor. The three parts of the kelp plant include the root-like holdfast, the stem (stipe), and a system of blades (leaves). They also have a number of float-

ation devices (gas-filled bladders) near the blades which provide buoyancy that enable the kelp stipe to remain in an upright position in the water column. At the surface, particularly at low tide, the sea surface looks like a nearly solid mat of kelp. Below the surface, the forest consists of stipes attached to the bottom by the holdfasts. The holdfast is attached to boulders or to the rocky bottom. As mentioned earlier, some of the rocky environments to which they may become attached are wave-cut platforms found offshore in fairly shallow water and rock reefs. The wave-cut platform has variable relief (usually ranging from a foot or so to nearly planar), depending upon the local resistance of the particular rock shelf. Rock reefs often result from geologic uplift from faulting or the presence of more resistant (hard) rock. From Santa Barbara south to Los Angeles (along the Transverse Ranges that are east-west compared to most mountains in California that are more north-south), these structures (folds and faults) are parallel to shore and roughly east-west. Remarkably, they are east-west because they have been rotated over millions of years about 90 degrees clockwise by tectonic processes associated with the San Andreas fault to the north, which is the boundary between the North American and Pacific tectonic plates. Nearly all the local offshore reefs that support kelp forests owe their existence to our active geologic environment.

Holdfasts are attached to the rocks with what looks like a root system, but they do not take up nutrients. Rather, the function of the holdfast is to hold the plant in place. If the holdfast breaks loose or is destroyed by some process, the kelp will float free and drift to the shore. During storms, the kelp moving near the surface will apply stress to the lower plant, causing the holdfast to come loose. The holdfast, with bits of rock, may be transported to the beach to become part of the sediment carried in the nearshore environment. This

process can move rock particles from offshore to the beach, while also distributing organic material from offshore to the beach.

The kelp forest flourishes in areas of upwelling nutrients and relatively cold water. Growth rates are greatly reduced in years when the marine water warms up, as, for example, during El Niño years when warmer water is present. There are a variety of organisms near the bottom of the kelp forest, including urchins which are spiny animals that feed on the holdfast of kelp. When urchins feed and break the holdfast, the kelp will float free and die. There are several predators of sea urchins, including humans, who collect them for their eggs, or roe, which is valuable, and sea otters, who eat the urchins.

Sea otters (Fig. 6.24) are a keystone species of the kelp forest. That fact is at the heart of arguments in favor of the conservation of this species along the California coast, including the Santa Barbara area. Before commercial hunting of otters brought them to near-extinction, their historic range extended from Baja California to Alaska and Russia. Because they have valuable fur, they were hunted to near-extinction during the 18th and 19th centuries, at which point there were too few otters left to support further hunting. Legal protection of the otters began in 1911, and their population has increased since then to exceed 100,000 otters today. Of these, about 2,700 sea otters live along the California coastline, mostly north of Point Conception, not far from Santa Barbara. I have seen otters in the past few years near Santa Barbara off shore of Shoreline Park and directly in front of the harbor. They are also present at Isla Vista, Coal Oil Point, and west to Gaviota and Hollister Ranch.

Sea otters are protected under the Marine Mammal Protection Act of 1972, as well as by the Endangered Species Act of 1973, and an effort to



Fig. 6.24. California Sea otter munching urchins, modified after US Fish and Wildlife Service.

increase their population in California is a long-term goal. Attempts have been made to establish sea otters on some of the Channel Islands, but that effort has been largely unsuccessful. Sea otters are moving as their population has increased, and they have tended to want to move south around Point Conception and into the waters of the Santa Barbara area. There have been regulations on the books to stop this migration. Local fishermen, with the support of the city government, have lobbied to not allow the otters to migrate into our waters, based on the observation that they take the urchins that the fishermen wish to collect and sell. The harvesting of sea urchins in recent years has been a profitable, if small, industry. The eggs (roe) of the urchins are considered a delicacy by some people, and they sell at a good price. Sea otters also feed on abalone and other shellfish. The classic picture of sea otters is a cute animal floating on its back in the kelp forest with a rock in its paws, bashing a shellfish before consuming it. Conservationists argue that the sea otter has an important role to play in our local kelp forest ecosystem. These undersea forests provide an important habitat for many other species of fish and other plants and animals. One of the favorite foods of otters is the sea urchin. The urchins feed on the bottom on the holdfast, which

is the root like structure that holds the kelp stem and fronds to the rocky bottom. When there are lots of sea urchins grazing along the bottom and feeding on kelp, they tend to eat and detach the holdfast. The kelp floats free, dies, and floats away to perhaps pile up on beaches. Where sea otters are abundant, as for example in some Alaskan kelp beds, there are few urchins. Those areas that lack sea otters and in which sea urchins are abundant have less kelp, and the ecosystem is impoverished, insofar as other species that depend on kelp are less abundant. Of course, the harvesting of sea urchins by fishermen plays the same role as the sea otter, and, if sufficient urchins are harvested, then kelp beds will be healthier.

An important point here is that the sea otters are a keystone species, and their presence or absence plays a significant role within the entire ecosystem. The otters' effect does not result from direct intervention by the otters. The otters neither feed on the kelp, nor do they protect individual kelp plants from being attacked by sea urchins. Rather, otters reduce the number of sea urchins that are present to eat the kelp. As the amount of kelp increases, there are more habitats for many other species, and, so, the biological diversity of the kelp forest is increased.

Recently, there have been discussions and meetings to consider the sea otter situation. Santa Barbara is in the so called “no-otter zone” set up over 20 years ago and supposedly managed by the U.S. Fish and Wildlife Service. I say supposedly managed, because management of the otter who choose to swim around Point Conception south to our waters and take up residency has proven to not be practical. Nevertheless, the question still being asked is: should the otter be allowed in or should we continue practices to try to exclude them? If the sea otters continue their tendency to migrate to their old habitats, it is difficult to exclude them.

You can try to trap them and relocate them, but that hasn't worked very well. They can be encouraged not migrate into our waters, but that has proven difficult and is questionable in light of the endangered species status of the otters. Recently, the tide of decision has shifted, and, in all likelihood, the sea otters will slowly migrate from Point Conception to areas further south, including the Santa Barbara area. The Environmental Defense Center in late 2009 filed suit against the U.S. Fish and Wildlife Service because the service had not reached a final decision concerning repeal of the rule to exclude otters south of Point Conception.

Whether the rule will be repealed or not (and it probably will be, as it is not enforceable from a human or otter perspective), it will probably be decades before otter have any real impact along our coast. Due to local pollution of nearshore waters, substantial increase in numbers of otters in the Santa Barbara area in the near future is unlikely. Should they become established in greater numbers, they would improve the health of our kelp forests and also provide an increase in eco-tourism activities by people taking guided trips to view otters. Let's now turn our attention to rivers—one of my favorite topics. I have spent much of my professional life in one river or another.

Reverence for Rivers

Every river is unique, just as every person differs in some ways from every other person on Earth. We each have different fingerprints and DNA, both of which may be used to differentiate between two people, even if they look very much alike. There is no fingerprint or DNA to separate rivers from one another, but there are many characteristics that are helpful. Some rivers are long, such as the Columbia River in the Pacific Northwest, while others are short, such as the Ventura River in southern California; some are wide, such as the everglades in

south Florida, while others are narrow (small rivers may be called creeks or branches). Examples of small, steep, boulder bed streams are abundant in the Santa Barbara area above the piedmont, at the foot of the mountain (examples include Montecito, Mission, Rattlesnake, San Antonio, Maria Ygnacio, and San Jose creeks). Some rivers have beds of large cobbles and gravel, such as the famous trout streams of Montana and Yellowstone National Park area, while others have a bed of sand, such as the Little Colorado River in Arizona. Some sections of rivers flow through deep canyons of hard granite rock, such as the Merced River in Yosemite Valley. Others flow through deep canyons with alternating layers of hard sandstone or limestone and soft rocks, such as shale, for example, the Colorado River through the Grand Canyon. Some rivers have wide floodplains (the flat land adjacent to a river that is occasionally inundated by water), such as the Mississippi River, while others have practically no floodplain at all. Finally, some rivers flow through forests with giant trees such as redwoods or Douglas fir, such as Redwood Creek in Redwood National Park, while others, such as the Mojave River in California, flow across the desert with little vegetation on the banks or adjacent areas.

Given the tremendous variability of rivers, the definition of what constitutes a stream or river is not entirely straightforward. While all rivers and streams have water flowing within a channel at least some of the time, this flow may vary from a few days a year to perennial flow. One simple way to define a stream or river is that it is a natural drainage channel on the surface of the earth with discharge (flow) at least part of the year. But when does a stream become a river? There is no easy answer, but a river has a relatively large, long channel, for a particular region, that generally has a number of smaller tributary channels that flow into it. A stream or river that feeds into another takes the name of the larger

one, and where they join is called the confluence. For example, a major confluence occurs where the Missouri River enters the Mississippi River. Natural channels that drain the land in more arid regions may be known as a wadi, gulch, or barranca. Whatever we call them, they are all variations on the same theme. That is, they are a natural channel of variable length formed by running water draining from the land. Some rivers start from a major spring where groundwater gushes forth from the earth in a large stream, whereas many others form from numerous small sources that coalesce into larger and larger channels.

The idea of a reverence for rivers and the centrality of water to life extends far back into human history. In 1977, hydrologist Luna Leopold argued that we need “deeper feeling concerning rivers,” and he brings attention to the concept of “reverence for rivers.” Leopold quotes Herodotus concerning the reverence of rivers by Persians in the 5th century B.C. Evidently, the Persian leaders placed a high value on rivers and made it a policy not to pollute rivers or allow others to pollute them. The relevant quote from Herodotus is, “They never defile a river with the secretions of their bodies, nor even wash their hands in one; nor will they allow others to do so, as they have a great reverence for rivers.”

The centrality of water to life has been talked about by many societies in many regions around the world. For example, about 1500 B.C., in what is now northeastern Louisiana, commerce in the lower Mississippi Valley was dominated by Native American cities which were home to thousands of people. The cities were tied together by rivers that served as major arteries for transportation of goods from the Great Lakes to the north and to the Appalachian Mountains to the east.

Native Americans in the region, including the Caddo, spoke of sacred medicine water emerging

from large hot springs. The Caddo legend of their creation speaks to the birth of their ancestors from spring waters. These waters are the hot springs of Arkansas, which is a famous site that has lured people to the area for thousands of years. Native Americans that lived in the region utilized the waters of the hot springs with natural mud baths to restore health and vigor. Tribes of people from the Great Plains and Rocky Mountains, as well as those of the southeastern United States, gathered near the springs to partake of the hot water, coming together in safety and peace, even though some of the tribes might have been at war with each other when not visiting the healing waters.

In the southwestern United States, Native Americans living in the harsh desert environments of southern Arizona as late as the 15th century when the Spanish arrived were a people known as the “river people” of the Pima. They lived on farming by irrigating their crops with the waters of the Gila and Salt Rivers. To the Navajo, living along the Colorado River, the waters were sacred. These Native Americans were said to bless the waters of the river with corn pollen when they crossed it, affirming that they recognized that without the river water they could not exist.

It is clear that earlier peoples have very graphic myths and statements concerning their reverence for rivers. For example, Luther Standing Bear of the Rosebud Sioux wrote, “We did not think of the great open plains, the beautiful rolling hills and winding streams with tangled growth as ‘wild.’ To us it was tame. Earth was bountiful, and we were surrounded by the blessing of the Great Mystery.”

When we speak of “reverence” for rivers, we move into the realm of our essence or our feeling level. Those with a reverence for rivers have a deep respect for rivers that is linked with feelings of awe and affection. Reverence may also be linked to science because we know that through the study of

science we can remove some of the mystery of how our world works; but this does not diminish our awe of the natural environment. Luna B. Leopold presented his concept of reverence for rivers to the scientific community in 1977 during a keynote address to the Governors’ Conference on the California Drought. In that paper, Leopold spoke of a balance or harmony in natural systems that have evolved and developed throughout the several billion years of Earth’s history. He elaborated on the desire of people to preserve the natural harmony, and he stated that this preservation should be incorporated into the management of rivers and water resources in general. He termed this “philosophy” of river management a “reverence for rivers.”

Today, Leopold’s philosophy is wrapped up in the environmental paradigm we term “sustainability.” The concept of sustainability is fuzzy to some and non-scientific to others. However, the term has a ring of truth for us. At the level of our human lives, we strive to sustain our relationships between our children, partners, friends, and ourselves. This is one of our very basic values. We also value environmental protection. In the United States, polls have consistently found that most people across the nation believe environmental protection should be a national priority, and that it’s important to protect endangered species and those facing extinction. Not surprisingly, one of the significant environmental problems facing the United States, according to the people surveyed, is the pollution of our air and waters. There is, evidently, a growing popular mandate for environmental protection and the development of a path towards sustainability of our renewable resources, including water, air, soils, and, by inference, human welfare.

So what is this sustainability we are talking about? Sustainability remains something we are still struggling to define. One definition is that sustainability is a type of development that ensures

that future generations will have an equal access to the resources of our planet. On the other hand, sustainability also refers to those developments that are economically viable, do not harm the environment, and are socially and environmentally just. It's important to recognize that sustainability is a long-term concept and, as a result, is something that happens over decades or even hundreds of years. It is also important to acknowledge that sustainability is most appropriate for renewable resources such as air, water, wildlife, and people. When we talk about the non-renewable resources, such as fossil fuels and minerals, sustainability is not possible, and the best we can do is to attempt to extend their availability through processes such as conservation and recycling.

A major obstacle to attaining sustainability of rivers and other renewable resources is the number of people using the resources. The number one environmental problem is the ever-growing population of humans. For most of human history on earth, our numbers were very small, and our impact on the environment was also small. With the advent of agriculture, combined with sanitation and modern medicine, all linked to inexpensive energy sources such as oil, we have proliferated our numbers to the point that we are producing global problems.

The total environmental impact from people is roughly estimated by determining the impact per person and multiplying that by the total number of people. As a result, as human population increases, so must environmental impact. It is impossible to obtain sustainability of rivers or any renewable resource without stabilizing human population.

Fish, Pools and Sustainable Ecosystems

An ecosystem is a community of organisms and its non-living environment where energy flows and chemicals cycle. Sustained life on Earth is a function of ecosystems, not isolated individual species. Stream ecosystems include a potentially large number of organisms in the ecological community, including plants and animals living in the stream, as well as those on the streambed or banks.

Physical factors that are important to stream ecosystems include the flow of the water (current), the substrata (rock, sand, or gravel) that the streambed is composed of, the temperature of the water, and the dissolved oxygen content of the water. The velocity of flow varies with the downstream slope of the channel (the steeper the channel, the faster the flow), the roughness of the channel bed, and banks that retard flow and reduce the velocity of flow. The current (down and cross stream velocity and turbulence) of a particular stream can be variable from place to place and with changing flow conditions. Different organisms (for example, fish and insects) adapt to variable flow conditions (fast, slow, deep, shallow, etc.). Substrata is important to fish and insects. Some fish seek shelter behind boulders or woody debris or under water rock ledges and overhangs. Some insects prefer gravel substrata, while bivalve mollusks, such as small freshwater clams, burrow in sandy substrata. Water temperature can vary significantly from day to night, seasonally and along a stream's course, and is critical to stream ecosystems. Some fish, such as trout, require relatively cool water and will seek out areas in a stream with cooler water, perhaps near a spring or in a deep well-shaded pool. In Rattlesnake Creek, there are a number of springs that emerge from the Coldwater Sandstone in the foothills above Skofield Park. Pools associated with the spring flow have cool water yearlong. These "cool pools" are critical to the

survival of trout during the dry summer months when much of the stream warms up or even dries up. The oxygen content of stream water varies with water temperature, cooler water having a higher concentration of dissolved oxygen than warm water. Photosynthesis of instream plants, such as algae, adds oxygen to stream water, and the physical mixing of the water as it flows allows more oxygen from the atmosphere to be transferred (dissolved) into the water. Dissolved oxygen is an important part of water quality. If oxygen concentrations drop below what stream organisms require for healthy productivity, the ecosystem may degrade. At very low oxygen concentration, fish and other stream organisms may die. Low oxygen may result from warm water temperature, due to deforestation that exposes a stream to direct sunlight rather than shaded light from streamside trees, or from the input of organic material (for example, raw sewage) that, as it decays by bacterial activity, uses dissolved oxygen from the stream.

Energy flow in all ecosystems begins with sunlight which fuels photosynthesis, the process whereby organisms use carbon dioxide, water, and solar energy to produce sugar and oxygen. Primary producers, autotrophs, that produce their own food from inorganic compounds and energy (in this case solar energy) in stream ecosystems include algae which are single cell photosynthetic organisms. In streams, algae generally are green colonial or filamentous-looking organisms forming long strands that move with the flow. Energy may enter streams directly via leaves and other organic material that fall into a stream and become food for a variety of insects living in the stream. Sometimes, leaves collect in pools at low flow, forming leaf packs that can be observed at low flow when the water is clear. Leaf packs support communities of macroinvertebrates (small insects that process the leaves and other coarse organic material, such as small twigs within the leaf pack).

A revolution quietly began in the late 1970s that continues today in the study of streams and rivers. Although rivers and streams have been studied for hundreds of years, there was little communication in the past between those who studied fish, those who studied the water, and those who studied the basic form of the channel. The biologists seldom spoke to hydrologists or geologists or engineers about their work, and each individual science was loaded with jargon, making communication difficult. Then, some remarkable headway was made in places like Oregon State University in conjunction with the U.S. Forest Service. A “stream team” was born! The team consisted of geologists, hydrologists, biologists, and engineers, with a common goal to understand forest watersheds and stream processes in the Pacific Northwest. In order to facilitate discussion, new terms were needed that could be easily understood by all scientists studying rivers. Rather than communicate in terms of scientific names of species of invertebrate animals (insects) in streams, the scientists used functional categories, such as shredders, grazers, collectors, and predators. When hydrologists, geologists, and biologists started talking to each other, they realized they had a lot in common and could learn more about how streams work through integration of their various fields of interest into a general field of stream ecology.

Southern steelhead are becoming an icon for the streams of the Santa Barbara area. Their presence reminds us of a time when streams ran free of human interference, and they are a sign of the ecologic health of a stream. Somehow, if steelhead are present in Mission Creek, Montecito Creek, Carpinteria Creek, and other local creeks, we believe we have a connection with a bit of unspoiled nature in our midst. The habitat and niche for southern steelhead trout is complex and variable. Using the stream team approach of com-

binning the study of biology, geology, and hydrology to understand these fish is critical. Steelhead (*Oncorhynchus mykiss*) are anadromous rainbow trout. Their habitat includes freshwater streams, coastal lagoons, and the ocean. Their niche is variable, depending upon what stage of their life cycle they are in and upon what habitat they reside in at a particular time. Adult steelhead swim up streams, such as Mission Creek, to spawn. Female steelhead dig out a nest (a “redd”) with their tails. The redds are surprisingly large, several feet in diameter. They can be recognized as an oval patch of clean gravel. A large female steelhead may have more than 10,000 eggs. While the female is depositing the eggs in the redd, they are fertilized by males attending her. One or two months later, depending on water temperature, the fry emerge from the redd. The fry live and grow in the stream for a year or so as juvenile fish. They prefer the cool water of deep pools in the mountains where high quality water is present year round. Suddenly (from a human perspective), a remarkable transformation begins to occur. The young rainbow trout start moving downstream as smolt and prepare for a life in the ocean. Not all of the young trout will migrate to the sea; some remain in the stream as resident trout. Resident trout, when they spawn, can produce steelhead offspring. For some of the young fish, the instinct to migrate is part of their nature. Thus, in the mountain streams, such as Rattlesnake Creek above Santa Barbara, steelhead trout will continue to be produced even though parent fish do not go to the ocean. Today, very few of those that go to the ocean can return to their ancestral spawning and rearing habitats due to the many barriers to migration that people have created (concrete channels, culverts, and road crossings). One of my students, Mr. Garrett Bean who completed a thesis on the pools of upper Rattlesnake Creek, observed an adult steel-

head above Skofield Park several years ago (there are not many). When the young smolt, which are a few inches long, move downstream in the late spring or early summer, they may spend time in a coastal lagoon (estuary) before going into the ocean. The best places to see southern steelhead locally are: 1) behind the Museum of Natural History (young steelhead are almost always present in the large pool there--stand on the bridge and look carefully, and you will see them) and 2) the deep pools of lower Mission Creek near bridges close to Bath Street from about W. Cota Street to W. Ortega Street. I have often seen adult steelhead up to 31 inches long (over 10 lbs) that have entered the stream to spawn after the first significant storm of the Fall-Winter. I suspect they would go upstream to their historical spawning grounds if they were not inhibited in their upstream journey by human-made barriers.

The largest pools are formed and maintained by high flows above bankfull discharge. Discharge is the volume of flow per unit time that passes a particular site. It is the product of the cross-section of flow and the mean velocity of flow (units are cubic feet or cubic meters per second). Bankfull discharge is a relatively high flow that just fills the channel. Sometimes the boundary of the bankfull channel (bankfull width and depth) can be recognized by close examination of the shape of the channel, the bank vegetation, or persistent water lines on boulders. Bankfull discharge has an average return time of 1.5 years (it occurs, on average, every year or so). Thus, bankfull flow is a relatively common high flow. Bankfull discharge is an important concept because basic stream shape (width and depth) and stream forms (such as gravel bars and pools) form as a result of bankfull flow. It is the bankfull discharge that is capable of transporting gravel and initiating scour and deposition of gravel in various parts of the stream channel.

