This book is dedicated to
Jim and Julie
Preface
Finding a Sense of Place and Purpose in the Golden State
Start Your Journey Here

Look out your window or walk down the street or on to the nearest trail. Use your senses to reconnect to your surroundings. What stories can you discover from a landscape that is screaming out to you? What are the natural and human forces that are shaping this place? How can you use modern technologies to not only measure and interpret what is there, but to imagine what it could be? How can we translate these signals into language we can all understand and into messages that are relevant to our everyday lives?

California may have started as an island paradise in someone’s imagination, but it has earned a publication and a project that can help us understand this most powerful state in the U.S. Just as geospatial technologies ignited the renaissance in geography that has made it more relevant and applicable and one of the top job-producing disciplines in today’s world, this publication and project is designed to provide the information and tools to power a new wave of geographic literacy, understanding and problem-solving that can carry our state forward.

Students and Teachers
In this third edition of Rediscovering the Golden State: California Geography, we are reaching out to a wide audience of people who want to better understand and appreciate California’s diverse natural and human systems and landscapes. An important component of this audience is made up of students and teachers studying the geography of California. The previous (second) edition in 2006 quickly became the leading “go-to” textbook on California Geography in colleges and universities throughout the state. It has also been used as a key reference for schools and workshops of all grade and age levels. This book is designed so that students will be able to:

- Examine the forces, processes, systems and cycles that shape California landscapes and impact its people.
- Identify the diversity, connections, and change that define the Golden State, including powerful connections between the state’s and the world’s many changing physical and human processes and landscapes.
- Apply geospatial techniques to research and identify places and events and to ask and answer today’s most important questions.
- Understand the major issues and solve problems that confront California today.
- Rediscover your sense of place.

Reaching Out to a Wider Audience
By 2012, Californians were still adjusting to and preparing for seismic shocks, changing climates, wildfires, water crises, and a variety of other hazards and changes in their natural environments. They were also adjusting to economic crises and social upheavals that had slowed population and economic growth and were further redistributing and concentrating wealth within specific California regions and communities. The impacts of accelerating revolutions in new technologies, the movement and settlement of its diverse and restless populations, and the search for a more sustainable energy future were also impacting the state’s people and landscapes. These and many others that you may be considering now are just a few examples of issues and problems addressed by geographers—and this book—that impact every Californian every day.

Increasingly, Californians are searching for new ways to improve their state and plan for the future. As their discipline has become more relevant and applicable to our world, modern geographers are responding by reaching out to these concerned citizens. Following that spirit, Rediscovering the Golden State: California Geography is written for those who want to better understand issues, solve problems, and help direct the path California takes through the twenty-first century. Accordingly, Rediscovering the Golden State: California Geography demonstrates how modern geography has evolved into a discipline that cuts across traditional boundaries, linking seemingly disparate real-world issues in a practical and useful fashion.
Preface

This third edition has further evolved to reflect the dynamic, stimulating, and thought-provoking environments and landscapes of the Golden State. It comes during a time of great adversity and promise that challenges every Californian every day to redefine and reimagine what has been called the California Dream. It is a time when Californians are divided in many ways socially, economically, politically and geographically. But, with all of our natural and human resources and diversity, geography helps us understand our connections and common goals so that we make the decisions and steer the changes that will continue to move our state forward as we also lead the world. And like the second edition, we challenge the reader to look beyond simplified stereotypes and assumptions to the sometimes complex realities that make California unique. You can see that this third edition is much more than an update; it is a refreshing reinforcement of the original unifying themes of previous editions, showing how unequalled diversity, powerful connections, and accelerated change continue to shape California’s landscapes through the twenty-first century.

In this book, you will see why there are still no rivals to the diversity of California’s physical forces and human processes and the landscapes they are creating in the twenty-first century. We continue to unveil powerful relationships and to reveal profound connections between seemingly disparate events and landscapes. We explore how Californians continue their attempts to confront and control remarkable changes that are dramatically shaping this state as we progress through the twenty-first century. If it was amazing how six years changed California between the first and second editions, it is astounding how the last six years have changed the state for this third edition.

Keeping it Relevant, Applicable and Up-to-date

In this edition, we once again take advantage of some of the most current geospatial technologies that will help illustrate concepts, clarify discussions, and lead to problem solving. Thanks to the efforts of Dr. William Bowen and the California Geographic Alliance, we have incorporated cutting-edge satellite images and maps that add color and challenge the reader to look further. We include just a few examples of some of the most current imagery on line that takes the viewer on breathtaking tours over the state, flying and observing from different directions. You will never again see California with the same perspective. We also use updated population and related human geography maps made by accomplished geographers James P. Allen and Eugene Turner (CSU Northridge) as presented at the California Geographical Society. We include select maps from geographers Mary Beth Cunha and Stephen F. Cunha of Humboldt State University’s Institute for Cartographic Design that also appear in their California Geographic Alliance Atlas. Geographer and artist Patty Kellner’s paintings of California landscapes add a colorful personal touch to the end of select chapters.

Finally, this edition is part of a new and larger project. You will have access to our “Visualizing California: Finding a Sense of Place and Purpose in the Golden State” Web page at www.rediscoveringthegoldenstate.com. There, you will find thousands of images and essays that tell captivating stories, including additional links to new data and other informative sites. This living Web site takes the viewer on a regional and then systematic exploration of the state, chapter by chapter. You will find maps, thousands of photos, and other information that will take you far beyond the scope of one book or geographic course; teachers should find more supporting information than you will ever need or have time to display in any single course.

You can see how we are dedicated to making this an even more relevant, colorful and user-friendly edition, a project that is designed for a wider audience. The additional photos and figures better illustrate important concepts and highlight important places. Refreshing updates emphasize recent changes and illustrate visions of the future California. It is designed for those who want to learn more about the processes that have shaped the state’s natural landscapes. It is also intended for those who want to learn more about our human landscapes and how geography has shaped the state’s human history. It serves people working in businesses, organizations, education, and government agencies, who must better understand and anticipate current and future trends. It is written for concerned citizens and policy makers who are responsible for making informed decisions that will move California in a positive direction. And it will serve well those who are simply curious, including those living in and out of California who just want to learn more about the Golden State and its continuing experiments.

To all of you, let this be your invitation. Here’s your opportunity to learn why geographers and geographic techniques play increasingly important roles in analyzing issues, trends, and problems, and in shaping the future of California. Rediscover your sense of place and the power of place; break through your barriers, and reconnect to your surroundings. If you are curious, we have opened the door for you by creating your best single source about California. From this publication, you can pick and choose the information that suits your needs, information that will help you better understand the most powerful and dynamic state in the U.S.

◆ SOME UNIFYING THEMES

Three very general themes shape our examination of California geography in this text. The diversity of California’s physical and cultural landscapes is exceptional. The array
of geologic processes and landforms, climates, plant and animal communities, and waterscapes in California continues to challenge our best natural scientists. And, though California’s diverse human geography is more than a reflection of the state’s natural history, its myriad human landscapes and cultures are sometimes products of the natural settings on which they are founded.

A good understanding of California’s geography must include the connections and relationships in time and space among so many aspects of the state’s natural and human environments. The first step is to appreciate how humans have depended on California’s natural settings and resources, and then to see how and why humans have impacted, modified, and exploited these natural landscapes. We can then begin to focus on more specific connections and issues within this larger framework. One example is how the distributions of natural resources and primary industries have influenced the nature and location of California’s modern economies and urban landscapes. The scales or scopes of interconnected problems and issues are often more specific, but they must always be considered under that larger, more general umbrella of connections and relationships, including those to the rest of the world.

Finally, the rate of change in California’s natural and human landscapes is remarkable when compared to any other state and to most other locations on our planet. These changes range from active geologic processes to unpredictable and anomalous patterns in weather and climate, from the expansion or destruction of certain species and entire communities of plants and animals to the enormous water diversion and flood control projects that have radically changed California’s waterscapes. Change helped define California’s natural environments even before the great human settlements and developments.

The changes wrought by California’s people are even more dynamic. Great migrations, which contributed to exploding populations, have occurred not only into the state, but within the state. Migrations brought a diversity of cultures into California, and the geographic and economic movement of these cultures has a significant impact on the state. There are few places in the world where people have such mobile and versatile lifestyles and careers. And there are few other places where people and their cultures, economies and landscapes experience such recurrent and dramatic upheavals. The ability to change continues to be an essential survival strategy in the state.

◆ ACKNOWLEDGMENTS

Thousands of students throughout the years at Santa Monica College and at colleges and universities throughout the state have inspired me with their thoughtful suggestions and input for this third edition. A few students contributed with specific research for this edition, such as Christine Menges, with her fine work updating species names in the chapter on biogeography, and Stefan Laage. Thanks to our most professional department chair Vicki Drake and to geographer Pete Morris for their insightful suggestions. There are also dozens of colleagues and professionals from across the state that can be added to the original list of professors and professional geographers who made valuable suggestions for this edition. During all of my California experiences growing up, going to school, working in private industry, and years of teaching, I have been lucky to have family, friends, colleagues, and students who color my life and my work with positive learning experiences. Without all of you, this publication would not be possible. Thank you for encouraging my love for geography and for California.

Thanks especially to Dr. William Bowen and the California Geographic Alliance for producing the impressive images and flyovers and to James P. Allen and Eugene Turner from CSU Northridge for their exceptional maps showing population and related trends. Mary Beth Cunha and Stephen F. Cunha contributed excellent maps made at the Institute for Cartographic Design at Humboldt State University’s Geography Department from their California Geographic Alliance atlas. Geographer and artist Patty Kellner contributed some of her inspirational paintings that add color and personality to the end of select chapters. You will notice several maps and phenomenal photos by photographer Rob O’Keefe, but his work building and contributing to our Web page helps to make this a one-of-a-kind project that will live on at www.rediscoveringthegoldenstate.com. These remarkable geographers and cutting-edge products combine to make this an exceptional and memorable publication.

The Association of American Geographers (AAG), Association of Pacific Coast Geographers (APCG), and the California Geographical Society (CGS) publications and conferences exposed a wealth of recent research that reinforced this edition. Past and present fearless leaders of the CGS deserve much credit for building an organization that should make all California geographers proud. Numerous other professional organizations and scholarly publications have contributed to the quality and credibility of this work.

Finally, special recognition goes to the professionals at John Wiley & Sons, Inc. and Ewing Systems for their dedication and patience throughout this process. Debbie Blume and Jan Ewing added their time, skills, and expertise that improved the quality, credibility, and success of this publication.

◆ ABOUT THE AUTHOR

William Selby is a native Californian who has explored every corner of the Golden State. He earned his under-
graduate degree in Southern California (California State University, Fullerton) and his graduate degree in Northern California (San Francisco State University). He has lived and worked in many diverse California landscapes and neighborhoods, from rural to urban, in both southern and northern areas of the state.

Professor Selby had extensive experience in private industry before beginning his teaching career in 1981. He then taught geography and science to a variety of grade levels and age groups before taking up his current position at Santa Monica College in 1985, where he has served in many leadership roles. He has also been a guest lecturer at UCLA, taught courses at UCI as a Visiting Professor and has led many teacher training workshops. His membership and participation in several professional organizations includes numerous presentations at the Association of American Geographers, Association of Pacific Coast Geographers, and the California Geographical Society. In addition to teaching a wide range of earth science and geography courses, Professor Selby organizes and leads many field trips throughout the state and beyond with his colleagues and students. He is recognized as an accomplished speaker on a wide range of subjects in geography and earth science.

His diverse research interests and professional and personal activities reflect Professor Selby’s devotion to geography, his love for the Golden State, and his concern for its future. This book combines his academic expertise and his practical experiences within California’s myriad landscapes, along with exceptional contributions from many other scholars and professionals, to present an invaluable guide to California in the twenty-first century.
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Chapter 1

Getting to Know the Golden State

From Dreams to Reality: An Experiment Called California

California has always been a land of legendary extremes. Stories of its incredible natural beauty, its extravagant wealth adjoining abject poverty, its diversity of natural resources and landscapes, and its violent and destructive natural disasters make world news headlines each year. These stories have been repeated since the first Spanish explorers and then settlers arrived here centuries ago. And, California’s people, both real and imagined, have always successfully competed with nature for the spotlight. Even its name originated from a mythical location.

Exploiting imaginations after the European “discovery” of America, the Spanish writer Garcí Ordóñez de Montalvo first named a place called California in his Las Sergas de Esplandián (The Exploits of Esplandián). Even in this first use of California in 1510, he fabricated an island paradise near the Indies where beautiful black Amazons were surrounded with riches such as gold and pearls.

The name California first appeared on Spanish maps labeling the Gulf of California and the Baja Peninsula in the 1560s. After the Spanish “discovered” California in 1542 and began moving and settling north in 1769, what is today known as California was often given the name Nueva (New) or Alta (Upper) California. As the first Spanish explorers and settlers sent their actual impressions back to their homeland, they described a landscape hauntingly similar to today’s. They painted pictures of wildly different landscapes that ranged between a comfortable paradise and a harsh land where agonizingly hard work and plenty of luck were required for survival. Similar expressions were recorded throughout the Spanish and Mexican Eras; such reports continued even after California became the thirty-first state in the United States in 1850. More recent writings continue to conflict as they portray a land of remarkable contrasts and contradictions.

Today, California’s unsettled population is always evolving, always moving on, creating repeated social upheavals that
leave its past in the dust like a forgotten stranger. It is as if California’s people are trying to emulate the turbulent forces that shape its natural landscapes as the world looks on. California is and will continue to be a celebrated culture hearth in the twenty-first century. Critics beyond its borders have tried to minimize the importance of this nucleus for our civilization, and although some Californians fear the responsibilities that accompany such esteem, California earns its attention. As the reality of the state’s stature with all its positive and negative features, becomes more apparent, every Californian continues to play a role in molding this great experiment, this model we call California.

Recent college classes (especially in literature) in California and across the country illustrate this fascination with the state and include such titles as “Visions of California,” “California Dreaming,” and “Global California: Crisis and Creativity.” Associate Professor Beverly Hogue at Marietta College in Ohio (who specializes in 20th Century literature) brought her students to California in 2011. She made it clear in an L.A. Times interview published in 2012: “The popular culture’s image of California is a place where anything can happen. We still see it as a place of possibility.” Perhaps it was once best expressed in a portion of the University of California Berkeley’s 2004 description for their course on California posted on their Web site, an expression that is just as relevant today: “California may be ‘a state of mind’—as bumper stickers say—but it is also the most powerful place in the most powerful country in the world. Its wealth and diversity in both human and natural resources has contributed to its extraordinary resilience, making it a center of technological and cultural innovation.” Their course description in 2012 included, “California has been called ‘the great exception’ and ‘America, only more so’.”

FOR THE STUDENT: KEY DISCOVERIES IN OUR CHAPTER ONE JOURNEY

- This book is a systematic, topical survey of the modern geography of California. It is designed to provide useful information that can help us understand the state, examine modern issues, and solve problems.
- California’s diverse natural and human landscapes represent ideal laboratories; they provide a wealth of opportunities to make scientific/geographic discoveries and to research a variety of processes, cycles, and systems that are shaping landscapes on many scales.
- The five fundamental geographic themes and six essential elements of geography are common threads that tie together topics covered in this and other chapters of this book.
- Diversity, connections, and change are evident in all California landscapes and in the processes responsible for shaping them; consequently, they are common themes used in this chapter and this book.
- Critical to our understanding of California is recognition of some important geographic factors. They include its large area and elongated shape, its situation in relation to the rest of the world, and the human/environment interaction that has shaped its landscapes.
- Early California remained relatively isolated even after the Spanish, Russians, and other invaders discovered and began settling it. Strong ties to Latin America developed, continued during the Mexican Era, and have been recently renewed. Since the mid-1800s and the Gold Rush, growing populations and advanced technologies have strengthened connections with other cultures and nations, particularly on the Pacific Rim.
- The state can be divided into diverse physiographic regions which are connected in profound ways and are experiencing different types and rates of change.
- The survey of the regional geography of California in this chapter introduces the state’s general landscapes and some of the processes that change them. In the survey, we sweep clockwise around the state from region to region. This information will serve as a foundation on which the more dynamic and scientific, systematic, and topical study of the state is constructed in later chapters.
- Though each physiographic region demonstrates unique and recognizable qualities, each also shares processes and landscapes with its neighbors. These differences and divisions and relationships and connections combine to shape modern California.
The first decade of the twenty-first century brought innumerable changes and dramas to California’s natural landscapes, many that you will read about in more detail in Chapters 2–6. Tectonic plates continued to shift and earthquakes rumbled across the state from the northwest coast to the border with Mexico. The steaming cauldron opened in the downtown Paso Robles parking lot during the 2003 San Simeon earthquake was finally filled by 2010. Not far away, the much anticipated and overdue Parkfield earthquake of 2004 finally became the most monitored temblor in history. The January 2010 6.5 earthquake and aftershocks 33 miles west of Eureka were reminders that plate boundaries are active off the northwest coast. NASA data showed that the Easter Day, 2010, 7.2 magnitude earthquake just south of the border shifted the crust up to ten feet in Mexico and even moved Calexico and surroundings on the California side 2.5 feet further south. Noticeable aftershocks continued rippling into California through 2012. The March 2011 tsunami that ripped from Japan did $50 million damage along the state’s coastlines, a gentle reminder of dangers lurking on the Pacific Ring of Fire.

Record drought that ravaged Southern California landscapes and paved the way for bark beetle infestations that devastated more than 50% of many mountain forests came to an end in 2005 only to repeatedly set the stage between unreliable heavy rain and snow years into 2012. Historic wildfires on slopes from the Sierra Nevada to San Diego County that took lives and thousands of homes earlier in the century were followed by other infernos such as the historic Station Fire of 2009 that ravaged the San Gabriel Mountains above Los Angeles. All of these blazes left surrounding lowlands vulnerable to deadly mudslides that inevitably followed with the rainy seasons. These events and other slides were reminders of the powerful external forces tearing away at uplifted landscapes created by the geologic forces just mentioned. While Californians continued their debates about how much water could be diverted from north to south without further damage to water systems in the Delta and Owens Valley, the future of the Delta remained uncertain. Colorado River water supplies became less reliable, and by 2011 an appeals court finally cleared the way for San Diegans to buy water from Imperial Valley desert farmers. At the other end of the state, Klamath Basin farmers near the Oregon border struggled with downstream Native Americans and the fishing industry for Klamath River water rights as the state pondered what to do with some dams that were no longer useful. It is not surprising that the twenty-first century brought little relief to decades of California water conflicts in our quest for sustainable water policies that you will also read about later.

Changes in the Golden State’s human landscapes were just as remarkable into the second decade of the new century and are outlined in Chapters 7–12. The state that had grown by about half a million people per year in the first years of the new century (almost the equivalent of adding the population of Boston or Cleveland or Washington, D.C. or Oklahoma City or New Orleans each year) had “slowed” to less than 300,000 per year during the recession at the start of the second decade of the century. By 2012, there continued to be no other state that rivaled California’s population of more than 38 million. And with continued immigration from other countries, no state or country can match California’s numbers in ethnic and cultural diversity, including the number of languages spoken and the number of people who speak them. California remains the number one agricultural state, leading in the production of numerous products for the nation and the world. And though extensive rural lands continue to support primary industries, these bucolic regions also endure as some of the state’s most economically depressed, fueling debates about the use of our natural resources.

More advanced, modern industries fuel California’s economy in the twenty-first century. Silicon Valley’s celebrated high-tech boom of the late 1990s crashed into a bust in the early 2000s and was surging again by 2012. Mislabeled and exploited energy deregulation at the start of the century that brought a brief power crisis was replaced with a steady rise in energy prices in the second decade and a search for the sustainable energy future that will carry the state forward. Still, robust recovery followed into 2006, boosted by a diverse balance of manufacturing, business services, trade, tourism, entertainment, retail, real estate, and government services. And though the state’s massive economy grew to the seventh most powerful on the planet by the start of the century, there was another continuing drama: economic realities and mismanagement left us with a government deficit larger than the total budget for most states and many countries. These and other events set the stage for ongoing dramas and upheavals.

Powerful forces joined the spread of suburbs into rural areas in the early 2000s. Examples include big box super stores that take advantage of local tax incentives to bring sprawling parking lots and retail revolutions with their low prices and plentiful products, while squeezing out more traditional businesses with stronger community ties. Most of the landscapes that were in California’s fastest growing regions (now the Inland Empire and Central Valley) are defined by such developments among classic and sometimes generic suburban sprawl.

By 2007, the perfect economic geography storm was brewing in California and by 2008, it descended in ways that would dramatically change lives, expectations, and landscapes in California for years. When the housing markets collapsed, the recession hit hardest in newer suburban and exurban neighborhoods full of new homeowners (mostly working and middle class), especially in the Central Valley and southern California’s Inland Empire. Though this trauma made more difficult the entire state’s attempts to improve its infrastructure and education opportunities, and to fight poverty and growing economic stratification, these inland communities and their people suffered the most. Many of these families surrounded by foreclosed properties and more than 15% unemployment rates lost their grasp on the California Dream, driving wider wedges between very different Californias. First, the growing gap between rich and poor is evident in nearly every California landscape. Second is the geographic gap between the culturally progressive and economically diverse coastal cities and the more conservative cultures within real
Meanwhile, the technology revolution continues to dramatically transform the way we interact, do business, and connect to our surroundings.

Yes, there are powerful forces reshaping and remaking California landscapes in the twenty-first century. Pessimists may claim that all this turmoil has left California adrift and ungovernable now as the ninth most powerful economy in the world, but we have heard that before. Optimists argue that many of these recent trends and experiments encourage debate about important issues such as the quality of our environment, housing, economy, and living and working conditions, all of which are addressed in this book. Whether we are waiting for the next big earthquake, anticipating and adapting to climate change, or the next economic turns or urban trends, change continues to help define Californians and their landscapes.

Some observers use a microscopic viewpoint to pick apart the very details that eventually come together to build California’s landscapes. Some of their precise observations and studies may pinpoint particular locations or focus on specific issues or problems, but investigators of detail must never forget the big picture. How are surrounding locations connected, and how are seemingly disparate events related? At the other end of the spectrum are those who would use a telescope to view California. They see the major trends and paint the state and its people with sweeping generalizations. Though this may be an easy method, it can provide an unrealistic picture that denies the specific exceptions and the uniqueness within California’s landscapes and its people.

You might study a single grain of sand on the beach or the mountains, rivers and coastal systems where it was eroded, transported and deposited. You might observe a street sign or homeless person on one city block or study the entire infrastructure of the metropolis where they are found. Alternating your scales of view helps strip away the film for a clearer vista.

Therefore, it is necessary to zigzag between these two approaches, going from the smallest to the largest scales and back again. A balance must be found between them in any meaningful study of California. This is a great challenge in a state that is so big and that has so many diverse landscapes with so many powerful stories to tell. It is also a challenge because most of California’s landscapes and its people fit somewhere between the extreme stereotypes that constantly bombard us from popular sources of information. The reality is that most Californians share the same basic values and dreams of many Americans and of people in other countries.

The big difference is that California landscapes and their people always seem a little closer to the edge. Although Californians’ dreams are lofty and spectacular and though they may have become more difficult to realize, they are still possible. Likewise, Californians’ fears of impending failure and disaster may also be deeper than other Americans. Like California’s landscapes, its people seem a little more willing to participate in the next experiment. They are always evolving, but they are also waiting for that next surprise, that next unexpected drama which must lie ahead in such a dynamic state.

Figure 1-1. Cameras mounted on this Google car show how they have accumulated thousands of 360-degree photos of many of your favorite locations in California. This survey car was crossing Lombard Street toward the Marina in San Francisco taking photos that you might have seen on Google’s website, another example of how technology has revolutionized how we study geography.
Consequently, this state continues to be ripe for research, planning, and innovation by modern geographers, whether they are formally trained professionals or amateurs and volunteers just testing the waters. Like California, geography continues to evolve and experience a renaissance. Modern geography has become a more practical, more useful discipline. It is being used by all of us to assess the sites or the environments of places where we live, work, and visit. And it is being used to understand the situations (or surrounding environments) of those specific locations and the relationships and connections between them.

**HERE’S CALIFORNIA**

**Finding the Golden State and Its Boundaries**

Consult a good map for this section. California’s northern border with Oregon is at 42 degrees N. The southern border with Mexico does not follow a line of latitude. It starts on California’s southwest corner just north of 32 degrees, 30’ N on the coast, and follows a line running slightly north of east, until it ends at the Arizona border (the most southeast corner of California).

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**Twenty-first Century Geography In California**

Just as California continued to experience extraordinary change into the twenty-first century, geographers around the nation and the world organized to define and direct profound changes caused by the renaissance in their own discipline. In 1994, they identified and agreed on eighteen National Geography Standards and organized them under six essential elements of geography. By 2009, geographers had refreshed and updated a second edition, “Geography for Life”, with more emphasis on geospatial technologies, globalization, and global environmental change. These published standards were built on the five original and fundamental geographic themes which focus on location, place, human/environment interaction, movement, and regions. These themes and standards are also among the common threads that stitch together this work on the geography of California.

How are essential geographic elements and standards addressed in this book? We will see California in spatial terms as we organize and analyze natural and human processes, systems, and landscapes. This requires the use of maps (both physical and mental) and other geographic tools and modern geospatial techniques. We will learn about the many places and regions that make up California. We will examine California’s physical (natural) landscapes and the processes that change them. We will also learn about the people and cultures of California, their human landscapes, and the processes that are changing them. Additionally, we will look at the connections and relationships between California’s natural environments and its people. Specifically, how has the physical environment affected human populations and landscapes? Then, how and why have humans modified California’s physical landscapes and used its natural resources? Finally, after interpreting California’s past, we will use geography to understand present landscapes and to plan for twenty-first century California.

Further response to the renaissance in geography came from the National Research Council with their 2010 report, “Understanding the Changing Planet: Strategic Directions for the Geographical Sciences.” Their eleven strategic questions/directions are designed “to focus research and leverage new technologies to harness the potential that the geospatial sciences offer.” Again, we address these topics throughout this book that include our physical environment, biological diversity, climate change, human population, migration and health, effects of globalization and how we do research and use maps to visualize and study the state.

Another way of looking at modern geography is to break it down into its basic subdisciplines. Physical geography focuses on natural landscapes and the processes responsible for them. Geomorphologists, climatologists, biogeographers, and hydrologists are among the many physical geographers. Human geographers study human landscapes and the people who shape them. They may have more specific interests, such as population, migration, cultures, economies, and rural or urban landscapes. Finally, modern geographic (geospatial) techniques are being used by all geographers. Computer cartography, GPS, air photo interpretation and other remote sensing methods, and widespread applications of geographic information systems (GIS) are tools of the twenty-first century geographer as they consistently rank near the top of job-creating industries. Regional geographers who study specific geographic regions must incorporate each of these subdisciplines and methods into their research.

Regardless of the specific method of study, it is obvious that California’s natural history and landscapes and its human history, its people and their landscapes are more than dynamic and diverse; they are connected and related in profound ways. They offer hidden secrets yet to be discovered, and they offer astounding surprises yet to be experienced. This is why modern geographers—and all Californians—must play key roles in the understanding of California’s natural and human landscapes and the people who inhabit them. They must also help drive California in a direction that will improve the living environments of all its people. If geography and geographers are left out of the critical decision making that will shape the future of our state, it will be unfortunate for geographers and a lost opportunity for all Californians.

Our knowledge of geography will enable us to better understand our state and direct it toward a more promising future.
Chapter One  Getting to Know the Golden State

The eastern border with Nevada follows the 120 degree line of longitude south—from the state's northeast corner on the Oregon border—to Lake Tahoe. From here, another straight line then trends southeast, still marking the California/Nevada border, and slices across lines of latitude and longitude until it ends at a point shared with the Nevada and Arizona borders in the Colorado River. From here, the border with Arizona follows the Colorado River south until it reaches Mexico at the far southeast corner of California. This eastern border and the Colorado River meander east almost making it to the 114 degrees W line of longitude, just east of the Whipple Mountains.

California's coast veers from just past 117 degrees W at the Mexican border, toward the northwest, far west of the 124 degree longitude at Cape Mendocino (the westernmost extension of California's coastline). The coastline's enormous range of longitude might surprise those who consider this a north–south trending state. San Diego's longitude is the same as parts of Death Valley and central Nevada, up to 650 km (400 miles) of longitude east of Cape Mendocino!

Consequently, this northwest–southeast trending, elongated state covers about 9½ degrees of latitude and more than 10 degrees of longitude on our earth. (Since lines of longitude merge closer toward the poles, you can see that a length of a degree of longitude is shorter than a degree of latitude through California. Then, you can see that the distance east-west even when measuring through the full range of longitude is shorter than the north-south distance through the state.)

Depending on the method and map projection used (use a good map in this section), the geographic center of California is somewhere in the area between these two example measurements:

- Latitude 37°, 9' 58.23" N
  Longitude 119°, 26' 59.3" W
- Latitude 36°, 51' 21.60" N
  Longitude 119°, 32' 59.3" W

The first location was often accepted after the 1970s, but some geographers have since noted that the term “center” is somewhat subjective in such a strangely shaped state. As another example, the second location was presented by Alon Yaar, a student at the University of Southern California, at the 1996 Annual Meeting of the California Geographical Society. The average of these and other measurements puts the center somewhere in the Sierra Nevada foothills about 35 km (just more than 20 miles) northeast of Fresno.

Therefore, if you find yourself around 37 degrees N and 119 degrees, 30 degrees W, you are near California's geographic center. Our review of California's odd shape and borders may seem to diminish the importance of such detail (see Figure 1-1).

Size and Shape Help Define California

So much of California is about being big. With approximately 411,013 sq km (158,693 square miles), or 101,563,520 acres, it is the third largest state, ranking behind Alaska and Texas. It is larger than Japan, Great Britain, Italy, or Norway. As previously noted, it is much longer than it is wide. A straight line from northwest to southeast along its coast runs about 1,220 km (nearly 760 miles), but there are at least 2,027 km (1,260 miles) of entire jagged coastline. (California's entire tidal shorelines—including inlets into bays and rivers and the outer coast and offshore islands—total far more than 5,000 km (more than 3,000 miles long). In contrast, California is barely more than 240 km (150 miles) wide from San Francisco to Lake Tahoe. At its widest, it is barely more than 400 km (250 miles) from Point Arguello to the Nevada border.

Diverse Natural Landscapes

This large area and long shape have contributed to the state’s number one ranking in so many categories within its natural and human landscapes. Its Death Valley has the lowest point in North America at 86 m (282 feet) below sea level. There are other desert valleys all the way to the Mexican border that drop below sea level. California has the highest mountain peak in the United States outside Alaska—Mount Whitney, at 4,421 m (14,495 feet). There are numerous other peaks higher than 14,000 feet, and they are all in the Sierra Nevada except White Mountain Peak (14,246 feet) and majestic Mount Shasta (14,162 feet). The variety of high mountains and deep valleys are a result of the many different geologic processes and landscapes contained in such a large state situated along active tectonic plate boundaries. California also has some
of the most varied and abundant earth resources on our planet. These geologic processes and landscapes are reviewed in Chapters 2 and 3.

Across such diverse topography and nearly 9% degrees of latitude, there must also be a wide variation of climates. From near Death Valley to the northwest coast, mean annual precipitation ranges from less than 5 cm (2 inches) to more than 250 cm (100 inches). Each year, temperatures in the state will range above 49°C (120°F) in the southern deserts to well below −18°C (0°F) on numerous occasions in the northern mountains. (The hottest temperature ever recorded in North America was 57°C (134°F) in Death Valley.) These changing climates are explored in Chapter 4.

Figure 1-3 Its location and situation and its size and shape help define the state of California. The boundaries and names of counties reflect a rich history.
Is Bigger Really Better?

There are disadvantages to having such a large, elongate territory contained in one state. Divisions between the resource-rich, rural north and the economic and political urban powerhouses of the south have always fueled talk of breaking up this one large state into two or three smaller ones. Since 1941, some northern California residents have argued for their own State of Jefferson that would merge counties at the very northern end of the state with the southern end of Oregon, locating the capitol inland at Yreka. The California legislature nearly split the state into north and south in 1965 and 1967. The idea became popular again during the 1990s, when every rural northern county voted to break away into its own state of “Northern California.” These water-rich Californians saw their rural values and lifestyles (supported by primary industries such as timber, mining, agriculture, and ecotourism) as no match for the perceived water-grabbing, cutting-edge urban giants to the south. But, statistics show that instead of benefiting from the creation of a new state of Northern California, these rural counties would have isolated themselves into one of the poorest states in the United States.

Still, whether perceived or real, the divisions exist. Northern Californians often share typical stereotypes and sweeping generalizations about the south, including images of high crime rates, air and water pollution, traffic jams, higher taxes, fast-paced, unrestrained lifestyles, and unmanageable cities. In response, some southern urbanites may try to paint northerners as backward isolationists lacking culture and living where there are fewer conveniences, little social life or excitement, and little opportunity to change and grow.

Meanwhile, the populations of the San Francisco Bay Area and parts of the Central Coast and Central Valley are often caught in the middle of this philosophical tug-of-war. They may despise Southern California attitudes and lifestyles, but they also see themselves as more cosmopolitan and more on the cultural and economic cutting edge than their rural neighbors to the north. Some claim this calls for a third state—a Central or Middle California.

Such divisions are enhanced by geographic distance. How does a resident of San Diego relate to events in San Francisco or the state capital of Sacramento, with a travel distance more than 800 km (500 miles) to the north, much less to someone in Crescent City or Alturas, more than 1,300 km (800 miles) north? And how can an effective and efficient state government operate across such disparate landscapes?

It becomes apparent that California’s very strengths—its size, the diversity of natural and human landscapes, and the various forces shaping them—can be construed as liabilities by those who would divide the state.

Proponents of division may not realize how California’s seemingly separate regions and people depend on one another and are connected in profound ways. Just watch as the north’s abundant natural resources flow south and the political and economic clout of the southern cities help balance and stabilize an otherwise isolated north. On the occasions when this enormous state recognizes its diverse economies and cultures as assets, the usual result is long-term stability, balance, and prosperity. When we ignore these unique assets, we struggle.

A splendid assortment of plants and animals have adapted to these variations in climate and other physical conditions. The tallest living things in the world—coast redwoods (Sequoia sempervirens)—grow on California’s northwest coast. The largest living trees in the world—Sequoia redwoods (Sequoiadendron giganteum)—grow in the western Sierra Nevada. The oldest individual living trees in the world—bristlecone pines (Pinus longaeva)—grow in eastern California’s White Mountains. The oldest living plants in the world—creosote bushes (Larrea tridentata)—grow as rings of clones in the southeast deserts. As this list of records grows, these “firsts” serve only as examples of the fascinating variety of plants and animals surveyed in Chapter 5.

All of these natural factors have combined with humans to produce diverse waterscapes scattered throughout California. Humans have now exploited these water resources by building some of the largest water projects in the world. This hydrology and efforts to build a sustainable water supply future is the subject of Chapter 6.

Diverse Human Landscapes

The assorted human invaders and settlers were just as diverse as the landscapes into which they moved (topics of Chapter 7). Their human landscapes have evolved to reflect California’s impressive size. In 2012, California’s population (according to the U.S. Census Bureau and the California Department of Finance) grew past 38 million. It not only has the largest population of any state, it is also the most diverse. California contains the greatest populations in the world of several ethnic groups living outside their countries of origin and it has the greatest number of people speaking the greatest variety of languages compared to any other state. These are topics of Chapters 7 and 8.

California also has, by far, the largest and most powerful economy in the United States and it ranks at least 9th in the world, competing with Italy and still ahead of India, Canada and Russia. Southern California alone would be near fifteenth in a worldwide list. California is the standout leader in agriculture, where it leads in the production of several crops. It is also near the top of timber, mining, and fishing industry states. These are topics for Chapter 9.

The state’s powerful primary industries are only surpassed by its modern, advanced industrial powerhouses. The trade, high-tech, finance, entertainment, and service industries in California have not only exploded past traditional industries, they are overshadowing developments
in other states and nations. Perhaps this helps explain why Los Angeles/Long Beach is the number one port in the country. These are topics for Chapter 10. Chapter 11 highlights some of the greatest urban landscapes in the world, including the Bay Area, southern California's coastal plains, and the relatively smaller inland cities. In Chapter 12 we apply geographic concepts and methods to understand current issues, solve problems, and look to the future.

Yes, Californians have built an assortment of fascinating and unrivaled rural and urban landscapes.

**California’s Situation**
California’s *situation* (its regional position in relation to other locations) has also had a profound impact on its evolution, history, and settlement patterns.

**Situation and Physical Geography**
The state is situated along tectonic plate boundaries, where dynamic geologic processes continue to shape a variety of landforms such as its giant mountain ranges bordered by deep valleys. You will find more details on geologic processes in Chapters 2 and 3. California’s middle latitude climates are influenced by the Hawaiian (East Pacific) Subtropical High Pressure System, which causes summer drought. Then, the Aleutian Low slips south during winter, ushering in storms to provide much-needed precipitation to the state. California is not far enough south to experience tropical climates; its location on the west coast and east side of the Hawaiian High ensures a cool ocean current (known as the California current) that moderates any tropical air masses moving toward the state. You will find specific definitions and details on weather and climate in Chapter 4.

California’s plants and animals have adapted to the middle latitude Mediterranean climates that dominate west of the major mountain ridges. Meanwhile, desert life forms must endure prolonged drought and temperature extremes common on the leeward sides of the very mountain ranges that were shaped by the geologic processes previously mentioned. For more on the state’s biogeography and hydrology, refer to Chapters 5 and 6.

**Situation and Human History**

*Isolation.* Most modern anthropologists agree that California’s first people were descendants of those who crossed over the “land bridge” into North America from Asia. Previously, the greatest ocean in the world had separated these otherwise mobile people from California. (Some California Indians have very different traditional stories and explanations of their origins.) Their populations eventually swelled to more than 300,000 before the Spanish arrived. Many Native Americans in California were often *isolated* by deserts and major topographic barriers, not only from other North American Indians but also from groups prospering in other California regions.

Later, these same barriers would help keep California isolated from the westward expansions of Anglo-Americans through the early 1800s. The Rocky Mountains, great southwestern deserts, and the Sierra Nevada combined to represent formidable barriers to overland parties that may have otherwise considered California.

Consequently, the first European explorers and settlers of California almost always arrived by boat. The Spanish sea expedition from the south headed by Juan...
Rodríguez Cabrillo was apparently the first to “discover” California for the Europeans in 1542. A number of Spanish and other European powers explored the California coast after him, including Sir Francis Drake, who claimed parts of California for England as early as 1579. The still isolated and distant regions of California would wait until 1769 before Europeans made any serious attempt at settlement. This is when Father Junípero Serra and Captain Gaspar de Portolá established the first settlement at San Diego. They continued north as Spain took formal possession of “Alta California.”

Even after 1769, California’s continued isolation contributed to slow growth and expansion of the early Spanish settlements. This left the door open to other invaders from the sea. These were the Russians from the north, who hunted sea otters down the northwest coast of California into the mid-1800s, until the otters were nearly extinct. They met little resistance in this wild land and established and settled Fort Ross between 1812–1841. California’s Russian River and other geographic features took names from these people and their distant homeland.

**The Latin American Connection.** By the early 1800s, the Spanish had already gained control of much of California. After the 1769 start, they spread their presidio-mission-pueblo plan to settle across California’s coastal valleys. They finally established solid land routes from New Spain (Mexico) north to “Alta California.” This introduced another major locational factor in California’s history and development: its strong ties to the people and cultures of the south—first Spanish, then Mexican (after 1822)—have had enormous influence on California’s human landscapes. This involves much more than the Spanish names of California’s streets, towns, and cities. It involves a Latino population and culture that has always played and will increasingly play a major role in California. It is a Latino population with roots that often extend far to the south of Mexico, into Central and South America. It is a Latino population that makes up the majority in many California schools, and it is expected to become the statewide majority in the twenty-first century. **Connections to Latin America** were rejuvenated by the late 1900s and they will continue to strengthen in modern California.

**Isolation Ends, New Connections Emerge.** During the mid-1800s, some of these connections to the south temporarily waned after the discovery of gold brought masses of people into California. This trend especially started with the ‘49ers. The Mexican government had already lost its grip on California as Anglo-Americans and people from all over the globe rushed in to find their fortunes. California’s isolation was broken forever, but the gold rush was just the first of many major developments that would gain the world’s attention. By 1850, California was already a U.S. state. California’s growth was accelerated by major developments in transportation and communication that strengthened its links to the rest of the world.

With these new technologies, the isolation that once thwarted California’s growth and development became an asset. As the population and economies of California cities such as San Francisco and Los Angeles soared in the beginning of the twentieth century, there were few other competitors in nearby states. California was certainly the focus of activity for a radius of more than 2,000 km (1250 miles). San Francisco became the financial center of the west from the mid-1800s through the early 1900s, and Los Angeles has held a commanding lead ever since. Throughout the 20th Century, California’s situation has increasingly encouraged growth of historical proportions.

By the mid-1900s, the state’s population and economy were number one in the nation, and Los Angeles’ only rival city in the United States was New York, more than 4,000 km (2,500 miles) away. The painful recession that hit in 2008 slowed population and economic growth for years; but today, this state is perfectly positioned to reap the greatest economic benefit from the advanced technologies on the horizon. This brings the third major situational factor into focus.
Advantages of California’s Modern Situation

Today’s Pacific Rim (referring to trading nations facing the Pacific Ocean) has become such an economic and cultural catchword, it is almost cliché. This is because many Pacific Rim locations have become modern economic, political, and cultural powerhouses. They include such giants as Japan, Korea, and China. California looks directly west to many of these economies and cultures, just as they look directly across the Pacific to California, both literally and figuratively. Additionally, the developing economies of growing Latin American countries ring the Pacific to the south. As highly sophisticated technologies, trade, finance, entertainment, and services are fueling California’s economic recovery and renaissance, the state is in a perfect geographic position to gain from the new world economies.

The connections are dramatic. There are not only more Asians in California than any other state, but Asian populations are growing faster than any other major ethnic group in California except for Latinos. Such changes are evident from the Little Saigons in Westminster and San Jose to Los Angeles’ Little Tokyo and Koreatown. From Monterey Park east of Los Angeles through the western San Gabriel Valley and in San Francisco’s Chinatown and Japanese Cultural Center, the economic and cultural ripples are profound. These ripples are now extending into every California community. Examples include the growing Asian communities along San Francisco’s outer districts, such as the Richmond and Sunset districts, in Millbrae, and throughout the Bay Area, especially from San Francisco to San Jose.

California’s situation on this planet has certainly shaped its history and influenced its modern landscapes. And thanks to modern communication, transportation, and other advanced technologies, the state is poised to exploit its advantageous situation in even more profound ways. These connections to the rest of the world—particularly to the Pacific Rim—will certainly have significant impacts on California’s future landscapes.

Human/Environment Interaction

Obvious connections between California’s natural and human landscapes are evident throughout the state. Natural processes and cycles have done more than create California’s physical landscapes; they have impacted and often controlled how humans settle and live on the land. And humans have often done their best to modify and exploit these same natural landscapes.

People Controlled by Nature

An overlay showing the state’s topography and densest human populations reveals quite a match. With a few exceptions, the most populous regions of the state have always been in flatter valleys and basins. These were, at first, usually locations with more abundant water (especially groundwater) that had drained down from surrounding watersheds and into the most fertile farmland. These lowlands were also easier to build on than surrounding steeper slopes, and they presented fewer topographic obstacles. Obvious exceptions include parts of San Francisco and the early gold rush towns established in the foothills of the Sierra Nevada during the mid- to late-1800s. San Francisco had exceptional advantages, including its convenient location where ships must enter the bay through the Golden Gate. The miners had to live near the gold, so their towns grew up around foothill and mountain mines.

As California’s soaring populations filled most of its coastal valleys and flatlands during the 1900s, people first began to settle at the foot of adjacent slopes. Those who could afford the extra costs of construction and access crept into the very mountainous terrain that had once confined them. Examples are scattered throughout the state, from San Diego County to the rim of the Los Angeles Basin, from the hills surrounding the San Francisco Bay Area, to recent invasions of former flatlanders into Sierra Nevada foothills.

Figure 1-6 The Golden Gate is the major break in the Coast Ranges that connects the Pacific Ocean with inland locations, including the Central Valley. The Spanish recognized its strategic location and the Gold Rush brought thousands through it. Today, many millions of people and billions of dollars of trade pass over and under its bridge, a magnificent landmark for California visitors, immigrants, and natives.
The price of a better view and distance from the urban basins is often higher than expected. Summer and fall wildfires and the winter mudflows that usually follow have devastated growing hill and mountain settlements from the Laguna Hills to Malibu, from the Oakland Hills to the Sierra Nevada and beyond. Great battles have erupted between the powerful forces of nature, which have always ruled on the slopes and in the canyons, and the pressures from encroaching urban settlers who try to control nature. Though these settlers risk paying the ultimate price by losing their dreams, other California residents are often forced to help protect them and then subsidize their losses when disaster strikes.

A host of other natural factors led to the concentration of early urban growth in the state’s coastal valleys and basins (the lowlands of cismontane California). Cismontane is a convenient term used in this book to describe more moist regions and landscapes on the Pacific Ocean side of major mountain barriers. In contrast, transmontane describes drier regions and landscapes on the inland or continental sides of the state’s largest mountain ranges. It was the cismontane coastal climates—mild compared to nearly every region that was a source of great migrations to California—that made for ideal living and working environments. From Hollywood films to aerospace to silicon chips, climate was and is a major drawing card for industry and people in the state’s coastal valleys. The coastline itself has more to offer than just a mild climate. Fishing, trade, and recreation draw even more people to the coast.

It is, therefore, no surprise that California’s largest metropolitan areas are, in order, housed within the Los Angeles Basin, the San Francisco Bay Area, and western San Diego County. The top four California cities in population well into the second decade of the twenty-first century all had oceanfront property, except San Jose, which is on the southern end of San Francisco Bay. (The top four within city limit boundaries are Los Angeles (3,810,000), San Diego (1,312,000), San Jose (959,000), and San Francisco (813,000). These are round estimates for 2011 based on U.S. Census and state sources. Each city’s population continues to grow in the twenty-first century.

Technology versus Environmental Constraints: Nature Controlled by People
Numerous other natural factors that were once critical no longer play major roles in concentrating human populations in California. The Native Americans once established their densest settlements where there were abundant water resources and native plants and animals. (The water-wise Spanish did the same, but focused on farmable lands.) Later, the location of certain minerals and other earth resources first broke California from its isolation and led to huge mining camps and towns in the Mother Lode. Especially within northern California forests, from the 1800s and well into the 1900s, towns grew to support the timber industry. And where the richest soils were deposited, agricultural service towns erupted to support productive farms. Today, less than 20 percent of California’s modern population is even indirectly involved in these original primary industries or living in what we now consider rural landscapes. Timber, mining, and agricultural activities and populations, although important to the state, are not even in the same league with California’s great urban population centers and modern economies.

By the late 1900s and into the new century, as the prime coastal locations filled, the great urban areas quickly spread east away from traditional coastal conveniences and into the inland valleys with hotter, smoggier summers. In southern California, Riverside grew to about 294,000 by 2011. The urban growth more recently spilled farther inland into even harsher environments, through mountain passes and into the high desert (including the Antelope Valley) and into the lower desert (including the Coachella and Imperial valleys).

In central and northern California, the people have recently poured into rapidly expanding urban areas of the Central Valley, and they have even crept up many Sierra Nevada slopes. The perception is that many of the prime coastal locations may still be attractive, but they are already discovered, overcrowded, and too expensive. Californians were and are now forced to move farther and farther inland to find their dreams. Fresno (500,000) and Sacramento (470,000) were the fifth and sixth most populated cities in California by 2011, while Bakersfield ranked 9th (352,000) and even Stockton (294,000) ranked thirteenth. And because these inland valley communities were the fastest growing just before the housing industry collapsed in 2008, they were the most devastated by the recession that followed.

Most modern Californians in these urban fringe areas are rarely forced to consider confronting their natural environments, except for the occasional wildfire or flood, a mountain lion or bear, or the construction-stopping endangered species that may interrupt their perceptions of order and tranquility.

The trend away from our dependence on the natural environment is especially noticeable when it comes to water. Just as the Indians settled along water courses, so the Spanish were careful to locate almost every mission, presidio, or pueblo near a reliable source of water. California’s early settlements were also near water sources. However, by the 1900s, Californians were proving that they could live and farm almost anywhere if they could import enough water. The irrigated farmlands of the San Joaquin and Imperial Valleys grew almost as fast as the urban populations of California. This was made possible by building the greatest water projects on the planet to divert water away from the water-rich but population-poor north, and toward the demanding populations,
economies, and political powerhouses of the south. Reliance on more efficient air conditioning and heating systems also encouraged growth into harsher climates with inexpensive land into the 21st Century.

Examples of how we are controlled by nature and how we are now controlling nature appear throughout this book. Although the occasional earthquake, landslide, flood, or drought are reminders of nature’s power, Californians are increasingly learning how to impact, control and exploit nature as they make more obvious human imprints on the landscape. Some knowledge of these issues is necessary to understand how the state’s natural and human landscapes have evolved and to predict how they will continue to change.

Figure 1-7 California’s landform divisions are often considered natural provinces or physiographic regions. Some boundaries are not clear.
California’s major topographic features stand out. More than two-thirds of the state is considered mountainous by the most conservative estimates. These topographic features are often the major players in controlling temperature, precipitation, and prevailing wind patterns. The distribution of plants and animals, soils, and drainage patterns are also frequently controlled by topography. We’ve already considered the powerful controls these topographic features have placed on people and their settlements.

Consequently, geographers and other scientists have tried to divide California into landform divisions sometimes called natural provinces or physiographic regions. Regardless of the names or more specific divisions, each region is considered somewhat different from the others. Each region’s natural landscapes have often supported people and human landscapes that are also somehow different from other parts of California. Now, we will sweep clockwise around California from region to region, starting with the northwest and ending back at the Central Coast. We’ll look at that middle part of the clock—the Central Valley—last.

Get out your maps and prepare for this brief journey through each of California’s diverse regions. Counties

Cultures and Economies of the Northwest

Throughout this book there are more details about the natural history of this region that has the heaviest rainfall (more than 250 cm [100 inches] per year) and greatest runoff in California. Deep canyons and rugged terrain have contributed to the region’s cultural and economic isolation; residents of Southern California may be as unfamiliar with the people of northwestern California as they are with its natural environments. Likewise, some of these rugged northerners have felt so detached from the south that they tried to form their own state. It started with a peaceful rebellion in 1941 that would have merged the most northern counties of California with the most southern counties of Oregon into a state called Jefferson with its capitol in Yreka. You might hear many locals still dreaming how this would bind their people and culture within one state they could call their own without all the outside interference.

Historically, primary industries ruled the economies here, but the region saw the peak of the timber industry come and go in the 1950s. As the timber industry worked overtime to cut the tallest stands of trees in the world, Redwood National Park and other reserves were created to protect some of the less than 10 percent of old-growth forest remaining in California. While the industry waited for its second- and third-growth forests to mature, it was also changing its methods of operation.

Timber jobs were lost as the industry began loading raw, unprocessed timber directly onto boats for processing overseas. Automation replaced many of the remaining jobs, and companies were finding timber at lower prices abroad. Jobs and towns in the region began to wither while environmentalists and industry management engaged in an ongoing controversy. Now, with less than 10 percent of California’s old-growth forests remaining, and much of that protected, these economies must rely on more efficient, sustained- yield timber production as they search for other sources of income.

By the 1970s and 1980s, illegal crops of marijuana had become so valuable to the region’s economy that marijuana wars broke out. To the embarrassment of some Californians living in the number one agriculture state, marijuana was reported as the top cash crop in California; much of it was being grown in the northwestern region. This underground economy and culture was repeatedly highlighted and sensationalized in the media until by 2012, a few researchers suggested the marijuana crops were worth more than the state’s total annual agricultural output. The area’s still slumping economies are left to depend on small manufacturing, retail trade, tourism, fishing, and a swelling retired population. Some communities have investigated bringing in government prisons or offshore oil drilling to create jobs. With few exceptions, such as the developments around Arcata Bay (including Eureka and Humboldt State University) and the connections made by Highway (Hwy.) 101, this land and its people (less than 1 percent of the state’s population) remain relatively isolated in some of the world’s most beautiful mountain and coastal scenery.
Getting to Know California: A Brief Survey of Its Diverse Regions

and the largest incorporated cities are listed for individual regions. City populations are estimates based on data from the U.S. Census and the State of California around 2011.

Northwestern California and the Klamath Mountains

Counts (north to south): Del Norte, western Siskiyou, Humboldt, Trinity, northern Mendocino, southwest corner of Shasta, western edge of Tehama

Largest Cities: Eureka (27,300), Arcata (17,300), Fortuna (12,000), Crescent City (7,500)

Among the obvious features that dominate northwestern California landscapes from the northern end of the Coast Ranges through the Klamath Mountains Physiographic Region are the exceptionally steep, moist, heavily forested mountain slopes. The Klamaths extend nearly 250 km (150 miles) north–south and are about 160 km (100 miles) wide. This entire region is bordered by the Pacific Ocean on the west, Oregon to the north, Shasta Valley and the Cascades (with Interstate 5 [I-5]) to the east, and the Sacramento Valley to the southeast.

Rocks of the Klamaths have been caught and lifted above the subduction zone where the continental plate rides up over the ocean tectonic plate (as defined in the next chapter). Like most California mountain ranges, granitic rocks are common (such as at Castle Crags State Park). However, California’s most rugged mountain range also exhibits more old metamorphic rocks than are found in most other provinces. Glacial features also remain as remnants of the Ice Age above about 1,675 m (5,500 feet) in this cool, damp range.

Within a high-density dendritic (branching, treelike) pattern, most major stream canyons of the Klamaths are eroded more than 300–600 m (1,000–2,000 feet) deep. Above these steep, narrow canyons, the Klamath ridges tower higher than 2,100–2,700 m (7,000–9,000 feet). The Scott Valley and Smith River’s coastal lowland are considered large valleys for this region. Scott Valley, the largest, is only about 0.8–8 km (0.5–5 miles) wide and 32 km (20 miles) long.

Similar heavily forested terrain south of the Klamaths—in the northern Coast Ranges—is cut by more regularly northwest–southeast trending streams. Throughout this north coast region, from the Oregon border into the northern Coast Ranges, are some of the state’s greatest rivers. Impressive discharges from the Smith, Klamath and Trinity, Mad and Eel, and other rivers and streams (reviewed in detail in Chapter 6) are common, especially during winter and spring. As the Coast Ranges trend farther south and away from this region, they generally become drier and less rugged. On some of the wettest coastal slopes, you will find the tallest trees in the world: “where the fog goes, the coast redwood grows.”

North/Central California with Its Southern Cascades

Counts: Siskiyou, Shasta

Largest Cities: Redding (90,300), Shasta Lake (10,100), Yreka (7,800), Mt. Shasta (3,400), Weed (3,000)

If not for its majestic composite volcanoes, this region would serve as a smoother transition from the Klamaths on the west to the Modoc Plateau on the east. However, standing on top of 3,189 m (10,457 feet) Lassen Peak (the most southerly of the major Cascade volcanoes), you can look south out of the Cascades and into the northern Sierra Nevada. Looking north from Lassen, you can see the ominous Mount Shasta in the distance. At 4,319 m (14,162 feet), it is the second largest volcano in the north–south trending Cascade Range. (Only Washington’s Mount Rainier is higher.) It rises directly up from Shasta Valley for nearly 3,355 m (11,000 feet). A few
active glaciers still creep down its slopes. There are several smaller volcanoes lined up within California’s southern Cascades. Some are still active with fumaroles and vents. Lassen erupted from 1914–1917.

This relatively long, slender physiographic region is cut into north and far south sections by the Pit River, which flows west out of the Modoc Plateau and into Shasta Lake. The region is bounded by the edge of Shasta Valley and the Klamaths to the west, Modoc Plateau to the east, and the Central Valley and northern Sierra Nevada to the south. Tucked behind the Klamaths (on the rainshadow side), California’s Cascade valleys are drier than valleys draining the slopes facing the Pacific Ocean, but precipitation, vegetation, and forest densities increase toward the higher, cooler, wetter slopes. Winters are colder and summers warmer than on Pacific-facing slopes; continental air masses are more common here. Likewise, cultures and economic activities may change from those within the wetter higher ranges to those more common to drier valleys and plateaus.

### The Northeast and Modoc Plateau

*Counties:* Modoc, Lassen, north tip of Plumas

*Largest Cities:* Susanville (17,500), Alturas (2,820)

Moving east from the majestic Cascades, the volcanic peaks are smaller and the broad, flat basaltic lava flows of the Modoc Plateau dominate the landscape. Surfaces of these thick lava flows average more than 1,350 m (about 4,500 feet) above sea level and may represent the southwestern extension of the Columbia Plateau. There are occasional interruptions by volcanic cones rising between 300–1,050 m (1,000–3,500 feet) above the plateau.

Even farther east, the Modoc Plateau breaks up into a series of dramatic fault-block valleys and mountains more characteristic (and actually a part of) the Basin and Range Physiographic Province. Examples include the lofty Warner Mountains in California’s northeast corner, which even support impressive stands of cool, damp aspen forest. The inland Alkali Lakes (in Surprise Valley east of the Warners) and Goose Lake to the west are examples of water accumulating in down-faulted basins. Another finger of the Basin and Range Province extends in from Nevada farther south, around Honey Lake. This region is bordered by the Sierra Nevada on the south.

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**People and Economies of North/Central California**

Since I-5 follows the western edge of this region, travelers are rewarded with views of impressive mountains on both sides of the interstate—the Klamaths to the west, the Cascades to the east. This major transportation corridor links Pacific coast cities in California with Oregon and Washington; it also breaks the isolation of regions to its west and east. Without it, California north of Sacramento would be even less recognized, with even a smaller population and economy. All of the major towns of California’s Cascades, which also serve the ranching and timber industry so important to the region, are located along I-5. It even slices through Shasta Valley, where cattle pastures are interrupted by some farming on the richer soils formed on sediments carried from the surrounding mountains. The farther you wander away from this northern California corridor, the more things have remained unchanged; there has been little population or economic growth beyond it. I-5 extends a similar influential ribbon well to the south, into the Sacramento Valley.

For those traveling north, just up from the Sacramento Valley, Redding welcomes visitors to the southern edge of the Cascades. This is the largest city in the north end of the state, and it represents the antithesis of the state’s three northern regions. (It could also be considered a part of the northern edge of the Sacramento Valley.) The city’s past aggressive development strategies have resulted in a series of generic malls and businesses, neighborhoods, and urban scenes reminiscent of larger population centers to the south.

While moving to Redding to escape the city, many people brought it with them. This is especially evident on the east side of the Sacramento River, which slices through the city. Today’s condominium and apartment complexes rest on bluffs overlooking the Sacramento River, and they overshadow an older town center with a rich history. Redding’s influential fingers stretch out for several miles into more extensively populated neighborhoods on the suburban/rural fringe and into nearby small towns.

The string of towns along I-5 north to the Oregon border is more characteristic of the region. Many serve as economic and population centers, although occasionally residents may have to travel north into Oregon or south back to Redding for goods or services.
The Pit River represents the only major water source in this region; it drains from northeast to southwest, bisecting it. To the north, some of the best examples of volcanic features such as basaltic flows, lava tubes, and cinder cones are displayed at Lava Beds National Monument. North of that are Tule Lake and the Lower Klamath Lake wildlife refuges and farms up to the Oregon border. Volcanic hillslopes are common south of the Pit.