Stream flow is often converged between large boulders or a combination of boulders and bedrock in the stream bank at or near bankfull discharge. The convergence effect on stream flow is like using your thumb on a hose to restrict flow and produce a faster stream of flow. The increase in the velocity of flow scours the stream-bed, producing a pool (Fig. 6.25). When the bankfull flow exits the pool, it may diverge, reducing the velocity of the flow, depositing gravel to form a riffle bar. This is an example of the well-known (to river hydrologists) convergence–divergence criterion (convergent

flow causes scour and divergent flow causes deposition). At low flow (which is most of the time), the pool has slow, deep water, and the riffle has fast, shallow flow. Water flowing over a riffle or rocks entering a pool produces the soothing sounds of the stream that calm our spirit. Large pools provide the best summer low-flow habitat for steelhead trout. At high flow when these pools are forming, stream flow may sound like a freight train roaring down the valley. Sometimes you can hear the boulders moving. If you are on the dry part of a gravel bar at high flow and place one end of a short round bit of wood (like a baseball bat) on the stream bed and place your ear to the other end, you can often hear particles being moved along the stream bed.

We conclude that pools form as a result of convergence of flow and scour at high flow. Pools at low flow have deep, slow moving flow and are good places for a summer wade, paddle, or swim. I published the idea that to understand pool formation it is necessary to consider the entire contin-



Fig. 6.25. Two pools in Mission Creek. The larger pool (lower) is below the old Mission dam, and the smaller pool (upper) is due to convergence of flow between boulders at high flow. Photograph taken before the Jesusita Fire in 2009.

uum of flow from low to high as the “hypothesis of velocity reversal” in 1971. The hypothesis has been tested several times and verified, and remains a topic of active research. When first published, it was very controversial, and one scientist wrote a critical reply. He stated I should read an introductory hydrology book, as the hypothesis was antithetical to all known hydrology. I replied in print that I believed research should go beyond what is known if new contributions are to be made. Scientists are critical and skeptical by nature, and I advise my students that you will need a thick skin if you go into science. I received a Distinguished Scientist award from the Geological Society of America in 2004, largely for the 1971 paper.

Pools and adjacent riffles are important as fish habitat. They are found in a regular repeating sequence of about 3 to 7 times the channel width (average spacing is about 6, close to 2π). Why the average spacing from pool to pool along a meandering stream is about 2π is not known. Speculat-

ing, the spacing related to pi (a constant of nature, defined as the circumference of a circle divided by its diameter) may represent a fundamental but unknown unit of stream length. The phenomena of a regular repeating wave of deformation (highs and lows) when one material (in this case water) flows over another (in this case the stream bed) is part of a general process. Wind blowing over a wheat field has a waveform, as does a dirt road over which cars pass (forming wash board-like, regular repeating bumps that annoy drivers). Step-pools that form as water flows over boulder steps in steep mountain streams are spaced closer (often 2 to 4 times the channel width, about pi).

The pool-riffle sequence provides for a more diverse hydrologic environment that increases the biologic diversity of stream ecosystems. Steelhead often spawn at the tail of a pool, feed on a riffle (they also feed in pools), and use the deeper part of the pool for a refuge from predators. If you observe a pool in Rattlesnake Creek and there are lots of insects on the surface, there probably are no fish in that pool. Insects are eaten by fish that cruise around the pool; you may observe the rise and small splash or subtle rings of displaced surface water as they feed. Restoration of streams often has an objective to provide alternating pools and riffles.

The 2009 Jesusita Fire burned much of the drainage basins of Rattlesnake Creek and upper Mission Creek. Winter storms of 2010 over the burn areas produced a flushing of silt, sand, and gravel. In Rattlesnake Creek, formerly large, deep pools filled with sediment (near Skofield Park, the pools filled with 2 to 3 feet of sediment). Large amounts of sediment were transported downstream, damaging pool environments near the Ortega Street Bridge where steelhead have been present in past years. As the sediment released from the fire works its way through the stream system to the ocean, the pool and riffle habitat will recover.

Riparian Zone

How we choose to interact and manage what remains free and wild in both our urban and non-urban environments reflects our values and is a direct indication of our depth of commitment to sustainability and future generations. Moreover, the environmental choices we make are measures of who we are as a people.

One of the earliest concepts concerning rivers and the interactions between physical and biological processes is that related to the identification of the riparian zone. The riparian zone is the part of the river system which includes the river channel and adjacent areas under the influence of the river. In general, it is defined as starting from the center of the channel and extending inland on both sides of a valley to areas that are periodically inundated by floodwaters; generally, the extent of the 20-year flood is used to define the riparian zone. The 20-year flood is the flow expected, on average, every 20 years. The probability that it will occur in a given year is 5 %. When tossing a coin, it is possible to flip 3 heads in a row, even though the probability of any one toss coming up heads is still 50 %. By way of comparison, three or more 20-year floods may occur in consecutive years.

The riparian zone is complex because it contains a different community of plants and animals than those found further upland beyond where periodic floodwaters reach. The soils in riparian zones are marshier and may contain wetlands. The floodplains of the world are within the riparian zones, where the vegetation is often adapted for life in more saturated soil conditions. For example, in the western United States, riparian trees are species such as cottonwood, alder, or sycamore, in comparison to more upland trees, which may be oaks or pines.

Sometimes, the edge of the riparian zone is easy to identify. For example, in arid and semi-arid regions, slopes may be nearly devoid of timber or

large trees, consisting of brush, cactus, and other vegetation adapted to arid conditions. However, adjacent to a stream or river in the region, there is a sudden greening where trees are abundant along the river channel--in stark contrast to the upland slopes. For example, in the chaparral environment of southern California, riparian zones consist of trees, such as alder, sycamore, and big-leaf maple, at the lowest elevations, and these give way to native oak trees beyond the flood levels that merge with the low brush and shrubs known as the chaparral.

The riparian environment of streams is incredibly important for ecosystems within and adjacent to a stream or river. Riparian vegetation shades the stream, cooling the waters, and is an important source for food to the stream or river. Leaves and branches fall in that are fed upon by insects in the stream. Insects that fall from the branches of trees and stems of grass provide food for fish. The fish, in turn, provide food for birds of prey and river otters, and, in some cases, large carnivores, such as the brown bears in Alaska. The bears and eagles then return nutrients from the fish to the land in one of the few short-term natural ways that nutrients from the sea are returned to the land. Erosion of marine sedimentary rocks also returns nutrients, but this is a process on the scale of geologic time. Finally, riparian trees, when they fall into a stream channel, produce large, woody debris which may be organized by stream flow into logjams that provide important habitat for fish and other living creatures within the stream or river system.

The role of “large roughness” elements and stream channel form and process, as well as biological function, is so important that it’s worth treating in a little more depth. Large roughness elements consists of large logs, limbs, and root wads that are greater than about a foot or so in diameter; large boulders greater than 3 feet in diameter; and bedrock exposures along a stream channel.

The accumulations of large roughness elements influence the pool environments by producing deeper and larger pools. Large roughness elements produce a variety of channel forms, including pools, riffles, and runs, as well as associated hydrologic variability that provides important habitat for fish. In virtually every forest stream of the world, from the mountains to the tropics, large roughness elements play an important part in forming and maintaining fish habitat. Next time you walk along the banks of a mountain stream, such as Rattlesnake Creek above Las Canoas Road, note the abundance of large boulders (and, sometimes, large woody debris) in the channel. In particular, note where it resides. Does it cross the entire channel, forming a step, or does it defend a bank of the channel? Most large deep pools in Rattlesnake Creek are produced by the convergence of flow at high flow, which causes scour. In other words, large roughness elements are associated with a pool because the debris sets up convergence of flow and eddies that leads to scour. In steep mountain streams, most pools are produced by boulders that are deposited in rough lines across the stream, forming a step-pool. The boulders form a step in the stream profile, and a scour pool forms below the step. Some large roughness elements are undercut (part of the stream flow passes under the boulder, forming hidden areas and habitat that provides important hiding places for fish from predators, such as birds). The large roughness elements may also provide shade in these undercut positions that helps cool the water—which may be necessary for certain species of fish.

River Continuum

One of the most significant principles of river ecology is the idea of the “river continuum.” Understanding this concept entails an understanding of the functional categories of organisms within stream systems. The concept of the river continuum is an idealized one that seeks to explain a succession of communities of organisms that exist along a river system, from its headwater areas in the mountains to midsections and, finally, to lower sections near where the stream may enter the ocean or a lake. In headwater regions, stream gradients often are steep. The stream may be entrenched in bedrock, and there may be abundant coarse gravel and boulders (large roughness elements) on the bed of the stream. Trees generally line the stream bank, and, hence, there is abundant shading, and water temperatures are cool. Branches and leaves fall from the riparian vegetation into the stream channels, and the dominant invertebrates are the shredders that are capable of feeding on this coarse organic material that enters the stream channel. If the river is wide enough, there may be communities of invertebrate animals, known as collectors, who are filter feeders that sift small particles from the water column. In relatively smaller areas, there may be algae growing that grazers will feed on. Finally, there are the ever-present predators. Further downstream, in the more central portions of river systems, the substratum is finer, and tree-lined banks cannot shade the entire stream, resulting in more plant growth. In these locations, the invertebrate community of animals includes grazers and collectors, which are the dominant species. Shredders are much reduced, and predators are still present. Still further downstream, where water depths are greater, more plants are growing. The invertebrate animals found in this region are predominantly collectors, along with the predators that eat them.

The above discussion is appropriate for discussing what happens at the “macro scale” in hydrologic environments, such as pools and riffles. In fact, the pool-riffle sequence creates contrasting environments and habitats, each with its characteristic assemblage of aquatic organisms. When we classify a stream or river into functional categories, such as pools and riffles, we enter the domain of descriptive ecology, with its dependence upon hydrology and geomorphology, to explain habitat diversity for different ecological functions. Some invertebrate species in gravel bed streams have particular adaptations that allow them to anchor or remain within the currents. For example, some larvae of mayflies are able to adjust their position and flatten their exposure to the flow; however, most of the macro-invertebrates must move around and, therefore, are vulnerable to the movements of the currents, and, accordingly, organisms drift downstream with the flow.

In a river, the macro-invertebrates are those animals that do not have a backbone or internal bony skeleton. They include insects, worms, crustaceans, and mollusks (clams, etc.). Some of the macro-invertebrates — called macro because you can see them with your naked eye and, generally, are on the order of a quarter of an inch or more in length — have different functions. Some are shredders that are capable of eating coarse organic matter, such as twigs or leaves. Others are grazers that move over the surface of rocks, feeding on algae films and other vegetation. The collectors are generally mollusks or various species of shelled organisms, like clams, that acquire their food from the water column through especially adaptive organs that collect their food. Finally, predators are those macro-invertebrates that prey on the other species in the stream or river environment. For example, one of the major predatory species is the dragonfly.

Along with the concept of the river continuum,

there is a downstream flow or drift of organisms that live in the water column and along the bottom of the channel. This is the natural flow, due to the transportation system of the river. This downstream drift or movement is compensated for, to some extent, by upstream movement of some of the invertebrate insects living in rivers. For example, some nymphs, such as those that develop from the eggs of the mayfly, grow through a number of stages and colonize habitats on riffles but then migrate to deeper pools. When they are flushed from the pools by higher flows, they migrate to side-stream environments that offer protection. When the nymphs emerge as an adult fly, they fly upstream, where eggs are then deposited in the main stream to again drift in the downstream direction. Nymphs of other aquatic insects also migrate upstream during part of their life cycles. Thus, we see that adult mayflies, upon emergence, swarm and mate and fly upstream to lay their eggs, sustaining colonization that helps compensate for downstream loss of organisms.

The concept of the river continuum works in explaining differences in populations of invertebrate species that ideally occur in the downstream direction of an idealized drainage basin and stream. However, there remain many exceptions to the idealized continuum because river basins are unique. That is, a stream may have headward reaches that have mountain streams that produce most of the sediment and water for the basin, and, as one goes downstream, depending upon the geology, there may be series of rock canyons and other environments that would interrupt the idealized continuum. Also, human use and interest in a river will disturb the idealized continuum. Building a dam on a river changes conditions both upstream and downstream of the reservoir.

Dams fragment river ecosystems into two parts (upstream and downstream). Downstream of a dam, the discharge of the river is greatly

changed as the pre-dam, natural frequency of floods and other high flows is changed. Generally, there are fewer and smaller floods following the closing of a dam. If the dam generates electricity, the daily flows may radically change with demand for power. This causes problems for fish that have to adjust daily to changing flows (high to low) and for the recreational use of the river by rafters. For example, in the Grand Canyon of the Colorado River, the flow over rapids can change quickly.

The amount of fine sand and gravel sediment is greatly reduced below a dam because it is trapped in the reservoir. As a result, less sediment is delivered to downstream beaches (most of the sand on a beach is delivered to the coast by rivers and streams). Loss of sediment below a dam often results in armoring (development of a surface layer of large gravel particles that resists downstream transport by river flow) of the streambed below a dam that forms as finer gravel and sand is transported out by “hungry water.” It is called hungry water because, in most rivers, there is a balance between the volume of flow and the volume of sediment being transported. Clear water released from a dam has the capacity to transport additional sediment, and it may scour the streambed and banks below a dam to achieve a new balance between the volume of sediment transported and the volume of flow of the water. This explains why channel erosion often occurs below a dam. Everything in the riparian zone, from the stream flow to the bank vegetation downstream of a dam, changes. In recent years, in order to sustain rivers and their ecosystems, people who manage river flow (releases of water) from a dam will occasionally and deliberately release moderately high flows to provide a more natural frequency of the flows that ecosystems require. This is a major change in river management. Sustainable rivers require sustainable flows.

Santa Barbara Coastal Wetlands: Sloughs, Estuaries (El Esteros), and Small Lagoons

An Estuary (*el estero*, locally) is a general term for a semi-enclosed body of water that is connected to the ocean. It is a zone of transition between a stream or river system and the marine environment. Estuaries are special places where land, beach, and marine processes are linked to produce a highly productive and dynamic environment. In such areas, processes of stream flow and groundwater flow interact in complex ways. Changing tides, beach deposition and erosion, and ocean waves that vary from mostly small beach building waves to large crashing breakers transform the lagoon and beach on a daily to seasonal basis. Low tide exposes mud flats with salt marsh vegetation and sinuous channels that braid across the estuary. Flooding during high tide can transport sediment, kelp, and woody debris into the estuary from the beach and ocean. Floodwaters can also bring in large amounts of sediment and woody debris from the upstream mountains. The level, temperature, and salinity of the water in an estuary can change quickly. Many types of life are drawn to estuaries, as are humans who harvest food, such as shellfish, birds, and fish.

Along the Santa Barbara coastline from Ventura to near Lompoc, there are three very different types of estuaries. The first and largest are those associated with our largest rivers. From southeast to northwest, these are the Santa Clara, Ventura, and Santa Ynez. The Santa Clara is one of the largest rivers in southern California, and the lagoon at the coast is the landward end of a large river delta known as the Oxnard Plain that extends inland to South Mountain near Ventura. The two lagoons (there are two mouths of the Ventura River) are on a small to moderate sized (scaled to the river size), wave-dominated delta that is clearly visible as a protrudence into the sea when driving south on US 101 toward Ventura from Sea Cliff. Matilija

Dam upstream has stopped about half of the sediment in the river system from reaching the beach. This has resulted in coastal erosion and changes in the river and river ecosystem. The dam is in planning stages to be removed. The reservoir is nearly filled by 6 million cubic yards of stored sediment, one-third of which are fine sand to silt, leaving little room to store water. As with most dams, it fragments the river ecosystem, blocking upstream fish passage.

The Santa Ynez River flows much of its course along or near the Santa Ynez fault. The fault has mostly a left-lateral, strike slip displacement. This means that, during a large earthquake, if you were looking along the fault (not across it), you would observe the land on the left side move toward you (perhaps as much as 15 feet during a Magnitude 7.0 to 7.5 earthquake). This is the maximum size range of earthquake that the fault could and eventually will produce. A Magnitude 7.0 to 7.3 earthquake (called the Lompoc Earthquake) occurred in 1927 offshore of Point Arguello, near where several small earthquakes occurred in March of 2010. The 1927 Lompoc earthquake produced a tsunami of about 6 feet at Surf Beach (west of Lompoc) and Pismo Beach.

Branches of the Santa Ynez fault are located beneath Gibraltar Dam, very close to Bradbury Dam (Lake Cachuma) and very near Lompoc. A seismic safety refitting was completed several years ago for Bradbury Dam. A large earthquake at Gibraltar Dam would heavily damage, if not destroy, the concrete structure. Another branch (south branch) of the Santa Ynez fault follows near Gaviota Canyon and can be observed where it disrupts marine terraces on Hollister Ranch. The lagoon of the Santa Ynez River is a large feature with a barrier beach and sand dunes. The lagoon sometimes extends over 2 miles inland and is confined to a large, wide valley and wave-dominated coast that

keeps the delta straightly aligned with the coast (it doesn't extend out like the deltas of the Ventura and Santa Clara Rivers). The Santa Ynez is a river forever changed by the three upstream dams and demand for water. Sediment flow to the coast is reduced, as it is caught and stored behind the dams, reducing the sand supply to the downstream river, delta, and coast. The sand that once flowed around Point Conception has been reduced, probably contributing to coastal erosion along the Santa Barbara Coast. A lot of the sediment also, at times of lower sea level (say 20,000 years ago), fed a series of offshore submarine canyons offshore of Point Arguello, funneling sediment into the western Santa Barbara Basin (western Santa Barbara Channel). Today, these canyons are apparently too far offshore to intercept as much nearshore sand as they did in the past. As a result, sand is transported by waves in the surf around Point Conception and eastward toward Santa Barbara. The river below Bradbury Dam (completed in 1956) has changed. It has become less braided and has more riparian vegetation. Floods that occurred before the dam was built delivered more gravel to the river, a process which favors forming the islands of a braided river. Large floods have been mostly controlled, and riparian trees and other vegetation do not scour out as often. As a result, the river channel is often narrower than before the dam construction. The river ecosystem has changed, and the large number of southern steelhead trout that once swam upstream to mountain spawning grounds have been all but eliminated. Those that remain have been squeezed into streams below the dam or are landlocked above the dam. Lompoc, on the inside of a large bend of the river, is partly on the floodplain of the river. Therefore, there is a significant flood hazard in wet years when Bradbury spills and tributaries downstream of the dams are running high. The flood of record was

in January 1907 with peak flow of 120,000 cubic feet per second (cfs). This is about the average flow of the Ohio River, a lot of water for a normally dry place like Lompoc. Floods in 1969 were about 80,000 cfs at Lompoc. The dam provides a false sense of security about flooding. A big upstream flood (which will eventually happen again) will pass through Cachuma, flooding the valley below. The answer – just say no to building on the floodplain.

Returning to the lagoons, the second type of lagoons consists of relatively large sloughs or *el esteros* associated with geologic structures that have formed fault-bounded depressions or synclines. Two prominent examples are the Carpinteria Slough and the Goleta Slough. These wetlands have historically included large areas of coastal wetlands (see Figure 6.22) and have interesting geologic histories related to earthquakes and deformation of the crust of the earth. Both of these wetlands were more extensive in the past and contained deeper water. With respect to Goleta Slough, large sailing ships during the Spanish exploration era were able to sail inland past Mescalitan Island, located just south of the wastewater treatment plant, to near where Hollister Avenue is today. Captain Sebastian Vizcáino sailed into the Santa Barbara Channel in 1602 and made note of large, permanent Chumash Villages with distinctive, well built, dome-shaped houses that looked like a half of an orange (igloo shape structures) made of a wood (willow) and whale bone frame with reed thatching cover. Some houses were about 35 feet across, (1,000 square feet), large enough for 40 or more people, with rooms divided by hanging reed mats. People slept on raised platforms. Over one hundred and fifty years later, the diary of Fray Juan Crespi from the Spanish expedition into California in 1769-1770 mentions the small (about 60 acre) island that was occupied by a large, prosperous Chumash town

with many homes and canoes. The island was a good site for a town because it was a defensible space, close to the sea, and protected from storm waves by the sand spit and the salt marsh with its abundant vegetation. For an interesting discussion of canoes and how the Chumash constructed and used them, read the 1995 book by UCSB Professor Emeritus Brian Fagan. The people on the island traveled to and from the town to the mainland by canoe. The canoes were up to 30 feet long, were seaworthy, and could be paddled by several men at a speed of several miles per hour. The canoes allowed the Chumash to fish kelp beds up to several miles offshore for bonito (a tuna), barracuda, sardines, and anchovies; to hunt sea mammals, such as otter; and to trade with the Chumash on the Channel Islands.

Mescalitan Island is bisected east to west by the More Ranch fault (a major strand of the Mission Ridge Fault System) that extends from near Ojai in Ventura County west to where the fault follows Devereux Creek until it goes off shore at the Sandpiper Golf Course. Along the way, the fault uplifts (up to the south) in many well-known spots in Santa Barbara and Goleta, including the American Riviera (Mission ridge), Hope Ranch, More Mesa, UCSB, and Ellwood Mesa. The presence of the fault on the island is probably what allowed the large Chumash town to persist. They would have needed a reliable supply of clean fresh water, normally not present in an area so close to the sea. There must have been a spring on the island that formed as groundwater moving from the mountains encountered the fault and was forced to the surface. The fault could produce a Northridge size earthquake of Magnitude 6.5 to 7.0 in the future. At any rate, the fault forms the structural, southern boundary of Goleta Slough. Today, the island is about one-half the area of what it was in the 18th Century. The missing half was used as fill to construct the early versions of the Santa Barbara Airport

The third type of estuary consists of small lagoons (much smaller than the Goleta or Carpinteria sloughs) that are not directly the result of lagoon bounding, faulting, and folding. We have identified over 20 of these small lagoons from Rincon Point west to the Gaviota coast. I have been studying them with PhD student Andrew Rich, one of my graduate students at UCSB. Andy went to many of these lagoons with a small boat that I purchased and a global positioning system (GPS) to map the size of the lagoons as well as their bathymetry (distribution of depth). Andy said it was interesting work, but stressful because the boat is so small and the borrowed, GPS equipment so expensive and not waterproof. One wrong move and the boat could capsize (fortunately that did not happen, although there were close calls). Imagine rowing a six foot boat, while avoiding obstacles such as sand bars and logs, with survey rods and differential GPS that can measure position and elevation very accurately. You easily can be distracted, because the small lagoons are often drop-dead beautiful and pristine, with a large variety of birds including ducks, blue heron, white egrets, and night heron, the latter which remind me of flying penguins.