Since this high plateau is in the rainshadow of the Klamaths and Cascades, it receives little precipitation (about 50 cm [20 inches] per year), and it experiences long, harsh winters while in the grip of dry continental air masses. Sagebrush steppe and juniper shrub savanna dominate the vegetation of the plateau, where surface water usually drains freely and is lost through the lava flows. Yellow pine and other forests appear on higher slopes, where orographic precipitation enhances water supplies.

**Isolated Cultures and Economies of the Northeast**

Like people in the northwest, residents of northeast California are isolated. Due to drier climates, timber is less important and ranching rules most of the economies. Grazing cattle and farmland stretch across almost every Modoc valley during summer, while events like the rodeo in Surprise Valley’s Cedarville evoke the culture of a land unfamiliar to many Californians. There is also some hunting, fishing, and tourism in this mostly culturally conservative region. Local unemployment can rise to 20 percent during the long, cold winters. In 1996, the Pit River Indians started a casino to attract revenue. A 2005 addition doubled its size and in 2012 they were advertising their latest remodel. The region does not tend to attract industry, business, or people because of its isolation and lack of economic development.

Susanville, near Honey Lake, is an exception. First, it is the largest town in the northeast. Second, it lies on the edge of the Basin and Range landforms more common to the east. Finally, it has stronger economic and cultural ties to the east in Reno and Nevada than to California because of easy access along Hwy. 395. Farther north, where Hwy. 395 crosses the Pit River, is the second largest town, Alturas. This is mostly an agricultural service town and is more typical of the northeast. Both Susanville and Alturas have their own tribal casinos.

How will the high-tech communication and computer revolution affect these northern California towns and their economies? It may still be too early to tell. However, as more people in higher income groups use technology to do more work at home, they are also able to move farther out from the urban fringe. There may be interesting long-term consequences for all California regions that have remained relatively isolated and undeveloped until now. By the second decade of the 21st Century, the peace and quiet offered by these bucolic rural outposts had not yet pulled great populations away from their urban cultures and conveniences. Locals have been known to give new arrivals two years to adjust to this lonely country before they consider them settled residents.

**Basin and Range**

*Counties:* Mono, Inyo

*Largest Cities:* Bishop (3,900), Mammoth Lakes (8,300, within the eastern Sierra Nevada but services northern heart of Basin and Range)

The heart of the Basin and Range Physiographic Province extends east of the Sierra Nevada and throughout Nevada. It is sometimes referred to as the “Trans-Sierra” to help
Getting to Know the Golden State

Looking west from Lone Pine toward Mt. Whitney, the highest peak in the United States outside Alaska, is Mount Whitney at 4,421 m (14,495 feet), and there are others not far behind. Sierra Nevada’s sawtooth ridgelines split in two to among some of the hottest and driest places on earth. The climates of some nearby valleys are almost as severe as Death Valley, where the mean annual precipitation is only 5 cm (2 inches) per year and the hottest temperature in North America was recorded at nearly 57°C (134°F). Even the common desert scrub vegetation struggles to survive in these conditions.

Streams flowing out of the eastern Sierra Nevada toward the Owens Valley once represented the only major source of water for the Basin and Range. Then, starting in the early 1900s, even this water was diverted to Los Angeles, drying first the Owens River and Valley and then impacting Mono Lake and Basin to the north. The resulting struggles over water between locals around the Owens Valley and distant Los Angeles continue today.

Consequently, recreation (including fishing), tourism, and service industries have long since replaced many of the formerly important primary industries, even in the Owens Valley. In contrast to northwestern and northeastern California, the Basin and Range is home to very popular destinations, and it is closer and more accessible to the southern California masses. Visitors crowd Hwy. 395 to Mammoth (one of the greatest ski resorts in the world) during the ski season. They meander on the roads to those eastern Sierra Nevada fishing holes and retreats or to visit Death Valley, Mono Lake, and other natural attractions in these open landscapes. Familiar small settlements in the Owens Valley along Hwy. 395—such as Little Lake, Lone Pine, Independence, and Big Pine—are dwarfed by Bishop, which is becoming more than just a tourist stop. You can eavesdrop on some of those rural western cultures by tuning in to one of their small town radio stations, though their laid back DJs are well aware of the many visitors from distant cities who may also be listening.

Sierra Nevada

Counts (north to south): Plumas, Sierra, eastern edges of Butte and Yuba, Nevada, eastern Placer, El Dorado, Amador, Alpine, Calaveras, Tuolumne, Mariposa, eastern portions of Madera, Fresno, and Tulare, northeastern Kern, western fringes of Mono and Inyo

Largest Cities: Paradise (26,300), South Lake Tahoe (21,600), Truckee (16,200), Auburn (13,400), Grass Valley (12,900)

Whether it is considered a physiographic province, region, or major landform, the Sierra Nevada competes with the Central Valley as the largest in California. It is nearly 650 km (about 400 miles) long and approximately 110 km (70 miles) wide. Its ridges trend northwest–southeast and several peaks rise well above 4,270 m (14,000 feet). The tallest peak in the United States outside Alaska is Mount Whitney at 4,421 m (14,495 feet), and there are others not far behind. Sierra Nevada’s sawtooth ridgelines split in two to

Figure 1-12  Looking west from Lone Pine toward Mt. Whitney (just to the left of the flag), you can see the dramatic 10,000 foot elevation gain across faults that are lifting the Sierra Nevada Mountains above the Owens Valley. This marks the start of north–south trending mountains and valleys typical of the Basin and Range that stretch east of here (behind us) and across Nevada.
Lake Tahoe has filled a down-dropped basin high in the Sierra Nevada. The area is famous for its winter skiing and summer vacations. Here, we are looking into pristine Emerald Bay and across Tahoe’s deep, blue waters toward the Nevada side in the far distance.

In contrast, the western slopes of this mighty range gradually rise above the Central Valley until they reach the top as far as 80 km (50 miles) to the east. This elongate region is bound by the Central Valley on the west, the Cascades on the north, the Basin and Range on the east, and the Mojave Desert and narrower Tchachapis to the south. This orientation makes the Sierra Nevada an almost perfect barrier to catch orographic precipitation from the winter storms that sweep from west to east across California from the Pacific. Tremendous winter snowfalls are common at higher elevations. When the snow melts, water pours into streams, rivers, and reservoirs toward the Central Valley, where it is used for farming or diverted to thirsty cities. Even greater snow packs accumulated during the Ice Age to build glaciers that carved spectacular scenery in the high country and in major canyons. Yosemite and Kings Canyon serve as outstanding examples of these landscapes. Numerous conspicuous glacial moraines (remnants of Ice Age glacial advances) were deposited at the eastern base of the range, pouring out from the deeper canyons.

The varied climates—from drier foothills up to towering peaks—have also produced life zones or belts of vegetation containing a fascinating assemblage of plants and animals that have been studied by biologists and biogeographers. They include the only stands of the largest (in bulk) living trees in the world, the Giant Sierra Redwood, or Giant Sequoia, (Sequoiadendron giganteum).

The granitic rocks so common in the Sierra Nevada are similar to those forming the cores of almost every other major California mountain range. Gold was discovered along the contact zones between these great granitic batholiths and older, mostly metamorphic rocks as some of the gold weathered out and into the streams. The discovery of gold in 1848 in the western Sierra Nevada foothills changed California forever. Thousands flocked from all over the world to the Mother Lode, and many of the gold rush towns they built are still there. Today, powerful human forces are molding new landscapes.

Explorer and naturalist John Muir properly named the Sierra Nevada “The Range of Light.” Many Californians still think of the Sierra Nevada as a place where spectacular scenery and rich natural history is protected by the expansive national forests and parks that make it world famous. It has been a barrier to air masses, water, plant and animal species, and people (such as the Donner Party). It contains one of the largest areas without roads in the United States outside Alaska. South of Tioga Pass, only two highways and one railroad cut through the range. During winter through at least early spring, the region becomes more inaccessible; snow typically closes the roads from Walker Pass in the south to the central Sierra Nevada north of Yosemite.

People Invade the Sierra Nevada

Today, the old mining towns that became agricultural and timber service towns are bulging with tourists, retirees, and even commuters! From Grass Valley and Nevada City to Sonora and beyond, housing developments and suburbs are spreading uphill from the Central Valley. In many cases, the escaping urbanites have brought their freeways, generic shopping malls, and other service-oriented landscapes. And though the higher elevations (such as in Alpine County) are more distant and have escaped this encroachment, there are local exceptions. Residents of Lake Tahoe (with bustling casinos across the state line) and Mammoth Lakes are fighting over how to control the growth of their crowded ski resorts and housing developments.

Public lands and parks are also feeling the pinch as Yosemite received more than 4 million visitors in 2010 alone. Daytime visitors from the Central Valley and weekend visitors escaping California’s great urban centers crowd resorts such as Lake Isabella and the lower Kern River at the Sierra Nevada’s southern end.

As many Sierra Nevada towns compete for more growth, jobs, and industry, the regional debate rages: Will tomorrow’s Sierra Nevada be set aside in parks and wild lands for recreation or will it serve as just another California suburb? As we debated this question, the region’s population increased more than 400 percent from 1960 to 2010. There is extensive discussion about the Sierra Nevada’s natural and human landscapes in this book.
Southern California Deserts (Transmontane Southern California): About 20 Percent of the State

Mojave Desert

Counts: southeastern corner of Kern, northeastern corner of Los Angeles, nearly all of San Bernardino leeward of coastal mountains, much of Riverside leeward of coastal mountains

Largest Cities: Palmdale (153,300), Lancaster (157,800), Victorville (117,200), Hesperia (90,700), Apple Valley (69,700)

The Mojave Desert begins just south of the Garlock Fault at the southern end of the Basin and Range and Sierra Nevada regions. Mountain ranges of the Mojave are not as commonplace or impressive as in the Basin and Range. Many of the Mojave ranges are older and weathered; they have crumbled into and filled the surrounding desert plains with much debris, especially in the western Mojave. Higher ranges of the eastern Mojave soar above 2,150 m (7,050 feet), including the Kingston, Clark, New York, and Providence Mountains. Throughout the Mojave, at the base of the steeper mountains, are the gently sloping alluvial fans and bajadas, depositional features common to California’s desert terrain.

Although the Mojave generally makes up what is often known as the northern deserts, or the “high desert,” it is punctuated by deep valleys and desert playas (usually dry salty lake beds). Just as in the Basin and Range, mineral-laden water may accumulate in these basins and evaporate to leave white, crusty salts on the surface. These lower basins are also home to some of the driest climates and hottest summers in North America. Soda Dry Lake and Silver Dry Lake basins near Baker and I-15 are examples. Like the Basin and Range, there are only a few locations where sand has been blown into dunes. The Devil’s Playground and Kelso Dunes are stellar examples southeast of Baker between I-15 and I-40.

The western corner of the Mojave begins east of Frazier Mountain and Tejon Pass (see Figure 1-3). This is a narrow wedge where the Sierra Nevada has tapered off into the Tehachapis and where these ranges intersect the Transverse Ranges at an acute angle. On the rainshadow side of these intersecting ranges, the wedge opens up into the desert basin toward the east, known as the Antelope Valley. The Mojave continues to widen toward the east until it represents an enormous expanse of diverse desert topography all the way into Nevada and northwestern Arizona. Just as the Garlock Fault separates the Mojave from the Basin and Range, Sierra Nevada, and Tehachapis to the north, so do the San Andreas Fault and other structures separate the Mojave from the Transverse Ranges on its southwestern border. The generally lower Colorado Desert Physiographic Province lies to the southeast of the Mojave.

Since so much of the Mojave Desert is higher terrain than its neighbor to the south, it is generally cooler and wetter than California’s hottest deserts. A few winter storms commonly produce snowfall each year. The thicker desert scrub and Joshua trees of the high desert may even give way to pinyon, juniper, and sparse forest at the highest elevations. These life forms and their surrounding landscapes are spotlighted in Joshua Tree National Park and the Mojave National Preserve.

Multiple Uses for Open Spaces in the Mojave. Substantial military and mining operations and limited grazing fueled the economies of the tiny settlements in the Mojave during the twentieth century, but the military presence was most noticeable. The Marine Corps Training Center north of Twentynine Palms, Antelope Valley’s Edwards Air Force Base, Fort Irwin north of Barstow, and China Lake Naval Weapons Center are good examples. Military activities required plenty of remote open space and the Mojave had it. Expansive San Bernardino County—the largest U.S. county and most of it U.S. government land—offered ideal settings for many of these military operations.

Transportation has always been vital to survival in this harsh, wide-open country. This is why most of the few people and economies of the Mojave Desert once clung to the services provided along its major transportation corridors. One example is Barstow, where train tracks and Hwy. 58 meet I-15 and I-40 and where the celebrated Route 66 once made the town famous. The traffic between Barstow and Las Vegas along I-15 and the trickle of sightseers to Death Valley kept little Baker’s pulse going. Trains, truckers, and travelers also converged on the little town of Mojave. Later, a huge storage facility for mothballed jet airliners was built in Mojave. Tehachapis’ wind farms decorate desert slopes above Mojave. Way out on I-40, near the Colorado River, the lit-
tle town of Needles once gained fame as the largest settlement near a proposed nuclear waste site in Ward Valley, but it is most famous as the desert stop between Arizona and California. Mass migrations of people from the coastal side of the mountains during recent decades has transformed the economies and landscapes, especially of the western Mojave and Antelope Valley. Some newcomers are retired, and some have found work in the high desert. Many moved their families to this harsher climate for more space and cheap housing, but the price they pay is a commute to and from the L.A. Basin that may total several hours each day. A heavy toll has been placed not only on the breadwinners and their families, but on the very desert environments that once represented an escape from urban life.

Giant malls, congestion, pollution, violence, and other urban problems are now commonplace in Palm-dale, Lancaster, and Victorville. Even that charming little Apple Valley of the 1960s—once just a wide spot on Hwy. 18 where a trailer park and hamburger stand were major landmarks—has a population near 70,000. The Joshua trees have come down and the housing developments have gone up. Far to the southeast of Antelope Valley's city lights are the strip of blossoming towns along the north edge of Joshua Tree National Park; landscapes from Twentynine Palms to Joshua Tree to Yucca Valley and Morongo Valley are gaining new populations. Some of this chaotic growth is spreading far into the Mojave, where you can find major malls and occasional traffic jams outside of Barstow.

Population growth in southern California desert counties averaged nearly 40 percent per decade from the 1960s into the 21st Century. Since many of those new homes were funded with risky loans, the mortgage crisis hit them especially hard in 2008. The resulting foreclosures and recession devastated these generic high desert neighborhoods.

The Colorado Desert

**Counties:** Imperial, southern and eastern portions of Riverside, far eastern edge of San Diego

**Largest Cities:** Indio (77,200), Cathedral City (51,600), Palm Desert (49,100), Palm Springs (45,000), El Centro (43,200), Coachella (41,500), Calexico (39,100)

Southeast of the Mojave, extending into the Salton Trough and Mexico and then along a strip of the Colorado River Valley, is the Colorado Desert. Often called the southern deserts, or the "low desert," it includes the farmlands and developments of the Coachella and Imperial Valleys. This region is tucked away on the rain-shadow side of the Peninsular Ranges to its west and the Transverse Ranges to its northwest. It is generally hotter and drier than the higher Mojave, and it probably has more in common with the deserts of southern Arizona and northern Mexico than it does with the deserts of California.

In contrast to the higher Mojave, the Colorado Desert's annual precipitation is below 13 cm (5 inches) per year, daytime highs frequently break 43°C (110°F), and overnight lows may not drop below 27°C (80°F) during mid-summer. Desert scrub dominated by the ubiquitous creosote bush is common in both regions, but the Colorado Desert lacks Joshua trees, which grow to the north in the Mojave. More common in Arizona and northern Mexico are the iconic saguaro cacti, which only grow naturally in California near a thin strip of the Colorado River but are imported into human landscapes of the Imperial and Coachella Valleys. However, several other species of cactus are common in the cactus scrub of the Colorado Desert's lower desert terrain, and in some desert canyons you will find the state's only native palms. They are beautifully displayed in Anza Borrego (California's largest state park) and at Thousand Palms Oasis.

The Salton Trough is being stretched and dropped in relation to the surrounding mountains, especially the Peninsular Ranges, which are being pulled away from it by tectonic forces reviewed in Chapters 2 and 3. The Palm Springs Tramway lifts travelers over some of these faults on the trip from this desert floor up to the cool forests of the Peninsulars' San Jacinto Mountains. Farther south, the Salton Sea was a mistake created and filled by overflow from the rampaging Colorado River in the early 1900s. It has since served as a sump for agricultural runoff from Coachella and Imperial Valley farms that are irrigated with the river's diversions to produce valuable crops year round.

*People and Their Landscapes Pour into Low Desert Valleys.* As the inland valleys west of the mountains fill with people, growth spills through Banning (San Gor-
Getting to Know the Golden State

Banning in San Gorgonio Pass along the San Andreas Transverse Ranges Physiographic Provinces is clear near Southern California and Mountains (Cismontane pump more energy into their economies. Date Festival or Coachella Valley Music and Arts Festival to owrock Golf Course, Palm Springs Air Museum, the annual and businesses look toward attractions such as the Shad-stores, and restaurants turn quiet again. Some residents evaporates in summer's sizzling sun when the streets, from November through April. This clean revenue source to escape northern winters and crowd the Coachella Valley. They often find some answers when the snowbirds arrive somewhere in the middle, still searching to find their roles. many Coachella Valley cities, such as Cathedral City, are with a majority Latino population, now competes as the poorest county in Southern California. Because agribusiness is the only major industry in the area and because there is a large pool of potential farm workers in Mexicali, just across the Mexican border, the future looks bleak for the Imperial Valley's working masses.

The long growing season and irrigation water from the Colorado River made the fertile farms of the Salton Trough possible. The region produces as great a quantity and variety of valuable crops as any area its size. Just a glance across this valley with its lettuce fields, grape vines, citrus groves, and towering date trees will serve as testimony to its productivity. Unfortunately, these advantages are barely translating into a subsistence-level income for much of the Coachella and Imperial Valleys' working class. A visit to some of the Imperial Valley's little towns provides testimony to this disparity. (Ironically, many Imperial Valley farmers supported a recent plan to take some fields out of cultivation and sell excess water to thirsty San Diego.)

While economic disparity is the rule in this region, many Coachella Valley cities, such as Cathedral City, are somewhere in the middle, still searching to find their roles. They often find some answers when the snowbirds arrive to escape northern winters and crowd the Coachella Valley from November through April. This clean revenue source evaporates in summer's sizzling sun when the streets, stores, and restaurants turn quiet again. Some residents and businesses look toward attractions such as the Shadowrock Golf Course, Palm Springs Air Museum, the annual Date Festival or Coachella Valley Music and Arts Festival to pump more energy into their economies.

The Peninsular Ranges and South Coast

The Peninsular Ranges have much in common with the Sierra Nevada. First, the core is primarily granitic rock that cooled to form a huge batholith after it contacted older, mostly metamorphic rock. Second, active faulting has lifted the block at steep angles above the desert floor on the east side; slopes drop down more gradually toward the coastal plains on the west side. Finally, because of this orientation, the Peninsular Ranges catch considerable orographic precipitation which accumulates and flows along major streams toward the west, mostly down the gentle western slopes toward the very ocean it came from.

However, there remain major differences between the Peninsular Ranges and the Sierra Nevada. First, they are not as tall or as massive as the Sierra Nevada. The highest peak is San Jacinto at 3,295 m (10,804 feet) at the northern tip of the Peninsular Ranges. They trend lower toward the south; the next range south of the San Jacintos is the 1,830 m (6,000 feet) average crest of the Santa Rosas. Second, they are farther south. Not only are they farther away from winter's major storm tracks, which makes them much drier, but they trend for nearly 1,300 km (about 800 miles) out of California and all the way down to southern Baja California.

Finally, the Peninsular Ranges are really a series of ranges interrupted by valleys (some substantial and deep) and parallel faults, many of which are still active. One example is the San Jacinto Plain, which sits between the San Jacinto Fault and Mountains to its east and the Elsinore Fault and Santa Ana Mountains to its west. More noticeable, however, is how the entire Peninsular Ranges are pulling away from the Salton Trough and the Gulf of California. They also include the Laguna Mountains, Palomar Mountain, and the islands trending parallel to them just offshore. They are bordered by the Salton Trough on the east, while the Transverse Ranges cut them off on the north.

Starting at the coast, a patchwork of coastal sage scrub yields to grasslands in the inland valleys and to chaparral on inland mountain slopes. In higher elevations
of the Peninsular Ranges, oak woodlands and then yellow pine forests become dominant. Isolated patches of cooler, wetter forests grow even higher in the San Jacintos and near a few of the highest peaks to the south. Among the few mountain resorts within these cooler forests are Idyllwild, between Hemet and Palm Springs, and Julian, in the mountains east of San Diego. The Palomar Mountain Observatory, east of Oceanside, has ranked as one of the world’s premier astronomical observation sites. It also looks down on some of the many inland valleys which interrupt these ranges.

Interesting coastal landforms include the mesas which gradually drop down from the range to marine terraces along the San Diego County coast. As these terraces overlook the ocean, they are occasionally sliced through by the westward flowing streams. The result can be seen in a drive along I-5, mostly on the flat, raised terraces, until there is the occasional drop into a deep stream canyon or valley and a view of the characteristic lagoon or estuary which has formed near the shoreline.

**San Diego County**

**Counties:** San Diego

**Largest Cities:** San Diego (1,312,000), Chula Vista (246,500), Oceanside (168,200), Escondido (145,200).

During the mid-twentieth century, San Diego County built an economy based on such staples as the military, retirement, tourism, and construction. However, this county with one of the mildest climates in the world became the fastest growing county in the state by the 1980s. It grew so fast that nervous residents began rallying around groups with names such as “Not yet L.A.” In spite of this reluctance, San Diego’s growth—at the expense of its fields of flowers and its citrus and avocado groves—was undeniable, and growth often occurred without plans or controls. The region’s history and quaint Spanish atmosphere and architecture were being swept away by a host of developments including generic housing tracts, new urban developments, development along Hotel Circle and the rest of Mission Valley, tourist attractions such as Sea World, a redeveloped downtown, and an enlarged freeway system.

A good place to view the results of these changes is at Cabrillo National Monument, which looks down on San Diego from atop Point Loma. (The monument was named after the Portuguese soldier of fortune who discovered California for Spain in 1542. San Diego was finally claimed and settled for Spain by Portolá and Serra in 1769.)

From Coronado to Mission Bay and Beach, from Old Town to Horton Plaza, from the Gaslamp Quarter and the convention center nearby, heroic efforts were made during the 1980s and 1990s to change San Diego for the better and sometimes to even preserve its charm. However, the city had become the second largest in California, and it was still growing. San Diego’s population sprawled up the coast through Del Mar and Encinitas and out toward San Diego Zoo’s Wild Animal Park. Even Oceanside experienced a burst in population and in construction to house all the newcomers. The masses then filled the gap between San Diego and Tijuana (Chula Vista is the county’s second largest city), and they have spread east into and around communities like La Mesa and El Cajon and along I-15 to cities like Escondido.

Like residents of San Francisco and its Bay Area, many who live in these extended communities often consider themselves a part of that larger domain known as San Diego. At the same time, they have also created their own more independent urban centers as San Diego County’s economy is forced to diversify along with its

**Figure 1-16** Northern San Diego’s coastline is more than a playground for locals; its beaches and mild climate attract tourists from around the world, such as winter’s “snowbirds,” and its population and economy have grown more diverse. Looking south from the rock formations of this more secluded beach, you can see distant developments growing along and up the coastal slopes.
cultures. The county’s historic economic dependence on the military and the “zoners” who come to escape southern Arizona’s searing summer heat is dwindling. High-tech manufacturing, biotech research, retail, and services have become economic staples. Meanwhile, the Latino population swelled to 32 percent by 2010 while Asians and Pacific Islanders (especially Filipino Americans) also play key roles in breaking the old stereotype of a traditionally white San Diego.

Today, residents can no longer blame traffic congestion, air pollution, crime, and economic bumps on Los Angeles. San Diego is a world class city now, and in the twenty-first century it will continue to be linked with its close neighbor to the south, a bulging and bustling Tijuana. As San Diegans struggle to fund and build a more efficient infrastructure, how will this region evolve through the second decade of the century?

Predictions of what will become of this great experiment range from exciting to frightening. Already, San Diego is beginning to meet head on the urban sprawl spilling south from southern Orange County, itself an outpost of the urban sprawl from Los Angeles even farther to the north. Only the open space of the United States Marine Corps’ Camp Pendleton prevents the merger of San Diego and greater Los Angeles. Will anything stop these cities from growing together into one coastal megalopolis that will eventually stretch from the San Fernando Valley or even the Ventura/Oxnard Plain well into Mexico? Will the slower growth that followed the mortgage crisis of 2008 and the recession that followed become a distant memory or a new trend?

Northern Fringes of the Peninsular Ranges or Southern Fringes of the Transverse Ranges?

Inland Empire

Counties: Southwest San Bernardino, western Riverside

Largest Cities: Riverside (306,900), San Bernardino (211,100), Fontana (198,500), Moreno Valley (195,300)

This brings us to some of those eastern inland valley extensions of the Los Angeles Basin (known as the Inland Empire) and to the south part of the Basin itself. From the retirement communities that flooded the valley around Hemet, to the gradual growth and more diverse economy of historic Riverside, these inland valleys experienced soaring growth rates after Orange County had filled up. Corona, west of Riverside, caught the population overflow that spilled around the Santa Ana Mountains and through Santa Ana Canyon.

Few communities will ever match the explosive growth once seen in Moreno Valley, east of Riverside. During the 1980s, this little community grew from less than 10,000 to a city of over 100,000. Its population soared to over 150,000 in the early 2000s. The influx of commuters eager for inexpensive housing often resulted in a loss of the area’s citrus groves and dairy farms. The irony is that residents brought the city they sought to escape with them. Many still must commute through torturous hours of traffic into the cities deep within the Los Angeles Basin to make a living. Whether the valley smog and long commutes are worth the bigger houses and yards is a question pondered in Moreno Valley neighborhoods every day.

The story is similar in San Bernardino and other inland valleys farther to the north, technically on the edge of the Transverse Range Province. The difference is that more urban poor of all ethnicities have flocked to these suburbs, assembling in neighborhoods troubled by gang activity and higher crime rates. Many locals and researchers extend the Inland Empire through the mountain passes and into many desert communities previously discussed, all on the opposite side of the mountains. It is true that these generally conservative suburbs sprawling away from the L.A. Basin are connected in powerful ways. Regardless of where you draw exact boundaries, the Inland Empire was one of the fastest-growing regions in California until the 2008 mortgage meltdown. The housing bust and recession that followed slowed growth for years as this region became an epicenter for foreclosures. By 2012, residents and leaders were still picking up the pieces, regrouping, and moving toward a less certain future.

Orange County

Largest Cities: Anaheim (341,100), Santa Ana (325,300), Irvine (219,300), Huntington Beach (190,400), Garden Grove (171,400)

If it is now difficult to believe that Riverside is where the first navel orange trees grew, a glance at the modern land-
scape makes it almost impossible to understand how the county and city of Orange got their names. The city of Orange was founded in 1873; the county was born in 1889. Even into the mid-1900s, fruit trees and strawberry fields were commonplace in Orange County. Orange County began growing as Los Angeles’ little sister just after the San Fernando Valley began to fill and long before those inland valleys to the east began to experience population growth. Newer communities to the east can learn some valuable lessons from the county of Orange.

Orange County first grew as a Los Angeles suburb. As agriculture gave way to land development and construction, an economic strip grew along the Santa Ana Freeway (I-5), the main link to Los Angeles. I-5 slices through inland Orange County, so it is not surprising that Disneyland grew up next to it and Knott’s Berry Farm was not far away. Backed by history and the county seat, Santa Ana became the most populated city until recent years. Anaheim competed, building its convention center across from Disneyland and not far from Anaheim Stadium (“The Big A”), where major league baseball had arrived in the 1960s in the form of the California Angels. It’s now known as Angel Stadium of Anaheim and the team name was changed in 2005 to Los Angeles Angels of Anaheim. Just as economic development increased where I-5 intersected with other new Orange County freeways, the focus of activity and growth shifted south.

By the 1970s, Orange County beaches had solid reputations; surfing, swimming, sunbathing, and the beach culture that supposedly personified Southern California were firmly established in the minds of visitors as typical of the Orange County coast. Laguna, Newport, and Huntington Beaches evolved to represent coastal playgrounds that were more convenient and less crowded than the long-established retreats on Santa Monica Bay to the north. This delighted city officials and developers because people, industry, and jobs flocked to southern Orange County. As this economic activity moved south, it affected communities near the beach and along the San Diego Freeway (I-405), such as Fountain Valley, Costa Mesa, and Irvine. Within about a decade, sprawling farms were converted to housing tracts and industrial sites, the inevitable result of rapid population growth.

Today’s economy continues to evolve, pushing high-tech and service industries into the limelight. Some observers make powerful arguments when they claim that the center of Orange County’s economy and culture is now somewhere around South Coast Plaza or even farther south. Farther inland, northern Orange County neighborhoods (in parts of Fullerton, Anaheim, and surrounding cities) and Santa Ana have become more ethnically diverse and similar to greater Los Angeles rather than the predominantly middle-class, white, conservative enclaves they once were. Boasting the third-largest and second densest county population in California, Orange County is now more than 34 percent Latino and more than 18 percent Asian.

Orange County’s wealthiest residents are concentrated along a huge check mark that extends from Huntington Harbor and Beach down through Newport and the Laguna coast. A leg of this area extends north and inland along the hills from the southern edge of Orange County and the San Juan Capistrano area, spilling around the Laguna and Irvine Hills. Evidence of a high-income population is occasionally seen along the western foothills of the Santa Ana Mountains and again in the Anaheim Hills and Santa Ana Canyon. We are now presented with an opportunity to identify trends and patterns of settlement and income distribution common to much of California. To better view and discuss this general pattern, we finally move north and work our way into the heart of Los Angeles and even farther into the Transverse Ranges.

**Los Angeles Area**

**Counties:** Los Angeles

**Largest Cities:** Los Angeles (3,810,300), Long Beach (464,000), Glendale (192,500)

In this section, we will continue our review of human landscapes as they blend into Los Angeles (L.A.). We will later review the natural landscapes of the Transverse Ranges. This is the reverse of our approach for previous regions.

**Exaggerated Human Landscapes.** Population, economic, and cultural trends in L.A. are similar to those of its southern neighbors, with three major differences: L.A. is the largest city; L.A. has been the traditional leader in trends; and, if California is a land of extremes, L.A. is a...
Looking for Patterns in L.A.’s Chaos. One pattern is true for almost all of California: Where the hills meet the water, wealth is present. From La Jolla and Del Mar to Laguna and Santa Barbara, there are numerous examples in Southern California. Like so many other trends, this pattern is exaggerated in L.A. Wealthy neighborhoods of the Palos Verdes Peninsula look down toward those of racially diverse working classes (including the largest number of Pacific Islanders on the mainland) in Long Beach, Compton, Carson, and the South Bay. Even farther west in the Palos Verdes hills, expensive properties offer a view away from this city of contradictions and toward the ocean.

From the upscale Hollywood Hills to Beverly Hills, you can look down on the poverty embedded in L.A.’s city lights. But, as you move toward the “West Side,” the poverty of the lowlands yields to wealth; generally, real estate prices escalate for land closer to the ocean. Residents farther west in the Pacific Palisades or Malibu may find it difficult to believe that there was a poverty-stricken, 57-square-mile segment of the L.A. area (mostly south and east of downtown) where the majority of residents were not even citizens into the 21st Century. That is an area larger than the entire city of San Francisco!

Income disparity and racial segregation were not in the original plan when the Spanish founded a little pueblo along the Los Angeles River in 1781. By the early 1900s, newspaper and railroad tycoons and land barons teamed up with William Mulholland to bring water to the swelling population of L.A. The quest for resources grew with the annexations of surrounding lands, the population increase, and the booming economy. The path was paved for the movie industry. By 1915, Hollywood (within the official city limits of L.A.) was already the movie capital of the world. The discovery of oil pulled great industries, such as in transportation and defense, to the L.A. area. This growing industrial base and the mild climate attracted increasing numbers of people. As a result, the service economy boomed, thus providing more jobs.

As we have seen in other regions of California, housing developments, construction, aircraft plants, and an impressive tourist industry replaced agriculture and oil wells. Freeways stretched the settlements even farther until they filled the San Fernando, San Gabriel, and more distant inland valleys. The settlements filled Orange County and the pressure finally squeezed them into the canyons. Like chain-reaction explosions, outlying cities erupted almost overnight, mostly along freeways and highways. More recently, they have spilled north toward Magic Mountain and into Canyon Country, creating the city of Santa Clarita with a population of more than 177,000, and even farther
L.A. Evolves. First, although many proclaim that L.A.'s issues and problems is that few can figure out, much less agree on, where this great city begins and ends. Because we've already considered Orange County, the eastern inland valleys, and some high desert suburbs, we are focusing here on Los Angeles County until we later sweep northwest and follow the Transverse Ranges.

There are many individual and unique neighborhoods within the city limits such as Echo Park, Boyle Heights, Silver Lake, Hollywood, Van Nuys, Woodland Hills, Westwood, Century City, and Venice, whose residents often identify more with their particular communities than with the city of Los Angeles. In the early 1900s, L.A. annexed many of these locations—especially in the San Fernando Valley—to expand its water rights. By the 1990s, efforts to preserve identity and uniqueness reached a feverish pitch; some residents of the San Fernando Valley saw their communities as so distinct that they launched a movement to secede from L.A.

In contrast, there is the long list of cities that are frequently considered part of the city of L.A. but are actually separate, official cities. A few examples are Santa Monica, Culver City, Beverly Hills, West Hollywood, and Inglewood. Finally, there are the unincorporated communities within Los Angeles County. They don't belong to any city, and they aren't official cities at all! East L.A. and Marina del Rey remained as examples in 2012.

Each of these communities proudly displays its own specific cultures, lifestyles, and human landscapes, but all of them are a part of that sprawling abstract painting, that great experiment we often call Los Angeles.

FINDING L.A.: DEFINING ITS BOUNDARIES

Part of the difficulty in discussing L.A.'s issues and problems is that few can figure out, much less agree on, where this great city begins and ends. Because we've already considered Orange County, the eastern inland valleys, and some high desert suburbs, we are focusing here on Los Angeles County until we later sweep northwest and follow the Transverse Ranges.

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neighborhoods, and some were left homeless. Many of them moved out to the hinterland. Cities like Palmdale, Lancaster, and San Bernardino have received an influx of these low-income families. Consequently, many distant suburbs have now also become complicated human landscapes with diverse assemblages of families who represent many ethnic groups, cultures, and income levels. They, too, have “escaped” the urban core.

Finally, too often, L.A.’s many rich and diverse communities have been improperly lumped together. It is tempting, especially while traveling through the Basin by freeway, to discredit L.A. as a bunch of generic housing projects that eventually grew into one another, emerging as a bland, expansive megalopolis. Such superficial observations are not only incorrect, they are unfair to the many dedicated residents who identify with and are active in their specific communities and neighborhoods. After all, we are talking about nearly 4 million people within the city limits and a population of over 15 million in the Basin and its connected settlements.

**Divided L.A.** Los Angeles still has an economic center that stretches from the central business district, west along the Wilshire Corridor’s concrete canyon, into Century City and Westwood. Otherwise, economies and jobs in the Basin are so spread out, freeways are often jammed with commuters going in both directions (to and from downtown) during morning and evening rush hours. Perhaps understanding these economies is just as difficult as understanding the complex cultures and neighborhoods that make up L.A. and California. Today, there is a new, powerful economic force that is putting pressure on Californians in general and Angelenos in particular: the global marketplace.

Current economic trends in L.A., as in most other California cities, are toward an economy with two distinct and very distant levels. Middle class manufacturing jobs have been replaced by two very different employment extremes. One extreme is represented by the high-paying, high-tech, research and development jobs and their associated high-level services (finance, trade, professional, and information technologies). On the other end are the growing low-paying, low-tech manufacturing jobs, such as garment sweatshops, and low-level services jobs, such as the fast-food industry and domestic workers.

The growing disparity in incomes and in levels of education and skills is tightening the social vise, increasing tensions between and within these classes, and challenging officials who are trying to figure out how to cope with the situation. To witness the impact these trends have on L.A.’s and California’s human landscapes, you need only walk through the streets of Pico-Union or South L.A. and then walk through the streets of Brentwood or Beverly Hills. And since most of the victims of the mortgage meltdown of 2008 were recent working and middle class homebuyers, the gap between rich and poor grew larger throughout L.A. and California during the years of recession that followed.

The increased economic competition is also raising tensions between lower-income groups. These tensions are evident in places like South-Central L.A., where Latinos have recently displaced African Americans to become the majority ethnic group. Intricately entwined economic and cultural trends are producing some fast-changing human landscapes throughout L.A. and California; such trends earn more attention here since they are common to most of California’s major cities.

**Transverse Ranges North of L.A.**

**Counties (west to east):** Santa Barbara, Ventura, northern Los Angeles and higher mountains to the east

**Largest Cities:** Oxnard (199,800), Santa Clarita (170,000), Thousand Oaks (127,600), Simi Valley (125,000)

**Moving Northwest, into Other Urban Centers in the Transverse Ranges.** Farther northwest is Ventura County, where the Ventura/Oxnard Plain’s rich agricultural fields are being consumed by the same kinds of industrial parks, shopping malls, and housing projects that took the San Fernando Valley and other L.A. suburbs by storm decades ago. Similar activities blossoming along the strip of Ventura Freeway (such as in Thousand Oaks) and in places like the spreading Simi Valley are strengthening the connections with L.A. Experiencing so many of the same economic trends as L.A., this was one of the fastest growing regions in California into the twentieth century. Oxnard outgrew its older neighbor San Buenaventura (Ventura) many years ago.

Still farther to the northwest is the beautiful and still relatively isolated strip of Santa Barbara coast. Past development has been mostly limited to that thin coastal plain with the ocean on one side and the steep Santa Ynez Mountains on the other. Limited water supplies should play less important roles in the future since many of these communities connected to the California Water Project after 1996.

In spite of tourists, the crowded downtown shops, a growing University of California, and development that encroached from surrounding communities, Santa Barbara retains much of its magic and charm and an atmosphere that is more reminiscent of old California. Perhaps this is because it was just far enough from the explosive growth of L.A. and, more recently, Ventura and Oxnard. Perhaps it is because land values and rents are very high, there are not many high-paying jobs, and it is too far to commute into L.A. Whatever the reason, when that dry sundowner wind blows through the imported palm trees, over the historic mission and toward
its scenic beaches, Santa Barbara can still shine like no other California city.

It could be said that the sprawling suburbs of Canyon Country and amalgamated communities of Santa Clarita represent the antithesis of Santa Barbara. They are strongly connected by commuters to greater L.A. Developments that gobbled up open land at historic rates and new residents are being surrounded with the same L.A.-style suburbs, traffic, and expensive real estate they thought they had escaped. Breaking away from these suburbs in the heart of the Transverse Ranges (far away from any beach) will probably require the use of a car and freeway. Just as many residents were struggling to redefine their communities so that past mistakes were not repeated, home values plummeted into the recession following the mortgage crisis that hit in 2008. Some new homeowners farthest from the coast lost up to 50% of their investments, causing economic ripples through every inland community.

**The Transverse Ranges—Natural Landscapes.** Now we will review the natural landscapes and processes that combine to form the Transverse Ranges.

The Transverse Ranges rise above and protect many southern California cities from winter’s cold snaps. This protection is evident when north winds must sink and be heated by compression to get to the coastal valleys below. What would be cool winds are modified to warm and dry, causing autumn and winter heat waves. When these Santa Anas blow during mid-winter, the mild southern Californian climate is the envy of snow shovelers in more wintry parts of the country.

However, these winds also bring the occasional wildfires that scorch the chaparral and coastal sage and even communities on the lower slopes of the Transverse Ranges. The winter mudflows that follow these fires race out of the mountain canyons and add to the destruction. They also add a little bit more material to the alluvial fans radiating out of the canyons and the more than 9,150 m (30,000 feet) of sediment already accumulated below the Los Angeles Basin.

The ‘Transverse Ranges’ name comes from the way they cut east–west, across the more common trend of landforms, through California. They represent rocks and slices of crust caught, crumbled, and lifted up throughout a wide region near the big bend in the San Andreas Fault Zone. The Transverse Ranges trend all the way from Points Arguello and Conception and the Channel Islands National Park on the west into the little San Bernardino Mountains and Joshua Tree National Park on the east. They are bordered by the Coast Ranges and Central Valley.

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**Nature and Open Spaces Accessible to Millions**

The Transverse Ranges have gained much of their fame because of their proximity to the Los Angeles Basin. On clear days, they seem to erupt from the edge of the San Fernando Valley and especially the northern edge of the San Gabriel and northeastern San Bernardino Valleys. These boundaries offer classic illustrations of dramatic human interactions with nature. The contrast between the Basin (with its warm winter sunshine, citrus groves, and palm trees) and the brilliant snowcapped peaks in the background was displayed on magazine covers and promotional brochures for decades. Today’s Los Angeles skyscrapers have replaced the orange groves in a modern version of these breathtaking views. Residents of the Los Angeles Basin from the valleys to Orange County and Santa Monica Bay beaches will recognize these familiar landmarks looming toward the north and northeast.

The chaparral on these slopes yields to woodland and yellow pine and even cooler forests at higher elevations that receive more than 75 cm (30 inches) of precipitation per year. This serves as important watershed, since much of the water flows down into the basin after accumulating in channels flowing through deep canyons. When the water out of the San Gabriel River and other channels is ponded into spreading basins at the bottom of the mountain front, it recharges future groundwater supplies. However, during heavy winter storms, it can produce dangerous and destructive flooding. This is especially true after summer and fall wildfires (such as the historic Station Fire of 2009 that burned a large portion of the San Gabriel Mountains) expose the slopes.

The cool forests and winter snows of the San Gabriels and San Bernhardinos have also been magnets for millions of visitors willing to brave winding roads and the short drive to escape the city. Weekend traffic jams bring the crowds who fill every picnic table, campground and trail, or winter ski resort. Here, especially along Angeles Crest Highway, is another example of how so many Californians strain to find a little piece of that remaining wilderness and open space that once helped make Southern California famous.

The same problems plague the smaller Santa Monica Mountains, which are also peppered with developments. Within them are Griffith Park and the Hollywood Hills to the east and the community of Topanga and the city of Malibu toward the west. The Santa Monicas are the most southerly of these Transverse Ranges and they are the only major mountain range to bisect a major U.S. city. Meanwhile, all of these diverse landscapes continue to star as scenery in countless Hollywood movies, TV programs, and commercials. Trending farther west, the northern Channel Islands are a structural extension of the Santa Monicas.

From the San Gabriels, the Santa Susana, Topatopa, and Santa Ynez Mountains finally trend out to Points Conception and Arguello. Gradually, the remaining ranches and agricultural service towns like those near the Santa Clara River will probably yield to the same developments that are surrounding them and have already been reviewed in this chapter. North of here, Coast Ranges landforms rule and trend in a more northerly direction. Landforms, coastal features, and coastal waters become decisively central Californian to the north.
to the northwest and the southern tail of the Sierra Nevada (and Tehachapis) and Mojave Physiographic Provinces to the northeast. The Peninsular Ranges make up their southern boundary, and the Coachella Valley is at their southeastern boundary.

The Transverse Ranges are typically quite rugged and especially lofty toward the east. The San Bernardino Mountains include the resorts of Lake Arrowhead and Big Bear and its popular ski slopes. San Gorgonio Mountain is the highest in southern California at 3,507 m (11,499 feet). Across Cajon Pass and trending west are the San Gabriel Mountains, with 3,070 m (10,064 feet) Mount San Antonio (Old Baldy) Peak towering above Wrightwood and its popular ski resort. The rugged topography trends farther west to 1,742 m (5,710 feet) Mount Wilson and its renowned observatory. After becoming one of the world’s premier astronomical observatories earlier in the 1900s, its importance faded in later decades, partly due to the explosion of city lights in the nearby L.A. Basin. Thanks to new technologies, it enjoyed a rebirth in the 1990s.

**A Geographic Pivot Point**

There is an outstanding geographic pivot point in California. It stands out because the bending San Andreas Fault meets the Garlock and other faults there. It stands out where the corners of five different physiographic regions intersect (the Coast Ranges, Central Valley, Sierra Nevada’s Tehachapi extension, the Mojave, and the Transverse Ranges). It stands near where three different mountain ranges and basins are wedged together with many different rock types. It marks the center for a major mountain barrier between air masses to the north and south. It displays an amazing mix of plants and animals that have crept in from cismontane and transmontane, central and southern California, from lower to higher elevations.

This pivot point sits on a definitive natural and cultural boundary between southern California and the rest of the state. Three counties (Ventura, Kern, and Los Angeles) intersect at this point near Frazier Peak and Tejon Pass. Even the cars, buses, and trucks on I-5 must strain to get over this barrier, as if some unknown force was trying to make them turn back before it was too late, to discourage them from entering that different world on the other side. All of these factors come together on the map and on the ground to create a unique landscape at this most unusual geographic pivot point. Perhaps this is why so many artists, photographers, and scientists have been attracted to these landscapes.

We are getting closer to the end of our clockwise sweep around the various regions of the Golden State. It’s time to head northwest from here, into the Coast Ranges. As usual, we will first look at the physical geography of the entire region, and then its human geography, saving the human landscapes of the San Francisco Bay Area for last. We will finally complete our journey with a brief view of the Central Valley.

**The Central Coast and Coast Ranges**

*Counties (south to north):* far northern tip of Santa Barbara, San Luis Obispo, Monterey, San Benito, Santa Cruz, Santa Clara, San Mateo, Alameda, San Francisco, Contra Costa, western edges of several San Joaquin Valley counties, Marin, southwestern Solano, Sonoma, Napa, southern Mendocino, Lake, western edges of Glenn and Colusa

*Largest Cities Well Beyond the Bay Area:* Salinas (151,200), Santa Maria (100,100), Santa Cruz

![Vineyards spread across bucolic landscapes of Central California’s southern Coast Ranges. The lone oak tree reminds us that our appetite for California’s fine wines has created an explosion of vineyards that are replacing some of California’s most scenic natural landscapes. Surviving oak woodlands may be seen farther up distant slopes.]
Here, we consider the Central Coast and Ranges west of the Central Valley. They trend northwest along the coast and the San Andreas Fault Zone from north of the Transverse Ranges, and finally blend in with the northern Coast Ranges and the northwest coast somewhere in Mendocino County. There is no clear northern boundary, but the northern Coast Ranges and Klamath Mountains tend to be higher, more rugged, and wetter.

Major mountain ridges and valleys of the Coast Ranges trend strikingly parallel to the northwest–southeast trending San Andreas and other splinter faults. They present formidable barriers to east–west travel throughout the range. San Francisco Bay is often used as the break between the north and south Coast Ranges, and with good reason. First, the path from the Golden Gate into the Bay and Carquinez Strait and on into the Delta is the only major natural break slicing across the Coast Ranges. This gash not only serves as a conduit so that ocean air can flow into the Central Valley, but also as a channel for deep-water vessels into the valley. It is the path followed by both saltwater, when it encroaches inland during high tide, and freshwater from the Delta that flushes the system during heavy runoff and low tide.

Ridges of the Coast Ranges tend to be lower in the south, ranging above 600–1,200 m (about 2,000–4,000 feet). Major ranges include the Santa Cruz Mountains down to Monterey Bay and the Santa Lucia Range down to Morro Bay. On the inland side are the Diablo Range east and south of the Bay Area and the Temblor Range farther to the southeast. Deep and sometimes broad valleys often parallel these ranges. The greatest is the Salinas. The Salinas River headwaters drain toward the northwest all the way from San Luis Obispo County. The river continues to flow northwest through the productive farmlands of a widening Salinas Valley, past King City and Soledad and toward Salinas. Finally, the Valley and its river spill out into the Monterey Bay and its submarine canyon, bounded by Santa Cruz on the north and Monterey on the south. Farther north is the Santa Clara Valley; it trends southeast out of San Jose and the Bay Area and into Hollister.

North of San Francisco Bay, the Coast Range ridges eventually reach higher and are more remote. The northern ranges also receive considerably more rainfall. This generally results in more lush forests, especially on western slopes, compared to the southern ranges. “The Redwood Empire” was named with these forests in mind. In Lake County, Clear Lake is the largest freshwater lake totally contained within California’s boundaries. Even in the northern Coast Ranges, the inland valleys are hot and dry during the summer. Good examples include the Sonoma and Napa Valleys, which receive abundant rainfall in the winter but turn warm and dry during summer, providing perfect grape-growing climates. Even farther north of the Bay Area, the valleys and the coast tend to be more narrow strips.

These coasts north and south of the Bay Area are also some of the most picturesque, photographed, and famous landscapes in the world. From Morro Rock to the cliffs that erupt out of the sea at Big Sur, from Carmel and Monterey Bays, to Año Nuevo, Pescadero, and Half Moon Bay, spectacular rock formations combine with a patchwork of plant communities and misty fog for some unparalleled coastal scenery. North of San Francisco, equally accessible and splendid coastal landscapes are on display from Stinson Beach to Point Reyes National Seashore and from Bodega Bay all the way up the Sonoma and Mendocino coastlines. Several of nature’s attractions more inland and close to Bay Area populations include Big Basin Redwoods in the Santa Cruz Mountains, Muir Woods in Marin County, and, farther north, the Russian River summer resorts near Santa Rosa. (The Russian River also follows an inland valley, flowing southeast until it turns west just before Santa Rosa and slices through the Coast Ranges to Jenner and the Pacific.) As we move even farther northwest in the Coast Ranges, primary industries, ecotourism, and rural cultures dominate the bucolic landscapes.

Human Landscapes of the Central Coast
Monterey Bay and the Salinas Valley probably have the richest history along this coast outside the Bay Area. There were once nearly 100 sardine packing plants during the great fishing boom along Cannery Row in Monterey. The fishing boats can still be seen in Monterey, Morro Bay, and other Central Coast spots. However, none of these coastal communities rely on fishing to fuel their economies as they did many decades ago.

Today, from Monterey Bay Aquarium and Carmel-by-the-Sea to Big Sur, San Simeon, and Morro Bay, tourism is king, and it is enhanced by some impressive art communities. The Monterey Peninsula entertains more than 2 million tourists each year; the shops and other tourist attractions in Monterey and Carmel are testimony to this. To the north, Santa Cruz is a historical tourist destination, especially for working folks escaping the Central Valley’s summer heat or the Bay Area’s crowds. This tradition continues, but a more diverse economy now includes modern industries and the University of California, Santa Cruz.

Between Monterey and Santa Cruz, once booming communities grew in the shadow of Fort Ord which helped fuel their economies. Since the military base closed, Seaside, Marina, and many other surrounding communities have looked toward other land uses and economic engines (such as Cal State University, Monterey Bay) to lead the way.

Meanwhile, nearby Salinas Valley communities have no identity crises. They continue to thrive in some of the
most productive farmlands in the world, the same places John Steinbeck wrote about. Here also is that same disparity in income we have noted previously between those who plant and harvest the crops and those who run the farms; it would look very familiar to someone from the Imperial Valley. By the 2010 Census, about 75% of the Salinas population reported to be of Hispanic or Latino origin. To the south, Cal Poly, retirees, and transplants from Southern California help fuel the economy and increase land values in the San Luis Obispo area. Gone are the days when you could sell your modest home in L.A. and buy a small ranch in these rolling scenic hills.

Finally, way down on the southern tip of the Coast Ranges (or northern Transverse Ranges) along the Santa Maria River is little Santa Maria, which at more than 100,000 is no longer so little. Santa Maria is not a tourist town, though attempts are being made to diversify its economy. Unfortunately, since the end of the twentieth century, it has experienced some of the problems connected to rapid growth (as commuters found cheap land in its exurbs) even though it is not a suburb attached to any city. It stands in real contrast to the picturesque, gently rolling hills with grasslands and oak woodlands so common to other stretches of Hwy. 101. If there is a nostalgic landscape typical of California’s mission days, you may find it along or near Central California’s Hwy. 101, but not in Santa Maria.

**Human Landscapes of the San Francisco Bay Area**

**Largest Cities:** San Jose (960,000), San Francisco (812,900), Oakland (393,000), Fremont (215,800), Santa Rosa (169,000), Hayward (145,900), Sunnyvale (141,100)

Although Bay Area residents may resist the idea, their human landscapes have much in common with Los Angeles. We can make a brief list of those common events that have had similar results in the Bay Area. First, as San Francisco, Oakland, and other traditional centers bulged during the middle to late 1900s, populations broke away to establish enormous outlying suburbs. Many went to the South Bay, others to the East Bay, and they more recently filled some open spaces north of the bay. Some even found inexpensive homes in more distant Central Valley exurbs only to participate in the tortuous commutes required to make a living. Second, like Los Angeles, portions of central San Francisco and Oakland experienced urban decay during and after the mid-1900s. Mainly white populations moved to the suburbs along with money and jobs while lower income families and minorities were left behind. This trend eventually impacted even San Jose’s downtown. Third, these problems were further exacerbated by redlining and the unwillingness of businesses to invest in some of these blighted communities.

Just as in Los Angeles, from the 1980s into the twenty-first century, urban redevelopment and gentrification attracted young professionals back to the city (especially San Francisco), and the poor were squeezed further, many to the outlying suburbs. The result is that some lower-income and minority families have populated a few of the suburbs far out on the urban fringe. As Bay Area suburbs grow, traffic jams, pollution, and crime may also grow. Today, public officials are striving to create efficient infrastructures that will serve the edges of what has evolved into a complicated megalopolis.

Finally, the economies of the Bay Area, like Los Angeles, have also evolved away from the traditional military and manufacturing emphasis to high-tech, trade, entertainment, and service industries. There is also a growing gap between the rich and poor, though it is less extreme than in Los Angeles. As in southern California’s Inland Empire, new homeowners of the working and middle classes (especially those who bought in new developments on the urban fringe at the start of the century) were most impacted when the real estate bubble burst by 2008. Thousands of these families lost their homes and were thrown into the tempest and suffering of the reces-

*Figure 1.22* San Francisco, built before the car, is still squashed together on its little peninsula. Cable cars in the foreground are reminders of The City’s celebrated history. The Bay Bridge is seen in the distance, rising up from the bay, peeking through downtown skyscrapers.
tion that followed. This (and rising fuel prices) at least temporarily slowed the great migrations to distant suburbs. All of these factors are playing important roles in shaping the Bay Area’s human landscapes.

**The Bay Area is Unique.** Perhaps, to the delight of northern Californians, there are also some major differences between their Bay Area and the Los Angeles Basin. Though many southern Californians cherish their beaches and surrounding mountain playgrounds, dramatic human-nature interaction seems to call out from more Bay Area landscapes. And though the Bay Area is not as famous for its warmer beach climates and cultures or its crippling traffic gridlock, its landscapes display more care and sensitivity to preserving their gifts of nature. You may be less comfortable jumping in the ocean without a wetsuit, but the Bay Area’s natural landscapes, treasures, and playgrounds seem more accessible to more of its people. You will find more frequent views of dramatic natural landscapes juxtaposed against dense human settlements. These settings continue to inspire emotions, music, art, and books like this, only with a Bay Area focus. How did this happen?

First, San Francisco experienced most of its growth and development before the automobile. Its narrow, pedestrian-friendly streets and diverse neighborhoods are packed close together. In this respect, San Francisco more resembles Boston rather than a typical California city. Second, unlike L.A. or San Diego, San Francisco is a tiny city in area; once it filled its little end of the peninsula, it could not expand outward. It had to become denser and grow upward, while the overflow populations were sent to neighboring cities. This is why “The City” has often been called the city without a suburb, in contrast to Los Angeles, which was once considered a group of suburbs without a city.

Second, there are no great lowlands in the Bay Area to support the continuous interlocking developments common in the Los Angeles basin. Instead, spreading populations have always been detoured around the huge bays and then often confined between steep hills. When all these factors are considered, it is easy to understand why so much unlikely development has occurred on such steep slopes that would otherwise seem to prohibit settlement. However, the real barriers are the great bays.

San Francisco has one of the world’s largest natural harbors. San Francisco Bay spreads out south of San Francisco and Oakland. Some great cities are built on the flatlands surrounding it. They include Alameda, Hayward, San Mateo, Redwood City, Palo Alto, Fremont, Santa Clara, and San Jose to the south. North of the San Francisco–Oakland Bay Bridge are Berkeley, Richmond, and the Marin County settlements. The sprawling communities north of San Pablo Bay include Petaluma, Rohnert Park, huge Santa Rosa, and the growing communities up along the Napa and Sonoma Valleys. From Vallejo, cities have even grown near the shores of the Carquinez Strait and Suisun Bay and into the Delta. The Bay Bridge and the Richmond–San Rafael, San Mateo, and Dumbarton Bridges represent bold attempts to link these cities. But, that giant bay which separates the city lights continues to be the most conspicuous part of Bay Area landscapes.

Finally, the Bay Area population, at more than 6 million, is still less than half that of the Los Angeles area. This and the dividing effects of the bays have made this
Getting to Know the Golden State

Famous for its experimental politics and as the location of the Great Golden Gate, the region a little more manageable and user-friendly. As proof of this, in the 1990s the region was temporarily taken off a federal list of urban areas with dangerously polluted air and it has met many more air quality standards than L.A. ever since. Another example is how the Bay Area Rapid Transit (BART) system has combined with other transportation services to deliver relatively convenient, reliable, and popular public transportation. The compact city of San Francisco has the finest transportation system in California, with the most options for its riders. This convenience also encourages tourism. “The City” is always near the top of urban tourist destinations in the U.S.

San Francisco erupted as a Wild West city almost overnight during the Gold Rush. The city’s strategic position had and still has everything to do with the bay and the city’s perch atop the entrance to it (the Golden Gate). It quickly became the financial capital of the west and held that distinction from the mid-1800s to the mid-1900s, until Los Angeles took over. Its ability to attract people from so many ethnic groups, cultures, and lifestyles, often shunned by their homelands, has prevailed since its early and wild gold rush days. The African American population in the Fillmore and Bayview-Hunters Point, Latinos in the Mission, Italian Americans at North Beach, the gay and lesbian community in the Castro, and some of the greatest concentrations of Asians and Pacific Islanders in the country make it difficult to find another city of its size with such cultural diversity.

San Francisco quickly grew from the mid-1800s as a real city with a real skyline and a definite central core. Slicing through today’s towering downtown concrete canyons is Market Street; for a short distance it easily triumphs over its southern counterpart—Los Angeles’ Wilshire Boulevard—as the city’s central strip. San Francisco’s central business district is still well defined as are most of its other districts and neighborhoods. It continues to evolve as a walkable, exciting, and entertaining urban center, but a serious housing crunch has been created by those who compete to live in The City. The growing populations were forced to other Bay Area cities. After WWII, Oakland was also developed and the masses spilled away from urban centers and settled south, east, and north around the bays and then, by the 21st Century, into more distant suburbs previously discussed. Just as in the L.A. area, each community has a unique story to tell. So don’t let San Francisco’s well-earned history and fame cast shadows on other big Bay Area cities. San Jose, Oakland, Fremont, Hayward, Sunnyvale, and others could be dominating urban centers in most other states.