Andy also analyzed rainfall that contributed water to the drainage basins that supply most of the fresh water input into the lagoons, as well as the slope of the stream channel just upstream of the head of lagoons. We determined that you could predict the size of a lagoon based upon rainfall data, the size of the drainage basin feeding the lagoon, and the slope of the channel just upstream of the lagoon. Predicting lagoon size is important because, if we are to restore coastal lagoon systems to better support wildlife, including endangered southern steelhead, we need to know what size they may have been in the past and what processes are operating today. We have completed a fair amount

of work on the Arroyo Burro Creek lagoon (Fig. 6.26) because it is a good example of a small lagoon with a coastal barrier beach that is accessible for study. We are also studying in detail Bell Canyon and Tecolote Canyon lagoons near the Bacara Resort because access there is good as well, and they are good examples of a barrier beach that, rather than consisting of a sand spit, often has a barrier composed of coarse beach gravels.

We call the small estuaries lagoons; others refer to them as blind estuaries because they are blocked much of the year by a barrier beach. That is, the water level in the lagoon is maintained because the barrier beach completely closes off the mouth of the lagoon. That does not mean there is no exchange of water between the lagoon and ocean. Water from upstream may still flow into the lagoon in the summer, or the stream may be dry. Large waves that originate far out in the Pacific occasionally may arrive at high tide and breach the lagoon. When this happens, sea water may partially fill the lagoon. When the lagoon is sealed by the barrier beach, groundwater seepage through the barrier from the lagoon to the beach may occur. You may see evidence of this at low tide in the form of a damp or wet place on the beach below the barrier. Sometimes, small rivulets of water form small (an inch or so wide) straight to sinuous channels flowing into the ocean from where the groundwater seeps out on the beach. In other words, the lagoons are leaky.

The processes that control what is happening in lagoons are related to wave action, storms, floods, groundwater flow, and other processes. Most of the lagoons in the Santa Barbara area are



Fig. 6.26. The small lagoon at Arroyo Burro Beach with a barrier beach that Arroyo Burro Creek flows through in this 2009 photograph. The berm often blocks the water flowing out of the lagoon, and the water level can be several feet deeper (up to the base of the sea cliff on the left).

formed due to entrenchment below marine terraces that are often about 100,000 years old and, as a result, tend to be long and narrow. During floods, these lagoons resemble a river flowing to the ocean that has broken through the barrier beach. Interestingly, the barrier often heals itself quickly (a day or so) by longshore transport of sediment following its opening. This is particularly true if the wave environment is vigorous and moving a lot of sand or gravel laterally along the beach. During the summer, some lagoons open due to overtopping by waves. Sometimes, people dig a channel across the beach barrier, and this can quickly lead to a lowering of water level within the lagoon as water drains to the sea. The bottom line is that we really don't know too much about how these lagoons are formed and maintained or about the specifics of the processes that are important in their formation and maintenance. During the next few years, we will be studying lagoons intensively and examining the relationships between beach processes, groundwater processes, and stream processes.

At low tide, when the lagoon is sealed by a barrier beach, you often notice a wet zone, and this is most likely ground water leaking from the lagoon into the ocean. At high tide, this ground water flow may reverse, flowing into the lagoon.

I have noticed another interesting morphological level at Arroyo Burro Beach. If you look at the eastern bank of the lagoon, you will see a sharp break where the vegetation ends, and, tentatively, I have called this the “lagoon-full level”. It is the level close to the height of the barrier beach and the level to which the lagoon often fills during the summer months. I have noticed similar indicators in other small lagoons, but we have not measured what that level is or if it is a significant feature or not. In summary, coastal lagoons are beautiful features found where our streams flow into the ocean, and, in more pristine places, are a good place for a warm swim. Also, they are places where there is significant aquatic habitat that is quite different from that on the beach or further up the stream valley. Another set of processes is related to nutrients in lagoons. I have noticed, following storms, that all sorts of debris from the ocean flow into the lagoons. This includes a lot of kelp, wood, and other debris. Thus, the ocean is adding nutrients to lagoons (as is the stream entering the lagoon), and this, probably, is an important process. As we learn more about these small lagoons, I am sure we will be fascinated by not just their beauty but also by their utility to the coastal environment. For example, there may be zones in the lagoon where there are very different water temperatures, and this will be important to life in the lagoon. Also, lagoon processes and chemistry (oxygen content and salinity of the water) must change quickly when the lagoon opens. In two lagoons, we have placed an instrument that records both water pressure and water temperature. The pressure correlates to the depth of the water, insofar as the instrument is on

the bottom of the lagoon. Thus, if the lagoon is deep because the barrier sand spit or bar is stable, we can record when the lagoon is full. If the barrier beach is breached, the water level in the lagoon will drop quickly. When the barrier is healed, the water level in the lagoon will raise. We will record all this and be able to determine the changes in terms of floods that blow the barrier out or high waves that overtop the barrier beach that seals the lagoon.

The environments we have discussed (el esteros, salt marshes, deltas, and lagoons) are part of the natural environment we have inherited for the prehistoric past. They provide important services to our coastal environment, such as soaking up floodwaters, filtering water through soil and plants, producing habitat for wildlife, and providing a buffer from storm waves. If they are sustained we will have a more stable coastal environment, with great places to enjoy and observe nature.

Sustainable Beaches

Accelerated consumption of natural resources, accompanied by destruction of habitat linked to a rapidly expanding human population, is disrupting many marine and land ecosystems on Earth. The beach, which has components of both, is particularly vulnerable as more and more people move to the coastal zone. Today, many areas in the U.S. with a large population or high population density are in the coastal zone. The definition of the coastal zone is somewhat vague. In a general sense it is the land and water adjacent to the coastline. The California Coastal Commission uses the concept for management purposes and the landward boundary is variable. Maps of the coastal zone are available to guide people who wish to develop within the zone.

It is expected that, eventually, most of the population will be concentrated along the nation's 93,000 miles of shoreline (including the Great

Lakes). Already, the nation's largest cities are in the coastal zone, and 75 percent of the nation's people live in coastal states. The bottom line is that there is accelerating interest and human use of the coastal zone.

The beauty of the Santa Barbara coast, with its distinctive smells and the sight and sound of wind and waves striking the beach or sea cliff, has inspired poets, song writers and artists ever since people first arrived on these shores. Coastal Santa Barbara is a dynamic environment where oceanic processes converge to produce landscapes that are characteristically capable of rapid change. Beaches, ranging from small pocket beaches below the sea cliff at Shoreline Park to long sandy beaches near Stearns Wharf, are some of the most popular places to visit for tourists and locals alike. In fact, all of our beaches from Rincon Point west to Ellwood Mesa are destination places to visit, with well-known names that include Carpinteria Beach, Butterfly Beach, East Beach, West Beach, Leadbetter Beach, Mesa Lane Beach, Arroyo Burro Beach (or Hendry's Beach), More Mesa Beach, Goleta Beach, Campus Beach, Isla Vista Beach, Coal Oil Point Beach, and Haskell's Beach (near the Bacara Resort).

Beaches are an important element of what helps define our area and attract visitors. They are our "Golden Eggs." The concept of sustainability with respect to our beaches is important because beaches, while wild and dynamic, are vulnerable to human interference. If we value the notion that we leave our beaches to future generations to enjoy as we have, then we had better learn what it would take to sustain them. Beaches are keystone landforms, that, if lost, will significantly change the quality of the environment. Envision a Santa Barbara coastline completely defended by sea walls (perish the thought). The walls would reduce land and sea cliff erosion, but at a cost to what many value most on a beach. The defended (armored)

beaches would be much narrower because sea walls reflect waves and keep sand in motion close to the wall. The local biodiversity of life on the beach (kelp, beach hoppers, sand crabs, birds, and summer grunion) would be greatly diminished on a narrow beach. To get to the beach would require you to navigate down walls, probably using concrete stairs. Contrast this with our variety of beaches today. It is a value judgment as to which you prefer, and that value will in part dictate future what our beaches will look like in decades and even centuries in the future.

Sandy beaches have a number of natural service functions including:

- Transport and storage of sand in the coastal zone
- Sediment supply for other ecosystems such as coastal lagoons, estuaries and sand dunes
- Wave dissipation that buffers coastal erosion (a thick mantle of sand helps protect the sea cliff from erosion); breakdown of pollutants and organic materials
- Cycling of nutrients
- Providing nesting and roosting sites for shorebirds and seabirds
- Filtering and discharge of groundwater through beach sand and gravel
- Maintaining biodiversity in the coastal zone
- Providing spawning habitat for sea turtles (not in Santa Barbara) and California grunion (a small fish that rides the high tide waves to spawn in upper beach sand on summer nights)
- Providing a food sources (sand crabs, beach-hoppers, bloodworms etc.) to migrating and resident shorebirds and large fish such as corbina
- Providing a valuable cultural and aesthetic resource for people as well as recreational opportunities.

To sustain our beaches as they are today will require a set of principles that utilize adaptive management practices. It will require flexible management that uses science as a basic component. Past management of beaches has been a mixture of success and many failures because we have not generally recognized or appreciated the fact that:

1. Coastal erosion is a natural process rather than a natural hazard. Erosion problems occur when people build structures (homes, restaurants, restrooms etc) close to the edge of the sea cliff or close to the high tide line on a sandy beach. The coastal zone is an area where natural processes associated with waves and moving sediment occur, creating constantly changing conditions. Because the coastal environment has a certain amount of natural erosion, the best land uses are those compatible with potential rapid change. These include recreational activities, such as sunbathing, walking, jogging, swimming, surfing, birdwatching, and fishing.
2. The beach environment is dynamic, and any human-caused interference with natural processes produces a variety of secondary and tertiary changes, many of which may have adverse, unknown or surprising consequences. Adverse consequences are particularly likely when engineering structures, such as groins and sea walls, that affect the storage and flow of sediment along the coast, are used.
3. Erosion control structures are often intended to protect the property of relatively few people at a large expense to the general public. Structures, such as sea walls, are most often used to protect developed property, almost never to protect the beach itself. Interests of people who own shoreline property

are not always compatible with the public interest, and it is not acceptable to expend large amounts of public funds to protect the property of a few.

4. Engineering structures, such as sea walls, that are designed to protect a beach may eventually destroy it. Sea walls often modify the coastal environment to such an extent that it may scarcely resemble a beach.
5. Once constructed, sea walls produce a trend in coastal development that is difficult, if not impossible, to reverse, leading to additional maintenance and larger structures, with spiraling costs. Over time, the cost of erosion control structures may exceed the value of the beach property itself. Recognizing that sea wall construction does not lead, from an environmental perspective, to sustainable beaches, several states have imposed severe limitations on future construction of sea walls to stabilize a coastline.
6. As sea levels continue to rise in response to global warming and coastal erosion becomes more widespread, the nonstructural alternatives to the problem should continue to receive favorable attention because of both financial necessity and the recognition that the amenities of the coastal zone should be kept intact for future generations to enjoy.

With the above principles in mind, what are the pillars of sustainable beach management? First, we need to acknowledge that the beach ecosystem has high biodiversity and important ecosystem services and functions and experiences large changes in sand supply through seasonal to decadal cycles. The map-view position of the beach with respect to the high tide line can vary several hundred feet over the longer cycles as sand supply ebbs and flows. Periodic El Nino events that bring strong

storm waves can deliver a lot of sand from the land to the coast, but, before it can be distributed along the shoreline, may cause accelerated beach erosion. Goleta Beach still has not recovered from the 1982-83 El Nino storms. These climatic events do produce waves of sediment that move along the shore in subsequent years. When the wave of sand passes a particular place, the beaches naturally grow, and, when it has passed the beach, may naturally narrow. In one person's lifetime, the position of a sandbar or long sandy beach will change appreciably through natural changes. In other words, our management should be flexible and anticipate cycles of change. Second, human interference in the coastal zone, such as building dams that blocks sand from reaching the beach or building structures such as a breakwater or groin or sea wall that blocks or retards the natural flow of sand along the coast, can enhance beach and sea cliff erosion. Third, beach management must consider the entire supply and transport of sand from sources in the mountains to the natural sink/loss down a

submarine canyon (this is the littoral cell). That is, management should not be piecemeal, but consider the entire littoral cell. Fourth, the approach that least damages beach ecosystems in the long term is one that is not structural and employs land use and soft technology of beach nourishment (deliberately adding sand to a beach). Beach nourishment is not free of ecological costs and doesn't always work for long; the sand added to a beach is sacrificial to some extent, as it will be transported away from the site of nourishment by natural longshore currents. On the other hand, the sand will nourish other beaches in the direction of transport by waves. Beach nourishment occurred at the western end of Goleta Beach in 2010 (Fig. 6.27). The sand was from sediment control basins that trapped sand following the Jesusita Fire of May, 2009. Winter rain induced a flushing of sediment of local streams in the burn area. The sand is supplied by The County Flood Control District. When sand is available, e.g., after storms, from these basins, beach nourishment is much more cost effective. All together, about 50,000 cubic

yards was added to the beach. This is about 15% of the sand that naturally moves along the coast. The sand placed at the western end of Goleta Beach, which is the location of a former outlet from the slough, did not last long – this was expected, as the location is the “erosional hotspot” because wave action at the small point called “Fish Rock” concentrates wave energy and erosion. The name “Fish Rock” probably has its origin in the fact that, since the time of Native Americans, the rock has been a place where people fish. Fish Rock remains a popular place to cast a line today.



Fig. 6.27. New beach nourishment at Goleta Beach in 2010. The supply of sand was from sediment control basins on local streams that filled with sediment following the Jesusita Fire in 2009.

Beach nourishment, as with any artificial process, such as beach grooming to smooth the beach and collect beach wrack (kelp, land plants, and animal remains and other debris on the beach), can cause problems. Beach wrack provides nourishment to many animals, including shore birds, foxes, and sand hoppers. In a word, wrack teems with life. Human manipulation on the beach that involves vehicles (in the case of nourishment, bulldozers and trucks) causes damage to beach life in and on the sand. However, beach nourishment that brings appropriately sized, clean sand certainly is preferable to a hard erosion control strategy that could interfere with sand flow and cause erosion problems from Goleta Beach to propagate east toward Santa Barbara. Having discussed a variety of subjects central to sustainability, let's consider the controversial subject of global change.

The Gaia Hypothesis: Changes in Santa Barbara?

At a meeting of the prestigious Royal Society of Edinburgh in 1785, James Hutton, considered the father of geology, said he viewed the planet Earth as a super organism. Hutton compared the circulation of Earth's water, with its contained sediments and chemical nutrients, to the circulation of blood in an animal. In Hutton's metaphor, the oceans are the heart of Earth's global system, and the forests are the lungs. Two hundred years later, British scientist and professor James Lovelock introduced the Gaia Hypothesis (a hypothesis is an educated guess, a scientific statement, that can be tested and is possible to be refuted by research), reviving the idea of a living Earth. Lovelock named the Earth system "Gaia," for the Greek Goddess Mother Earth.

The Gaia hypothesis is best stated as a series of hypotheses:

1. Life significantly affects the planetary envi-

ronment. Very few thinking people would disagree with this concept. Life, through photosynthesis that releases oxygen to the atmosphere, has been a big player in the evolution and maintenance of the chemical composition of Earth's atmosphere for several billion years.

2. Life affects the environment for the betterment of life. This hypothesis is supported by some studies that have shown how life on Earth plays a significant role in regulating planetary climate so that it is neither too hot nor too cold for life to survive (the so-called Goldilocks Hypothesis from the story of the three bears). For example, it is believed that single-cell plants (plankton) floating near the surface of the ocean partially control the carbon dioxide content of the atmosphere and, thereby, the global climate. Dimethyl sulfide is released by marine plankton through their life processes. The gas gives the "smell of the sea" we notice when visiting the beach or ocean. Dimethyl sulfide oxidizes to form small particles that are important nuclei for fog and rain that nourish the sea and land. They also cause more clouds to form (from the same condensation nuclei) that reflect incoming solar radiation which helps cool Earth. Marine plankton that photosynthesize draw carbon dioxide from the atmosphere, as all plants do. Thus, if the lower atmosphere and ocean warms, leading to more plankton blooms in the ocean, then more carbon dioxide is drawn from the atmosphere. Carbon dioxide, the gas that makes soda, beer, and Champaign bubbly, is a greenhouse gas emitted by both natural processes (for example, by wild fire that burns plants or by the decomposition of dead plants and ani-

mals in soil by fungi and bacteria) and human processes (mostly from burning fossil fuels). Reduction of carbon dioxide in the lower atmosphere is a cooling mechanism. The plankton are participating in negative (self regulating) feedback. Initial warming of the lower atmosphere and sea leads to more plankton (they grow better in warmer water) and more photosynthesis which cools the atmosphere by lowering the concentration of carbon dioxide in the atmosphere. Self-regulation of the temperature of the lower atmosphere by plankton in the ocean supports the Gaia Hypothesis.

3. **Life deliberately or consciously controls the global environment.** There are very few scientists who accept this third hypothesis. Interactions and the linking of processes that operate in the atmosphere, on the surface of Earth, and in the oceans are probably sufficient to explain most of the mechanisms by which life affects the environment. In contrast, humans are beginning to make decisions concerning the global environment, so the idea that humans can consciously influence the future of Earth is not an extreme view. Some people have interpreted this idea as support for the broader Gaia hypothesis. Sometimes I think we have met Gaia and she is us.

Gaia to some people is a spiritual as well as a scientific concept. They see Gaia linked to the higher worlds that Rudolf Steiner wrote about in 1947, long before the present rediscovery of the Gaia concept. Environment as sacred ground and the power of religion in supporting the environmental movement are emphasized in the writing of Gary Gardner for the Worldwatch Institute. Some people of faith are preaching to their congregations about human-caused environmental

degradation to Gaia (Earth), likening it to holes in the arc (our home, Earth) from which light from the Holy Spirit escapes. As religion becomes more Earth-centered, avoiding future environmental degradation becomes a higher moral priority and duty to our planet.

The real scientific value of the Gaia hypothesis is that it has stimulated interdisciplinary research to understand how our planet works as a whole system. As interpreted by most scientists, the Gaia Hypothesis does not suggest foresight or planning on the part of life but, rather, those natural processes of feedback in the biosphere, atmosphere, and hydrosphere that are linked to each other in complex ways. Without Gaia thinking, that is, thinking about the entire Earth as a system with integral parts (life, rocks, ice, air and, fire) all linked in complex ways, we would know less about our planet.

Santa Barbara is linked to the global environment in many ways. We live on the Pacific tectonic plate which is part of the global tectonic system we call plate tectonics. Our water and energy resources are linked to the hydrologic and rock cycles, and the former is closely linked to the global climate system that constantly (albeit, usually slowly) changes (warmer to cooler), with cycles of about 100,000, 40,000, and 20,000 years, due in part to changes in Earth's orbit and tilt (that also cause seasonal change) through the amount of solar energy Earth receives. Milutin Milankovitch, in the 1920s, calculated the cycles and suggested they might drive changes from glacial to interglacial conditions, especially for the stronger 100,000 year cycles related to Earth's change in orbit around the sun from more circular to more elliptical. Although global climate has faithfully changed with the Milankovitch Cycles over the past 1 million years, they, by themselves, are too feeble to cause the dramatic changes we observe in the geo-

logic climate record that is preserved in sediments and glacial ice examined from cores from ocean basins and glaciers. A core is collected by drilling sediment or a glacier and extracting a continuous sample that is as long as the hole is drilled and usually at least a few inches in diameter. The sediment is retained in a core barrel. Cores, when removed, look like a straw for sipping a drink, but the inside of the straw is solid sediment or glacial ice. Cores are cut in half and samples extracted for study. We have learned a lot about Earth history from studying cores. For example, ice cores from glaciers contain bubbles of air encapsulated in the ice when the snow fell. We can sample that air in the bubbles and measure the carbon dioxide content of the atmosphere of the past. This has been done for glacial ice several hundred thousand years old. We can also sample dust in the ice and measure the amount of pollutants, such as the heavy metal lead. Particularly high concentrations of lead in glacial ice from Greenland glaciers were found during the time of the Roman Empire (500 BC to AD 300). The Romans used lead for many things, including pipes bringing water to homes and public baths; cups, plates and eating utensils; and pots in which grape juice for wine was produced. Lead toxicity can result in lead poisoning (including brain damage). A few years ago, while on sabbatical leave, I observed the lead pipes that delivered hot water to the large Roman baths located in the city of Bath in southern England. Perhaps lead toxicity affected the Roman Emperor Nero who was rumored to be playing his lyre on the night of July 18, 64 A.D. while Rome burned below him. Christians in Rome (a small religious group at the time) became Nero's scapegoat for the fire, and many were infamously sacrificed (fed to lions) in the remaining Roman amphitheater. Bones of ancient Romans have been found to contain high concentrations of lead. High concentrations of lead are also found

in 20th Century glacial ice, especially when lead was a common additive to gasoline.