Moving Away from San Francisco and Oakland. Just to the south there is Daly City, a bedroom community suburb identified with a 1960s song about “ticky-tacky” little boxes on the hillsides. Across the bay lies Berkeley, famous for its experimental politics and as the location for the state’s first University of California. There’s quaint Point Richmond, with beautiful views across the bay on one side and Richmond on the other with its refinery, working class, and notable African American community. From here, across the Richmond–San Rafael Bridge and connected to San Francisco by the Golden Gate Bridge is Marin, one of the wealthiest counties in the United States. Marin County residents have staged some monumental and successful battles to keep out the developers who have filled surrounding lowlands. However, the string of swelling suburbs in counties to the north of San Francisco along Hwy. 101 skipped all the way up to Petaluma, Rohnert Park, and Santa Rosa.

Almost as a mirror image with the north, the communities of the South Bay have experienced impressive, but earlier, growth as they culminate in California’s third-largest city, San Jose. When communities northwest of San Jose bathed in the industrial and technological riches brought by Stanford researchers and the computer industry during the 1970s, their lowland area took the name “Silicon Valley.” San Jose housed many of the workers in these new industries until it earned the reputation of a little L.A. without the culture. As its bedroom communities grew together, they drained San Jose’s downtown and created an enormous suburb, complete with malls, traffic jams, and smog.

Unlike San Francisco, San Jose had plenty of room to grow, so it surged ahead of The City in population later in the 1900s. The fingers of development have crept even farther southeast and into the Santa Clara Valley communities of Morgan Hill and Gilroy. However, after high-tech industry slumps into the early 1990s, a magnificent boom in the late 1990s, followed by another downturn in the early 2000s and another boom by 2012, the area’s cities are considering methods to diversify their economies. As San Jose continues to claim the title, “California’s City of the Future,” its residents and officials work hard to define what that future city should be.

All of this is similar to the massive developments in the East Bay’s inland valleys. Mount Diablo now looks down on the daily traffic jams and congestion created as Concord and Walnut Creek grow together. These inland valleys are shielded from direct sea breezes, so they are hotter and drier during the summer. The valleys, with their new developments, extend even farther east to Pleasanton and Livermore with its renowned research laboratories. The story is all too familiar as many of these East Bay communities are also competing for high-tech and service industries to fuel their economies.

The developments have spread even farther east, into the Delta and Central Valley. Commuters are finding less expensive homes out there, but they are also spending long hours commuting toward Bay Area jobs. Although most residents claim they don’t want to create another Los Angeles, it is not difficult to visualize another megalopolis stretching from San Francisco north through
Santa Rosa, south past San Jose, east through the East Bay, into the Central Valley, and all the way to Sacramento. Developments have already spilled into and filled these valleys with their views of Mount Diablo. These trends are familiar: the search for affordable land and space moves California growth farther inland. The collapse of the real estate market that rippled through and devastated some of these communities after 2008 is a reminder that past experiences may not always be the best predictors of future trends in the exurbs.

We have reached the Central Valley. This is the center of our clock and the end of our journey.

Central Valley

Counties (north to south): southern tip of Shasta, Tehama, eastern Glenn, western Butte, eastern Colusa, Sutter, western Yuba and Placer, Yolo, Sacramento, northeastern Solano, San Joaquin, Stanislaus, Merced, southwestern Madera and Fresno and Tulare, Kings, western Kern

Largest Cities: Fresno (500,200), Sacramento (469,700), Bakersfield (351,600), Stockton (293,600), Modesto (202,400)

Natural Setting

The Central Valley (or Great Valley) competes with the Sierra Nevada as the largest province or landform in California. It stretches more than 640 km (400 miles) from southern Shasta County south to the Tehachapis and more than 80 km (50 miles) at its widest from the Coast Ranges to the Sierra Nevada. It is also bordered by the Klamaths and Southern Cascades to the north, while its southern end is near that geographic pivot point with four other physiographic provinces.

This extensive, mostly flat valley near sea level exhibits remarkable uniformity, especially for a California region. It is divided into two sections at the Delta. The Sacramento River and its tributaries drain the northern part of the valley (the Sacramento Valley) into the Delta. The San Joaquin River and its tributaries drain most of the San Joaquin Valley into the Delta, except for far southern portions, which exhibit inland drainage.

This elongate valley has been downwarped for millions of years between the Sierra Nevada and Coast Ranges. It has also been filling with thousands of feet of sediment during that time. Oil is extracted from some of the relatively older sediments in and around the San Joaquin Valley, while productive aquifers are also tapped for their valuable irrigation water. But the younger surface sediments are even more productive. The soils formed on them are some of the richest in the world.

The Central Valley receives scant precipitation compared to its surrounding mountains. However, for millions of years, rivers and streams flowing out of these mountains (especially off the western slopes of the Sierra Nevada) have delivered rich sediment and abundant water to this basin. Native grasslands once dominated the valley and wide paths of riparian forests grew along its waterways. During heavy runoff, water frequently ponded to form huge lakes in the southern San Joaquin Valley, while the Sacramento and San Joaquin Rivers often flooded much of their valleys and their delta.

People Bring Changes to the Central Valley

The greatest water projects in the world have controlled annual floods and distributed the water more evenly throughout the year. These projects have also allowed ocean vessels to navigate along waterways to places like the Port of Stockton and past Sacramento up the Sacramento River. They have also stored tremendous amounts of water for irrigation in what is the greatest and most productive agricultural valley in the world. The result was the early demise of those native grasslands. These topics are addressed in more detail later in this book.

Evidence of agricultural productivity can be witnessed while traveling along Hwy. 99 or I-5 during any summer when caravans of trucks are full of tomatoes, onions, cotton, and other crops. Great cattle yards, such as those along I-5, harbor thousands of cattle just before they become hamburgers for the fast-food restaurants that originated in California and now line those monotonous strips of Central Valley highways. (By 2010, the multi-billion-dollar dairy and beef industries were the first and fifth agricultural commodities in California.) Californians can thank the Central Valley for making the state number one in agriculture in the United States.

Even the weather contributes to this productivity. Sun rules during spring, summer, and fall and growing seasons are long, especially in the southern part of the valley. However, stagnant weather conditions that trap summer smog also allow winter’s dreaded cold tule fog to settle and thicken out in all directions within this lowland protected by barriers on all sides.

Human populations are now also settling into these massive lowlands, consuming some of the most productive farmlands in the Valley, and bringing the same issues and problems we have seen elsewhere: traffic congestion, pollution, inadequate infrastructure, crime, urban sprawl, the loss of open space, and how to diversify and modernize the economy. These dramas that have already been played out by so many California cities in milder climates closer to the coast are now being repeated in the Central Valley as its cities begin to grow and merge together into what could be California’s new and most surprising megalopolis of the twenty-first century. The difference in this region is the powerful grip agriculture has had even on many urban economies and cultures since people settled in the Valley. Evidence includes the myriad dealers displaying their latest tractors, other farm equipment, and repair services along the highways.
A Journey from South to North in the Central Valley

Bakersfield is king of the southern San Joaquin Valley. This area has taken the nickname “Nashville West” because of country music’s popularity in the area. The honky-tonk sound was refined here in the cowboy beer joints and nightclubs as more than one country western performer and native son gained national fame. This city was built on the Kern River where wealth from rich agricultural land and nearby oil fields was enhanced by major transportation corridors which cut through the area.

Fresno combines with its smaller neighbors to the south (including Visalia, Tulare, and Porterville) to represent the focal point of the central San Joaquin Valley. It also straddles Hwy. 99, but it is near the entrance to celebrated Kings Canyon and Sequoia National Parks to the east. It once earned the title “Raisin Capital of the World,” a label that could only be attached to such an agricultural giant. (Nearby Selma has claimed that title more recently.)

The agribusiness that dominates throughout the Valley also rules here where the Valley’s ethnic diversity (including an especially large Latino population) stands out. Its economy has been diversified by such additions as a large Cal State University campus. On the western side of the Valley opposite Fresno, farms give way to more extensive cattle grazing on drier lands.

North of Fresno, smaller communities are strung out along Hwy. 99 and the major railroad lines that parallel it. They culminate with the larger Modesto and even larger Stockton, with its deep-water port. Here is where the waters of the San Joaquin and Sacramento Rivers converge to flood their delta. The miles of Delta channels meander around below-sea-level islands that are protected by a complicated system of connected and aging levees, zigzagging across the landscape like so many exposed earth worms. Here is also where the East Bay’s urban sprawl is spilling farther east to meet Valley developments. Mount Diablo seems to punctuate the southwestern horizon of all of these Delta landscapes.

Moving north into the Sacramento Valley, there is Davis, a bicyclist’s haven made famous by its UC campus with a traditional emphasis on agriculture. Finally, there is Sacramento, the modern state capitol and California’s fastest-growing urban area where the meandering Sacramento and American Rivers meet. This was another Wild West product of the Gold Rush; it also erupted almost overnight in the mid-1800s. Until sediment from hydraulic mining clogged the Sacramento River and its tributaries, boats hauled people and cargo past Sacramento to the gold fields and towns and back to San Francisco. Ships returned decades later after the sediment had finally been flushed.

Sacramento and Beyond. Meanwhile, Sacramento’s location at the end of the transcontinental railroad kept the attention of business people, shipping industries, and land barons across the state. Agriculture ruled for decades, but its importance continues to wane within a more diversified economic environment. This includes a reduced military presence, the official state business for thirty-six million Californians, industrial parks, commercial districts, and a Cal State campus.

It is appropriate to complete our clockwise sweep of California here in Sacramento. It is the center of some of California’s most magnificent history. It is in the center of this enormous physiographic region spread along the state’s midsection. It is the center of the state’s political structure, and it is now experiencing the same profound changes and confronting the same problems and issues common to nearly every California city.

How can we deal with the rapid growth that so often destroys the identities of our cities and communities? What will happen to the open space and productive farmlands consumed by our seemingly insatiable appetites for continued growth? How will we attack the modern urban problems such as congestion, pollution, crime, and quality of life while we build the economies and infrastructures required to serve California’s people?

These and other questions continue to haunt Californians, partly because we fail to put aside our partisanship and self-serving agendas long enough to come to some productive compromises. Once again, this time as the Sacramento urban area expands and even begins to meet with developments expanding from the East Bay, we are becoming the victims of change instead of making change work for us. Will we manage to come together and create better living environments that will improve...
our quality of life? Some answers may be found in landscapes within Sacramento and throughout California.

Perhaps there are clues in the beautiful Victorian homes that have been preserved (some now housing small businesses) along the tree-lined streets and near the old Governor’s Mansion east of downtown Sacramento. Perhaps there are answers in the displays assembled by each California county in the hallways of the State Capitol building, which may represent attempts by residents and officials to define who they are and show where they are going. A walk down Capitol Avenue and onto the bridge over the Sacramento River, then back into refurbished Old Town reveals a mix of our past and current landscapes and leaves hints of possibilities for the future. Even the simple contrasts between the Downtown Plaza and the adjacent open K Street Mall suggest that we cannot decide which basic urban environment is best; perhaps it is actually a combination of diverse landscapes and choices which make us most comfortable.

These kinds of observations once again take on a grander scale as we move out of the downtown and into surrounding neighborhoods and outlying communities. How do we deal with the growing gap between rich and poor, the interaction between diverse cultures, and the human landscapes these trends inevitably produce? Look around for the changes and trends that leave their marks on every California town and city.

What is to become of the smaller agricultural service towns and the sweeping farmlands north of Sacramento? How are the larger settlements strung up through the Valley (such as Yuba City and Marysville, and Chico with its CSU campus) dealing with the quiet that returned after busy I-5 bypassed them far to the west years ago? As some of these historical agricultural towns deflated in the late 1900s, communities like Chico reinvented themselves into the new century. You might notice this in Chico’s downtown music festivals and farmer’s markets that bring the more progressive college crowd together with a more traditional rural culture. How far will the Central Valley’s perfectly square roads and developments encroach up Sierra Nevada slopes after they are forced into the twisted patterns that match the more rugged topography above the Valley? Was the real estate collapse of 2008 and recession that slowed growth an aberration into the second decade of the 21st Century or a newly established trend? Perhaps we can try to imagine what it will be like to climb to the top of the conspicuous Sutter Buttes volcanoes for a view of Sacramento Valley landscapes 50 or 100 years from now.

As Californians debate so many of these issues, we see once again that California’s diverse natural and human landscapes and people are related in profound ways. And they are always changing.

**Figure 1-25** Looking west, out of the Sierra Nevada foothills and into the expansive farmlands of the Central Valley. Grasslands and oak trees are still being transformed into orchards here, while some distant valley farmlands are being squeezed by suburban growth.
Layered beneath the Central Valley are thousands of feet of sediments washed down from the surrounding mountains during millions of years of geologic history. These and other California rock formations reveal fascinating clues about some of California’s most distant past.

In the next chapters, we will begin with these ancient California landscapes and work our way to modern natural landscapes. In later chapters, we will review the various human patterns and landscapes scattered about the state. This begins our systematic study of the related topics that combine to make California geography so captivating and useful through this twenty-first century.
We are reminded every time a California earthquake adds elevation to another mountain or a landslide rips apart another hillside slope that dynamic and sometimes violent geologic processes are shaping California. Each individual geologic event seems dramatic, but each event is a fleeting moment in California’s geologic history. The cumulative effects of millions of these events over millions of years are responsible for leaving us a landscape puzzle without rival. The puzzle would be solved if we could fast-forward a film showing crashing tectonic plates, mountains being lifted out of the ocean, and other geologic events that have so gradually distributed various rocks and ores to produce today’s California landscapes. Armed with modern tools and techniques, and the explosion of new discoveries in earth science, geologists are gradually solving the puzzles of California’s past. They are learning that, in terms of geologic time, California’s landscapes continue to experience relatively quick and dramatic changes.

In this chapter, we explore the basic geologic concepts that help us understand the constructive (endogenic) and destructive (exogenic) processes responsible for California’s past, present, and future physical landscapes. We will use the rock cycle to better understand the geographic distribution of minerals, rocks, and earth resources that have such historic and economic significance. We will step back millions of years into a very different California; this will help us place current and future events and landscapes in proper perspective.
AN OVERVIEW OF PLATE TECTONICS IN CALIFORNIA

Since there is ample evidence that California has been positioned on or near tectonic plate boundaries for more than one billion years, some knowledge of plate tectonics is required to understand the state’s geologic history. The relatively thin, brittle lithosphere of Earth, which includes the even thinner crust, is divided into several large and numerous smaller plates. These plates are riding on top of the softer, plastic-like asthenosphere of the earth’s upper mantle. As the asthenosphere gradually flows, the brittle tectonic plates riding above are dragged along. There is tectonic activity (the breaking and bending of the lithosphere and its surface crust) because portions of this upper mantle and its overlying plates are moving. Different types of boundaries and geologic processes are common between these shifting tectonic plates. Three major types of active plate boundaries continue to shape California’s landscapes: diverging plates, converging plates, and sliding plate boundaries.

Diverging Plates
A diverging or spreading boundary is currently located far off the Pacific Northwest coast in the eastern Pacific, including off the northern California coast north of Cape Mendocino. As two ocean plates separate, new ocean
OUR PLACE IN GEOLOGIC TIME: FINDING PERSPECTIVE

We’ve known for many decades that there are billions of galaxies each with their own billions of stars in our universe. Within our own Milky Way Galaxy, astronomers by 2012 had discovered planets that appeared somewhat similar to Earth revolving around some closer stars. Our Earth and Sun and its planets are not alone, so where did we come from? What is our place in the universe and where are we going? Though California is just a small part of our little Earth, our state displays plenty of evidence that might shed some light on these mysteries.

Except for rare and dramatic catastrophic events, many of the processes that shape natural landscapes of our planet and our state are excruciatingly slow in human terms. Because we only live to be about 1/60-millionth of the Earth’s age, we must leave our egos behind to understand geologic time, earth history, and the evolution of California’s physical landscapes. With so much geologic activity in California, studies of the state have played major roles in unscrambling Earth’s complicated history. These studies have also allowed planners to realistically anticipate and prepare for the geologic events and natural hazards that are likely to affect California in the future.

One result of this research is the Geologic Time Scale, or Chart, or Divisions of Geologic Time, compiled, studied, modified, and used by thousands of scientists from many different fields of study around the world. The scale chronologically organizes Earth’s and California’s natural history into great Eras, which are divided into shorter and more specific Periods or Systems, which are further subdivided into shorter and more specific Epochs or Series as shown in Figure 2-1. Each time category is recognized for unique events and organisms that are found in the rock record. We will refer to these divisions of geologic time throughout this chapter as they were approved by the U.S. Geological Survey Geologic Names Committee in 2010. Let’s looks at the chart.

For example, the Paleozoic Era began at the end of the Proterozoic Eon of the late Precambrian; scientists estimate that the Paleozoic Era began more than 540 million years ago and ended about 250 million years ago. From oldest to youngest Periods, the Precambrian is followed by the Paleozoic

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**Figure 2-1 Geologic Time Scale.** Geologic time is divided into Eras, Periods, and Epochs.

<table>
<thead>
<tr>
<th>Years Ago</th>
<th>Era</th>
<th>Period</th>
<th>Epoch</th>
<th>Some Events in California</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000–11,500</td>
<td>Pleistocene</td>
<td>Holocene</td>
<td>Geographers study California.</td>
<td></td>
</tr>
<tr>
<td>Millions</td>
<td>Neogene (New designation)</td>
<td>Pleistocene</td>
<td>First people settle California. Glaciers erode Sierra Nevada and Northern Mountains.</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>Cenozoic</td>
<td>Cretaceous</td>
<td>Tertiary</td>
<td>Pliocene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jurassic</td>
<td>Old designation</td>
<td>Miocene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triassic</td>
<td></td>
<td>Oligocene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eocene</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Paleocene</td>
</tr>
<tr>
<td>65</td>
<td>Paleozoic</td>
<td></td>
<td></td>
<td>Thin sedimentary basin deposits. San Andreas Fault System evolves.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sporadic mountain building, volcanism, erosion push shoreline farther west.</td>
</tr>
<tr>
<td>250</td>
<td>Mesozoic</td>
<td></td>
<td></td>
<td>Mountain building continues, shoreline pushes west: subduction, Nevadan Orogeny, granitic plutons, Franciscan Complex.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Violent upheavals, continent encroaches west. Deposits in broad marine shelf, subduction, metamorphism, metasedimentary “roof pendants.” “California” is below the sea.</td>
</tr>
<tr>
<td>540</td>
<td>Precambrian</td>
<td></td>
<td></td>
<td>Shallow ocean/continental margin deposits. Complex metamorphism/igneous intrusions. The oldest rocks.</td>
</tr>
<tr>
<td></td>
<td>(Proterozoic Eon)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Crust forms to fill the gap, causing older rocks on the two plates to be shoved farther apart. The discovery of this sea-floor spreading zone in the 1960s helped scientists solidify the plate tectonics theory. Today, ocean floor between Baja California and mainland Mexico is expanding as Baja slides farther away. As the Gulf of California opens wider, this rifting extends into California where the Salton Trough crust is stretching, thinning, and dropping and the Peninsular Ranges are also sliding west, away from the North American Plate. The dynamics of these forces and structures are far more complicated, and extensive volumes on the topic have been published by dedicated geologists.

Converging Plates

A type of converging plate boundary (which once impacted almost all of California and now only occurs off the far north coast) is subduction. In this process, thin dense ocean plate crashes into thicker but less dense continental plate. The continental plate rides up over the

GEOLOGIC TIME (continued)

Era, which is divided into the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Permian Periods. The Mesozoic Era started about 250 million years ago with the Triassic Period, then Jurassic Period, and finally ended more than 65 million years ago at the end of the Cretaceous Period. The current Cenozoic Era began more than 65 million years ago. In previous studies, the Cenozoic Era began with the Tertiary Period, grouping the Epochs (from oldest to youngest) Paleocene, Eocene, Oligocene, Miocene, and Pliocene. At the end of this Tertiary Period (now considered to be more than 2 million years ago), the Quaternary Period began with the Pleistocene Epoch and its Ice Age. The Holocene Epoch started more than 11,500 years ago, after the Pleistocene Ice Age, which brings us to modern times. In this chapter, we will refer to the Tertiary and Quaternary Periods due to tradition and convenience, though some geologists argue that they be replaced with the Paleogene and Neogene Periods, which divide our Cenozoic Era more evenly. At least the Epochs are the same and these terms are easily compared. So, we are currently in the Holocene Epoch (which started more than 11,500 years ago) of the Quaternary Period of the Cenozoic Era.

The many modern rock-dating techniques provide clues to the ages of rock formations and events in California. Absolute dating techniques are used to analyze the decay of radioactive isotopes and indicate the age of a rock within a small percentage of error. Rocks are dated using the radioactive decay of unstable elements; each isotope has a known "half life” as it constantly decays into a different product. Potassium-argon, uranium-lead, lead-thorium, and rubidium-strontium are examples of methods used to date older rocks.

Relative dating techniques, such as the use of fossils, layering of sediments, and adjacent geologic structures, are used to determine the sequence of geologic events in a region. Today, there are dozens of modern dating techniques; different methods may be used on the same rocks to verify dates and decrease the range of error.

Radiocarbon dating is used to date organic matter in very young deposits.

Figure 2-2 Morro Rock represents what’s left of the inside of an ancient volcano. This is proof that today’s geologic landscapes are much different from more than 20 million years ago. The famous rock is made of dacite. Millions of years of weathering and erosion stripped away exterior volcanic features, then humans chipped away for surrounding fill.

Figure 2-3 Here at Devil’s Punchbowl above the Antelope Valley, sediments were horizontally deposited and lithified many millions of years ago. Dramatic tectonic activity along the San Andreas Fault Zone then lifted and tilted them almost vertically. Today, this geologic history is exposed by differential weathering that leaves the most resistant rock layers standing out.
An Overview of Plate Tectonics in California

sinking ocean crust, sometimes in a series of jerky events causing major earthquakes, compression, folding, and mountain building. Subducted below all of this is the ocean plate, which begins to melt. Major pockets of molten material (magma) form under pressure and frequently erupt to the surface, forming chains of major volcanoes. Today, the Cascades represent such a series of volcanoes, trending north from Lassen, Shasta, and the smaller volcanoes on the northern edge of California into Oregon, Washington, and Canada. Figure 2-4 shows diverging and converging plates.

Historical subduction has influenced at least some part of California’s geology since the Precambrian Era. The Sierra Nevada, Coast Ranges, and Klamath Mountains all contain some rocks dragged from distant regions, then plastered and molded together by these collisions. The complex geology of today’s Klamath Mountains is mostly the result of subduction. An ancient sea-floor spreading center was itself jammed into and under California starting about 30 million years ago, giving birth to another type of plate boundary—a transform fault known as the San Andreas.

**Sliding Plate Boundaries**

The boundary between two plates that slide past one another is known as a transform fault. The San Andreas is arguably the most famous transform fault in the world. It marks the main boundary where the giant Pacific Plate slides to the northwest at about 5 cm (2 inches) per year against the North American Plate. As we will learn, this is a very complicated fault system. There are places where the two plates seem to jam together, creating a boundary almost resembling converging continental plates, where great mountains are built. There are places where the fault creeps and other places where it is locked until it unleashes tremendous energy in catastrophic shifts. There are hundreds of smaller faults and slivers of crust which are related to this activity. Even the extension that has been pulling the Basin and Range apart may be blamed on stretching along this plate boundary, although other hypotheses might also explain this activity. Figures 2-5a and 2-5b show sliding plate boundaries.

**Figure 2-4 Diverging and Converging Plates.** An oblique view looking north and slicing through a model of Earth’s crust in northern California. Ocean crust is subducted below the Pacific Northwest’s continental crust. Millions of years ago, before the San Andreas Fault system evolved (such as during the Mesozoic Era), subduction dominated most of what is now California.

**Figure 2-5a Sliding Plate Boundaries.** An oblique view (looking north) of right-lateral movement along the San Andreas Fault—one of the world’s most famous sliding plate boundaries.
It is clear that California’s landscapes have been shaped on an evolving and active continental margin, a dynamic boundary between tectonic plates. Geologists have considerable knowledge of the most recent interactions, but the details become fuzzier as the rock records fade away into the hundreds of millions of years past. The accumulating knowledge about recent dynamics will help geologists anticipate future geologic events.

Now that you have a grasp of some basic geologic concepts required to understand California’s physical landscapes, we are ready to summarize the state’s geologic history. If you find this early history a little too detailed for your tastes, you might skip to the Cenozoic Era discussion to build your geologic bridge to the present or even the next section on ores and earth resources.

**CALIFORNIA THROUGH THE AGES: A GEOLOGIC HISTORY**

**Precambrian (Pre-Phanerozoic)**

Scientific evidence places Earth’s age at about 4.6 billion years, but the oldest rocks found in California are dated at just more than 1.8 billion years. A tumultuous geologic past has destroyed older evidence or has greatly altered the oldest survivors, so we know the least about California’s most ancient landscapes. However, isolated patches of metamorphic gneisses and schists from 1.7 to more than 1.8 billion years old are scattered particularly about the Basin and Range, Transverse Ranges, and the deserts of California. The Basin and Range contains some of the best remnants, where older rocks are often covered by unaltered and slightly younger sedimentary rocks.

The oldest Proterozoic Eon (later Precambrian) gneisses and schists represent metamorphic basement rock of a continental crust ranging between 1.72 to 1.82 billion years old that contains numerous, slightly younger, granitic intrusions. Whether these rocks are encountered at the base of the San Gabriel, San Bernardino, Chocolate, or Oroopia Mountains or in the northwest Mojave or in such Basin and Range locations as the Black Mountains of Death Valley, they indicate that California’s dynamic geology is an ongoing process.

Samples from the San Gabriel Mountains suggest deep crustal levels of continental metamorphism and the intrusion of a variety of igneous material—more evidence of California’s complex geologic past.

In the Basin and Range, slightly younger sedimentary marine deposits common to continental margins suggest that a Proterozoic (late Precambrian) sea must have covered most of what is now California; in other parts of the state, these deposits have been altered or eroded away. Significant exposures of sedimentary rocks from nearly every subdivision of geologic time from the Proterozoic Eon to the Cenozoic Era are found in ranges surrounding Death Valley. Shallow ocean deposits and primitive fossils in this area are typical of those along a passive continental margin and suggest a quieter period during the latest Proterozoic Eon into the early Paleozoic Era in California.

**Paleozoic Era: California Below the Sea**

As expected, the younger Paleozoic Era rocks are more widespread in California than their older Precambrian counterparts. Therefore, it follows that we know much more about California’s geologic history from the Paleozoic Era of more than 540 million to 250 million years ago. Rocks from the Paleozoic Era are found throughout eastern and southern California and in portions of west-central California and the Klamath Mountains. These rocks indicate that the shoreline ran north–south from what is now southern Idaho, through central Nevada to southeastern California; coastal waters ranged from very deep in the north (where more than 10,000 m [32,800 feet] of deposits are found) to shallow in the south (where deposits thin to about 1,000 m [3,280 feet]). Great thicknesses of limestone were deposited on the broad, shallow marine shelf that represented most of Paleozoic California. Almost all of California remained below the sea during the Paleozoic Era.

**Paleozoic Era Northern California**

However, Paleozoic rocks also suggest periods of very complex tectonic activity, especially in the north during the early part of the Era. While most of California was a broad marine shelf, deeper water deposits in the eastern
The Rock Cycle

Before we trace California’s geologic history, we must review the rock cycle—a basic concept that helps explain the formation, classification, and names of specific rocks (see Figure 2-6). There are three major rock categories: igneous, sedimentary, and metamorphic.

We begin with the igneous rocks, which were completely melted, then cooled and crystallized. Two main criteria are used to classify igneous rocks: the environment where (and how quickly) they cooled, and their chemical composition. Intrusive igneous (plutonic) rocks cooled slowly in an environment deep below the earth’s surface; they have large crystals or grains. Extrusive igneous (volcanic) rocks cooled and crystallized quickly near or at the earth’s surface; they have much smaller crystals.

The chemical composition criteria show that igneous rocks with the most quartz and feldspar minerals are high in silica (silicon and oxygen). They are usually lighter in color and weight, and they are known as felsic rocks. Igneous rocks with minerals higher in iron and magnesium are usually heavier and darker. They are considered mafic rocks. We are now ready to combine these two criteria to identify some of the more common igneous rocks.

Granitic rocks are intrusive igneous rocks with large crystals that contain abundant quartz and feldspar. These lighter-colored rocks with their large grains make up the cores of nearly every major mountain range in California. Anyone who has explored the Klamath, Transverse, or Peninsular Ranges and especially the Sierra Nevada has seen these felsic rocks that cooled deep below the earth’s crust from enormous magma chambers. The famous boulders of Joshua Tree National Park and the Alabama Hills are just two examples of how these various grades of granitic-type rocks have been lifted up and are now exposed throughout California.

Exposures of basalt in California are in direct contrast to granitic rocks because they are extrusive igneous lava flows that cooled quickly at the surface. Therefore, they have very small grains. They also have more iron and magnesium, and are, consequently, darker. Since these mafic rocks must get very hot to melt, they often produce runny and less violent eruptions. The flows and lava tubes at Lava Beds National Monument and the flows around the northern Owens Valley serve as just two examples of obvious exposures of this common California extrusive igneous rock. But, the Cascade volcanoes’ eruptions often consist of more felsic material that melts at lower temperatures, producing viscous, gooey eruptions that can be very violent. These rocks trend more toward the andesites and sometimes the much more felsic rhyolites. Mount Shasta and Lassen Peak are examples of these majestic composite volcanoes that produce more violent eruptions with slightly lighter materials.

There are excellent examples of almost every other type of intrusive igneous rock (such as the diorites and gabbros) and extrusive igneous rock (such as obsidian, scoria, pumice, and tuff) somewhere in California. Most extrusive igneous rocks are remnants of past volcanic activity that has long since ceased.