Returning to our discussion of Milankovitch Cycles, we believe these cycles are a climate forcing mechanism that explains the timing and some of the climate change (warming or cooling). Here, we define climate forcing as an imposed change of Earth's energy balance (a change that influences the amount of relatively short wave solar energy, sunshine, that reaches the atmosphere and is readmitted by Earth as longer wave infrared radiation, Earthshine). We call it an energy balance because the input of solar energy is essentially balanced by the outgoing energy emitted by Earth to space. Other forcing mechanisms are large volcanic eruptions that place small particles high in the atmosphere, reflecting incoming solar radiation that can cool the earth for a year or so. The sun itself is another climate forcing mechanism, related to small changes in solar output over cycles as short as 11 years. A more recent climate forcing (warming) is caused by the release of greenhouse gases (for example, methane and carbon dioxide) by natural processes and by humans (especially carbon dioxide released from burning fossil fuels, such as coal).

Santa Barbara's water resources will change if Earth continues to warm. We might expect more and longer droughts, more intense wildfire, and less reliable water supplies from Northern California. If the water of the Santa Barbara Channel warms in the future, we may see ocean ecosystems more similar to those of San Diego and Baja California.

Larger changes occur in the arctic due to global warming than in lower latitudes. This is known as Polar amplification. More rapid warming in the arctic is due, in part, to melting sea ice, glaciers, and permafrost. Snow and ice (in the arctic) reflect much more sunlight than water and bare rock. What occurs is positive, self-enhancing feedback. The more ice and snow on land that melts,

the more rock is exposed, thus increasing the absorption of energy from the sun that is warming the land. Warmer rock emits more heat back to the atmosphere, warming it. This in turn causes more snow and ice to melt, and more rock is exposed. This is a positive feedback cycle because warming leads to additional warming. As glacial ice on land melts and seawater warms and expands, the global sea level rises. Rising sea level increases the threat of coastal erosion around the world, including Santa Barbara where it is a problem already.

We are all interested in changes that will affect our families, society, and the world. The sorts of changes we might encounter are many—varying from gradual to accelerating, abrupt, chaotic, or surprising. Some changes will affect our local, regional, or global environment. Research Professor Daniel Botkin at UCSB writes that the environment is always changing, and that change is necessary to sustain life as we know it on Earth. This implies, as Botkin asserts, that the so-called “balance of nature” is a fallacy. Change is the norm, and people have caused many changes over the past few thousand years. Furthermore, as human population has increased, human-caused change has accelerated

The best source of data with which to examine past change is the geologic record. A natural warming (not as fast as that today) occurred from about 1000A.D. to 1400A.D. It was called the Medieval Warm Period (possibly caused in part by an increase in solar energy reaching Earth). The warmer conditions allowed the Vikings to colonize Iceland, Greenland, and North America. They were chased out of Iceland and North America by The Little Ice Age that started about 1400 A.D. and lasted until the mid-late 1800s when the recent warming started. Professor Brian Fagan of UCSB studied the Medieval Warm Period and concluded that Western Europe, Greenland, and Iceland flourished during warmer conditions that allowed

more food to be grown and the population to increase. However, the warming further south in what is now the Southwestern U.S. and Mexico evidently caused prolonged drought and famine. Long-standing, highly developed societies such as the Anasazi (Chaco Canyon) and the Maya in the Yucatan collapsed in spite of their considerable efforts to manage their water resources. The Little Ice Age brought cooler, wetter conditions to Western Europe that were accompanied by crop failures and the Black Death (bubonic plague) that destabilized and depopulated the region. So we see that climate change, whether cool to warm or warm to cool, causes serious problems to people. We are concerned today because the present warming exceeds that of the Medieval Warming Period, is occurring much quicker than can be explained by change in solar input, and appears to be accelerating in the arctic.

The present, as stated by John Lewis Gaddis, can be considered a singularity through which the future must pass to become the past (history). Think a bit about that statement. The future eventually becomes the present and passes to the past (history). Sometimes an unexpected event, called a contingency, changes everything. An example is the asteroid that struck earth 65 million years ago that, according to Walter Alvarez, contributed to the extinction of the dinosaurs and the rise of mammals. The main regimes of big history include cosmos, Earth, and life. To this, in the context of environmental science and the Gaia Hypothesis, we add humanity. When we think about the future, we need to act in the present to produce a future environment that our grand and great grand children can live, love, and prosper in. With a global perspective in mind in mind, let's consider the controversial subject of global warming.

Global Warming: The Science

The major tools for studying global change include: evaluation of the geologic record from sediments deposited in ocean basins and lakes; evaluation of glacial ice that has formed over thousands to hundreds of thousands of years; monitoring of concentrations of gases in the atmosphere and water quality and abundance on land and in the oceans; and development of mathematical models that attempt to predict what the future may hold. Models are not data; they require data linked to equations that explain changes in mass, water content, temperature, and energy (and other variables). Of the methods of studying climate change, the strongest and most reliable evidence (data) are: 1) monitoring (the short record, the last 150 years for surface temperature, and atmospheric CO₂ at Mauna Loa Hawaii since the 1950s), and 2) evaluating the geologic record (the long record going back hundreds of thousands of years). The Mauna Loa record is remarkable, demonstrating without a doubt the increase in CO₂ from about 315 ppm (parts per million) 50 years ago to 390 ppm today. At 100 ppm, the concentration is 0.01%; at 390 ppm the concentration is about 0.04%.

One of the global changes we are most interested in is climate. We used to think that climate change was a slow process with warm and cool cycles, lasting hundreds to thousands and even one hundred thousand years or more. We now know that climate change may be significant over time intervals as short as decades.

Although we term the recent changes as climate change it is really anthropogenic global warming and its potential consequences we are concerned about. The mechanism that is believed to be producing most of the recent global warming is known as the enhanced (human influenced) greenhouse effect. Common greenhouse gases include water vapor, carbon dioxide, methane, and man-made

chemicals, such as chlorofluorocarbons. The greenhouse effect is a natural process that keeps the near surface temperature of Earth agreeable for life. Something like 97 percent of the greenhouse warming is due to water in the atmosphere in the form of water vapor and small particles of water.

I am now going to attempt to explain climate change in more detail. As an analogy, consider a checking account that is free to use but has no interest earned. Assume you initially deposit \$1,000 and each year over 12 months you deposit \$500 and write checks for \$500. You do this for many years and at the end of the time still have \$1,000 in your account. That is, for any system, when input equals output for some material (in this case dollars), the amount in the system is constant. Here, I define a system as any part of the universe that can be isolated in your mind, in real existence, or in a computer for the purpose of study. A system is also a set of components that are linked and interact with each other. Examples of systems include a forest, a river, a city, the atmosphere, or the entire planet Earth. Carbon in the atmosphere is a system and, as with our checking account, has inputs and outputs. For at least 300 years (and probably more like 10,000 years since the last glacial period) prior to the industrial revolution (1750), the inputs were nearly the same as outputs, and the amount of carbon dioxide (CO₂) in the atmosphere was nearly constant at about 260 to 280 ppm. This was not a perfect balance or equilibrium (which is generally not found in nature), but change hovered slightly above and below 280 ppm. During glacial and interglacial periods of the past 650,000 years, CO₂ was as high as about 300 ppm in warm interglacials and as low as 180 ppm during maximum glacial periods, but never as high as today (390 ppm).

The amount of carbon in the atmosphere is accounted for in units of billions of tons of car-

bon (GtC), or billions of tons of carbon dioxide (GtCO_2), where 1GtC is equivalent to 3.67GtCO_2 . The amount of carbon per year that naturally enters the atmosphere by respiration of plants and animals, decomposition of organic material, and wildfire is over 100 GtC per year, and the amount of carbon naturally removed from the atmosphere (mostly by photosynthesis and a variety of marine processes) is also over 100GtC per year. Before the industrial revolution and burning of fossil fuels in the industrial age (since 1750), the input of carbon to the output in the atmosphere was nearly balanced, and, so, the concentration of CO_2 was nearly constant. That is, prior to about 1750, human input of carbon in the atmosphere was removed by natural processes. As more and more fossil fuels were burned, more and more CO_2 entered the atmosphere, and the balance changed. Today, about 7 GtC/year enters the atmosphere from burning fossil fuels. As more fossil fuels were burned more carbon was taken from the atmosphere through photosynthesis and marine processes. However the balance of input to output could not be maintained, and about 4 GtC per year is added to the atmosphere each year. That is, natural processes can only remove about half of the carbon emitted by burning fossil fuels. Thus, the concentration of CO_2 has risen to about 390 ppm (2010) since the industrial revolution, and the increase has accelerated in recent decades. The increase of about 100 ppm CO_2 since 1750 (through the greenhouse effect) is sufficient to explain most of the recent global rise in temperature of the lower atmosphere (about 1.8 degrees Fahrenheit. Some people wonder how the human emissions of CO_2 that are only a few percent of total natural emissions could cause the observed warming. Remember that the natural inputs of CO_2 are nearly matched by outputs (they are a push.), but human inputs caused the total concentration over many decades to increase. The

ability of the natural system to remove the additional carbon added to the atmosphere from burning fossil fuels is only sufficient to remove half of the increase, and, thus, carbon increases in the atmosphere. If we assume the annual rate of growth today of CO_2 to be about 0.3% (which is on the low side for recent years), then the time for CO_2 to double is about 230 years. For our bank account example this is as if we increase the amount by only \$3 per year (0.3% increase per year). Thus, we conclude that the small imbalance in the carbon cycle in the industrial age caused by burning fossil fuels over many years has caused sufficient change to account for most of the recent warming.

To summarize, the human-induced portion of the greenhouse effect is predominately due to carbon dioxide, whose emissions are accelerating as we burn more and more fossil fuels, such as coal and oil. The actual physical and chemical processes that result in warming of the atmosphere from greenhouse gases are complex, but the net result is that these gases trap heat within the atmosphere before it is radiated back out into space, raising the temperature of Earth's atmosphere. As long as carbon dioxide and other human-induced greenhouse gases increase, it is expected that Earth's temperature will continue to increase. How much that increase will be is a subject of debate. If the total increase in temperature is only a degree or so during the next century, then we will likely be able to adapt to the change.

Almost everyone today is aware that scientists are particularly concerned with global warming. We began keeping records of global temperature in about 1860, and the warmest decade on record is 2000 to 2009. Although 2008 was the coolest year since 2000 (due to strong cooling in tropical Pacific Oceans), it was the 9th warmest since temperature records have been taken. Keep in mind that a few warm years or a warm decade is not sufficient

to claim that long term global warming is occurring. A 100-year record is a much better indicator of change. Since about 1900, the average global land temperature has increased to approximately 1.4° Fahrenheit (F) above the average for the 20th Century. An increase in temperature of 1.4° F may not seem like much, but about 70 percent of the increase occurred in the last 30 years, which suggests warming is accelerating. The average increase in global temperature is somewhat misleading because temperature increases in polar areas are about twice as much as in the mid-latitudes and equatorial regions. Thus, the Polar Regions are our canary in the cage telling us of potential changes that may cause problems. Recognition of potential human-induced global warming is not new to the scientific community; scientists dating back to the late 1800s raised red flags.

The glaciers in Glacial National Park are in retreat and may be gone in a few more decades. Alpine glaciers from California to Alaska are fast disappearing as Earth warms. The World Watch Institute, in their publications of vital signs for 2006-2007, reports that sea ice in the northern hemisphere is at its lowest level in recorded history. During 2005, glaciers in Greenland alone lost approximately 53 cubic miles of ice. On a global basis, sea ice during the past 40 years has thinned as much as 40 percent and decreased in extent by about 10 percent. Global climate change results from many natural processes, but the rapid rate of change observed in recent decades far exceeds those expected from natural variations in the amount of sunlight the earth receives or from natural (non-human caused) changes in atmospheric gases.

Before leaving the science of global warming, I want to comment on the recent release of hacker obtained e-mails by some climate scientists in favor of human induced global warming that have been criticized as trying to silence scientists that

are skeptical of human induced global warming. Scientific inquiry at its highest ethical level requires honesty, skepticism, and openness. Any attempt to influence science by anything other than sound scientific reasoning and the application of the scientific method, where hypotheses are tested in attempt to reject them (that is, disprove them), is not science. Having said this, scientists are humans and passions in science, as in many endeavors, can run high. It can take decades for a hypothesis to be accepted and become a stronger scientific statement known as a theory. I know this first hand. My first published paper after finishing a master's thesis at UC Davis and before completing a PhD at Purdue University was a hypothesis to explain why pools in streams scour at high flow. I was personally criticized for years –told the hypothesis was antithetical to all known hydrology and that I should read an introductory textbook on the subject. That was years before e-mail. I wonder what the e-mails would have said were they common in the early 1970s. Thirty years later, I received a distinguished scientist award from the Geological Society of America for that hypothesis, which has been tested and found true several times, but still is not an accepted theory. To date, it appears that, while some of the climate change e-mails indicate a less than admirable attitude toward others with a different view, the climate data speaks for itself. Recent (last few decades) increase in the average temperature of Earth is largely due to emissions of carbon dioxide. Change in other climate forcing processes, such as solar activity, can account for no more than 25% of the observed increase. Because of the importance of climate change to human society, hypotheses are being tested as quickly as possible. However, details of climate change will continue to emerge and be tested, and it will be decades before we can look back and say we adequately understand the details of climate

change. By then (a few decades in the future), we will have more data. The question is, should we wait decades for more data if the change projected now may cause significant adverse consequences to society in the near future? Perhaps we should apply the Precautionary Principle and implement cost-effective strategies to reduce potential consequences of climate change now to avoid potential future problems that we have good reason to believe will happen. There is nothing we can do to reduce warming in the next 2 to 3 decades, as additional warming is in the pipeline (we have already emitted the greenhouse gases that will cause warming during that period). What we do now could have a big impact on where warming will go the rest of the century.

Global Warming: What the Future May Bring

A famous philosopher, George Santayana, stated in 1905 that “those that cannot remember the past are condemned to repeat it.” It is a matter of debate whether cycles in human history and society repeat themselves. However, natural processes and hazards do repeat over time, even though they may happen for different reasons. For example, a large flood may result from a spring storm or may result from rapid snow melt or failure of a dam. What can we learn by examining the past with reference to global climate change (for example, global warming)? Turning to history, over an approximate 300-year period from 950 to 1250 AD, the Earth was considerably warmer than normal (normal is by convention the average surface temperature from about 1961 to 1990). The warm period is known as the Medieval Warming Period (MWP), and we can learn some lessons from that event. It’s only a few hundred years ago, but we don’t know very much about the MWP except that it was warm, perhaps nearly as warm as it is

today. Most scientists who study the indicators of past climate report that it probably wasn’t quite as warm as today. However, parts of the world, including Western Europe and the Atlantic, may have been warmer some of the time than it was in the last decade of the 20th Century. During the MWP, there were definite winners and losers. In Western Europe, there was a flourishing of culture and activity (think Camelot, and the lusty month of May). Human population grew as harvests were plentiful and people generally prospered. During that period, many of the European’s famous cathedrals were constructed.

During the MWP, sea temperatures evidently were warmer than today, and there was less sea ice. The famous Viking explorer, Erik the Red, embarked on a voyage of exploration near the end of the 10th century A.D. When he arrived at Greenland with his ships and people, including women and children, they set up settlements that flourished for several hundred years. They were able to successfully grow crops that included corn that had never before been cultivated in Greenland. They were also able to successfully raise their animals and evidently enjoyed a prosperous life. During the same warm period, Polynesian people in the Pacific, taking advantage of winds and currents flowing throughout the Pacific, were able to sail to and colonize islands over vast areas of the Pacific, including Hawaii.

While many people prospered in Western Europe and the Pacific during the MWP, other cultures were not so fortunate. There were long, persistent droughts (think human generational long) that were partially responsible for the collapse of sophisticated cultures in North and Central America during the MWP. The people living near Mono Lake on the eastern side of the Sierra Nevada in California, the Chacoan People in what is today Chaco Canyon in New Mexico, southwest-

ern United States, as well as the Maya civilization in the Yucatan of southern Mexico and Central America, are examples of societies and civilizations that collapsed. At Chaco Canyon, the collapse was not sudden but apparently occurred over a period of decades. As prolonged drought caused conditions necessary for agriculture to deteriorate, the people moved away to places with a more consistent water supply. The exodus from the canyon apparently occurred over a period of decades by various sizes of groups which made the decision to move elsewhere. They left many items (pots, etc.) that were too large to carry behind in their great houses.

Along the coast of Santa Barbara and the Channel Islands, the MWP disrupted Chumash life, causing problems in food distribution and water. The channel had cool water during the MWP, and marine resources were plentiful. Prolonged drought caused problems, as people had to relocate to locations with a dependable water supply. Inland, the droughts stressed oak trees. Although oak trees do fine with a dry season, prolonged drought can weaken and kill them. This was a problem for the Chumash who depended on acorns for a major part of their food supply. Some Chumash people evidently relocated during the MWP, insofar as villages with a more dependable water and food supply grew larger. While the MWP evidently caused significant stress to the Chumash on the coast and islands, the society did not collapse.

Today, we are concerned with present warming trends. Should warming continue as expected, we may face prolonged droughts in the southwestern United States, as well as in other parts of the world. Droughts could reduce our ability to produce the food that nearly seven billion people upon the Earth depend upon today. When the MWP ended, it was followed by the Little Ice Age (LIA) that lasted several hundred years from the mid 1400

to 1700 CE. The cooling of the LIA made it more difficult for people in Western Europe, and, during that period, there were storms, wet periods, heat and cold, and climate change that caused a number of problems. Crop failures occurred in Western Europe. The population was devastated by the Black Plague that reached out into the Atlantic and Iceland by about A.D. 1400. With the cooling, sea ice expanded. There was environmental stress, and trade was restricted with Greenland. The colonies in North America and Greenland were mostly abandoned. Part of the reason for the abandonment in North America and, particularly, Newfoundland, was that the Vikings may not have been able to adapt to the changing conditions, as did the Inuit peoples living there. As times became tougher, the two cultures collided, and the Vikings, as fierce as their reputation is, were not as able to adapt to the changes.

We do not know much about specifics that caused the MWP. Although details about it are obscured by the lack of sufficient climate data during that period, it appears that there was a bit more solar radiation reaching Earth during much of the period. Studies of the frequency of sunspots (dark blotches on the sun surface that are associated with an increase in solar activity) that correlate with carbon 14 in the wood of tree rings of known age suggest that some part of the warming was due to increase in temperature due to the sun. Carbon 14 is, thus, a climate surrogate. Carbon 14 is produced in the upper atmosphere when nitrogen 14 is hit with cosmic rays from space. When there are more sunspots, there is an increase in the solar wind with ionized particles that reflects cosmic rays. Thus, when sunspots are more abundant, less carbon 14 is produced, and, conversely, with fewer sunspots, more carbon 14 is produced. There are cycles of sunspot activity; the most recognized is the 11-year cycle. Although changes in

sunspot activity can increase or reduce solar energy reaching Earth, sunspot frequency by itself can explain no more than about 30% (usually less) of observed changes in the average temperature near the surface of Earth. There is also evidence that the LIA was a time when the solar radiation that reached Earth was a little reduced (there were less sunspots). Nevertheless, we do know that it was warm during the MWP, and we can't blame the burning of fossil fuels. What this obviously suggests is that more than one set of conditions may cause global warming. It does not mean that the present warming is not the result of the burning of fossil fuels (that is all but certain). We learned through historic study (anthropology) that the changes in the most recent past warming (MWP) had winners and losers. Today, the world population is approaching 7 billion, and half of us live in cities. The world population during the MWP was about 500 million, and agriculture was blooming. Persistent droughts during the MWP apparently caused pain and suffering over much of the semi-arid areas of the world, from coastal California to the southwestern USA, as well as in Central and South America. This is a red flag! The potential effects of prolonged, persistent drought and loss of food production for the world, should present warming continue, is a serious threat.

I believe that the preponderance of evidence supports the hypothesis that recent global warming has a significant human footprint. Particularly good data relevant to this issue since about 1960 includes: 1) temperature measured at regular intervals at many localities on Earth; 2) regular measurement of solar activity; and 3) regular measurement of changes in the concentration of greenhouse gases in the atmosphere. The data has been collected by scientists from universities and national agencies, such as NASA and NOAA (National Oceanic and Atmosphere Administration).

Careful evaluation of the data collected since 1960, when linked to data from the geologic record (from sediment and glacial ice), has led me (and most scientists) to conclude that much of the warming results from human activity.

I also recognize that skepticism in science is a positive activity, and that most scientists are skeptical by nature. Some scientists (a small minority) are skeptical that recent warming is caused by human activity. I disagree but respect the right of others to disagree with me, and I continue to read and evaluate their position (they have a place at my science table).

Much of the increase in CO₂ in the lower atmosphere, along with the increase in temperature of the lower atmosphere, is thought to be a result of human activity, especially burning of fossil fuels, which have increased the concentration of carbon dioxide in the atmosphere by approximately 30 percent since the beginning of the industrial revolution. Present levels of carbon dioxide in the atmosphere are higher today than they have been at any time during the past 1,000 years and, perhaps, even the past 650,000 years. We know this because we have collected small samples of the past atmosphere trapped in air bubbles of glacial ice. When we date the glacial ice where we collected a sample, we can measure levels of carbon dioxide in the atmosphere of the past. The average temperature of the lower atmosphere is apparently also higher than at any time in the last 1,000 years, including the MWP that occurred around 1100 A. D. and lasted over 200 years. It is reported with a high degree of certainty that the global temperature of the past few decades is greater than at any time in the past 400 years. High quality data from the MWP is scarce, but the geologic record (using proxies for temperature, such as oxygen isotopes or tree rings) suggests (with lower confidence than for the past 400 years) that it was not as warm as today, and that the rate of

change (increase in temperature) was slower than the rise in temperature since 1960. The warmer temperature of the MWP may have been due to an increase in solar energy reaching Earth. Solar energy has been reliably measured in the past few decades and has been nearly constant. Thus, increase in solar energy can't explain the rapid rise in global temperature during the past 50 years.