Completely different criteria are used to classify the second major category of rocks—sedimentary rocks. These rocks are formed when older rocks are exposed to weathering and erosion. The materials are then transported, deposited, and lithified into a different solid rock. Sedimentary rocks are very common because the processes that produce them are constantly at work on the earth’s surface. When pieces of the original material are lithified, clastic sedimentary rocks form. They are classified according to grain size: conglomerate, sandstone, siltstone, claystone, shales, etc. When chemicals that were dissolved in water are precipitated out or organic sediments accumulate, nonclastic sedimentary rocks result. These chemical sedimentary rocks are classified by their composition, such as limestone (made of calcite), dolomite, gypsum, chert, and rock salt.

Metamorphic rocks represent the third major category of rock. They are changed by heat and/or pressure that does not totally melt the original rock. In this process, sandstone or chert can be changed to quartzite, limestone to marble, and shale to slate. Schist and gneiss are greatly deformed rocks at higher levels of metamorphism.

In the rock cycle, geologic processes are constantly transforming one major rock type to another. Since every phase of this rock cycle is and has been evident in California, we see every major rock type exposed somewhere in the state. Hiding in each of these rocks is a story, a page in the geologic history of California.

Figure 2-6 The Rock Cycle. The rock cycle continues to shape California landscapes.
Klamaths and northern Sierra Nevada, where volcanic debris from islands to the west was mixed with oceanic crust, are typical of a subduction zone. Imbedded fossils common to east Asia indicate the material was dragged on the ocean floor from the western Pacific to the subduction zone in California where it was pinched with island arcs and basins into the continent. As the continent rode over these subducted rocks, material was welded onto its edge where great periods of mountain building occurred (such as the Sonoma orogeny), and the continent grew westward into the Mesozoic Era.

For example, today’s Sierra Nevada was a continental shelf and slope environment during the Paleozoic Era. Sediments accumulated up to 9–10 km (5–6 miles) and were compressed and folded with increasing volcanic material to the north. Farther south in the Sierra Nevada, the Paleozoic basement metasedimentary rocks are often called “roof pendants.” From Tioga Pass in Yosemite to west of Big Pine, these strata represent a nearly complete assemblage of Paleozoic Era history, but the pieces are scattered about. These rocks can often be seen as distinct layers on top of the younger granitic rocks in high Sierra Nevada landscapes. They are a westward extension of the same rocks found in the White and Inyo Mountains, but they are more metamorphosed. These hornfels, cherts, marbles, slates, and quartzites have been dated using radiometric techniques and fossils, and they reach thicknesses near Mount Morrison of about 9,700 m (32,000 feet).

The Shoo Fly complex (in the northwestern Sierra Nevada) and the Duzel and Gazzelle Formations (Klamaths) are typical of Paleozoic Era rock formations to the north and west. They contain more volcanic material mixed with the sediments from the sea floor and continent that were crushed together and metamorphosed in a subduction zone. In the Klamaths, the older Trinity Ophiolite (Ordovician Period) lies below the Silurian Duzel and Gazzelle Formations and represents the largest outcrop of ocean crust and mantle in North America. These conditions are evidence that the area we now call the Klamaths and the entire area northwest of today’s central Sierra Nevada must have experienced many violent geologic upheavals during the Paleozoic Era.

**Southeastern California During the Paleozoic Era**

In the Basin and Range, especially in Death Valley, Cambrian Period strata of up to 5,200 m (17,000 feet) thick lie on top of older Proterozoic (late Precambrian) rocks. Above these are younger limestones and dolomites deposited in a warm, shallow sea which represent (in the Inyo Mountains) the thickest Paleozoic Era carbonate deposits in North America. Total thickness of Basin and Range Paleozoic deposits are up to 11,000 m (36,000 feet)! How can exposed rock formation sequences be that thick when surrounding mountains and slopes do not even approach those heights? These formations have been lifted, contorted, and tilted up from their original horizontal positions. Thick deposits and hundreds of millions of years of geologic history are revealed as the edges of these now exposed and steeply dipping layers are eroded.

In the Mojave Desert, Paleozoic Era rocks are not as common and deposits are not as thick as the Basin and Range, and there is evidence of a more stable continental platform. Deposits are especially found in Mojave’s eastern ranges. The thickest (in the Providence Mountains) is up to 3,000 m (10,000 feet); some late Paleozoic rocks are found in the Ord Mountains near Victorville.

Paleozoic Era rocks in the eastern Transverse Range were also deposited on a broad shelf. In the Peninsular Range, outcrops of Paleozoic metasedimentary and metavolcanic rocks appear on some slopes; most of these rocks were later highly metamorphosed into the current schists and gneisses. A Paleozoic Era limestone has been processed for cement near Riverside.

**Mesozoic Era: Where Were the Dinosaurs?**

The shoreline and continental margin of North America continued to migrate westward during the Mesozoic Era.
(starting almost 250 million years ago). As the ocean plate was subducted below it, additional material was scraped and plastered onto the continent’s edge. Most of the widespread igneous, metamorphic, and sedimentary rocks from the Mesozoic Era are a result of continental accretion along this very active plate convergence boundary.

The most common and familiar Mesozoic rocks are the granitic plutons that make the core of most of the major mountain ranges in California. These rocks formed after material was subducted with the ocean plate below the continental plate, then melted to form enormous magma bodies. The deep melt eventually cooled and crystallized over millions of years. Perhaps the second most familiar Mesozoic rocks are in the Franciscan Complex (melange) of the Coast Ranges. This melange accumulated when exotic igneous and sedimentary material was brought to and crushed against the continental plate by the subducting ocean plate.

An obvious example of the extent of this Mesozoic Era activity is evident even in the Klamaths. Here, both pre-Cretaceous Period plutons (formed from subduction, melting, and recrystallization) and blueschist (scraped onto and squeezed against the continental crust) can be found. A more complete review of these Mesozoic events, and the rocks left behind, follows.

Most of California remained below the sea during the start of the Mesozoic Era, but an exceptionally prolonged and active period of subduction began by the late Triassic Period and continued with only a few interruptions through the Jurassic and Cretaceous Periods. By the end of the Triassic Period, mountains had already been lifted in eastern California and the shoreline was pushed west. By the end of the Jurassic Period, volcanic and sedimentary material subducted below California had melted into enormous granitic magma chambers. By the Cretaceous Period, this melting had intensified, eventually producing the great intrusive igneous rock bodies that are now found throughout California.

Farther west, collision of these plates was also plastering large volumes of exotic materials dragged from the western Pacific and the ocean plate onto the edge of the continental plate. Ocean crust, sea-floor sediments, and volcanic rocks were crushed together and squeezed up to form the Franciscan melanges of the California Coast Ranges. The Franciscan melange includes many different types of rocks contorted together. It has many names (such as Franciscan Assemblage), and it is often called the Franciscan Basement in the Coast Ranges. Specific rocks include chert and serpentinite, but it is dominated by sandstone and shale and greywacke and averages many thousands of feet thick. It is found in spots from the northern to southern California coast, but it is especially common in central California. For years, geologists debated the origin of these complex rocks until the extent and importance of Mesozoic Era subduction was understood.

These collisions resulted in one of the greatest mountain-building episodes in California’s geologic history—the Nevadan orogeny (during the Jurassic and Cretaceous Periods). As the mountains were built higher, the sea was pushed even farther to the west. By the end of the Jurassic Period, the Nevadan Mountains rose abruptly above the ocean along what is now the

**Figure 2-8** Granitic rocks, laced with high-silica veins, are uplifted and exposed, thanks to vertical faulting. These can be seen from the Palm Springs Tramway ride, as you are lifted from the hot desert floor to the cool forests in the mountains towering above.

**Figure 2-9** Here is a close up of serpentine.
eastern Great Central Valley; ocean waters would never again encroach east of that line. Toward the end of the Mesozoic Era, those great Nevadan Mountains blocked the sea from eastern California; therefore, the sediments found with other rocks from that time in the Basin and Range and most of the Mojave are terrestrial. As the Nevadan Mountains were lifted higher during the Jurassic and Cretaceous Periods, near what is today’s Sierra Nevada, their weathering and erosion also accelerated. The enormous volumes of sediment were carried west, filling deep ocean basins and then shallower seas; the resulting rock formations are found scattered throughout California west of today’s Sierra Nevada. Such Cretaceous Period deposits are more than 7,600 m (25,000 feet) thick below the western Sacramento Valley; total accumulation of the various rock formations is even thicker in other parts of the valley. These Great Valley shales, sandstones, and conglomerates are very orderly compared to their complexly contorted Franciscan melange neighbors to the west.

Mesozoic Era Rocks
Rocks left behind by the geologic processes of the Mesozoic Era are important in many modern California landscapes. These processes and their remnant rocks deserve a more detailed review here, starting at the beginning of the Mesozoic Era (refer to Figure 2-1).

Pre-Nevadan rock formations, even in today’s Sierra Nevada, indicate that marine sediments were still being deposited at the start of the Mesozoic Era. Examples of these roof pendants, similar to their Paleozoic Era ancestors and up to 3,000–4,000 m (10,000–15,000 feet) thick can be found in Plumas County. They include such rock formations as the Hosselkus limestones and Swearinger slate near Taylorsville and other formations with Triassic Period marine fossils. As expected, no roof pendants (deposits) are found in the record after the Nevadan orogeny of the middle Jurassic Period. Such intense mountain building must have created an erosional environment.

During much of the Triassic Period, a shallow sea deposited mud as it advanced and retreated across what is now the Mojave, but the shoreline usually meandered through it, leaving the eastern Mojave above water. Mesozoic Era wood deposits in the McCoy and Palen Mountains near the Colorado Desert date to this time. Volcanic activity also left rocks behind; examples can be found near Barstow. By the Jurassic Period, terrestrial deposits (such as the red windblown desert Aztec sandstones) were the rule in today’s southeastern deserts.

Almost all Mesozoic Era rocks after the Triassic Period in the Coast Ranges, Sierra Nevada, and Klamaths formed as a result of subduction and/or mountain building. This includes the Sierra Nevada batholith rocks dated at 88–206 million years old.

In the Basin and Range, older sedimentary rocks deposited in marine conditions of the Triassic Period yield to volcanic rocks and then to the widespread granitic rocks formed later during subduction from the middle to late Mesozoic Era. Such granitic plutons in the White Mountains are dated at 70–225 million years. It is not surprising that few Mesozoic Era sedimentary rocks have been observed in the Basin and Range because it was dominated by extensive mountain building during that period. Similar plutonic rocks of similar ages are found farther south, underneath the Mojave and at the base of its desert mountain ranges and at the core of the Transverse and Peninsular Ranges. One specific example of the extent of these Mesozoic subduction zone rocks is found at the base of the Fish Creek Mountains (west of the Imperial Valley), where metamorphic gneisses and marbles are mixed with the same granitic rocks found just to the west, in the Peninsular Range.

Cenozoic Era: Geologic Bridge to the Present
We have covered about 98.6 percent of California’s geologic history, leaving only about 65 million years to go!
Since our focus now progresses to more recent and some future processes and landscapes, it is fortunate that nature has left far more evidence of California’s recent past. In this section we turn our attention to the Cenozoic Era processes that have left ancient rocks and landscapes behind, especially the processes and landscapes up to the Pleistocene Epoch. These rock remains have had less time and opportunity to be altered, so they tell a much more detailed story compared to their older counterparts. As we approach the most recent Pleistocene and Holocene Epochs, our discussion of California’s geologic history will yield to the next chapter and the more recent and current processes that are causing modern landscapes to evolve.

Recall that by the end of the Mesozoic Era, the great Nevadan orogeny had ceased, and the emplacement of Sierran plutonic rocks (including the great granitic plutons in the Klamaths and in ranges to the south) was complete. Degradation destroyed much of the ancient Sierra and Mojave mountains by the end of the Mesozoic and into the Cenozoic Era, though uplifting forces would return to these regions later in the Cenozoic Era. Just as the ancient shoreline had shifted west early in this Era, so had tectonic action shifted west to the Coastal Ranges. That is where we pick up the story.

Sedimentary Deposits Tell the Cenozoic Era Story in Western California

Western Cenozoic Valleys and Basins Fill With Clues to the Past. The Great Valley continued to form as a structurally downwarped basin during the Cenozoic Era. It was also filling with sediment, mostly from the eroding mountains to the east. By the end of the Pliocene Epoch, the sea had retreated west for the last time; except in a few coastal depressions, it would never again visit either the Central Valley or the Coast Ranges. The retreating sea left enormous volumes of marine Cenozoic rocks in almost all California depressions and valleys west of the Sierra slopes. These Cenozoic basins include the Eel, San Joaquin and Sacramento, Santa Rosa, Livermore, Santa Clara, Salinas, Santa Maria, Carrizo Plain, Ventura, Los Angeles, San Diego, and Imperial-Coachella Valleys. The Ventura basin’s 15,000 m (50,000 feet) of sediments may be most complete middle and late Cenozoic rock
records on Earth. Similar but much thinner deposits were left in the Colorado Desert and at the base of the Peninsular Ranges.

**Where to Find Western California’s Cenozoic Record.**

Record of the entire Cenozoic Era can be found scattered about in the sediments of the Coast Ranges, sediments mostly washed down from adjacent terrestrial environments. One problem is that these sedimentary rocks have been broken apart and displaced (in some cases, hundreds of kms [miles]) by tectonic activity, especially along the San Andreas Fault Zone. Nevertheless, it is clear that the ocean encroached only as far as the Coast Ranges and into the Central Valley a few times during the Tertiary Period, only to be forced out, time and again, by tectonic activity. The rocks suggest varied landscapes of steep uplands built by rigorous tectonic uplift adjacent to deep, structurally downwarped depressions which filled with the sediments from the uplands. It follows that some Cenozoic sedimentary rocks are terrestrial, but they alternate with thicker and more common accumulations of marine sediments, especially in western California.

To the north, the plant fossils in sedimentary rocks and tuffs of the Weaverville Formation northeast of Weaverville in Trinity County were deposited in a swampy flood plain covered with numerous lakes.

In the Santa Cruz Mountains, more than 6,700 m (22,000 feet) of Tertiary Period, mainly marine strata accumulated on top of late Cretaceous Period marine sediments. The deposits formed in deep to shallow sea environments and even alternate with thinner terrestrial deposits. These alternating beds make up the conspicuous ridges and valleys of the Santa Cruz Mountains; they have been quarried and have even produced some oil and gas.

Other Tertiary Period formations of the Coast Ranges include Paleocene Epoch submarine fan deposits scattered from Point Reyes south to the Santa Lucias, and Eocene Epoch coal beds and clays that were apparently deposited in tropical conditions. When the sea encroached again in the Miocene Epoch, it deposited diatomaceous material in long, deep basins. The very common Monterey Formation is the result, and it is found from Point Arena north of San Francisco, south into the Transverse and Peninsular ranges. The high organic phosphates and diatoms help make up this thin-bedded, light-colored, deep ocean basin deposit. Beautiful exposures can be observed south and east of Monterey, in the Santa Lucia Range above the Salinas Valley, at Montana de Oro State Beach south of Morro Bay, at Shell Beach, and in other locations along the Central Coast. Spotty, related exposures are seen far to the south, such as at Point Dume, west of Malibu. In the Santa Monica Mountains, this related unit is known as the Modelo Shale.

In the Peninsular Ranges, the Silverado Formation in the northern Santa Ana Mountains is made of Paleocene Epoch nonmarine sands, clays, and coal. Farther south, the source of the rounded pebbles representing stream and submarine deposits of the Eocene Poway Formation in San Diego is probably from northwestern Sonora, Mexico! Some of these deposits were later dragged farther away from their sources, as far northwest as the Channel Islands. Dramatic changes in geography must have occurred since they were deposited. Though thick deposits of Pliocene Epoch rocks in the Peninsular Ranges are nonmarine, the Pliocene San Diego Formation contains abundant and outstanding marine fossils. However, these are limited to the immediate coast in the San Diego area and they are not thick compared to their Pliocene Epoch counterparts in the Los Angeles and Ventura Basins. The location of the Pliocene Epoch San Diego shoreline was probably close to today’s.

It is clear that thick nonmarine sections from the Miocene, Pliocene, and Pleistocene Epochs continued to accumulate in local basins up to today. Even since the Pleistocene Epoch, impressive accumulations (thousands of meters) of terrestrial alluvial deposits have filled almost every California coastal and inland valley; many of these lowlands continue to subside at the mercy of sustained tectonic activity as they also continue to fill with sediments.

![Figure 2.12](image.png) Sedimentary layers of sandstones and conglomerates are lifted, exposed, and weathered at Topanga State Park. As rock strata dip toward the right, differential weathering eats through the weaker layers, leaving indentations, while more resistant layers stick out.
Pre-Miocene Epoch deposits from the Cenozoic Era are probably so rare in the Mojave because a new mountain-building period in the early Cenozoic Era may have lifted the Mojave block up to 4,500 m (15,000 feet) by the start of the Miocene Epoch. This also explains why so much early Tertiary Period sediment accumulated, especially in coastal basins to the south and west; one source was this eroding upland. However, there is some record of pre-Miocene Epoch conditions in the Mojave.

Fossil pollen and animals found in the Miocene Barstow Formation of colorful Rainbow Basin suggest deposition in a climate similar to northern Mexico today, with semipermanent inland lakes. The few Oligocene Epoch deposits in the Mojave and Basin and Range (such as in Titus Canyon in Death Valley) indicate a wetter, savanna climate with abundant plant and animal life. Petrified wood and vertebrate fossils found in the Miocene Ricardo Group at Red Rock Canyon north of Mojave were also deposited in savanna grasslands with moderate rainfall.

Evidence once suggested that the Sierra Nevada was dominated by lower hills into the Miocene Epoch, having been severely eroded since the Nevadan orogeny. This would have allowed moist air masses to invade inland more frequently during the Tertiary Period. By 2010, a study published in the journal Geology by scientists from the Berkeley Museum of Paleontology and Yale had created some doubt, suggesting this mountain range may have reached its current height much earlier—up to 50 million years ago. This would have had major impacts on the type of life forms that could have survived on the mountains and the inland side of the range. Regardless, the geology abruptly changed again, and by the early Miocene Epoch, the Mojave block was warped into a structural depression. Inland drainage and deposition would rule thereafter, creating thick accumulations of nonmarine deposits up to today.

Sediments deposited below dry desert lake beds from the Basin and Range south reveal a rich floral and faunal history in the late Cenozoic Era. All Cenozoic deposits in the Mojave are nonmarine, except for a segment in the western Antelope Valley. Layers of volcanic debris alternate with ancient lake sediments, with up to 3,000 m (10,000 feet) locally deposited mostly since the Miocene Epoch. Mojave’s Cenozoic volcanic activity began in the Oligocene Epoch, peaked in the Miocene Epoch, and has decreased to today.

Most sedimentary rocks in the Colorado Desert were deposited in the Cenozoic Era, and most of these are nonmarine. The oyster beds that were deposited between the end of the Miocene and early Pliocene Epochs in the Salton Basin are exceptions. These sediments, known as the Split Mountain and Imperial Formations, were deposited when a shallow sea invaded the Salton Basin from the south. By the end of the Pliocene Epoch, the sea was blocked out by the building delta of the Colorado River. Deposits of the nonmarine Palm Springs Formation followed in the Salton Basin.

**Volcanic and Tectonic Activity and Landscapes in Cenozoic Era California**

**Cenozoic Era Events and Landscapes in the Coastal Ranges.** Except for the area around Clear Lake (north of San Francisco Bay), the sporadic Cenozoic Era volcanic activity in the Coast Ranges has ceased, leaving behind some spectacular landscapes. About 29 million years ago (mya) the East Pacific Rise was overridden and consumed by the North American Plate. This event produced a series of Miocene Epoch volcanics that have weathered into fascinating landscapes in the Coast Range. A line of fourteen early Miocene Epoch volcanoes that run along the West Huasna fault from San Luis Obispo to Morro Bay (including Morro Rock) have been stripped and eroded down to their more resistant plugs or necks.

In Pinnacles National Monument above Soledad in the Salinas Valley, there are a variety of volcanic rocks that erupted during the Miocene Epoch; they have since been dragged hundreds of kms (miles) to the northwest along the west side of the San Andreas Fault, perhaps from the western Antelope Valley. Some of these rocks (especially the pyroclastics) have weathered into spectacular cliffs, caves, and boulders. Pliocene Epoch volcanic activity has left a variety of volcanic rocks and landscapes above the Napa Valley, including Mount Saint Helena. This activity shifted from the Sonoma area in the Pliocene Epoch to the Clear Lake area today.

To the south, some of the most extensive Miocene Epoch lava flows in California are found in and around
the Santa Monica Mountains. These Conejo volcanics were frequently extruded below the sea before the mountains were built; they have weathered into impressive buff- and rust-colored slopes and cliffs that are sometimes mistaken for sandstone.

**Volcanics and Tectonics in Transmontane Cenozoic California.** Cenozoic Era volcanic activity was far more widespread in much of eastern California, especially on the Modoc Plateau. Successive basaltic flows built the plateau during the Tertiary Period. Today’s volcanic surface on the Modoc represents the modern southern edge of the Cascade Mountain Range. More recent volcanoes and cones have erupted on top of the older lava plateau.

Shasta Valley Cenozoic Era volcanic rocks were first formed from the Eocene through the Miocene Epochs in today’s western Cascades. Volcanic activity shifted east after the Miocene Epoch (5 mya), forming the more recent High Cascade volcanic group, including such great volcanoes as Mount Shasta.

Farther south, in the Basin and Range and Mojave, scattered volcanics of the early Tertiary Period were also formed near converging boundaries. Later, the development of right-lateral transform motion and the San Andreas system ended that convergence by the mid-Tertiary Period. Since the Miocene Epoch, east–west crustal extension and crust thinning were mainly responsible for volcanic activity in the region. This stretching has also resulted in the block faulting that has shaped Basin and Range landscapes extending east from eastern California.

◆ **MINERALS, ORES, AND OTHER EARTH RESOURCES**

In this chapter, we have examined some of the dynamic geologic processes and the remarkable diversity of rocks they have left behind during the last 1.8 billion years. It should not be surprising to find within California some of the most impressive varieties and quantities of valuable minerals, ores, and other earth resources compared to anywhere on our planet. These valuable earth resources have helped shape human history, and they continue to play a vital role in the state’s economy. California’s earth resources have attracted many people and much industry during the last few centuries. Knowledge of the distribution of those resources will lead to a better understanding of the geography of California. In this section, we will look at the distribution of some of the more interesting and precious earth resources in California. Previous information covered in this chapter will serve as a foundation for our discussion.

Nearly all of the gold, silver, and many other metallic ores found in California rocks were originally formed by similar processes in or around the Mesozoic Era. In and near subduction zones, ocean and continental crust materials incorporated into magmas would become granitic plutons. As these magmas pushed toward the surface, they came near or contacted older, mostly sedimentary and metamorphic rocks. As the magmas cooled, the most felsic magmas with various minerals in water were often the last to squeeze into cracks and joints we now call veins. These high quartz and feldspar veins then cooled and crystallized with their precious mineral deposits. Since the 1800s, miners followed these veins and contact zones in search of gold and other ores. Today, a map showing these contact zones is inevitably a map showing the location of most of the metallic mineral deposits and mines in the state of California.

There are some important exceptions to this rule. At some locations, after being uplifted and exposed, the minerals were eroded away from their slopes and deposited into the sediments of ancient rivers and lakes; they became placer deposits. These processes continue in some areas today. Other rare earth minerals were formed by unusual processes in rocks with unique chemistries.

**Gold from the Mother Lode**

Since the more than 100 million ounces of gold mined in California have had such a dramatic impact on the history and economy of the state, we start with the most famous gold discovery in California. John Sutter commissioned James Marshall to build a sawmill to supply wood for new settlers on the American River. (Sutter’s Mill is in modern-day Coloma.) It was Marshall who, on January
Evolution of the San Andreas Fault System

After skipping around California to visit the various Cenozoic Era geologic processes and their landscapes, we have painted a simplified picture of how California’s physical environments evolved to the near present. We will close our Cenozoic Era journey by examining one of the most important developments in the geologic history of California—the formation of the San Andreas Fault system (see Figure 2-5a [p. 43] and 3-8 [p. 70]).

About 29 mya, the North American Plate finally began to override and devour the East Pacific Rise. As this source of enormous volumes of new ocean crust was itself subducted, tiny portions and then larger segments of the edges of the Pacific and North American Plates began sliding past one another instead of converging. (Many modern geologists consider that explanation too simplistic. They now refer to obduction or underplating to describe these dynamics.) Regardless, the right-lateral movement along the newly born San Andreas strike-slip fault caused forces on California rocks and landscapes to become less compressional and, in some places, more extensional.

In eastern California, the crust was stretched and thinned; block-faulted ranges were elevated as adjacent basins dropped. The eastern Sierra Nevada was faulted upward as its neighbor below (the Owens Valley) dropped. Death Valley and Panamint Valley and so many others like them fell below their adjacent ranges. From the Basin and Range south into California deserts, resulting inland drainage salt basins were already formed and filling by the Pliocene Epoch.

Since the Miocene Epoch in western California, the San Andreas lengthened and gradually migrated eastward. It represented the boundary where the Pacific Plate (Earth’s largest crustal plate) was grinding past the North American Plate. Rocks, blocks, and tiny pieces of plates caught near the strike-slip fault zone were rotated, crumbled, and crushed. These independent segments and landscapes were the victims as great mountains (such as the Transverse and Coast Ranges) were folded and faulted, and landscapes contorted near these plate boundaries. Total displacement of some rocks that were first broken along the fault zone is as much as 560 km (350 miles). There are hundreds of smaller, but still significant, branch faults that are at least indirectly related to the same forces.

Though there are many different active geologic processes across the state, a primary focus of our attention remains the San Andreas Fault Zone, the movement between these two plates, and the direct and indirect impact it has had and will have in shaping so many California landscapes. These topics earn more attention in Chapter 3.

24, 1848, first stumbled upon the flakes of gold that would almost instantaneously bring hundreds of thousands of gold seekers to the Mother Lode. Most of the gold of the Mother Lode is found along Cretaceous Period (see Figure 2-1) white quartz veins dated between 108–127 million years near the Melones Fault. At the Kennedy and Argonaut mines near Jackson, miners dug shafts in the bedrock up to one mile long, following the steeply dipping veins.

Much of the originally exposed gold was weathered, eroded, and washed from the veins and deposited downstream millions of years ago during the Eocene Epoch. Miners took these placer deposits and even used hydraulic placer mining (with high-powered water hoses) to blast the ancient gold-bearing sediments from hillsides. The tremendous destruction caused by the cutting of slopes and the choking of downstream rivers and streams with sediments is documented at such places as Malakoff Diggins State Park northeast of Grass Valley. Here, steep cliffs remain where monitors blasted hillside gravels in California’s largest hydraulic mining operation. Hydraulic mining was banned by the California State Legislature in 1884 to stop this destruction and the disastrous flooding it caused downstream.

In other locations, gold deposits were covered with volcanic ash about 20–25 mya. Miners dug through this pink tuff to get to the gold, then used the cinder blocks for building materials. In some areas, dredging of water-deposited sediments has been a successful gold recovery method. Though it has always been an important ore in the state’s economy, gold production had already peaked in California by 1852. Today, numerous historical and modern gold mines dot the landscapes of the Mother Lode and represent a variety of gold-mining processes. The largest gold nugget ever mined in California weighed 88 kg (195 pounds) and was found at the Carson Hill mine. Near Grass Valley, the Empire Mine produced gold worth up to $1 billion. A few decades ago, the Jamestown and Carson Hill mines extracted more than 200,000 ounces of gold per year from open pit mines. By 2010, a developer was making grand plans for developing the Jamestown site as a major tourist resort, while the Carson Mine’s open scar stood out from its landscape.

A Mix of Valuable Earth Resources in the North

Some deposits and deeply weathered rocks scattered around the Klamaths contain chromium, nickel, and cobalt near the surface. The soils at Gasquet Mountain northeast of Jedediah Smith Redwoods State Park and beach placers near Crescent City are examples. Zinc and
copper are found in metamorphic rocks dating back to the Paleozoic Era.

In the West and East Shasta Mining Districts, sulfide minerals carried in solution from nearby plutons have produced iron and more than 400,000 tons of copper and zinc. Specific minerals include the most common: pyrite (with iron), chalcopyrite (with copper), and sphalerite (with zinc). Magnetite (with iron) occurs with an intrusion into the McCloud Limestone near the Shasta Iron Mine. The Altoona mine (west of Castella on the east fork of the Trinity River) takes mercury that was deposited in ancient hot springs. Gravels, clays, and limestone (such

Figure 2-15 You can still pan for small flakes of gold washed along the American River and other rivers in the Sierra Nevada. The water washes weathered and eroded materials downstream, where heavier gold deposits can be separated. In contrast to the frantic gold rush more than 150 years ago, these are mostly recreational activities today.

GOLD IN THE KLAMATHS

In the Klamath Mountains, Major Pierson B. Reading first discovered gold in 1848 along the Trinity River near Douglas City south of Weaverville. The French Gulch District became the most productive in the Klamaths. Here, granitic and dioritic dikes squeezed out from the Shasta Bally batholith during the Nevadan orogeny; they were injected into the siltstones, shales, and slates of the Paleozoic Era Bragdon formation. Gold was found along these veins and contact zones. The processes that formed gold and other precious minerals in the Klamaths are similar to the Sierra Nevada and the rest of California.

Again, much of the gold was eroded away from the original veins and deposited along ancient streams, rivers, and shorelines. Such placer deposits are common close to the Oregon border. Extensive dredging has been quite destructive along the south fork of the Scott River in Scott Valley. Near Hornbrook, where I-5 meets the Oregon border, the late Cretaceous Period Hornbrook conglomerate and the mid-Tertiary Period Weaverville Formations contain placer deposits. Further south, the nonmarine conglomerate, sandstone, shale, and tuff of the Weaverville Formation are exposed around Weaverville and Hayfork. Its lignite and gold were deposited on a wet tropical flood plain dotted with lakes millions of years ago.

In the northwest Klamaths, gold and platinum have been found in the sedimentary deposits of the late Miocene Epoch Wimer Formation. One gold producer is the Grey Eagle Mine started in the 1980s near Happy Camp. Happy Camp has also claimed to be the “small-scale gold prospecting capital of the world”, though some Sierra Nevada towns might argue. About 20 percent of California’s gold has come from the Klamaths, making the region second only to the Sierra Nevada in gold production in California.
Figure 2.16 Map from page 25 of Humboldt State/CGA Atlas: “The Gold Rush.” Credit: Stephen F. Cunha, Mary Beth Cunha, Humboldt State University, Department of Geography (Atlas of California, 1979, California Spatial Information Library, USGS Digital Elevation Model).
Chapter Two  Geologic History and Processes

FOSSIL FUELS

History

Fossil fuels, especially oil and gas deposits, have impacted the history and economy of California since the 1800s. In this state, oil and gas have always been far more abundant than coal; they supplied California industries and residents with most of their energy needs during the 1900s. For a few decades during the mid-1900s, California led all other states in petroleum production. Availability of abundant petroleum since the early 1900s has played a major role in the development of California’s automobile society.

Fossil fuels usually form in thick layers of sedimentary rocks containing high organic content trapped over millions of years. They then accumulate in porous rock along linear folds and faults where the oil and gas is “trapped” (see Figure 2-18). It should be no surprise to find that most of the fossil fuel discovered in California rocks has been toward the west, below the Central Valley and Coast Ranges and especially in the deeply folded and faulted structures that make up the coastal and offshore basins toward the south. This is also why you will often notice oil platforms in clusters and lines.

By now, many of these great petroleum reserves, especially the most accessible, are exhausted using traditional technologies. The shoulder-to-shoulder oil wells that once covered southern California landscapes such as Signal Hill and Huntington Beach are gone and so is most of the inexpensive, high-quality petroleum. Some of the old oil fields are still productive, such as the cluster of oil rigs near Hwy. 14 along the San Gabriel Fault in the San Gabriel Mountains.

By 2012, higher fuel prices were supporting new technologies that promised dramatic increases in oil and gas production in California and other locations in North America. Hydraulic fracturing (fracking) and horizontal drilling techniques took center stage. Oil companies inject fracturing fluids or pumping fluids (a mixture of water, chemicals and sand) under high pressure. This creates fissures that accept and accumulate previously trapped hydrocarbons that flow out of rock pours where they can be pumped. Horizontal drilling allows further access to multiple fractures from one well.

Great care must be taken to case and cement these wells as they are drilled to protect groundwater supplies. Critics are also concerned about the disposal of accumulated wastewater, the chance of seismic activity associated with these operations, and concerns about our ongoing addiction to fossil fuels. Then, there are the air pollutants and local impacts at the surface. As leaders tried to draft regulations addressing these concerns, single oil companies estimated up to 100 million barrels of oil were accessible from the Monterey Shale alone using these methods. Natural gas fields around the state were also being reassessed with much greater production potentials.

Costly Offshore Reserves

Many of the oil operations have been moved out to more expensive and dangerous offshore platforms to tap reserves deep below the sea. These costly offshore rigs can be seen lined up off Huntington Beach and from Ventura to Santa Barbara in the Santa Barbara Channel. Since an offshore platform blew out in January 1969, consideration of environmental haz-

Figure 2-17 Some rock formations below the San Joaquin Valley and others scattered on- and off-shore in California are still producing oil. Wells are usually drilled into faults, folds, and other geologic structures that act as traps within oil-producing sedimentary rocks. This oil field is just outside Bakersfield.

Figure 2-18 Drilling for Oil. Oil and gas may pool within various structural traps deep below California. Geologists map these structures before they drill for fossil fuels.
ars has played a major role in the industry. That 1969 accident produced a devastating oil spill that spoiled 20 miles of Santa Barbara beaches and killed thousands of birds and other wildlife. It and other historical oil disasters have created public relations nightmares for some oil companies. Many potential fields off the northern and central California coast are in, or adjacent to, pristine and delicate wildlife habitats that most Californians are not willing to risk for the sake of oil.

**Fossil Fuels In and Near the San Joaquin Valley**
A series of folds in Tertiary Period sedimentary rocks south of Coalinga, along the boundary of the Central Valley and the Coast Ranges, down to the southern end of the San Joaquin Valley, have produced tremendous amounts of oil and gas. One example, the Kettleman Hills, represents Cenozoic Era rocks with marine fossils that were folded together in a long antclinal dome and now conspicuously pop above the valley floor. They have produced gas and nearly 500 million barrels (71 million metric tons) of oil. Other domes with oil and gas fields, mostly to the south, include Elk Hills, Lost Hills, Buena Vista Hills, McKittrick, and Wheeler Ridge. Gas was first discovered in this region in the early 1900s; fields at Elk Hills (1919) and Buttonwillow (1927) became major gas producers.

Gas in the Sacramento Valley
Interestingly, gas was first used in Stockton in the 1850s; Cretaceous Period rocks below the Sacramento Valley have since produced most of the gas in California. A few of the major gas fields (usually with high quality gas at high pressure found with little oil) are at Sutter Buttes (discovered in 1933), Willows, Dunnigan, McDonald Island, and Rio Vista. The one field at Rio Vista has produced nearly 100 trillion cubic meters (3,500 trillion cubic feet) of gas and could be the largest onshore natural gas field in the state.

Few Fossil Fuels in the Coast Ranges
In the Coast Ranges, mostly marine Tertiary Period rocks in the Santa Cruz Mountains produced small amounts of asphalt, oil, and gas into the mid-1900s. Northeast of Mount Diablo, the coal beds and clays of the middle Eocene Epoch nonmarine Comengene Formation were probably deposited in tropical conditions. From 1860–1920, the six mines of the Mount Diablo coal field west of Antioch were California’s major coal producers. However, this low-grade lignite was no match for the energy sources provided by the great oil and gas fields discovered later in California. Consequently, these quartz sandstones were finally mined for glass.

as the McCloud Limestone) are also mined in the Klamaths, mostly for construction materials.

**Earth Resources and Mines in Transmontane California**

**Basin and Range**
The famous metallic mines of the Basin and Range are now only part of California’s history. Like many of the metal mining districts in California, most of the ores were found along the contact zones in older rocks intruded by granites. Of the many mines that dot the landscape, the earliest was Cerro Gordo near the top of the southern Inyo Mountains. It began producing lead and silver, but it became a zinc mine in the 1900s. Silver was mined in the 1870s from mines around Panamint City, which once grew to 1,500 people, near Panamint Pass in the southern part of that range.

There is an exhaustive list of celebrated, but abandoned gold, silver, lead, and zinc mines scattered about the landscapes of the Basin and Range. The famous Bodie gold mines were producing in the 1870s and 1880s; Bodie is only a ghost town today, preserved as Bodie State Historic Park, but there are plans for renewed mining to the southeast. By 2011, local environmentalists were debating with Cougar gold over potential development of new mining operations in the Bodie Hills. Most other mines, such as those at Skidoo, Chlote Ridge Cliff, and Ballarat had come and gone by the early twentieth century.

Today’s mining in the Basin and Range focuses on talc and saline minerals. Talc is also concentrated where igneous plutons have intruded into older metamorphic rocks in the ranges. However, health hazards caused by exposure to dangerous asbestos fibers have taken their tolls on California talc mines. Saline minerals are concentrated as evaporates on and near the dry lake beds in the basins. One of the best examples is Searles Dry Lake, where chemical industries have dominated the economy in little Trona for decades.

**Mining from the Mojave to the Southern Deserts**
Moving toward the Mojave, along Hwy. 395 (south of Ridgecrest and southeast of the El Paso Mountains), is the Randsburg Mining District, which has mainly produced gold, silver, and tungsten. This time it was where Proterozoic Eon (late Precambrian) rocks were intruded by younger plutons; veins with ores were left behind. In the on-and-off-again Yellow Aster deep mine, gold was found along boundaries where granitic ore-rich fluids invaded the Rand schists. Caverns dug at the Kelly Rand silver mine, closed in 1928, followed ore-rich rhyolitic intrusive veins. Randsburg is often recognized as the best
preserved mining town in Kern County. Sporadic mining activity at the Atolia tungsten mine followed the veins of a Nevadan granitic intrusion, although placer mining has left spoil mounds behind.

Silver was worked during the late 1800s on the south side of the Calico Mountains northeast of Barstow. Here, Pliocene Epoch igneous bodies and their solutions intruded into the sedimentary rocks of the Miocene Barstow Formation. Calico, first a mining town and then a ghost town, is now rebuilt as a tourist spot north of I-15. Colemanite was also mined in the early 1900s from shales of the Barstow Formation in the northeast Calico Mountains.

Many of the volcanic cones from Barstow to Amboy have been mined. Cinder and clay have been taken from Pisgah Crater. Dish Hill is famous for its volcanic bombs with their olivine and granitic cores.

Mines with catchy names such as Antimony Gulch, Copper World Mine, and Birthday Mine near the Mountain Pass Mining District indicate something special. Located north off I-15 between Baker and the Nevada border south of Clark Mountain, the high desert’s Mountain Pass Rare Earth Deposit has the largest known deposits of rare earth minerals. Gold was also discovered here; today, 25 percent of the world’s rare earth minerals (mainly carbonates) are found at Mountain Pass in a unique 1.4 billion-year-old high carbonate intrusion and sill that squeezed through older gneiss and is now found at depths down to at least 3,000 feet.

This is a perfect opportunity to show how such activities as mining in California are still so powerfully connected to the global marketplace. After the Mountain Pass mine was briefly closed in 2002, Molycorp Minerals was mining again there by 2010 and was expanding to phase 2 of their Project Phoenix by 2014. Why? The district contains 17 different elements that are essential to the electronics industry, such as in products like digital camera technologies, flat screen TVs, cell phones, batteries, light bulbs and even fighter jets. As mining at Mountain Pass expands, it will ease U.S. reliance on China’s mining products, as the Chinese government has used rare earth minerals as leverage in world politics. Molycorp will use saltwater cleansing to deal with the pollution problems responsible for the mine’s last closing.

North of Desert Center, the famous Eagle Mountain Mining District contains the largest deposits of iron ore in California. In Mojave’s Providence Mountains, where granites intruded into the Cambrian Bonanza King Limestone, scores of minerals formed, including magnetite and hematite, which were processed at the Vulcan mine during the 1940s.

Gold mines in and around the Chocolate Mountains include the Picacho and Mesquite mines, where the ore is found in Jurassic Period metamorphic rocks. The Mesquite began production in 1987, was restarted in 2008 and was producing more than 100,000 ounces (worth over $100 million) per year into 2010 and it may contain up to three million ounces of reserves. In the far southeast corner of California, the Cargo Muchacho Mountains produced gold since 1781. United Mining Company (Tumco) operations built a town of 2,000 in the searing heat near the start of the twentieth century as they dug into the Jurassic Period Tumco metamorphic rocks. American Girl Mine operations were terminated there in 1999 and by 2012, the mine was on the market for $3 million. Today’s high-tech operations are dominated by heavy machinery that carries the blasted rock out of deep veins. It is then crushed and chemically processed to extract the relatively small quantities of ore. Since worker safety and the environment will always be concerns in the United States, global gold prices and efficiency standards will determine whether such mines can continue to operate.

Salts and other Minerals from Desert Playas

From sodium chloride to carbonates to borates, many salts and mineral deposits have been taken from the mostly dry playas in the Basin and Range and south through California’s deserts. Most accumulated as a basin’s floodwater, lake water, or groundwater evaporated. Some of the most visible results can be

**Figure 2-19** California’s Petrified Forest is just outside Calistoga and wine country. The forest was quickly buried, then groundwater seeped into the logs, precipitating silica that would turn them to stone. Weathering and erosion has since exposed them.
found at Searles Valley and Dry Lake, with their strange tufa formations (the Pinnacles) and the nearby chemical processing plants at Trona.

Borate minerals such as colemanite were taken from the Pleistocene Epoch mud of Death Valley beginning in 1882; this remained California’s only commercial source of borax until 1926. The borates were taken all the way to Mojave on wagons pulled by the famous twenty-mule teams. Then, in 1913, the Kramer borates were discovered just one mile north of Boron, including the higher quality kernite which is easier to process into borax. Borax production has been centered at this location since 1928, where the kernite is taken from an open pit mine in the Miocene Kramer deposits. In 2012, the company website announced that Rio Tinto Borax operated the state’s largest open pit mine in Boron, one of the planet’s richest deposits, as the company supplied nearly half the world’s demand for refined borates “essential to life and modern living.”

The salty surface at Bristol Lake near Amboy is packed with evaporite minerals. Trenches are dug up to 6m (20 feet) and allowed to fill with the high-mineral water. Table salt and calcium chloride are among the salts extracted after the water evaporates.

In the sands of Kelso Dunes in Devil’s Playground, previous attempts at mining heavy metals have failed.

Valuable Earth Resources in the Coastal Mountains and Valleys

Peninsular Ranges

In the Peninsular Ranges, gold and nickel were carried into veins when magmas intruded into older Julian Schist near today’s Julian Mining District. This geological process should now sound very familiar because we have touched upon it many times in this chapter. This made Julian the historical center for gold and nickel mining in the Peninsular Range.

The famous Mesa Grande, Pala, Rincon, and Ramona gem sites near the headwaters of San Luis Rey River in the Peninsular Ranges formed in conditions typical for California gems. Within these Cretaceous Period pegmatite dike intrusions high in boron and lithium are cavities the size of rooms with giant crystals of tourmaline, beryl, garnet, and topaz. Mining of tourmaline peaked in the early 1900s. Similar gem sites are scattered throughout the Peninsular Ranges.

New rare earth minerals are being discovered at one of the world’s most famous contact metamorphic mineral sites, the Crestmore limestone/marble quarries near Riverside. When Nevadan granitics intruded into these Paleozoic Era limestones, rare trace elements formed more than 140 minerals.

In the northern Santa Ana Mountains, the nonmarine deposits of the Paleocene Epoch Silverado Formation contain some coal, clays with high aluminum content, and plenty of glass sand. These have been mined for nearly a century.

Coast Ranges Mines

The Coast Ranges did not play a significant role in gold production compared to the Klamaths, Sierra Nevada, and the California deserts until the 1980s. In the northern Coast Ranges’ Mayacamas Mountains, north of Lake Berryessa near Knoxville, the McLaughlin Mine became one of California’s largest gold producers into the 1990s. Mercury, arsenic, antimony, tungsten, and thallium were also found in the ores there. This leads us to another dramatic geography lesson.

From this area to the Sulphur Bank mercury mining operations at Clear Lake is a legendary example of how we measure and clean up toxic pollutants remaining from past careless mining operations and who should be held responsible. By the 1990s, Sulphur Bank was a federal EPA Superfund site as high levels of mercury were found in local water supplies. By the 2000s, dangerous mercury contamination was still being measured in water around the region’s mining operations, including in Clear Lake especially near mounds of waste that were dumped many decades earlier. A classic controversy continues as scientists have tried to determine how much water contamination originates from careless past mining and how much is naturally emerging from the area’s hot springs and geysers. Estimated clean-up costs have ranged up to $40 million as contaminated tailing and waste rock were once even used to make bricks and to build roads and houses in the area. Meanwhile, though the McLaughlin Mine became known as one of the most ecologically sensitive gold mines, previous mining contamination in the region combined with natural sources to produce some of the largest mercury emissions in the state by the early 2000s. Recently, in the McLaughlin Ecological Preserve operated by UC Berkeley, scientists were experimenting to learn how natural wetlands could be used to filter toxic heavy metals out of the water.

California’s Coast Ranges have produced up to 85 percent of all U.S. mercury. Though mercury was discovered first in Santa Barbara County in the 1700s, the New Almaden mine near San Jose was the first to produce mercury in 1824. It later became the deepest mercury mine in the world.

The New Idria mine between King City and the Central Valley was established in 1859 and was the largest producer of mercury in the United States until 1965. In the 1800s, it was notorious for the low pay and dangerous working conditions it offered its mostly immigrant workers. But, it is only one example of the hot, horrendous working conditions that poisoned thousands of mercury mine workers as people imagined quick profits from California’s natural resources.

California’s state gem (benitoite) is found only near the San Andreas Rift Zone in southern San Benito County.
 Appropriately, the large, attractive, six-sided blue-to-white crystals of this mineral are found with serpentinite, California’s state rock.

This section has covered only some of the more important mineral and ore localities in California. There are many more sites in the state. You might visit our supporting web site for more details.

◆ SOME FINAL WORDS◆

In this chapter, we have summarized the geologic history of California. We know more about the many similarities and differences between the processes and landscapes that dominated California millions of years ago and the California we see today. We have also located some of the more common and important rocks and resources that were left behind by those dramatic historical events and landscapes.

The major themes of this book are evident within this chapter. An unrivaled diversity of rocks, landscapes, and earth resources remains from California’s tumultuous geologic past. The connections between past and current geologic processes and the landscapes they have created are clear. Connections between the distribution of these landscapes and earth resources and California’s diverse human geography (from migration and settlement patterns to economic trends) are also evident. Just as geologic processes and landscapes continue to change, so do the local and global economic forces that determine the value of earth resources such as gold. Which earth resources will be valuable and which mining operations will continue to thrive in the twenty-first century? A host of factors, from environmental quality concerns to the global marketplace, will help determine the answers to such questions and the subsequent impacts on California landscapes.

Chapter 3 will examine current California landscapes and the modern geologic processes that are shaping them. If you are interested in more details, go to our appendix, “California Rocks and Minerals,” to fund a field guide on our supporting web site.

◆ SOME KEY TERMS AND TOPICS ◆

<table>
<thead>
<tr>
<th>Cenozoic basins</th>
<th>Geologic Time Scale or Chart</th>
<th>placer deposits</th>
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<tr>
<td>contact metamorphism</td>
<td>granitic pluton</td>
<td>plate tectonics</td>
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<tr>
<td>continental margin</td>
<td>hydraulic placer mining</td>
<td>rare earth minerals</td>
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<td>earth resources</td>
<td>Modoc Plateau</td>
<td>rock cycle</td>
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<td>East Pacific Rise</td>
<td>Mother Lode</td>
<td>roof pendants</td>
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<tr>
<td>fossil fuels</td>
<td>Nevadan orogeny</td>
<td>Sierra Nevada batholith</td>
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◆ ADDITIONAL KEY TERMS AND TOPICS ◆

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<th>Cenozoic Era</th>
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<th>Ores</th>
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<td>magma</td>
<td>Paleozoic Era</td>
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<tr>
<td>fossils</td>
<td>mercury</td>
<td>Precambrian</td>
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<td>Franciscan Complex (melange)</td>
<td>Mesozoic Era</td>
<td>salt deposits</td>
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<tr>
<td>granitic intrusion</td>
<td>metamorphic rocks</td>
<td>sedimentary rocks</td>
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<td>mining districts</td>
<td>serpentine</td>
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<tr>
<td>gold</td>
<td>oil platforms</td>
<td>Tertiary Period</td>
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In this chapter, we will explore the modern topographic features (geomorphology) of California and some of the more recent and current geologic processes that continue to shape them. This is the nebulous area where the geologic history that left ancient rocks and landscapes behind gradually yields to the current processes that are shaping modern landscapes. The processes are similar, but the magnitude and location of geologic events continues to change. At times, the line separating the past from the present is very blurry, while the connections between past and present geologic events become more clear. Today, we have the privilege of witnessing not only the diversity of recently formed landscapes that have had little time to be altered, but also the current events which continue to change California landscapes.

You can see why some Californians may consider this privilege a curse. However, the earthquakes, landslides, mudflows, and other events we refer to as natural disasters are simply nature’s more dramatic examples of how our landscapes continue to evolve and to change. Without these events, California landscapes would not be as diverse and spectacular. They would become like many quieter places on our planet that are more distant from plate boundaries and therefore more homogeneous—places where connections between natural processes and the landscapes they have created are less evident.

We have learned that California has experienced a tumultuous geologic past. Today, Californians are forced to recognize that the state continues to be a focus of geologic activity. California is still located along plate boundaries where the internal (endogenic) tectonic forces that build mountain ranges (some might call them constructional) are dominant. In turn, the newly emerging landscapes that are so common throughout the state are perfect targets for aggressive attack by external (exogenic) agents of weathering, erosion, and mass wasting. These cycles of change continue in California and they inevitably impact everyone, even those who attempt to ignore them.
In the first half of this chapter, we will locate and describe some of the more important mountain-building forces at work in California today. These emerging landscapes become vulnerable to aggressive denudational (exogenic or destructional) agents, including weathering, mass wasting, and erosion.

Modern volcanic activity is evident in at least four separate regions within the state: the Cascades and Modoc Plateau, the eastern Sierra Nevada into the Basin and Range, the Imperial Valley south of the Salton Sea, and in the mountains north of the Napa and Sonoma Valleys. Generally, such volcanic activity poses no threat to California’s major population centers.

Because California is located along plate boundaries, a variety of active faults and other geologic structures exist. The most important and famous structural feature is the San Andreas Fault; however, faults are found in almost every region and are responsible for building diverse landscapes.

It is likely that major earthquakes will continue to impact the majority of Californians and could potentially cause the nation’s greatest natural disasters.

Weathering processes aggressively attack exposed rocks, breaking them into smaller particles, which may form soil or be vulnerable to mass wasting and erosion. Differential weathering frequently results in distinct and scenic landscapes throughout the state.

A variety of mass wasting processes continue to shape landscapes and threaten Californians in many regions. They range from slow movements that are barely noticeable to sudden, massive, and catastrophic landslides or debris flows and mudflows.

External agents that erode, transport, and deposit material in California leave a multitude of landforms. Glaciers modified landscapes in northern California mountains and the Sierra Nevada. The effects of wind are evident in some desert and immediate coast locations. Waves and currents shape the coastline. However, fluvial processes and their landforms (made by running water) are far more important and dominant.
The major volcanoes are surrounded by dozens of smaller ones, all lying on the western edge of successive lava flows of the Columbia Plateau. In California, Mount Shasta and Lassen Peak are the most remarkable of the southern Cascades; they merge with the Modoc Plateau lava beds, which extend into California’s northeastern corner. These majestic composite volcanoes are formed from a combination of successive and often violent eruptions of ash and cinder and lava flows that occur inland and parallel to a subduction zone. Moving east, less violent eruptions have poured less viscous (more runny) lava flows over the Modoc Plateau. (The nature and classification of various volcanic rocks is reviewed at the beginning of Chapter 2.) Farther southeast, north–south trending parallel faults are creating valleys and mountains somewhat similar to landscapes of the Basin and Range to the southeast.

Our survey of active volcanism begins on the northern end of California, north of the Mendocino Triple Junction (where the Juan de Fuca, Pacific, and North American Plates meet). Refer to Figure 2-4 on page 43. This is also where the sliding between the Pacific and North American Plates that dominates central and southern California gives way to subduction. North of this point, the Gorda oceanic plate (a southern cousin of the Juan de Fuca oceanic plate) is forced beneath the North American continental plate; this is the only place in California where subduction continues to play a significant role in shaping geologic events and landscapes.

As basaltic crust of the oceanic plate is shoved below the less dense material of northern California’s continen-
tal crust, sediments and pieces of both crusts are scraped together and carried down with the oceanic plate in a process often termed underplating, rather than subduction. Deeper and now east of the original subduction, these materials are heated and then melted under pressure. Occasionally, portions of these huge magma chambers move toward the surface. They incorporate materials from the less-dense continental crust into the melt and finally erupt to form the Cascade chain.

Cascade Volcanoes. Mount Shasta is the most glorious of all California volcanoes and one of the largest and most recently active of all the Cascades. At 4,319 m (14,162 feet) above sea level, this isolated structure rises more than 3,100 m (10,000 feet) above the surrounding countryside. This composite volcano (or stratovolcano) is made of cinder and ash deposits and andesitic lava flows, some more than 17 m (50 feet) thick. It is steepest near the top with a 35-degree slope and grades to only a 5-degree slope at its 17-mile diameter base. At the top, the main Hotlum cone is so youthful (last erupted in 1786), there has been very little erosion. A conspicuous satellite cone—Shastina—emerges from the side of the larger structure and is older. The youngest lava flow on Shasta is more than 9,200 years old. Smaller basaltic shield volcanoes and their flows are noticeable north of Shasta.

Lassen Peak (on the southern end of the Cascades east of Redding) began to form more than 11,000 years ago on the remnants of the devastated ancient Mount Tehama. It is now one of the largest plug domes in the world. An explosive eruption began in mid-May 1915. It included mudflows and a cloud of steam, cinder, and ash up to 7,500 m (25,000 feet) that was seen from Sacramento. Thick, pasty dacite flows were also squeezed up like toothpaste. Less significant steam eruptions ended in 1921, but the volcano exhibits some of the best examples of fresh volcanic features (such as fumaroles, mud pots, boiling lakes, and foul-smelling vents) in the United States.

At 3,187 m (10,457 feet) above sea level, Lassen Peak now looms above the devastating avalanches and mudflows of its latest eruption. A succession of plant communities invading this newborn landscape wait for the next inevitable eruption. A hike through the impressive hot springs and steam vents of Bumpass Hell or to the summit of Lassen Peak could accentuate your experience at today’s Lassen Volcanic National Park.

Numerous smaller volcanoes dot the landscapes of the Cascades and Modoc Plateau. Volcanoes surround the Medicine Lake Highland on the eastern edge of Siskiyou County, and lava flows have dammed Medicine Lake. Here, about 5 million years ago, the Mount Hoffman volcano collapsed, leaving a 65 sq km (25 square mile) caldera. Younger lava flows have filled the caldera. More recent eruptions of at least 100 cinder and lava cones distributed pumice and tuff across this landscape as recently as 1910. The older basalts grade to more recent rhyolitic eruptions. Some of the best examples of glassy obsidian flows in California cover more than 4,200 acres at nearby Glass Mountain.

The California Cascades have experienced at least seventeen eruptions at Mount Shasta, Lassen Peak, and the Medicine Lake Highland in the last 2,000 years. Future eruptions, including massive landslides, ash and cinder, glowing gas clouds, lava flows, and mudflows typical of felsic composite volcanoes, are probable. Long-term predictions of the exact timing of these eruptions are unlikely, but days of earthquakes and swelling often precede them. Such eruptions since the Pliocene Epoch have
produced these landscapes strewn with cinder (weathered from red to black), scoria, pumice, and obsidian.

**Modoc’s Volcanic Landscapes.** The north–south trending faults along which most recent Cascade eruptions have taken place become more pronounced as we move farther east through the Modoc Plateau. The Modoc is actually on the southwestern edge of the Columbia Plateau and has been built up to 1,500 m (5,000 feet) by successive, extensive, runny, basaltic lava flows from the Miocene to today.

At Lava Beds National Monument, some flows are less than 1,000 years old. More than 300 lava tubes formed here as lava floods cooled and crusted on the surface, allowing magma to drain away below, opening these now cold ice caverns. Prehistoric mastodon, camel, and human remains have been found in these tubes; numerous cinder cones dot the surface above the lava flows.

To the south, Burney Creek plunges over the edge of a resistant basaltic lava flow just before flowing into Lake Britton at McArthur-Burney Falls Memorial State Park. The falls spill over a lava flow that covers porous tuffs and formerly weathered surfaces. All of these rock layers are being cut and exposed by the cascading water, but the lower porous rocks carry groundwater, which erupts as impressive natural springs flowing out at up to 4.6 million liters (1.2 million gallons) per day, adding to the spectacle.

In summary, cones, domes, plugs, glass flows, and pumice are common across the Modoc Plateau’s basaltic surface. All but the youngest volcanic features have been cut by a series of parallel faults. These north–south trending faults become so dominant toward the east that the Warner Mountains and Surprise Valley are often considered part of the Basin and Range.

**Eastern Sierra Nevada/Basin and Range**

Extensive and recent (Pleistocene Epoch to today) volcanic activity is common from the eastern Sierra Nevada into and north of the Owens Valley and at points east in the Basin and Range. From Mono Lake to the Mammoth Lakes area and Long Valley, you will find some active or recent volcanic features. They include the impressive Mono and Inyo Craters, Devils Postpile, and pumice covering much of the surface between. Cones and volcanic fields are scattered in, around, and east of the Owens Valley; the valley rises abruptly on the north end, up to the Bishop volcanic tableland.

**Mammoth and Beyond.** Stanford earth scientist Gail A. Mahood’s research team’s dating of volcanic rocks around the Mammoth area (published in 2010 by the Geological Society of America) is among recent projects confirming active volcanic activity in the region. More than 700,000 years ago, after nearly three million years of less significant eruptions and lava flows in the area, a spectacular volcanic explosion suddenly blew apart a giant volcano, leaving the Long Valley Caldera. Fiery clouds of ash and pumice rained down and viscous lavas flowed away from the eruption. Deposits of the pinkish Bishop welded tuff (up to 1,500 m [5,000 feet] thick) that make up the tableland are found many kms (miles) away on surrounding landscapes. Traces of airborne material from this eruption have been found as far away as the Great Plains states. The caldera collapsed after the eruption and Long Valley was left behind.

Just to the west is Mammoth Mountain, a volcanic cone built from about ten glassy eruptions between 190,000–40,000 years ago; it is much younger than originally thought. Farther west is Devils Postpile, where a thin, andesitic lava flow cooled about 600,000 years ago. While cooling, it contracted and cracked into nearly per-
fect six-sided columns. Many of these individual vertical columns have been shaved flat at their tops by glaciers; others are now weathering into piles of rubble.