Obviously, California and Santa Barbara are linked to the global climate system, and some estimates have been made as to changes likely to occur in California and, thus, Santa Barbara. We expect that global warming will result in California's climate being drier in most regions, while, in the Sierra Nevada, there will be more rain and less snow. A warmer California will likely lead to water shortages (more prolonged droughts), an increase in wildfires, and changes in marine and land ecosystems. These changes will impact our quality of life. Scientists at the University of California, Santa Barbara have determined that some of these changes may be manifested as early as 2030! Here in Santa Barbara, we obtain some of our water from the state system of dams and reservoirs in northern California that trap annual snow melt. With a warmer California, there will be more rainfall in the Sierra Nevada, but less water will be stored as snow. As a result, it will be more difficult to maintain the storage facilities (dams) that deliver water to southern California. John Melack, a professor at UCSB, has stated that he fears there will be too much water at the wrong time and too little water when we need it. Frank Davis, another professor at UCSB, has studied potential effects of global warming on California and believes that the hotter, dryer summers will likely lead to an increase in the number and intensity of wildfires, which are arguably the most serious natural hazard the people of Santa Barbara face.

Professor Steve Gaines with the Marine Science

Institute at UCSB has, with others, evaluated the effect of potential global warming in California on marine environments. With global warming, sea temperatures are rising, and that will affect the environment of the Santa Barbara Channel and the Channel Islands. Warmer sea temperatures would damage the kelp forest, insofar as they prefer cool water. Gaines has speculated that, with warming sea temperatures, the distribution of marine species that we see now will likely move towards higher latitudes, and we will have an environment that is more similar to the coast of Baja California. As the sea temperatures increase, there will be changes in the availability of nutrients which will change the food chain of the Santa Barbara Channel.

One of the consequences of global warming that we are concerned about is a rise in sea level. Santa Barbara is a coastal community, and higher sea levels will increase coastal erosion. There are two main reasons why the sea level is rising. First, with the warming ocean water, the water expands. Second is the melting of glacial ice. Both of these together will probably cause the sea level to rise globally about one foot by the year 2100. In a worst case scenario, if the Greenland Ice Sheet were to collapse, the sea level could rise as much as 20 feet, probably over several hundred years or longer.

The Santa Barbara Landmark Committee, in August of 2007, decided we should paint a "Blue Line" across streets of downtown Santa Barbara to delineate the worst-case scenario. In other words, they wanted to paint a line that would depict where the sea level would be if it were to rise 20 feet. The purpose of the project was to raise awareness of global warming, and it was intended as an art project. What it did was to cause controversy and anger among people living seaward of the blue line. They were worried that property values would decline on that side of the line. The project was abandoned, and rightfully so. Education is important in plan-

ning to reduce effects of global warming, but our target should not be the “worst case.” This is like planning for the 1000-year flood or a magnitude 8 earthquake. Both of these events would cause tremendous devastation, but they are unlikely from a planning perspective. However, we do need to anticipate and be prepared for a magnitude 6.5 earthquake and the 100-year flood. These events are much more likely to occur in coming decades.

The important point with respect to global change in California is that predicted change is apparently happening now. The effects so far are relatively minor, and there is still time to work out a plan to minimize potential adverse effects of warming. Dr. James Hanson, a famous NOAA scientist, has predicted that we have at least 10 years in which to take appropriate reaction before changes may become rapid and, perhaps, irreversible with respect to the effects of climate change.

The big question is what we should do about potential global warming. There are two basic ways to approach adjustments to global warming. First, we may do nothing and simply learn to live with future climate change. However, this may have unanticipated and serious adverse effects if warming goes beyond a few degrees. Second, we can work to mitigate global warming or to reduce its severity by reducing emissions of greenhouse gases, particularly carbon dioxide. For power plants burning oil, natural gas, or coal that account for about one third of U.S. carbon emissions, we have the technology to remove the carbon dioxide following burning and to inject it deep into the earth where it will permanently (from a human time perspective) reside. Even as we transition from coal to natural gas, we will need to address carbon emissions. We have a long, successful history of carbon sequestration in the geologic environment (carbon sequestration is the capture and storage of carbon). This solution recognizes that

fossil fuels will remain an important component of our energy well into the 21st century. We have a successful history of carbon sequestration in oil fields where carbon dioxide is injected to help recover more oil than otherwise could be obtained. Several successful test projects in North America and Europe have been underway for several years to evaluate large-scale carbon capture and underground storage in the geologic environment.

The United States has about 5 percent of the world’s population, but emits about 20 percent of the world’s atmospheric carbon dioxide. While the federal government has embarked on an ambitious study of global warming and recently acknowledged that potential problems are looming, it has generally lagged in coming forth with concrete solutions. It’s unfortunate that the United States did not join much of the rest of the world in the 1997 Kyoto Agreement, which has been adopted by approximately 180 countries. The Kyoto Agreement has the objective of controlling and reducing emissions of carbon dioxide. While the agreement has flaws, it is a step in the right direction. Although the U.S. government has not endorsed the Kyoto Agreement, a number of states and local governments have taken steps independently to control emissions of carbon dioxide to levels suggested by the agreement. California is one of the states that are taking steps to reduce emissions of greenhouse gases.

A 2006 report initiated by the U.S. Government and completed by the National Academy of Science concluded that human-induced global warming is happening, and that we need to address the problem sooner rather than later. The meetings in mid December in Copenhagen brought the U.S. back to the international table. Although no binding agreement or treaty came from the meeting, it was another small step in that direction.

Scientific uncertainties remain concerning

global warming, but they are concerned with the amount of change expected, how ecosystems will adapt to warming, and the severity of consequences such as sea level rise - not whether or not the warming is happening. For example, we know life has adapted to changes in the past, and, in fact, change is the norm in ecosystems over time. The question is, are changes from global warming this century going to be something we can live with, or will they lead to droughts, reduction of global food supply, and other adverse changes that will stress our modern society to the breaking point? I am an optimist and believe we will rise to the occasion and make the right choices. At any rate, the evidence from the study of past changes in the geologic record suggests that we have some time (a few decades) and that the consequences from climate change probably will not be abrupt. By abrupt, I mean catastrophic with catastrophic consequences. The world will not come to an end because of global warming. We are not talking about saving Earth. Our planet will support life for several billion years more. What we are concerned with is the future of our species over the next few hundreds to few thousands of years. Now is the time to make commitments to ensure we have a future on Earth that, while changing, will enable our children and theirs to look back and say we made the right decisions. In other words, we hope they will look back with thanks rather than with regret.

RIVER LOVERS CREED

Born of this earth, nurtured by knowledge, science and values:

- *I believe in reverence of and respect for rivers; will teach my children and others that they might also revere rivers.*
- *I recognize the centrality of water to life, and will not litter, pollute, or degrade rivers.*
- *I recognize and celebrate each individual river for its diversity of geology, hydrology, channel, and floodplain.*
- *I will value ecological processes in rivers and pledge to help conserve biodiversity of hydrologic and biologic environments of rivers and floodplains.*
- *I will experience rivers either as an individual or in small groups, whether it be for walking, hiking, picnicking, meditating, boating, swimming, painting and photographing, wildlife and bird watching, or catch and release fishing, for personal reasons as it enriches my life. I will keep only my memories and leave only my footprints.*
- *I will defend rivers from human manipulation that degrades river environment or reduces biodiversity.*
- *I will support sustainable watershed and river management and restoration so that my and other people's children will inherit quality rivers to enjoy.*
- *I will support floodplain regulation and zoning as the only reasonable way to both reduce societal loss to floods and to preserve natural river function.*
- *I believe in and will support the right of scenic, wild, free rivers in today's hectic world to exist.*
- *I believe that urban rivers have community value far exceeding commercial value and support urban river parks.*

E.A. Keller 2001

Great Places to See Some of the Natural History of the Santa Barbara Area

Introduction

There are many great places in Santa Barbara to view the natural history, and we have discussed these in some detail in the book. Without a doubt, our favorite place to pass some time is the Harbor and Stearns Wharf. From the wharf or breakwater there are, on a clear day, views to the Santa Ynez Mountains (a large anticline), the Riviera (Mission Ridge Anticline), the Channel Islands (an anticline), the Mesa (another anticline), and, sometimes, east to Red Mountain (a really big anticline). Our landscape has been produced by rapid and ongoing uplift and folding of rock that forms linear hills (anticlines). Between the anticlines are low areas, synclinal basins, filled with sediment, as for example downtown Santa Barbara and Goleta Slough.

There are always interesting things to see and do in the harbor area. Just watching the boats and people can be fun! The birds are not to be missed, and seals frolic about. Gray whales like the harbor and visit at the mouth on occasion, as do great white sharks (though very rarely).

For those of you who wish to visit some of my other favorite places, I have developed the following list. All of these are easy to get to, and I hope you enjoy your excursions. The accompanying map (Fig. 7.1) shows the general location of the places that I describe below. I have listed my favorite places alphabetically.



Fig. 7.1. Map of the Santa Barbara area from approximately Rincon Point west to Ellwood Mesa. Locations shown are discussed in the chapter as places to visit where the access is relatively easy and some of the natural history of the Santa Barbara area may be observed.

Arroyo Burro Beach

Arroyo Burro Beach (Fig. 7.2 and 7.3) is one of my favorite places in Santa Barbara. It is a local's beach with a fine restaurant and offers plenty to see in the natural environment. You can go there during the winter and walk along the beach and collect shells as well as beach glass. If you turn to the left at the restaurant and go (east) towards Santa Barbara, you will pass through some interesting places. First you will come to Arroyo Burro Creek Lagoon. This small lagoon is separated from the ocean by a barrier beach (Fig. 7.4 and 7.5). These types of lagoons are sometimes called "blind lagoons." When the creek is in flood, the lagoon is more like a small river flowing quickly to the sea. Crossing the mouth of the lagoon when it is in flood and water is racing across the beach can be dangerous.

High flow through the lagoon probably scours the bed of the lagoon, but little is known about the processes operating in these small lagoons. It is clear that the lagoon at Arroyo Burro was much larger in the past. The present parking lot just west of the lagoon was part of the earlier lagoon which extended west where the lawn is today and north across

Cliff Drive. The steep slope just west and north up toward Hope Ranch is a steep slope that may have been produced by erosion along Arroyo Burro Creek as it flowed into the larger lagoon in the distant past.



Fig. 7.2. Arroyo Burro Beach is a wide, sandy beach during the summer months. Following winter storms, much of the sand is moved offshore a bit. The beach is known to have a small grunion runs in the summer months.



Fig. 7.3. Just east of Arroyo Burro Beach is a high sea cliff that is approximately 85,000 years old. The rocks are predominantly Miocene shale of about 6-18 million years. Along this section of the coast there are some very interesting rock structures, including shale that is impregnated with tar and a variety of marine mammal fossils.

Walking along the beach east of the lagoon, you can find rocks that are impregnated with tar. These rocks represent the guts of an old oil field that has been uplifted in the past 100,000 years. The marine terrace high above the beach at the Douglas Family Preserve has beach sands on the surface which were deposited by wind and waves about 85,000 years ago. Here and there at the base of the sea cliff and out on the beach, some of the boulders contain whalebones and other fossils.

They are not easy to find or see, but, if you look closely, you will find some. Some of the bones are large, such as whale vertebrae, but most are small pieces. The rock is Monterey Shale of Miocene age that is 6 to 18 million years old. When the silt and clay (derived from the land by rivers and streams) that became the Monterey Shale was being deposited millions of years ago, the depositional environment was deep water (at least several thousand feet). In other words, the deposition was in a deep ocean basin. Whales that die in deep water sink to the bottom to become “whale falls” on the bottom. A dead whale weighing many tons attracts a group of specialized organisms (scavengers),

including eel-like hagfish, fish, and crabs that feed on the carcass for months or longer. The carcass can support an ecosystem (an island of life) on the deep ocean floor where there may not normally be much in the way of large fish and crabs (there usually is not much food). Whalebones, after being picked clean, are buried by the sediment and may become fossilized. The process of fossilization is fascinating - bone is



Fig. 7.4. Arroyo Burro Creek Lagoon looking north. The lagoon was much larger in the past before being partially filled to produce the parking lot and other structures. It remains a long, narrow lagoon that receives fresh water from Arroyo Burro Springs. During the summer, inflow is primarily from large springs along Los Positas Road.



Fig. 7.5. Arroyo Burro Beach Lagoon looking south to the Channel Islands. The barrier beach is breached at this time. When the beach is closed off, the lagoon level is several feet higher.

replaced by mineral deposition, keeping the basic shape and structure of the bone intact.

Moving back to the beach, be careful walking at the base of the sea cliff, as most of the large angular fragments of rock on the beach arrived there after falling from the sea cliff. Sunbathing on the beach near the base of the sea cliff, surrounded by rocks, soil, and vegetation that has recently fallen from the cliff, is not advisable.

If you wish to see large landslides, walk west 15 to 20 minutes from Arroyo Burro Beach to the Hope Ranch Area. You can see the head scarps (steep, cliff-like, bare ground slopes at the top of the slide and hummocky topography (disturbed land sloping first one way then the other). Look closely at the slides and you will observe how active slides can affect the beach. Often, the toe of the slide moves out on the upper part of the beach, bringing rock, soil, and vegetation into the wave zone. Water is often seen seeping from the toe of the slide out onto the beach. Slide material does not usually last long on the beach because it is removed by wave action at high tide. When you see slide material on the beach, it usually means the slide is active.

West of Arroyo Burro Beach, you can observe “burned shale,” recognized as pink rock that looks something like the colorful sandstone you might find in New Mexico. The origin of the pink color is due to rapid oxidation of tar in the rock, resulting in the shale burning. Several years ago, a fire below Hope Ranch started in the sea cliff from a landslide exposing tar. The fire evidently began by spontaneous combustion, much as oily rags may spontaneously burst into flames. The process of oxidation of the tar generates the heat that starts the fires in the newly exposed tar. The oil-rich shale may burn for several months or even years. As you walk along the beach, you will see several places where this has occurred (there is orange oxidized

shale). Burning shale is the origin of the so-called Santa Barbara volcanoes. There have not been real volcanoes in our part of the world for millions of years, but the smoldering tar will burn, and flames may occur at the surface, turning the rock pink.

Carpinteria Beach

Carpinteria beach is a must for everyone to see. Sometimes called “the world’s safest beach,” it reminds me of the quintessential tourist beach vacation spot. During the summer, small platforms are placed offshore, and children frolic in the waves, swim out to these platforms, and socialize. Further to the east at the Carpinteria Beach State Park are other features of interest. For example, you will find Tar Pit Beach which is famous for tar seeps. It is a place where you can see crude oil boiling—not really boiling but seeping from the beach sands. Some of the small points and terraces have an abundance of tar deposits. In the past, the tar was mined, and it was a location where a number of Pleistocene fossils of large mammals were collected. Further along, just past the State Park, you will come to the harbor seal haul out and rookery area. At certain times of the year, access is restricted, but it’s an interesting place and seals are almost always present.

Ellwood Mesa and Coal Oil Point

Ellwood Mesa is a special place to many people. It can be accessed via numerous locations near the Santa Barbara Shores development by driving south from Hollister Avenue. At Ellwood Mesa, you can see the topographic rise (a linear hill, up to the south) produced by the More Ranch fault and fold, which is part of the Mission Ridge Fault System. The fault is the longest, most continuous on-land fault on the Santa Barbara coastal area, extending from near Ojai to offshore near the east end of the Sandpiper Golf Course in Goleta. The fold forms

an easily visible gentle rise to the south in the 45,000 year old marine terrace we call Ellwood Mesa. You can see the linear (east to west) uplift looking south (toward the ocean) at several locations from Hollister Avenue near the golf course. The fault, on the mesa proper, is near the base of Devereux Creek that flows east into Devereux Lagoon (a slough). Actually, the creek follows the fault and flows west to east. Streams often flow along faults because the faulting produces topography that determines where water flows. Most of our streams flow from the mountains south to the ocean. Occasionally, they flow east to west (or the other way) along a linear uplift (fold). For example, Cieneguitas and Atascadero Creeks start in the mountains and flow south to near Hope Ranch where they are diverted about 4 miles west by uplift along the Mission Ridge Fault System (More Ranch fault). Atascadero Creek flows about 3.3 miles along the north side of Hope Ranch and More Mesa into the Goleta Slough. Both the Hope Ranch and More Mesa uplifts are up to the south because the Mission Ridge fault is a south side up reverse fault. The fault plane is inclined south, and the upper plate has moved up relative to the lower plate. To experience how Hope Ranch was uplifted, assume a standing position and hold your hands together as in prayer (fingers pointed out, not up). Now face west (toward Gaviota), point your fingers (and hands) to the west, and tilt your hands to be inclined south (toward the ocean). The fault plane is the plane between your hands. Now move your upper hand up, and you have simulated the south side up displacement that has uplifted Hope Ranch.

Where the More Ranch fault is exposed in the sea cliff at its western (on land) end, you can observe that the ancient 45,000 year old wave-cut platform is offset vertically about 20 feet. That amount of vertical separation is the result of at least 6 large earthquakes. The return time of large earthquakes is 5 to 7 thousand years (assuming

3.3 feet of uplift per event). That doesn't mean the earthquakes occur like clockwork every few thousand years. Earthquakes may be clustered in time and space. Work by Larry Gurrola, my former PhD student who completed his dissertation on the Santa Barbara earthquake hazard, revealed that the More Ranch fault moved three times between about 35,000 to 40,000 years ago (perhaps a cluster of earthquakes). We do not know when the most recent prehistoric earthquake at Ellwood Mesa occurred, but it could have taken at least 10 large earthquakes in the past 45,000 years to produce the fold we observe.

If you walk at low tide east about 3/4 miles from the beach access at the Bacara Resort, you can find the fault where it heads off shore. Do not climb the sea cliff, as that is dangerous. The fault is best observed from the beach at low tide. You may notice that there are stream deposits near the top of the sea cliff where the fault goes off shore (you can see buried channel deposits). What is happening is that the headwaters of Devereux Creek have been eroded away by coastal erosion over the past 45,000 years. In other words, the western part of Devereux Creek extended further off shore in past times.

Ellwood Mesa, the Mesa has a number of large eucalyptus groves. During the winter, monarch butterflies in great numbers congregate there. That is a great time to visit the mesa and just lie flat on your back and look up into the trees and ponder what drives these beautiful insects to make their long migration to the Santa Barbara area. In reality, they are not much different from the people of the eastern United States who visit us in the winter to avoid the cold weather. In Florida and other places, we call these people "snow birds" because they generally fly here in airplanes. The monarch butterflies also come by air, and their journey is much longer but no less interesting and mysterious.

Coal Oil Point, near the outlet of Devereux Slough, is the location of world-famous tar and oil seeps in the nearshore environment off of the point. The seeps are aligned with east to west faults and folds on the seabed. Devereux Slough is a small, seasonal lagoon that is a habitat for a number of birds and other living things. In front of the slough is a field of sand dunes which are not particularly common along our coastline but can be found at several points, including Devereux Slough and at UCSB. The Devereux Slough area is part of the Coal Oil Point Reserve that is managed by UCSB. If you contact UCSB, you can find out about when you can visit, who might lead trips, and so forth. During part of the year, part of the beach is closed because it is a nesting spot for birds known as the Western Snowy Plover (a threatened species along the Pacific Coast, due mostly to loss of habitat). The University has a program that trains students and other people to help watch plover nests and inform the beach-going people about the birds and protection of the nesting area. These small birds lay their eggs right on the beach in the gravel and are vulnerable to dogs, people, crows, and other predators. Considerable effort has been expended to protect plover nesting and increase the abundance of the small birds at Coal Oil Point.

Lookout Park at Summerland

The beach below Lookout Park (Summerland Beach) is a tourist attraction, as is the small town of Summerland with the several shops and restaurants that are fun to visit. Lookout Park is on an uplifted marine terrace about 100,000 years old. The park has a playground and enough grass for a nice lunch or to view the sunset. Views, as the name suggest, are great from the park. The beach is sandy, often with gentle waves, and is a good place to swim, catch surfperch, or just hang out on the beach (see Figure 2.9a). The beach in the early 1900s looked

much different than today. There were many oil wells back then, part of the interesting history of Summerland. Speaking of interesting local history, now is a good time to present some of the legends and stories about a famous local geologist.

Years ago, when I wanted to study the earthquake hazard of Santa Barbara; I was in the field with Tom Wilson Dibblee Jr. (Tom Dibblee to most of us) who was a friend to me for many years. I used to visit him at his home on Mission Street, close enough to the Mission to walk to Fiesta Pequena. Tom had constructed a large office above his garage where he housed his maps and rocks. He personally mapped much of California. I will always remember his “Loretta stones” around his office and property. Loretta was his wife of many years, and he collected round stones of various sizes from around the state. On each stone he drew a smiling face of Loretta. He told me once, “She was a good little wife.” He obviously loved her immensely and honored her with his Loretta stones. Tom was a very special person in that his brain was wired to map geology. He could literally map the geology while riding in a car or riding a bicycle downhill. I once met Tom in the Ojai Valley while walking up Sisar Canyon. I was rounding a corner, and down he came in a cloud of dust on his bicycle. He had his maps with him and was making corrections to the geologic map of the area. I asked Tom why he used a bicycle, and he said he would walk his bicycle up while mapping and then, when he got to the top of the hill, would turn around and ride down at full speed for the thrill of it—and also it would get him to the bottom of the hill quickly where he could start up the next canyon. Stories about Tom Dibblee are legendary. When he would go mapping in the field in the Santa Maria area, he told me that he would live for weeks on road kill. By that, I don’t mean animals. The produce trucks

that went along US 101 on curves would spill some of their loads, and he would pick up heads of lettuce and broccoli and so forth and subsist on this for weeks at a time. The people at the US Geological Survey who were paying him to do the map could not believe the vouchers he would submit for his food, as they were nearly zero. I didn't believe all this until over 15 years ago when I began to go to lunch with Tom on a weekly basis at Goleta Beach in order to discuss geology. He had a mind that could really help you. He could remember every place that he had visited and what the geology was there. During lunch, he would often eat lettuce, raw corn, and maybe a piece of toast. Whatever it was, it worked well for him, and he lived into his nineties. At any rate, while coming back from Ventura one day in the 1980s, I asked Tom if he knew of places near Santa Barbara where there were young folds and faults. I was becoming suspicious of the dogma that Santa Barbara was free of active faults and had a small earthquake hazard compared to Los Angeles

(never mind that Santa Barbara was nearly destroyed in the 1925 earthquake). He mentioned several locations where he had mapped folds and faults, including Ortega Hill. We had an extra few minutes one day, so I and some of my graduate students stopped just west of Lookout Park, and, lo and behold, we observed one the most beautiful anticlines that I have seen along our coast. The anticline is large enough to make an impression of what folding can do to the landscape.

The beach to the east and west is also a good place to visit and to observe the effects of sea walls upon the width of a beach (see Fig.2.27 for the sea wall to the east). To the west at Ortega hill, there is a large cement sea wall (go there only at low tide as high tide can be dangerous at this small point). Notice that, in front of the sea walls, the beach is quite a bit narrower and adjacent to the walls. Now walk out on the beach below the park and look toward Santa Barbara and the Mesa. This is a good place to see the double fold that forms the Mesa. It looks like a two-humped camel.

Guardians of Moonlit Sand at Arroyo Burro Beach

Sunset brings the changing of the guard at Arroyo Burro Beach

Vibrant to subdued colors of red orange on water and sand slowly with fading light gives way to night

Later as the moon rises gently lighting the beach with silver rays from water to the beach another heron arrives

Not a conscious decision A force of evolution

Guardians of moonlit sand

Two herons day and night Not competing Sharing at very different times the bounty of the estuary and beach

How they came to share and not compete is a wonder of nature Something to celebrate

Science can explain the mystery of their connection to nature Not the wonder

Guardians of moonlit sand

A dark shape wading in the shallow swash of the expended surf More like a long legged penguin than a heron

More common on the nearby estuary and lagoon

Now on the beach late on a summer night

Knowing grunion

A stocky bird with colors of white grey and black

Bathed in moonlight Sharing the beach with others of their kind

The barking sound of the breaking waves melds with the soft swash on the beach No grunion yet

Up and back goes the moving water of the swash

The night heron stand solid

Guardians of moonlit sand

— Ed Keller

More Mesa Beach

You can reach More Mesa Beach (Fig. 7.6) by walking from Arroyo Burro Beach or walking from Goleta Beach (Fig. 7.7), and there is a trail from the top of the Mesa as well. More Mesa Beach is a beautiful location with a very high sea cliff. Some of the rocks in the sea cliff are gravels and sands overlying the Monterey Shale that are slightly folded into a broad syncline and probably represent an old channel of a creek that was flowing to the ocean. At Hope Ranch Beach (which is private), the small canyon is a remnant of, probably, a larger stream that once flowed through Hope Ranch. The main stream was blocked by uplift of the Mission Ridge fault system to the north, near the entrance to Hope Ranch. If you stand on Goleta Pier and look to the east, you will see some black rocks. These form a small point that is clearly visible, and there are some landslides there. If you cross Goleta Slough, being careful to do it at a tide position when there is little if any water coming out of the slough, and walk to the east, you will come to these black rocks which are tar flows. Pass the first ones, and you will come to a place where tar flows out of the sea cliff onto the beach. It is a “tar fall.” This reminds us that we are in a petroleum-rich area. Some of the



Fig. 7.6. View to the east from Goleta Beach toward More Mesa Beach. This section of coastline is very interesting because of the large tar seeps that can be seen from Goleta Beach as dark, black rocks.



Fig. 7.7. Inlet of Goleta Slough. When the slough is emptying during low tide, a lot of water moves swiftly to the ocean. If the inlet is open at high tide, the flow is reversed and partially fills the wetland.

tar we see on the beach comes from natural sources, such as erosion of these flows, and others come from seeps offshore. There probably always has been tar on our beaches for many thousands of years, and it has been used by people for a variety of purposes. For example, native people used it to caulk canoes and baskets and to attach tools to wood shafts.

Painted Cave

Painted Cave is one of my favorite places, in part because it is located in a small canyon environment that is usually incredibly quiet and still. I say “usually” because our canyons can be very windy at times. The sounds from movement of the wind can vary from that of a gentle teasing breeze to something more like an out of control freight train. Moving water over rock produces a gentle rhythmic natural music at low flow that is a pleasure to our ears. During storms at high flow, the stream swells with water and moving sediment, and the sound can be heard from far away as the power of the stream is made known above all else in the canyon. On the usual quiet days, the presence of the place projects an overwhelming feeling of peace. Stop for a while in the canyon and experience what the Chumash did and consider why it may have inspired their art.

Cave paintings are fairly common along the southern front of the Santa Ynez Mountains. One small cave has a painting of a swordfish (Fig. 7.8).

Painted Cave State Historic Park is located directly below the community of Painted Cave that is sited on a prominent, gently folded sandstone ridge (Eocene Coldwater Sandstone) overlooking



Fig. 7.8. Small Chumash painting of a swordfish in a small cave. Photograph courtesy of Dave Harris.

the Pacific Ocean and Channel Islands. Imagine the people who, in ancient times, entered the canyon, discovered the cave, and recorded their presence on the rock.

The slope below the Painted Cave community is littered with large pieces of sandstone that have rolled, toppled, or fallen down the slope. We do not know when the large pieces of sandstone came down the slope. Most likely, it was during moderate to large earthquakes; we know that earthquakes cause many slides. The Magnitude 6.7 Northridge Earthquake in 1994 triggered about 11,000 landslides over an area of about 4,000 square miles. Most were small slides, but dozens of homes were damaged or destroyed, and a number of roads were blocked by slides. I mention the Northridge Earthquake because that event is what we can expect in Santa Barbara in the future. The most recent such event that impacted Santa Barbara was the Magnitude 6.8 earthquake in 1925 that caused extensive damage to the city and surrounding area.

You can access Painted Cave from a road off of Highway 154. The turn is to the right, and you follow up a windy road about 2 miles. Parking at Painted Cave is a bit tricky, with space available for only a small numbers of cars.

The cave was most likely formed by rock weathering (physical and chemical processes that break down rocks near the surface of the Earth). The small honeycomb-shaped pits on the outside of the cave are known as tafoni and are produced by weathering of the rock. The weathering process that forms tafoni starts with water and salts delivered by fog and dew from the ocean. The water and salt infiltrate the rock about an inch, and, when the water evaporates, the salt forms mineral crystals near the surface of the rock. As the crystals grow between and around the grains of the rock or in small fractures, they expand (increase in volume) and force small bits of the rock to flake off, forming holes that eventually look like the inside of an egg carton. The outer surface of the rock may harden due to mineral precipitation, forming a crust.

The process that forms tafoni is known to produce caves (it is called cavernous weathering). Hemispheric pits and small caves on the undersides of overhanging blocks of rocks in exposed cliffs have been reported in semiarid areas in California and other semiarid regions in the world. As tafoni develops, it often grows larger, both upward and inward, producing openings in the rock (caves) of various sizes. The weathering pit that we call Painted Cave is large for a tafoni, although larger ones have been reported.

If you walk up the very short trail and look into the cave, you can see the beautiful paintings done by the Chumash people. There is an open framework iron gate (Fig. 7.9) guarding the entrance, but you can easily see through to the paintings. We don't know when these paintings were done,

but it probably was in the last few hundred years or so. According to research by the Santa Barbara Museum of Natural History, the paintings are thought to have been completed in the past 1,000 years. One round painting (a black circle outlined in white) could depict a solar eclipse of the sun that occurred in 1677 (consistent with the age estimate). A numerical date of the paint, using Carbon-14 in the organic component of the paint (radiocarbon dating), has not been done, and, therefore, the age is an educated opinion (guess). The paintings were done over a period of time, and some earlier images are partly covered by more recent ones. The dominant colors of the artwork are black, white, and red. Red to black paint can be made from iron oxide minerals (ochre or he-



Fig. 7.9. Entrance to Painted Cave. The honeycomb structure on the left is a tafoni. Larger tafoni are also shown as pits. The cave itself is probably a large tafoni structure. At several other locations on the south flank of the Santa Ynez Mountains, tafoni pits occur, and a number of these have paintings in them.

matite), and white paint could be made from the mineral gypsum (calcium sulfate) or diatomaceous earth (mostly silica from diatoms, a form of plankton) from the Monterey Shale. Organic binders, such as animal oil and charcoal, were evidently also used, along with crushed plants and water.

While you're visiting the cave, look across the road at the small creek, sit on a rock, and meditate on the mountain environment and the processes that cut our canyons, including torrential storms and flooding that periodically occur. Let the land talk to you, and it may reveal the secrets of the creation of the canyon. One of the ways I study the landscape is to imagine the processes that operate, such as uplift by earthquakes, stream erosion, landslides, and wildfires. Then try to imagine these processes happening as a series of events. Imagine uplift by earthquakes, which increases the slope of the land, which induces stream erosion, which erodes the canyon walls, which increases their slopes, and which triggers landslides. Occasional wildfire strips the vegetation, releasing sediment that is flushed from the canyon by winter storms that cause high stream flow. Imagine that you are a bit of sandstone rock experiencing these processes. Feel the power of an earthquake moving you to the surface to be transported down slope by water and wind. Feel the power of running water over your surface lifting you and moving you along the bed of the stream. You feel the collisions with other particles, abrading you and eventually transporting you to the coast. At the coast, you join countless other bits of rock from the mountains and move along the coast. Imagine the power of the waves, their sound and fury in the surf zone moving you up and back in the swash zone, but also along the coast. Eventually, near Point Mugu, you are transported down a submarine canyon by a turbidity flow to the deep-sea basin. After a time

(millions of years), you will be compacted and cemented with other grains into new rock. Again, by earthquakes, you are uplifted to become part of the mountains, only to erode again. This is the great geologic cycle. When you do this thought experiment, you become part of the landscape, and, through geologic time, you gain insight into how the land changes from birth to maturity and decline, eventually to be born again.

Rincon Point and the Santa Ynez Range

Rincon Point is one of the premier surfing localities in the world. On certain days, a near-perfect break occurs and surfers may ride waves for a long distance. The point is due to the fact that Rincon Creek enters the ocean at that spot, bringing in large volumes of coarse debris that have built out the point. There is a north-south fault present there that also may play a role. There is a small park at Rincon Point and you may walk down to the beach.

Rincon Point is a good area from which to view the Santa Ynez Range. Figure 7.10 is taken from La Conchita, and the point and mountains are clearly visible on a clear day. In Figure 7.10, I have provided some labels of the major geologic and physical features of the landscape. The point protrudes out into the ocean, and the background is the Santa Ynez Range. The origin of the range is complex, related to active folding and faulting that probably have been occurring for over the past 0.5 to 1 million years. Approximately 20 years ago, I noticed that the range crest dropped systematically from the east to the west, and there are three main segments of the range. These are shown in Figure 7.10. Each segment is curved but, together, they form the long topographic expression we know as the Santa Ynez Mountains. The major boundaries between segments are at San Marcos Pass and Gaviota Canyon. Uplift that produced the Santa Ynez Range is related to the Santa Ynez fault on the north side of the

range, as well as to a deeply buried reverse fault that has produced the series of anticlines associated with each segment. One of my former graduate students, Tim Tierney, worked with me and completed a thesis on the origin of the range and the segments. The geologic evidence clearly shows that the oldest segment is above Santa Barbara, and the youngest segment is west of Gaviota Canyon to Point Conception. Probably, these segments formed somewhat together over a period of hundreds of thousands of years, but the earliest and best-developed segment with the highest topography is to the east, and the youngest segment with the lowest topography is to the west. Together, they form a complex anticlinal fold which we call an anticlinorium (complex anticline). Also shown in Figure 7.10 is the outline of La Mesa and the Riviera. The City of Santa Barbara is nestled between these two anticlines. Notice that La Mesa anticline is a complex fold consisting of two

anticlines with a syncline in between. If you wish to observe this, simply drive south on Cabrillo Boulevard from U.S. 101 and go up the hill to the top and then down in the central portion of the syncline and then back up again, before going down to the lower Mesa.

In summary, Rincon Point is a great place to visit for surfing and walking, and, from there, you can see on a clear day much of the structure of the Santa Ynez Range.

Rocky Nook and Skofield Parks

Rocky Nook Park, located near the Santa Barbara Mission, is littered with large boulders. They look like Easter eggs on Easter Sunday, scattered around the landscape (Fig. 7.11). These boulders are evidence of a very recent, giant debris flow that occurred about 1,000 years ago. The origin of the rocks is in the Skofield Park area (located on Las Canoas Road, about one mile from the junction with Mission Canyon Rd.) where a large landslide occurred and blocked Rattlesnake Creek (the major tributary of Mission Creek). The best place to view the landslide is near the top of mountains on Gibraltar Road, near where paragliders launch. The landslide will appear as a one-half bowl-shaped depression (like a horseshoe open to the west) from the ridge down to the park. Las Canoas Road parallels part of the landslide scarp, which is the steep slope above the road. The flat parts of Skofield Park, where you can play horseshoes, volleyball, or football, are slump blocks that have rotated back toward the mountain. Nearly the entire park is within the landslide mass. The slide brought down large boulders from the ridge top alluvial fan that is about 125,000 years old. A good place to visit the fan is the site of the former Mt. Calvary Retreat House that burned during the Tea Fire in November of 2008. The driveway in front of site of the former buildings provides a view

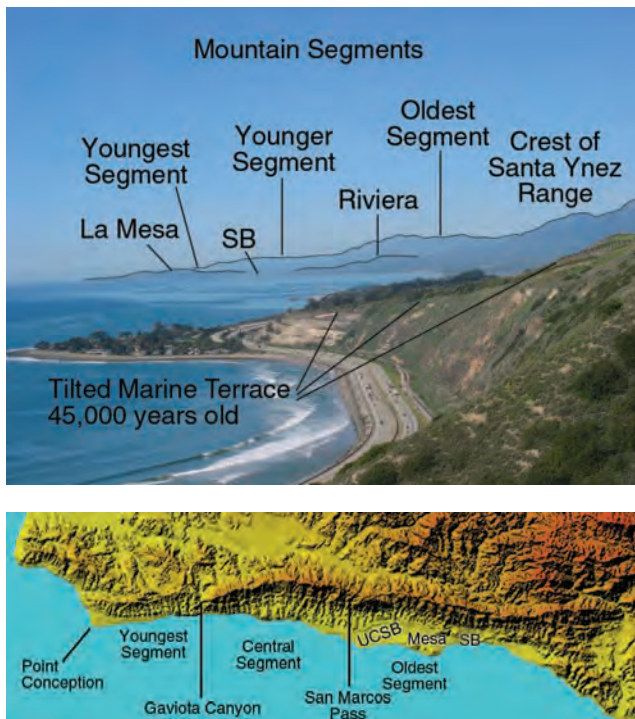


Fig. 7.10. Rincon Point looking west and along the Santa Ynez Range. The range is segmented into three main parts, each one dropping to a lower elevation to the west. Also from this location, you can see La Mesa which is a double anticline with a syncline in between. Santa Barbara is the low-lying area between the Mesa and the Riviera.



Fig. 7.11. Large boulders surrounded by oak trees in Rocky Nook Park. The boulders were delivered by a catastrophic, large debris flow about 1,000 years ago. Throughout the park, the boulders are scattered like Easter eggs on a lawn.

looking toward the ocean and Santa Barbara. The steep slope is the top of the slide. The steep slope down to Skofield Park is called the head scarp. The head scarp is curved and about 3,000 feet long and 250 feet high. The uppermost few tens of feet are comprised of the alluvial fan gravels, some of which are huge.

Skofield Park today is one of the crowning jewels of Santa Barbara. Generations of people have visited there, celebrating all sorts of events including family reunions, birthdays, and weddings. Youth groups camp there and experience nature. It is a special place. The park is also remote, which is much of the charm. My neighbor saw what was probably a mountain lion there today, even as I write this. He described a large cat with a long tail. Large bobcats that are common in the canyon have a short tail. I wonder if there was a mountain lion here several days ago. I was walking my dogs, including Bo who is a large Portuguese water dog that we have lived with for several years before the president made them famous. He ran ahead bark-

ing after what I assumed was a squirrel. Suddenly he stopped and ran back begging to be protected! I thought at the time – did he see a mountain lion? He has never been afraid of anything before.

The park has a home in the grounds where a park employee (caretaker) lives full time. This is an absolutely essential position, as this park, because of its more remote location, needs someone there, especially at night. We all will remember what happened when an open fire in Montecito most likely was responsible for the Tea Fire. Without supervision, people sometimes do foolish

things. Skofield Park is a park for all seasons; fall to spring brings many things, from changing leaf colors along the creek to the bloom of renewal in the spring. May it always have a caretaker and be open all year.

The dam formed by the landslide at Skofield Park blocked Rattlesnake Creek and Canyon for a period of time (a few months to a year or so, depending on precipitation and runoff). When the landslide dam became saturated or overtopped, it failed (blew out) and sent a large debris flow with boulders bobbing on top down the canyon to the Rocky Nook Park area and beyond. The flow would have made a tremendous noise (like a freight train) as it swiftly flowed down the canyon. It was several tens of feet thick and moved faster that you could run if you were an Olympic runner. If such an event were to occur again today, many homes and buildings, including the Museum, would be destroyed, and the loss of life would be catastrophic. The bottom line is that two of our favorite parks were formed about a thousand years ago from a short

series of events. If you walk around Rocky Nook Park, you will see various places where boulders are piled in linear hills, sometimes across the valley, sometimes parallel to it. These are debris flow features. The lines of boulders parallel to Rattlesnake Creek are debris flow levies that formed when the debris flow came down and pushed the boulders to the side. The boulders were easily transported by the debris flow because the water and finer material was of the same density as the rocks, and they just sort of bobbed along on top of the flow, being pushed to the front and to the sides. So, go to Rocky Nook Park, have a nice picnic, and walk along the creek. Ponder how the large boulders have changed the creek. In several locations, large boulders cause convergence of flow and the formation of large pools that form excellent fish habitat. This section of Mission Creek nearly always has water in it because the groundwater flowing from the mountains goes up against the backside of the Riviera and the Mission Ridge fault. The fault itself helps push groundwater to the surface, and, so, this section of creek is nearly always wet. While you are there, you can go to the Santa Barbara Museum of Natural History and view the geology maps of Tom Dibblee, along with many other interesting geological exhibits. If you go out the back of the museum and towards the south, you will see a high hill. That is the location of the Mission Ridge fault and fold. Again, the stream here is wet nearly all year, and, almost always (except when pools are filled with fine sediment following wildfire flushing of sediment as they were in 2010), you can see young rainbow trout, some of which will go to the ocean to become steelhead trout. If you walk to the south from Rocky Nook Park toward the Mission, you will notice, just east of the Mission, what appears to be a shallow depression that is linear and runs to the south and then turns west at the Rose Garden. This is an ancient channel of Mission Creek that

was probably the main creek 40-60 thousand years ago, before the path of the creek was blocked and diverted by the uplift of Mission Ridge along the fault and fold. Walk along this channel and ponder what Mission Creek would have been like 40-60 thousand years ago flowing there. You can see little flat places adjacent to the channel that were probably small stream terraces, and, here and there, boulders poke up. Over the 40-60 thousand years, sufficient dust and the transport of other materials have filled in the channel by several feet, but you can still clearly see where the channel went. A fair amount of groundwater must still flow through the area because one sees sycamore trees that are a river and wet-loving species often found along stream channels. If such an event were to occur again today, many homes and buildings, including the Museum, would be destroyed, and the loss of life would be catastrophic.

While in Rocky Nook Park, you may also wish to observe the hill across the stream. This is a location where the stream cuts directly through Mission Ridge, and, if you look carefully, you may observe the south “limb” of the gravels that form part of the fold we call the Mission Ridge anticline. The gravels were originally deposited nearly horizontal, and today, at one location in Rocky Nook Park, they are tilted to the south. Also along the stream, you may view a white shale rock which is Monterey shale of Miocene age. At Rocky Nook Park, the beds of the shale are nearly vertical with the gravels deposited on top of them.

Chumash People were in the canyon 1,000 years ago and must have witnessed the debris flow. There is a Chumash story that goes something like this: Sun’s nephew, Spotted Woodpecker, was the only one saved in the flood. It’s not known why the floods came or how they started, but the water kept rising higher and higher. All the people drowned except Woodpecker, who found refuge in

the tallest tree. Woodpecker appealed to Sun, who dried the land, and the water receded. Large rocks in the mountains are the remains of people who died in the flood.

There are several ties between the Chumash oral narrative about the flood and the debris flow that came from Skofield Park down the canyon, forming Rocky Nook Park and the land the Santa Barbara Museum of Natural History is sited on. The landslide dam would have created a lake and flooded the land. When the lake overtopped and disintegrated, there would have been a wave of floodwater, followed by the debris flow. The mention in the narrative of the woodpecker is interesting because, of course, Rattlesnake Creek has considerable oak woodlands. The mention of the large rocks in the shapes of people who drowned is also interesting, in that large rocks on the surface are present in Rocky Nook Park downstream past the museum. We believe that the debris flow oc-

curred only about one thousand years ago, and, certainly, the Chumash in the area would have taken notice of such a large event. The fact that they have stories about “the flood” is interesting, and the parallels to the debris dam, flood, and debris flow are intriguing. The reference for the narrative is: Thomas C. Blackburn. 1975. *December’s Child: A Book of Chumash Oral Narratives*. Berkeley, CA: University of California Press.

Santa Barbara Botanic Garden

The Santa Barbara Botanic Garden is a place to visit and see some of the indigenous plants from Southern California, as well as plants from many other areas. The site is interesting geologically because of the large debris flow flat one encounters when entering the garden and looking to the north (Figure 7.12). The flat is a remnant of the top of a truly gigantic debris flow that probably occurred 40,000-60,000 years ago. The flow must have roared down the canyon towards Santa Barbara, depositing several tens of feet of coarse debris flow deposits. If you walk down one of the trails into the canyon, you will encounter the flow deposits. A good place to observe them is at the historic Mission dam. If you look above Mission Creek from the dam (to the east), you will see a number of very large boulders in the steep slope, some exceeding ten feet in diameter. Imagine these bobbing down the canyon in the debris flow. They are in the bottom of the canyon today because, as Mission Creek eroded through the debris flow deposits, the large boulders would roll to the bottom of the canyon.



Fig. 7.12. Santa Barbara Botanic Gardens looking north to the Santa Ynez Range. The flatland with the beautiful wildflowers is a debris flow flat. A large debris flow came down the canyon, probably 40,000-60,000 years ago, and deposited several tens of feet of boulders. The flat surface is the remnant of that flow. Walking to the canyon from the debris flow flat, one descends through the debris flow down to the historic Mission dam. Photograph taken in 2010, courtesy of Tom Muneio.

If you examine some of the boulders and rocks near the Mission dam, you will see some interesting, manmade holes in the rocks. These generally occur as half holes that are split open, looking something like a banana turned inward. These probably are the holes drilled by the Spanish when they would crack the boulders to obtain building material for the dam and other structures. These interesting historical relics are present throughout much of Mission Canyon and Rattlesnake Creek Canyon. Looking closely, you may find some of the quarries. At any rate, they hand-drilled these holes and probably placed wood in them that expanded

and, pounded in, would split the rocks into usable blocks for construction.

In summary, a visit to the Santa Barbara Botanic Garden is a must for hiking and observing some of the interesting features of the Santa Barbara landscape.

Santa Barbara Channel

To many of us, the best way to see the Santa Barbara Channel is from a boat offshore (Fig. 7.13). The touring options in Santa Barbara are excellent, and you will get a first hand view of the Santa Barbara channel. You can cruise along

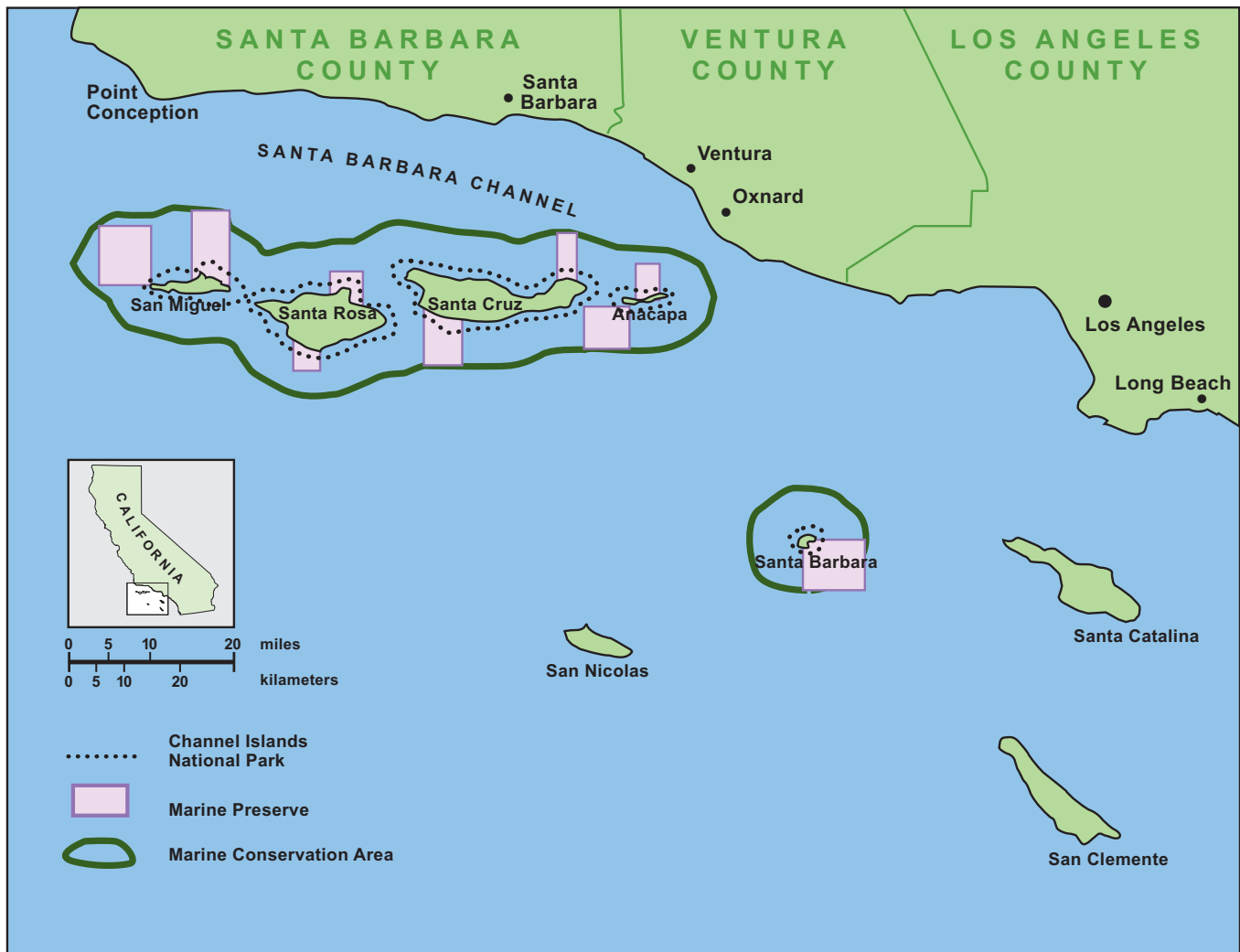


Fig. 7.13. Map of the Santa Barbara Channel showing the Channel Islands with the National Park boundary, marine reserves, and marine conservation areas. Modified after California Department of Fish and Game.



Fig. 7.14. The green flash over the Santa Barbara Channel. This photograph was taken above Tucker's Grove Park and is courtesy of John Grube.

the coast in a private boat or take one of the several excursions that are offered by several touring companies, including the Santa Barbara Sail Center, run by my friend Skip Abed (Double Dolphin and all sorts of boats) and Sea Landing's Condor Express or Captain Don. Private charters are available for sport fishing or exploring. On a number of trips to the Florida Keys and Victoria Island, Canada, I have chartered a sport fishing boat because I have found the skippers of those boats know the waters and wildlife very well and like to discuss what they know. One such skipper and friend of mine is Captain David Bacon of the Wave Walker. We have talked about exploring the origin of Painted Cave on Santa Cruz Island. The cave (perhaps the largest sea cave in the world, at about 1300 feet long, 160 feet high, and 100 feet wide), along with several others, is probably the result of erosion along rock fractures, but a lava tube in the Santa Cruz Island Volcanics cannot be ruled out. Geologic observations should re-

veal the origin of the cave. In the spring, there are many whale watching trips for observing the annual migration of the grey whales that come very near to shore. I once had a bet with a colleague that had never seen a grey whale that we would see one within one hour near Easter at UCSB Campus Point. We walked out there, and, within about 20 minutes, saw several whales. It was about sunset, and I mentioned that sometimes you can observe the "green flash" from this location. Just on cue, as the sun went down, the flash occurred, as if by magic (Fig. 7.14). The green flash (the top of the sun turns green for a very short time – a flash) is an atmospheric-sun optical phenomenon usually visible in Santa Barbara over the ocean for less than a second. I have seen many sunsets, but the green flash only two times. The reason for the green flash is complex but apparently results from refraction processes (bending of light waves) related to layers of air of different temperature. At the time of the flash, the atmosphere behaves like a weak prism. For a more complete explanation go to: <http://www.mtwilson.edu/vir/parkinglot/greenflash/>.



Fig. 7.15 Dolphins frolicking in the Santa Barbara Channel, probably chasing fish. Photograph courtesy of Eric Zimmerman at UCSB.

During much of the year, you can venture further out in the channel to see the abundance of marine life (Fig. 7.15), including the giant blue whales, often south of Santa Cruz Island where they are feeding on krill. The blue whale is the largest animal that has ever lived on Earth. It is larger than any dinosaur, and seeing one of the giant sea mammals is a memorable event. On a whale watching trip aboard The Condor Express, someone mentioned that the heart of the blue whale is about the size of a Volkswagen car. Certainly, you can imagine this, given the size of the whale, and sometimes, if you're close, you can actually hear the heartbeat. While in the channel, you will probably see many dolphins and occasional pods of killer whales, as well as other whales and a variety of other marine mammals. On several trips out of the harbor in a small boat, I have seen sea otters leisurely floating in kelp beds. It is an exhilarating feeling to be in a small boat and be approached by whales, seals, and dolphins. The important thing to remember is to not harass the animals in any way, but to enjoy their wonder and the excitement of seeing nature. The way I usually do it on my own small boat is to position my boat well in front of any dolphins or whales that are moving through the area and turn my engine off and let them decide whether or not to come and visit me. One time, further north, I was doing just that and heard a giant whoosh—to my right was a young grey whale that came up next to the boat, head out of the water, and we were looking at each other eyeball to eyeball. He was curious, and I was in a state of wonder. He stayed there for a few seconds and then submerged under my boat, and I didn't see him again.

While cruising along the coast to the east or west from our harbor, you can observe the landforms from Carpinteria to Ellwood Beach in some detail. Often, you can clearly see the folding and

faulting in the sea cliff. However, do not go too close to shore! Finally, at some locations I have seen true wonders of nature in the nearshore environment of the channel. In one instance, I came upon a school of anchovies that was corralled by dolphins and fish into a tight bait ball. Bonita and barracuda were feeding on the anchovies, as were the dolphins. Amazingly, in the middle of the school was a blue shark whose length exceeded 10 feet. Above it all were seagulls and diving pelicans, all joining in a marvelous show of life and nature unfolding before my eyes.

While sailing or cruising the surface of the channel, remember what lies below. There is the Beast in the Channel about half way from Santa Barbara to Santa Cruz Island. It is a large anticline along the sea bed that is known as the 12 Mile Reef or Mid Channel High (see Fig. 1.6). The anticline is growing (propagating) west as a result of earthquakes, and, off of Goleta, the nose of the anticline is beneath a very large submarine landslide (about 75 square miles) only 5 miles off shore of UCSB (Fig. 1.8). Faults that produced the beast could generate a Magnitude 7+ earthquake, and swarms of small earthquakes have occurred there in recent years. The anticline is also where subsurface exploration has revealed large tar mounds (tar volcanoes, the size and height of a sports arena), as well as numerous pits of various size (from a few feet across and deep to more than 100 feet cross) that I call hydrocarbon induced topography (HIT) which look like sink holes. Most HIT are the smaller features, with the larger pits and mounds occurring along the boundary fault that has a role in the formation of the anticline.



Fig. 7.16. Shoreline Park looking east to the Harbor and, in the distance, Red Mountain.

Shoreline Park

Shoreline Park and its pocket beaches, located on the Mesa about 1.25 miles southwest of Sterns Wharf on Shoreline Drive, is perhaps the most beautiful of our parks (Fig. 7.16 and 7.17). However, it needs a little love. The coastal park is a great place to walk along the top of the sea cliff, observing the wavy pattern of the top of the sea cliff which has been formed by many small landslides and some not so small. In the last year or so, a small landslide has displaced part of the sidewalk downwards, and this can be seen near the stairs to the beach in the central part of the park (see Fig. 2.17). As these small landslides occur and the top of the sea cliff retreats inland, the best management strategy is to periodically move the fence inland. You can try to fight Mother Nature, but, generally, with little success—especially in dynamic, changing environments such as at Shoreline

Park. The present fence should be replaced with a shorter one similar to the rest of the park, and the sidewalk should be replaced. The restroom is close to the sea cliff, but I wouldn't worry too much about it until it is clear that it will soon end up on the beach (then it should be moved). Let's be clear, Shoreline Park has an erosion problem and a landslide problem. It is nothing new and results from natural processes. The erosion rate is highly variable at about $\frac{1}{2}$ foot per year, with several feet going all at once some years and little change most years. In several hundred years, much of the park will have eroded into the ocean. While we have this marvelous site, let's celebrate and enjoy it.

Near the center of the park is the W. Don MacGillivray Lookout Point. The point is dedicated to Don who was a past mayor of Santa Barbara and who played a significant role in park preservation. A commemorative plaque for Don is along the



Fig. 7.17. Shoreline Park looking east. The modern wave-cut platform is on the right. The white rocks in the center portion of the photograph are the Monterey Shale of Miocene age. On top of that, the deposits are beach sands which sometimes contain fossils, as well as sediments derived from the hills above this site. The marine terrace here is a relatively flat surface with age approximately 60,000 years, 2010.

short rock wall at the point. Another commemorative plaque at the point states that the park was dedicated on December 12, 1968 to the people of Santa Barbara as a place for all to enjoy forever.

At Santa Barbara Point (east end of the park), you can look toward the harbor and see the sea cliff as it was prior to the construction of the harbor. The stadium at City College is built on the old sea cliff. Walk down and on to Santa Barbara Point at low tide and look up, and you may see a fossil locality. My students and I collected fossils at the site on the east side of the point a few years ago. The sea cliff is nearly vertical, kept that way by wave erosion. If you walk down the path from the point to the west end of Leadbetter Beach, you can observe the contact near the top of the cliff between the white Miocene Monterey Shale and the young terrace deposits. Along that contact, you can see boulders that were deposited on the ancient beach, much as they are today. Then, as today, boring pholads

(rock boring clams) drilled beautiful round holes in the shale and beach boulders. When you walk the beach, look for rocks with these holes—they are very common and make interesting rocks to collect. A few seashells and broken shells (shell hash) were also deposited with the ancient beach sands. Imagine what it was like 60,000 years ago, when those shells were rolled in the surf and ground up as they are today at the point.

Larry Gurrola, who completed a PhD with me studying the earthquake hazard of Santa Barbara (with permission of the city), rappelled down the sea cliff at the fossil locality. He lowered buckets of terrace sand and gravel with

fossils to where we were waiting on the beach. We searched for hours, using large screens archeologists often use, for a solitary coral to date. We never found a coral, but we collected small gastropods (snails) from which we evaluated oxygen isotopic data O-16 and O-18 to determine that the terrace was Oxygen Isotope Stage less than 85,000 years old (probably about 60,000 years old). The small snail (about ½ inch long), when alive, has some purple color in parts of the shell that fades over thousands of years to a more whitish color and is called olivella. It is the shell the Chumash used on the Channel Islands to make beads (used as money). We also collected terrace beach sands that Professor Lewis Owen (University of Cincinnati) dated using the method of luminescence that measures the energy of photons released in selected minerals in terrace sands. Luminescence helped establish the age of the marine terrace at Shoreline Barbara Point at about 60,000 years.

Walking to the west from Santa Barbara Point at low tide, you will see many beautiful areas where the Monterey shale has been intricately folded, faulted, and sculptured by wave action. Also, here and there, you may see bits of cemented beach sand, sometimes as high as two or three feet above the beach, that is known as “beach rock.” The variable level of beach rock demonstrates that the height of the sand on the beach goes up and down with the seasons and storms by several feet. Water seeping from the sea cliff contains the necessary ingredients that, along with biological activity, have cemented some of the beach materials together, forming this beach rock. You will see many small seeps (springs) where this occurs as water flows out on the beach, and maybe you will observe a bottle cap being incorporated in the beach rock. While you’re near the Shoreline Park area, you can also go up the famous “Thousand Steps.” Actually, there’s closer to 200 or so steps that go up a small canyon. The steps have historical interest, as La Mesa dwellers have talked about them for several generations. Undoubtedly, there was a trail to the beach prior to the building of the steps, but Thousand Steps remains an interesting place from which to observe small seeps of water that help erode and weather the sea cliff rocks and concrete stairs. While you’re there, be mindful that rocks occasionally fall from the higher areas above the stairs, and that this is a potential hazard. I know of no one who has been hurt by falling rocks, but it’s not beyond expectation at some point. So, just be careful—I wouldn’t go there during a big rainstorm—and enjoy the stairs and the opportunity to view the sea cliff rocks, as well as the small landslides and seepages of water. The base of the stairs is a good place for surf fishing. My son and I have caught a variety of fish there over the years.

UCSB Campus Point and Beach

UCSB has one of the most desirous locations of any university in the world. There are about two miles of beach with sand dunes, points, surfing areas, swimming areas, and places to just walk and sit and study and meditate. Campus Point is very interesting because there is a high marine terrace and a low one (Fig. 7.18). The high one is 45,000 years old, and we have dated it by several different ways. At Campus Point itself is a small area, uplifted from the general beach, with a flat top. We believe this is the remnants of part of the sea floor that was uplifted by a large earthquake that probably occurred in the recent geologic past. If you walk along the beach at low tide in the winter, you can clearly see where the modern wave-cut platform is about six feet below the flat area. Walk to the east toward Goleta Beach, and you will come to Fish Rock, the last rock outcrop before Goleta Beach. If you look carefully there, you will see another raised platform that is much narrower but about the same height above the presently wave-cut platform. On the side facing Goleta Beach, there are some pits about the size we see and identify as tide pools. However, these are 6-8 feet above where they should be and are most commonly found. I believe they might be ancient tide pools that were present at a lower elevation before the earthquake that uplifted the area. If it was an uplift from an earthquake, then it must have been a large earthquake, probably a magnitude 7 or greater somewhere out in the channel, that uplifted this part of the coast.



Fig. 7.18. Campus Point looking west out into the Channel and the Channel Islands. The modern present wave-cut platform is clearly visible in the center portion of the photograph. The terrace that the university is built upon is approximately 45,000 years old. The young, flat surface at the point is most likely the result of a recent, very large earthquake that uplifted part of the sea coast. Alternatively, it could be a small terrace produced by a high stand of sea level several thousand years ago, known as the Mid-Holocene High. I personally prefer the interpretation that this small terrace was produced by an earthquake of magnitude 7+, 2010.

A Final Thought

I have listed some of my favorite places to visit and see the natural history of Santa Barbara. There are many, many other places that you can go. You can take day hikes up our canyons and take long walks along the beach. One of my favorite walks is from Arroyo Burro Beach to UCSB. I have done this several times, and, in fact, when I teach a class on coastal processes, I have students walk that beach over a period of several days at low tide, taking close notes of what they observe and relating that to the beach form and process. Anyway, that walk is a great one. Another great walk is from Arroyo Burro Beach to the harbor, and you can do that at low tide in not much time - maybe a couple of hours. You can observe a number of interest-

ing geologic features including beautiful rock formations of the 6 to 18 million year old Monterey Shale with numerous folds and faults. The color of the rock varies from white, white with black tar, and yellow to orange and variegated. Individual rock layers (beds) vary in resistance, some eroded more than others, to form interesting shapes that you can use your imagination to interpret as animals, birds, and people. You will pass by Thousand Stairs, Santa Barbara Point, while looking for shells, beach glass, and fossil whale bones as you walk along the Mesa, Shoreline Park, Leadbetter Beach, and, eventually, past the Yacht Club to the breakwater. A walk out on the breakwater which protects our harbor from waves is not to be missed. There are views to Sterns Wharf, be-

yond to the American Riviera (Mission Ridge Anticline), and of the Santa Ynez Mountains. Perhaps you will stop at one of the restaurants for a meal and visit the Maritime Museum. If you tour the harbor, check out the commercial fishing boats that come and go (sometimes selling fresh fish), the U.S. Coastguard boats, the water taxi Lil Toot, the Santa Barbara Sail Center, and Sea Landing. A few feet further on is the famous Stearns Wharf with all its exciting sounds and activities from fishing (standing or sitting at the end of the pier without a rail); I marvel that more people do not fall in (I am sure some have, but I have never witnessed it)! On the wharf is something for everyone, from all sorts of restaurants to shops and the Ty Warner Sea Center. Stearns Wharf is steeped in Santa Barbara history going back more than 100 years.

Another great beach walk is out near the Baccara, which has a nice coastal access area. This area is located west of Goleta, and the resort has set aside some parking areas and access to the beach is easy. At the beach, you can see some of the small coastal lagoons that form such important fish habitat for endangered southern steelhead trout. If you turn to the east and walk past a pier, you will come to where the More Mesa fault emerges in the sea cliff. If you observe closely at that location, you can see that the 45,000-year-old terrace is offset by a number of feet by the fault. The south side of the fault is uplifted relative to the north. We have a number of radiocarbon dates and other dates of the Mesa at this location, and it is about 45,000 years old. So, go out there and enjoy our environment, walk along the beach, and ponder some of the forces of nature that have produced Santa Barbara, the land of dynamic beauty.

OCEAN LOVERS CREED

Born of this earth, nurtured by knowledge, science and values:

- *I recognize the centrality of water to life, believe in reverence of and respect for the oceans of Earth, and will teach my children and others to also revere oceans.*
- *I will realize and teach others to realize that the ocean is not infinite, and that local actions may cumulatively affect the oceans of the World.*
- *I will not litter, pollute, or degrade oceans, and will not support activities that do.*
- *I will defend oceans from human manipulation that degrades their environment or reduces biodiversity.*
- *I will support sustainable ocean management and restoration so that my and other people's children will inherit quality oceans to enjoy.*
- *I will value ecological processes in oceans and pledge to help conserve their biodiversity.*
- *I will experience the ocean either as an individual or in small groups, whether it be for meditating, sailing, kayaking, surfing the waves, wind surfing, diving or snorkeling, pleasure boating, swimming, painting and photographing, wildlife and bird watching, or catch and release fishing, for personal reasons as it enriches my life. I will keep my memories and leave as small of an impact as possible.*
- *I believe in and support the right of parts of our oceans, through sanctuaries and parks, to remain wild in today's hectic world.*
- *I believe that urban coastal areas have community value and support marine parks near urban centers.*

Appendix: A Story of early California you can embellish and tell to your children

The Princess and the Sea Captain: *A Legend of Early California*

A work of fiction

by

E.A. Keller and Valery Rivera Keller

© August 3, 2008

Story Outline: Once Upon a Time in Early California in a Magical Kingdom

Princess Esmeralda, daughter of Queen Calafia, is born on Santa Rosa Island (a utopian land where people live in harmony with each other and the land). Her father was a Spanish explorer who died on the Island shortly after her birth. The name “Calafia” is legendary—in the same league as *El Dorado* and other places where the Spanish Conquistadors searched for gold and jewels in about the year 1500 A.D. Calafia is the name for a beautiful warrior queen who ruled a utopian island empire, and probably is the origin for the name “California.”

The surviving Spanish explorers return to their home port of Malaga, and they then visit the Alhambra Palace in Granada where they tell stories about a large island ruled by the warrior Queen Calafia (Spanish explorers thought what is now California was an island because of the large Gulf of California). One of the returning explorers who lived in Granada has a young son (nicknamed “El Burro” because he is so stubborn), and he tells his son stories about Queen Calafia and the riches to be found on her island.

Eighteen years later, Captain El Burro (he is still very stubborn), the son of the explorer who told the stories, sails to Mexico, Southern California, and the Channel Islands in search of gold and jewels. He is fixated on gaining riches for his family and for Spain. He intercepts Queen Calafia in a large canoe on the high seas near Santa Rosa Island making the channel crossing from the Santa Barbara coast to her island stronghold. Her mother, Queen Calafia, and others on the boat escape by swimming the short distance to the island. El Burro abducts Princess Esmeralda, who has emerald green eyes, for a ransom on the Island of Anacapa (surrounded by a high sea cliff). The canoe is hidden at the west end of the Anacapa Island. She is strong and rejects his crude and selfish advances. She has a pet island fox, and, while trying to escape the island at the west end where she finds the canoe, is saved from a shark (Big Tooth who tips the canoe) and drowning by a school of dolphins, led by Santiago (the dominant dolphin).

El Burro, the gold hungry rogue who is also a conceited bore, confronts Queen Calafia on her home island of Santa Rosa, not knowing of her power to transform people. She captures him but doesn't know where the Princess is held. Rather than kill him, she consults with tribal elders, who see something potentially good in El Burro's spirit, and advise the Queen to give him the face of a burro. She tells El Burro that the only way he can regain his handsome looks is for Princess Esmeralda to profess her love for him.

Captain El Burro returns to the mainland and his lair at Arroyo Burro Beach and Lagoon near Santa Barbara. He has a dream and comes to believe the treasure is hidden in a sea cave on Santa Cruz Island. He finds the cave, but rather than discovering gold and jewels encounters a spiritual teacher deep in the cave. Training with the teacher he has a spiritual awakening, and abandons his search for gold and exploitation of the New World. He seeks knowledge, truth and justice, and love.

Captain El Burro returns to Anacapa Island. Princess Esmeralda is given more freedom on Anacapa and she interacts with other villagers, an island fox (Rosy), a sea otter (Trouble), and a dolphin (Santiago).

Captain El Burro remains on Anacapa. At first the princess is repulsed by him, although he treats her kindly. A large earthquake occurs and he is seriously injured while saving Esmeralda. While he recovers, they get to know each other much better. She slowly begins to like Captain El Burro, in spite of his appearance, and he falls in love with her. She eventually professes her love to him. He is transformed back into a handsome man, and they are married on Santa Rosa Island.

The legend lives on, and to this day you can sometimes see the green twinkle of her eyes just as the sun sets in the west over the magical land of the Channel Islands and the Santa Barbara Channel.

Themes

Love conquers all

Love is transformational

Main Characters

Captain El Burro (handsome, stubborn, and, at one point, with the face of a burro)

Queen Calafia, who lives on Santa Rosa and has magical powers (given only to the Queen) to transform people and animals

Princess Esmeralda, daughter of Queen Calafia and the Spanish Explorer who died on Island after her birth

Alma, the Princess' advisor, caretaker, and guardian (think fairy godmother)

Conception, sidekick and alter ego of Captain El Burro (think Sanchez of Don Quixote)

Alcu, Spiritual Teacher who instructs Captain El Burro deep in the sea cave on Santa Cruz Island and imparts knowledge and compassion (think of Yoda in Star Wars)

Santiago, the dolphin who befriends Esmeralda and protects her when she swims in the sea off Anacapa where she is held

Rosy, an Island Fox (miniature fox, size of a kitten, pet of the princess)

Big Tooth, great white shark who patrols the islands with other sharks

Trouble, a sea otter (a fun-loving practical joker)

Main Scenes

1) Queen Calafia on Santa Rosa Island where Princess Esmeralda is born. The Queen's husband, Esmeralda's father, is a Spanish explorer who dies shortly after she is born (killed by an infection). Illustrate village life and growing up in harmony with the environment. Incorporate Chumash views of the world. There is an oral history handed down generation to generation. A collection of oral narratives of the Chumash is presented in the book, "Decemblers Child," which is based on the work of John P. Harrington and edited by Thomas C. Blackburn. The first oral narrative in the book speaks of the three worlds defined by the Chumash - the world in which we live, but also the one above and the one below. To the Chumash, the world in which we live was the center and the biggest island. They believed that two giant serpents held up the world, and, when they moved, they caused earthquakes. The world above was sustained by a giant eagle that, when its wings were spread, caused the phases of the moon and the flow of water in the streams and in springs of the earth.

The three sacred parts of the environment for the Chumash were earth, air, and water, with the sun as their principle god. The Chumash listened to their elders and passed on their stories and wisdom. They passed on the ideas that the earth is on top of the waters of the ocean and that there are three elements that must be treated with caution. Those elements were wind, rain, and fire, with the rainbow being the shadow of these elements that compose the world.

- 2) The Alhambra Palace in Granada, Spain - Story of Queen Calafia being told by the returning explorers.
- 3) Captain El Burro, a stubborn and money-hungry rogue, hears the stories and sails to The New World in search of riches for his family and for Spain
- 5) Captain El Burro abducts Esmeralda while she is crossing the Santa Barbara Channel. He imprisons her on Anacapa Island.
- 6) Esmeralda despises Captain El Burro (who has difficulty communicating with her as she speaks Chumash) and resists his advances. He is enamored by her beauty and spirit
- 7) While imprisoned on Anacapa Island, Esmeralda has a pet Island fox (Rosy) for company.
- 8) Esmeralda attempts to escape from Anacapa, and dolphins save her from a great white shark (Terror) and drowning (Santiago to the rescue). She returns to Anacapa.
- 9) Captain El Burro confronts Queen Calafia to demand ransom for Esmeralda. Rather than kill him, Queen Calafia wisely places a magic spell on Captain El Burro, and the handsome captain's face is transformed into that of a burro. She tells him the only way he can be transformed back is if Esmeralda professes her love for him.
- 10) Captain El Burro returns to the mainland and his lair at Arroyo Burro Beach and Lagoon near Santa Barbara. He has a dream and comes to believe the treasure is hidden in a large sea cave (one of many) on Santa Cruz Island.
- 11) Captain El Burro sails to find large sea cave on Santa Cruz Island where he believes treasure is hidden. There deep in the cave he encounters a spiritual teacher who teaches him the Chumash language and transforms his thinking from seeking only riches to deeper thinking about himself and others.
- 12) Captain El Burro returns to Anacapa, and Princess Esmeralda is given her freedom. She interacts with other villagers, an island fox (Rosy), a sea otter (Trouble), and a dolphin (Santiago) and rejects Captain El Burro.

13) El Burro remains on Anacapa Island and saves Esmeralda during an earthquake. He is seriously injured, and as he recovers with her care, the Captain and the Princess talk, walk, and swim with sea otters, dolphins, seals, and whales. In spite of his burro features, she falls in love with him.

14) With her love, he is transformed back into a handsome captain and they are married on Santa Rosa Island.

15) They are married on Santa Rosa Island by the spiritual teacher, and Rosie, Santiago and Trouble are transformed to people for a day.

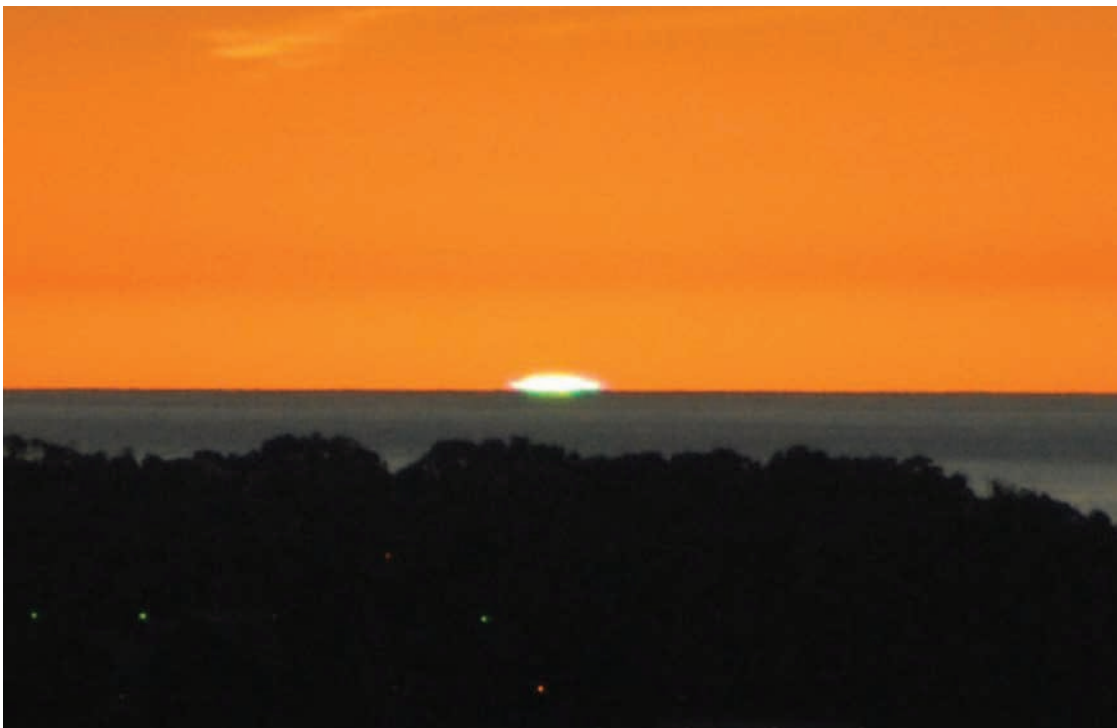
16) Sunset over the Santa Barbara Chanel today with the green flash—a twinkle of Esmeralda's eyes.



Location on Channel Islands: Anacapa foreground, Santa Cruz, upper left, Santa Rosa, upper right (faded image here)



Mainland site: Arroyo Burro Lagoon, much larger in 1500s



Green Flash—Esmeralda's green eyes remain in the channel to this day. Photo by John Grube

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Appendix: Short Glossary

Active fault: a fault that has been shown to be active during the past 10,000 years. Such faults are thought to be capable of producing a future hazard.

Alluvial fan: a fan-shaped landform that forms a segment of a cone, generally where a stream or river emerges from a mountain front. Sediments deposited on such landforms are a combination of mudflow or debris flow deposits and stream flow deposits.

Alluvial fan flooding: a specific type of flooding that is characterized by rapid, shallow flows in unpredictable channels that may change rapidly in time and space.

Anticline: a type of fold that has the shape of an arch. Examples in Santa Barbara area include the Mesa, Ortega Hill, the Riviera, and Hope Ranch.

Beach: the accumulation of loose material at or near high tide. In Santa Barbara, most of our beaches are composed of sand derived from the Santa Ynez Mountains, but may also include coarser material such as pebbles and boulders. Some beach material is also produced from sea cliff erosion.

Beach erosion: removal of sand from the beach area by wave or wind action. Beach erosion occurs when more sand leaves a stretch of beach than arrives by movement along the coast.

Beach rock: a type of rock that forms as water emerges from the sea cliff onto beach sand and is cemented by calcium carbonate. Beach rock is fairly common at the sea cliff below Shoreline Park, but also occurs in other places in the Santa Barbara coastal environment.

Bentonite: a clay mineral that formed from the weathering of volcanic ash. Most commonly in Santa Barbara, it is found within the Miocene age Monterey shale. Bentonite is an expansive clay, which can crack sidewalks, streets, and foundations of buildings.

Big Bend of the San Andreas Fault: the San Andreas fault has a sharp left bend that is responsible for producing the shortening across the Santa Barbara area and is important in producing the Western Transverse Ranges.

Bioswales: small, artificial channels with natural vegetation that are used to remove pollutants, including nutrients, before they move into another body of water. Bioswales are used at UCSB Manzanita Village and are designed to reduce the growth of algae in Campus Lagoon.

Catastrophe: a massive disaster that is characterized by large loss of human life and/or property where recovery will be a long and slow process.

Channelization: a harsh treatment of streams or rivers that often include straightening, deepening, and even concrete lining. A short section of Mission Creek near US 101 has been channelized, as have been some streams in the Carpinteria and other areas.

Debris flow: a rapid downslope movement of mud, rock, and boulders. Some debris flows can be extremely large and produce catastrophes.

Earthquake: natural shaking and vibrating of earth materials caused by the breaking of rocks along a fault. The major earthquakes on Earth are associated with plate boundaries.

Ecological restoration: application of ecological principles to restore the land and ecosystems. In Santa Barbara, restoration is going on at a variety of sites, including Arroyo Burro Creek, UCSB, and many other areas.

Ecosystem: an ecosystem includes a community of organisms and its non-living environment in which energy flows and chemicals cycle.

Ecotourism: responsible travel to an area's natural and cultural environments that conserves the environment and improves the well being of local people.

Environmental unity: the principle that states that everything affects everything else or, as sometimes stated, it is not possible to do only one thing. The principle is particularly important in being proactive about potential environmental problems.

Extraterrestrial impact: Earth is occasionally struck by comets or asteroids. It is a hypothesis that one that struck near Chicago 12,900 years ago may have had far reaching impacts for the continent, including Santa Barbara.

Fault: a fracture in the crust of the earth, along which displacement of rocks has occurred.

Fault line: refers to the line drawn on a map that shows the location of a fault. Actually, the fault is not a line but a plane, but is a line on a map.

Flood: over-bank flow of streams and rivers that causes potential damage to human facilities or may lead to loss of human life.

Floodplain: the relatively flat land adjacent to a stream or river that is produced by lateral migration of the channel or over-bank deposition. The channel and floodplain are part of the river system and develop in harmony.

Flood proofing: the process of protecting a building from flooding by building it above flood level or having gates that may be closed to keep water from entering a building.

Seawall: a structure constructed to reduce or eliminate beach or sea cliff erosion. They may be composed of concrete, wood, or steel. Over a period of decades, seawalls are thought to cause environmental damage by reducing biodiversity on the beach and leading to a narrower beach.

Fold: a bend in rock layers that may be either an arch-shaped structure, known as an anticline, or an inverted arch structure, known as a syncline.

Global warming: generally refers to anthropogenic changes as a result of burning fossil fuels. There have been many natural global warming events, but the 20th century rise in temperature is unprecedented in its rate of change and much of it due to human activity.

Isla Calafia: an Ice Age island in the Santa Barbara Channel. It was a small island during the Last Glacial Maxima about 20,000 years ago, when sea levels were approximately 430 feet lower than today.

Holocene: the most recent interval of geologic time, extending from approximately 10,000 years ago to present.

Landslide: relatively rapid downslope movement of rock and/or soil. Landslide is a general term for all types of downslope movement.

Last Glacial Maxima: the time period of approximately 20,000 years ago when glacial ice last reached a maximum. Associated with this time were sea levels as much as 438 feet lower than they are today.

Littoral cell: the cycle of movement of sand from the mountains to the beach and along the shore to an eventual offshore deposit area, often at the base of a submarine canyon.

Marine terrace: refers to a relatively flat landform, which has beach and land deposits on top of the wave-cut platform that represents an ancient coastal environment.

Mediterranean climate: a specific climatic zone that is characterized by warm, dry summers and wet, cool winters.

Mesa: mesa, which is Spanish for table, refers to the flat top marine terraces in the Santa Barbara area.

Mission Ridge fault: the Mission Ridge fault is a long east-west fault that has been responsible for uplift of the Riviera, also known as Mission Ridge.

Mission Ridge fault system: an east-west system of faults that extend from near Ventura and goes offshore at Ellwood Mesa. The fault includes a number of different fault strands that are associated with features such as the Riviera, Hope Ranch, More Mesa, and Ellwood Mesa.

Natural disaster: an event that occurs over a relatively limited time span and is limited to a particular area. The event causes significant loss of life and/or property damage.

Natural hazard: processes such as floods, earthquakes, and landslides that produce a hazard to both people and their property.

Natural service function: refers to natural processes that are hazardous, but also produce benefits to the earth and people. Examples include fertile soils on floodplains and mountains that are produced by earthquakes.

Plate tectonics: the theory that the outer part of Earth is broken into a number of large plates that are moving relative to one another. Sometimes these plates collide or move by one another or one is forced under another. Plate tectonics over geologic time have produced the ocean basins and major mountain ranges on Earth.

Pleistocene: the general period of geologic time from approximately two million years ago to about 10,000 years ago. It is an epoch of the Quaternary.

Radon gas: a naturally occurring radioactive gas that, when present in our homes, can produce a health hazard.

Salt marsh: a type of wetland, which is periodically flooded by salt water. Salt marshes in the Santa Barbara area are found in the Carpinteria Slough as well as Goleta Slough and other coastal lagoons.

San Andreas fault: the plate boundary between the North American and Pacific Plates. It is located north of Santa Barbara.

Sand dune: accumulation of sand from wind processes. Sand dunes vary widely in size and a number of relatively small dunes are found at UCSB and other places along the coast.

Santa Barbara Fold Belt: a system of nearly east to west folds and faults in the Santa Barbara area from the Santa Ynez Mountains south to the Santa Barbara Channel.

Santa Rosae Island: the large channel island that is the combination of Anacapa, Santa Cruz, Santa Rosa, and San Miguel today. Santa Rosae was present during the Last Glacial Maxima about 20,000 years ago.

Scarp: a steep slope generally produced by faulting, folding, or erosion. For example, the sea cliff is an erosional scarp, whereas faults produce fault scarps and folds produce fold scarps.

Sea cliff: the relatively steep cliff or scarp formed as the wave-cut platform develops due to coastal erosion. Sometimes a whole series of wave-cut platforms developed due to uplift of the land and coastal erosion over periods of 10s to 100 thousand years or more.

Sea wall: a structure (parallel to the shore) often constructed of concrete, large rocks, or wood pilings to protect coastal development.

Seismic sources for the Santa Barbara area: A fault that can produce an earthquake .See Table 2.1 where potential magnitude of earthquakes are shown.

Shoreline Angle: the angle at or about present high tide formed by the intersection of the sea cliff and wave-cut platform.

Steelhead trout: a rainbow trout that migrates to the ocean and returns again to spawn. Southern steelhead trout are listed as endangered species. They are found in a number of our local streams, including Mission Creek, Carpinteria Creek, Montecito Creek, and a number of others. However, these populations are very small.

Surfer's ear rot: refers to diseases that include ear infections that may develop from swimming in polluted ocean water most commonly found after a rainstorm where run-off from urban lands is contaminated.

Sustainability: development that ensures that future generations will have equal access to what our planet offers. Sustainable development is economically viable, does not harm the environment, and is socially just.

Technological fix: with respect to natural hazards, refers to attempts by people to control natural processes such as landslides and floods. This has had mixed results.

Tsunami: seismic sea waves generally generated by submarine earthquakes. These waves have very long wavelength and move rapidly across the open sea and may increase in height dramatically at the shoreline.

Vernal pool: small wetlands, generally on the tops of some of our mesas, that support a particular ecosystem and are valuable habitat during particular times of the year. Vernal pools are generally only wet during the winter months.

Wave-cut notch: a notch produced by wave action at the base of a sea cliff. See Figure 2.22.

Wave-cut platform: relatively flat surface produced by wave erosion, most commonly exposed at low tide during the winter when the sand has moved slightly offshore.

Wildfire: a rapid biogeochemical oxidation process that occurs every few decades in the chaparral environment of Santa Barbara.

Uniformitarianism: a fundamental principle of earth science, which states that the present is the key to the past. That is, by studying present day processes, we may be able to better recognize processes that occurred in prehistoric times. We may also turn this around and say that we can look at present and historic processes to help predict areas where similar process such as landslides or floods may occur in the future.

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