Volcanic activity in the Mammoth/Long Valley area continues in the latest of a sequence of four spasmodic periods since about 190,000 years ago that have included eruptions of many varieties and chemistries. A series of strong earthquakes (a few at more than 6 magnitude) rocked the area on Memorial Day weekend, 1980. Strong shaking caused visible ground motion east into the Nevada desert, swayed chandeliers in distant Nevada casinos, and caused dangerous rock slides in the Sierra Nevada. By 1982, more than 3,000 earthquakes were recorded as a magma chamber moved up to about 5 km (3 miles) from the surface. These earthquakes, increased activity at Hot Creek, and significant ground swelling in Long Valley caused geologists to warn residents and officials that an eruption could occur.

Unlike the Mount Saint Helens disaster, which was unfolding to the north in southern Washington State, there was no eruption. Instead, the activity calmed considerably, only to become active again in significant spasmodic events that continue to keep geologists’ and residents’ attention. This activity, especially at first, impacted businesses and real estate interests in and around Mammoth Lakes.

To the north, the line of Mono and Inyo Craters has erupted from a few thousand years ago to the last few centuries along a fault zone. Mono Craters are just south of Mono Lake and are composed of viscous rhyolitic materials that squeezed to the surface, forming conspicuous pumice cones, rings, and steep-sided flows. They have

More Evidence of Volcanic Activity

Other indicators of recent and continued volcanic activity scattered about the Basin and Range include numerous hot springs. Excellent examples are found surrounding the Owens River from the Mammoth/Crowley Lake area south into the Owens Valley to Coso Hot Springs. The subterranean pressurized hot water associated with some of these areas (particularly near Mammoth and Coso) should continue to represent potential sources of hydrothermal energy.

One more example of a recent short-lived eruption is at Ubehebe Crater at the northern edge of Death Valley. This maar volcano erupted when groundwater was superheated by a heat source that neared the surface. The resulting pressurized steam exploded through the older sedimentary rock layers, raining layers of dark ash and cinder down on the surrounding desert surface. There were no lava flows, but the deep, dramatic crater left behind is best described by its name—Ubehebe is an Indian word for “big basket.” Smaller craters are prominent on the surrounding desert surface.

The recent volcanics of this region are usually, but not always, confined to the eastern Sierra Nevada/Range. Just to the west are remnants of the last Sierra Nevada volcanic episodes (some younger than 3.5 mya), all in the high Sierra Nevada. These are in the headwaters of the San Joaquin River and along Golden Trout Creek before it dumps into the upper Kern River south of Kern Hot Spring. They also include cones along the headwaters of the South Fork of the Kern River.
formed during the last 40,000 years. At the northern end of Mono Craters is Panum crater. It has a pumice and ash ring, a central obsidian plug, and ash deposits that are slightly more than 600 years old. Five-hundred-year-old Paoha and Negit Islands in Mono Lake experienced minor eruptions in the 1890s. Flows of obsidian and pumice at the steep and deep Inyo Craters are as young as 550 years. There are many other recent volcanic features in the area, such as Wilson Butte and Obsidian Dome near Deadman Summit and Hwy. 395 and geologists would not be surprised to see a small eruption in the region in the near future.

To this point, we have examined three very different kinds of volcanic activities and landforms. Runny basaltic flows are characteristic of the Modoc Plateau, a mixture of runny basaltic and viscous rhyolitic eruptions and flows are common north of the Owens Valley, and the composite giants of the Cascades are mostly intermediate in chemical composition. Different volcanic landscapes are evident as we explore south and east into and beyond the Owens Valley.

**Exploring Volcanic Activity and Landscapes Into the Owens Valley.** Heading south, the Owens Valley and surroundings are littered with fresh and often conspicuous ash and cinder cones and dark lava flows. From Crater Mountain and the other outstanding peaks and lava flows south of Big Pine to the 60,000-90,000-year-old basaltic flow at Sawmill Canyon northwest of Independence, it is clear that magma sits just below the surface of the faulted blocks and stretched crust of the Basin and Range.

Farther south, in the less than 25 km (15 miles) area from Little Lake across Rose Valley and northeast to Coso Hot Springs, there are at least fifteen basaltic cinder cones and thirty rhyolitic tuff cones, including pumice, obsidian, and dark lava flows. Some of the youngest landscapes are Red Hill and the prominent, related 10,000-year-old lava flow cut by the Owens River at Fossil Falls north of Little Lake. This is a memorable stop along Hwy. 395 for a view of recent volcanic features. Lava flows that have poured through canyons out of the southern Coso Range to the east are so fresh, one might experience the illusion that they continue to advance. Similarly recent volcanic features stand out along State Hwy. 190 from Olancha to the Panamint Valley in the northern Coso and Argus Ranges.

**Imperial Valley South of Salton Sea**

Just north of Bombay Beach on the east side of the Salton Sea, the sliding plate boundary defined by the San Andreas Fault gives way to diverging plate boundaries to the south. A series of spreading centers are not only pushing the Peninsular Ranges away from the mainland, they are stretching and pulling the Imperial Valley apart. These series of transform faults and pull-apart basins in the thinned crust eventually yield to the activity along the East Pacific Rise in the Gulf of California that is pushing the Baja Peninsula away from the Mexican mainland. Modern volcanic features, geothermal fields, and seismic activity south of the Salton Sea are evidence of the active thinning and pull-apart basins.

Southwest of Niland, along the southeastern edge of the Salton Sea, are five young pumice and obsidian domes with names such as Mullet Island, Red Island, and Obsidian Butte. They only rise to about 45 m (150 feet) above the basin surface, but they and the mud volcanoes and hot springs around them are proof that volcanic activity continues to impact the area. At least six different geothermal fields have been identified in the Imperial Valley region. By 2011, the Geothermal Energy Association reported more than 20 plants were producing electricity there, contributing a large part of the geothermal production that totaled about 5% of the state’s electricity.
demands. The industry sees great potential for increased production. However, corrosion from the high dissolved mineral content (10–39 percent) of the water continues to hamper the efficiency of these operations. This volcanic activity continues south into Mexico.

**Sonoma to Clear Lake**

Volcanic activity dominated landscapes starting in the Sonoma area at the end of the Pliocene Epoch and continued migrating north to reach the area around Clear Lake at the present time. Basaltic flows and rhyolites are found, but the dominant rock is andesite. Pyroclastics and lava flows extruded from various volcanoes are common in the mountains above the Sonoma and Napa Valleys. They cover hundreds of square miles in the Coast Ranges' Sonoma, Howell, and Mayacamas Mountains. They include the broken rhyolites of Mount Saint Helena looming above Healdsburg and the Russian River (not to be confused with Mount Saint Helens in Washington). From Lake Berryessa to south of Clear Lake, the cinder cones, pumice, basalt, and obsidian flows are even younger, dated to the last several thousand years. An example is Mount Konocti, which rises above the homes, golf courses and country clubs on the western shores of Clear Lake, with its layers of intermediate lava flows, ash, and cinder deposits.

There is still enough activity to boil residual heat water that has seeped through underground fissures, especially in the Mayacamas Mountains. Most of the resulting hot springs are located near the headwaters of Big Sulphur Creek, which eventually pours into the Russian River near Cloverdale. The Geysers Resort and geothermal power plants are also located in this area east of Cloverdale. These wells are some of the largest geothermal energy producers in the world, producing enough energy for a city of more than 500,000. Though the area is small, there are few corrosive chemicals in the dry steam; this contributes to a more efficient energy source. California's popular and dependable Old Faithful Geyser is southeast of this area, near Calistoga.

**Summary of Modern Volcanic Activity and Landscapes**

There are other hot springs and isolated pockets of related activity that branch away from the four volcanic areas discussed in this section. (See our “More Evidence of Volcanic Activity” box.) Perhaps most notable are the springs along the San Jacinto and Elsinore Fault Zones, where underground water has seeped deep into faults and contacted hot rocks. Examples include the historical Elsinore sulfur springs and spa, Warner Springs, and Murrieta Hot Springs. Additional hot springs along the San Jacinto Fault are San Jacinto, Soboba, Eden, and Gilman Springs. Palm Springs and Borrego Springs are other examples of the many hot springs that have attracted visitors and helped shape the history and economy of California.

This concludes our examination of the four major volcanic regions that are currently active in the state. The first two (the Cascades/Modoc Plateau and the eastern Sierra Nevada/Basin and Range) are the major and extensive regions; the last two (Clear Lake/Sonoma and Imperial Valley) may be smaller areas in California today but each of these landscapes has been built and/or directly impacted by recent and current volcanic activity.

If your favorite volcano or volcanic rock was not mentioned in this section, it may be in an ancient volcanic field that is no longer active. If so, refer to Chapter 2, where the rocks and landscapes left behind by past geologic events are described. When you review some of the ancient Mojave volcanic landscapes covered in Chapter 2, you will better appreciate the thin, fuzzy line separating the past from the present. Once again, you will see how each chapter in this book is connected to the next, just as different events and landscapes are related in California.

**Modern Tectonic Processes and Landforms: An Introduction**

When you look over a California landscape on a clear day, you are looking across faults or folds in California’s
crust. You are viewing the structures and surface features that result from the bending and breaking of rocks under stress along or near the boundary between the Pacific and North American Plates. These same tectonic processes that move the ground beneath your feet during an earthquake also create diverse and often spectacular landscapes. Because California’s unique geologic situation offers the potential of great human disaster, we must continue to learn about tectonic processes and how to live with them.

Unlike the more scattered distribution of volcanic activity, active tectonic landforms dominate or impact nearly every California landscape. In this section, we will focus on the common and widespread tectonic processes and the more interesting and important specific landscapes they have created. We will begin with a very general introduction to these landscapes as we make a clockwise sweep around the state, starting in the northwest.

In the Klamaths, river terraces represent elevated valley floors that have been recently raised up and incised by rejuvenated streams. Numerous volcanoes in the Cascades are lined up along fractures in the crust. To the east, these faults dominate the landscapes into Nevada and south into the Basin and Range, where along them, adjacent blocks of crust are lifted up and dropped down. Lake Tahoe has filled such a basin. The eastern Sierra Nevada is being lifted above the Owens Valley, and Death Valley is sinking along such faults. Though ancient but similar tectonic activity is often responsible for the older eroding mountains of the eastern Mojave, active faults become more dominant toward the west, closer to the San Andreas Fault Zone.

Farther south, the Coachella and Imperial Valleys continue to stretch and drop as the Peninsular Ranges are lifted and pulled away from them by a series of active faults. Finally, we sweep back north into the Transverse and Coast Ranges, where the tormented crust along the San Andreas Fault Zone and its branches is being folded and faulted, creating dominant landscapes trending mostly parallel to the plate boundary. Fresh marine terraces (wave-cut platforms lifted above sea level) so common along the California coast are also indicators of recent mountain building. Caught between much of this activity is the Great Central Valley and some smaller California valleys that have been structurally squeezed and downwarped, only to fill with sediment.

What do we know about specific tectonic processes shaping individual California landscapes, and what future threats do they pose to Californians? To answer these questions, we must always begin with California’s situation in relation to global tectonics.

Worldwide, mountain building often occurs at much faster rates than denudation (landscape destruction) even though the weathering and erosion that causes denudation occurs everywhere, unless an area is being buried beneath sediment. Tectonic activity that causes mountain building only occurs in particular regions and in specific locations, usually along crustal plate boundaries. With few exceptions, active tectonic activity builds young mountain ranges along those plate boundaries faster than they are destroyed; older mountain ranges are now isolated farther away from plate boundaries as they gradually erode to a more subdued or even flat landscape.

Most California landscapes are being built as a result of movement along or near the boundary between the largest tectonic plate on the Earth’s crust (the Pacific Plate) and the continental North American Plate. Even in northwestern California north of the San Andreas Fault, a piece of ocean plate spreading away from the Pacific Plate causes folding and faulting as it jams into and is subducted east below California’s continental crust. Like objects floating on a river of thick mud, the brittle surface plates of California’s lithosphere are carried by slow-moving currents within the plastic-like asthenosphere below. At the surface, the brittle Pacific Plate is grinding into and sliding past the North American Plate at about 5 cm (2 inches) per year toward the northwest. (This is roughly the same rate your fingernails grow.)

Specific Tectonic Processes and Landscapes

Though much of this movement occurs along the San Andreas Fault Zone, numerous individual segments of crust caught near plate boundaries are being bent, broken, contorted, and rotated. These forces are so powerful that most of California’s mountain ranges and other landscapes are relatively youthful in geologic time. Many are currently being built faster than they are denuded, though the fresh, steep slopes are perfect environments for accelerated weathering and erosion. We will focus on these external processes and the resulting hazards and landscapes in the next section.

Now, we will examine some specific internal tectonic processes common in California, the resultant landscapes, and the hazards they represent. We will begin with the most important structural feature in California, the San Andreas Fault, and then sweep around the state.

The San Andreas Fault System

Two of the greatest earthquakes in California history occurred on the San Andreas Fault. The 1857 Fort Tejon earthquake (magnitude about 8) ripped a segment of the fault more than 300 km (200 miles) long from central California to Cajon Pass. The infamous 1906 San Francisco earthquake was just as powerful, causing more than 5 m (16 feet) of slippage. The quake and subsequent fire nearly destroyed the entire city and heavily damaged other towns and cities in the region. It was this earthquake that brought so many geologists from around
the world to focus their attention on California and the
San Andreas Fault Zone.

Geologists now understand earthquakes along faults to be caused by the stress that builds up in rocks that are locked together, causing strain to build along these sliding plate boundaries. As the plates gradually grind past one another, stress and strain builds until the rocks along this boundary must break. Like a rock thrown in a pond of water, energy waves emanate away from where the rocks break and move; these are the seismic waves felt during an earthquake. Geologists have also learned that the San Andreas Fault is more than 1,200 km (740 miles) long, that it has generated such earthquakes for many thousands of years, and that there are branches of hundreds of smaller faults running roughly parallel to it.

The fault began to form at least 30 million years ago when a portion of the East Pacific Rise spreading center was itself subducted and consumed below the North American Plate. The era of subduction that had dominated California’s geology for millions of years slowly gave way to sliding along the lengthening San Andreas Fault system. This process continues today as geologists trace the fault south from the Mendocino Triple Junction west of Cape Mendocino; subduction is dominant north of this point while sliding rules to the south. Because the San Andreas Fault and its related structures are responsible for so many landscapes and geologic hazards in California, it is prudent to examine it more carefully.

Tracing the San Andreas Fault. From its northern end, the San Andreas Fault roughly parallels the northwest–southeast trending coastline to Point Arena and farther southeast to where the Garcia and Gualala Rivers follow its path. It is sometimes easy to follow along the landscapes it has helped to shape from Bodega Bay to the elongated Tomales Bay and back offshore near Stinson Beach. (The Earthquake Trail near the Nature Center at Point Reyes National Seashore offers a rewarding experience for anyone interested in geology and the San Andreas Fault.)

Trending just a few kms (miles) west of San Francisco, it comes ashore again on the San Francisco Peninsula between Daly City and Pacifica. Outstanding linear ridges, valleys, sag ponds, and offset streams mark its course through the Santa Cruz Mountains. It trends beneath San Andreas Lake and Crystal Springs Reservoir and on southeast through other Coast Ranges. Some of the most remarkable faulted surface features in the world (especially seen from the air) with dramatically offset streams are observed along the San Andreas Fault in the Carrizo Plain (west of the Temblor Range, in the southern Coast Ranges).

Just to the south, near the intersection with the Big Pine and Garlock Faults and other structural features, the San Andreas Fault takes a more easterly turn into Tejon Pass. Just as the fault trends more west–east at the “Big Bend,” the Transverse Ranges are also aligned in a more west–east trend. Many folds, thrust faults, and other structural features have built these mountains along the plate boundary that we are following. Once again, the fault is easy to follow by air from the Palmdale area on the inland side of the San Gabriel Mountains into Cajon Pass. As it trends into San Gorgonio (Banning) Pass toward the Coachella Valley, it breaks into several branches; the pass has been dropped along these faults as the San Bernardino and San Jacinto Mountains are being lifted on each side.

The fault zone continues along the east side of the Coachella Valley to just east of Bombay Beach and the Salton Sea. Groves of California fan palms and other green vegetation line the path and identify where crushed and weakened rocks along the fault zone allow ground water to seep toward the desert surface. South of the Salton Sea, the San Andreas Fault yields to the stretching and pulling-apart more typical of the Gulf of California.
**MOVEMENT ALONG THE FAULTS**

The San Andreas is a right-lateral transform fault, or a right-slip fault. This means that if you stand on a block looking across the San Andreas Fault, the block on the other side of the fault will be moving to your right. This horizontal movement causes streams that flow across the fault to be offset to their right. Rocks on opposite sides of the fault zone have been displaced up to 300 km (185 miles) since the Miocene Epoch. Rocks on the east side of the San Andreas Fault in the Little San Bernardino, Chocolate, and Oroopia Mountains are matched with rocks on the west side of the fault in the San Gabriel Mountains and farther north in the Transverse Ranges. Figure 3-11 shows relative movement along the San Andreas Fault.

Likewise, other rocks east of the fault in the San Gabriels and other Transverse Ranges are matched with rocks on the west side of the fault as far as Pinnacles (east of the Salinas Valley) and the Santa Cruz Mountains. These rocks were broken apart and dragged away from their original area of formation along opposite sides of the fault. As geologists learn that the San Andreas Fault has been actively sliding for millions of years, they are also gathering much more detailed information about recent movements and the possibility of future activity.

The fault is divided into northern and southern sections, where rocks are locked until there is a major earthquake. However, in portions of central California, where the fault is straighter, it appears to move more frequently in smaller events. Walls and curbs in Hollister are bent along a creeping section of the San Andreas Fault called the Calaveras Fault. Near Parkfield, moderate earthquakes greater than five magnitude have occurred on the average of every 22 years. (See “Anticipating the Next Earthquake,” page 74.) Meanwhile, historical earthquakes and recent research have shed light on the frequency of the big events along the more jagged, temporarily locked southern and northern sections.

Numerous geologists have added to our knowledge of California earthquakes and the landscapes they create. But it was Kerry Sieh who, by the late 1970s, had a trench dug across the San Andreas Fault at Pallet Creek south of Pearblossom. There he studied the frequency of earthquakes that break alternating beds of deposited sediments. Using the results of his and others’ work, seismologists have shown that major earthquakes of about eight magnitude have broken the rocks along this section of the San Andreas Fault and moved them up to 8–12 m (26–40 feet). Such events have occurred at intervals averaging between 130 and 185 years for the last 2,000 years. Since the last great event on this southern section of the fault occurred in 1857, and we know that rocks along the plates are accumulating stress at about 5 cm (2 inches) per year, it is likely that the “Big One,” with a magnitude near 8, will occur soon.

**What Are the Risks?**

During the early 1990s, research led seismologists to estimate that there was about a 60 percent chance of a major earthquake along this southern section of the San Andreas Fault within about 30 years. Because the fault southeast of Cajon Pass and east of the Coachella Valley has been locked much longer, the chances for a major earthquake there may even be greater. Conversely, geologists estimate the chance for a major event on the northern section of the San Andreas Fault north of Hollister to be a bit less. However, the fault zone is far more complicated than these estimates might suggest.

Though movement between the plates is mainly relieved by infrequent strong earthquakes along the San Andreas Fault, considerable stress is relieved by smaller earthquakes along nearby branch faults. Some of this movement is vertical, not horizontal. The reason goes back to those tiny slivers and other plate pieces that are caught, crumbled, mangled, and rotated along the plate boundaries. These hundreds of related faults are usually parallel to the San Andreas Fault, but they can be very complex and even difficult to locate. They have also helped build and impact landscapes within many kms (miles) of the San Andreas Fault.

With the inclusion of these smaller faults, geologists put the chance of another disastrous earthquake somewhere in the Los Angeles area at more than 80 percent in the next 30 years. Similar conditions caused by different faults have led seismologists to estimate more than a 75 percent chance of an earthquake of at least 6.7 magnitude in the San Francisco Bay area by 2030. These figures reflect studies done by the United States Geological Survey (USGS) and will surely be updated throughout the twenty-first century.

It is important to note that seismologists have changed to a more precise method of measuring earthquakes. The older Richter scale used a seismograph to measure the intensity of seismic wave energy released during an earthquake. A one-
MOVEMENT ALONG THE FAULTS (continued)

point increase on the scale represented roughly ten times more wave amplitude, but more than thirty times the amount of released energy. The modern moment-magnitude scale is similar, but measures more precisely the total energy released by quakes, emphasizing the area of rock rupture and the distance the rocks move along a fault during an earthquake.

When rocks break, the primary energy waves move fastest away from the focus, causing the ground to first shake from the compression and rarefaction (expansion) of the ground below. The secondary waves move more slowly away from the focus and represent shearing or undulations that cause the ground to sway and rock during an earthquake. Surface or longitudinal waves are often known as L waves. Many Californians have experienced enough earthquakes to roughly estimate their distance. A hard jolt with no discernable difference in motion could mean the earthquake epicenter was very close. Lengthy shaking from fast-moving primary waves, followed by extended rolling and swaying motions could indicate a very distant quake.

The amount of damage caused by an earthquake depends on three basic factors—magnitude, distance from the focus, and makeup of the substrate. In other words, the closer you are, the greater the shaking. Additionally, substrate of solid bedrock moves much less than substrate composed of the unstable loose sediment and fill usually found in California valleys and coastal areas. Especially dangerous is the loose material used to fill wetlands and bays, which may also have high water content, causing liquefaction when shaking begins.

The same two factors that combine to produce the greatest risk from earthquakes in California have also caused the most damaging earthquakes in California history. They occurred on faults along or near the San Andreas Fault system, and they occurred in or near population centers. The greatest damage was often on unstable substrate. The infamous 1906 San Francisco earthquake ripped more than 400 km (250 miles) of the San Andreas Fault up to 7 m (21 feet) apart in spots from Cape Mendocino to north of Hollister. More than 3,000 people were killed, and much of The City was burned to the ground. Cities as far away as Santa Rosa were heavily damaged or nearly destroyed.

During a World Series baseball game between the San Francisco Giants and the Oakland Athletics in October 1989, the 7.0 magnitude Loma Prieta quake struck along the San Andreas Fault system near Santa Cruz. Geologists believe that compression along a bend in the San Andreas Fault caused the horizontal and vertical thrust movement. The World Series was postponed, and more than 40 percent of downtown Santa Cruz was destroyed.

Though San Francisco was 70 miles north of the epicenter, liquefaction destroyed buildings built on the Marina District fill. A section of the Bay Bridge fell, and across the bay, the double-decker Nimitz Freeway collapsed on helpless commuters. The quake killed sixty-two people and caused $6 billion in damages. Residents and businesses have rebuilt, but retrofitting of older structures continues. The next disaster could be produced by one of several branch faults in the San Francisco Bay Area, where seismic activity has increased in recent years.

Anticipating the Next Earthquake

For years, scientists have used California as their laboratory to better understand earthquakes, hoping that predictions might someday be possible. Today, rock formations and statistics are studied to estimate recurrence intervals along particular faults. Central California’s Parkfield area along the San Andreas System became famous in the 1900s for experiencing moderate quakes (more than 5 magnitude) about every 22 years. As the 1990s dragged on, the Parkfield quake was overdue.

In December 2003, a 6.5-magnitude quake hit close to nearby Paso Robles, destroying part of the downtown, killing two, and opening a parking lot into a cauldron that was known as “the Hole from Hell” by locals. But this was not the anticipated Parkfield event. Finally, in September 2004, the 6.0 temblor hit, centered just 7 miles southeast of Parkfield. A multitude of sensors, from seismometers, to strainmeters, to creepmeters and cameras made this the best-monitored earthquake in history. National media converged on the 37 residents who have affectionately labeled their town “the earthquake capital of the world.” Scientists continue to learn from such quakes: one of the town’s road signs might read “Now entering the North American plate,” but no person yet knows exactly when the next temblor will strike.

The real dangers of tsunami along the California coast are covered in the section on coastal processes within the final chapter of this book.
Figure 3-11 The San Andreas Fault and Other Major Faults. As this right-lateral fault slices through California, edges of the Pacific Plate slide northwest against the North American Plate. Locations of some major earthquakes are also noted.
Smaller Faults in the Bay Area. From the Calavaras Fault to the south, to the San Gregorio Fault offshore, to the Rodgers Creek Fault to the north, the most dangerous branch fault in the Bay Area is probably the Hayward Fault. It is capable of unleashing an earthquake as powerful as the Loma Prieta quake, but with destruction similar to the January 1995 earthquake in Kobe, Japan, which killed more than 5,000 people. This is because the Hayward Fault runs along a line nearly connecting the major East Bay cities of Richmond, Berkeley, Oakland, and Hayward. UC Berkeley’s football stadium was built on this fault; you can see the displacement as an expansion joint opens up, gradually tearing the stadium in two.

Engineers and scientists at the 1995 meeting of the Earthquake Engineering Research Institute estimated that such a quake, which is overdue, could move rocks along the fault up to 3m (10 feet) in 22 seconds, kill thousands, and cause ten times the damage of the Loma Prieta quake. Perhaps it is geographic irony that many California cities were built along linear lowlands aligned with the dangerous faults which have shaped them. But in the Bay area alone, geologists have predicted the combined chance of a damaging magnitude 6.7 or greater earthquake along the San Andreas or other smaller faults at more than 75% by 2030. The picture is even more complicated in the Los Angeles area and throughout southern California.

A remarkable increase in the frequency of earthquakes, mainly along thrust faults, began in the 1980s. To the north, the devastating 1983 Coalinga quake measured 6.7 magnitude, followed by the 1985 5.9-magnitude Kettleman Hills quake. Then, six strong earthquakes hit parts of southern California between 1987 and 1994. Within the

Smaller Faults Cause Big Disasters in Southern California. The Newport-Inglewood Fault Zone trends roughly from Century City through the Baldwin Hills and Inglewood through the South Bay and south to Newport Beach. The geography of this fault is hauntingly similar to that of the Hayward Fault in the Bay Area; it is capable of producing magnitude 7 earthquakes directly below a line of densely populated cities. The 1933 6.4-magnitude Long Beach quake on this fault forced Southern Californians to recognize their vulnerability and led to some of California’s first stringent building codes to make structures more earthquake resistant.

A relatively quiet period followed, but at 6 A.M. on February 9, 1971, the 6.7-magnitude San Fernando (Sylmar) quake began a new period of activity. This quake killed sixty-four people and caused half a billion dollars damage. Damage to the Van Norman Reservoir left a few feet of dam between a wall of water and residents of the San Fernando Valley. Building codes were further strengthened after this event, due to the additional knowledge gained by engineers. These new building standards would save scores of lives in the years ahead.

That San Fernando quake also focused more attention on the numerous thrust faults that slice their way through the Transverse Ranges and the entire “Big Bend” region along the San Andreas Fault. Geologists began to confirm that many other thrust faults like the San Fernando and Santa Susana were capable of causing equally powerful quakes. Many of these faults are called blind thrusts because they are buried beneath sediment, and they do not always leave surface fractures when they move. They are part of the complicated faults and folds of the Transverse Ranges Compressional Zone; the Pacific Plate jams into the North American Plate at this bend, squeezing and folding smaller pieces of crust. The result is formation of the Transverse Ranges and the usually parallel faults that have helped build them.

Figure 3-12 Around Wallace Creek on the Carrizo Plain, there are excellent examples of right-lateral displacement along stream courses. You are looking directly across the San Andreas Fault.
Los Angeles area, the 1987 Whittier Narrows quake measured 5.9 magnitude, the 1988 Pasadena quake measured 5.0 magnitude, and the 1991 Sierra Madre quake measured 5.8 magnitude. These seismic events pale in comparison to the two earthquakes that followed.

The most powerful of these events hit east of the San Andreas Fault near the Mojave desert town of Landers, on the southern edge of the eastern California shear zone. Occurring in June 1992, the Landers quake measured 7.3 magnitude. It caused slippage of nearly 7 m (20 feet) along the Landers-Johnson Valley and Homestead Valley Faults. Left behind were fresh scarpers more than 2 m (6 feet) high with several meters of noticeable right lateral slippage at the surface. It was followed by another powerful earthquake in the nearby mountains near Big Bear, which was felt in Arizona and Nevada, and it triggered days of numerous earthquakes on faults throughout California and even into Montana. Just to the northeast, in October 1999, the 7.1 Hector Mine earthquake broke the Lavic lake fault about 50 km (30 miles) north of Joshua Tree. Rocks were displaced up to 5.2 m (17 feet) over 41 km (25 miles) of fault line.

The Landers and Hector Mine earthquakes were significant because they validated the arguments of geologists who believed that major movement between the two plates was migrating east of the San Andreas Fault. Damage was heavy, but the major jolt and aftershocks were centered far from areas with high population densities, sparing many hundreds of lives and billions of dollars of damage. These events proved once again how earthquakes continue to shape California landscapes and build mountains.

The most destructive earthquake in U.S. history hit Northridge at 4:31 A.M. on January 17, 1994. This 6.7-magnitude earthquake destroyed 3,000 homes, entire shopping centers, schools, parking structures, freeway bridges, and overpasses; it killed sixty people, including fourteen residents of the collapsed Northridge Meadows apartments who were crushed to death. Extensive damage throughout and north of the San Fernando Valley and surrounding the base of the Santa Monica Mountains totaled more than $20 billion. The focus of this quake was 18 km (11 miles) below the San Fernando Valley on a blind thrust fault dipping at an angle of 35–45 degrees.

No surface ruptures were found, but parts of the Santa Susana Mountains (including Oat Mountain) moved nearly 21 cm (8 inches) northwest and were pushed up nearly 38 cm (15 inches) during the seconds of the initial quake and its thousands of aftershocks.

There are dozens of similar thrust faults in and near the Transverse Ranges, particularly beneath the Los Angeles Basin. While geologists watched as these processes gradually changed landscapes, they became concerned that this exceptionally active period was a result of increased stress built up in this section of the San Andreas system—stress that may soon be released by a more powerful earthquake. Interestingly, a short period of quiet occurred in this region from the late 1990s into the second decade of the 21st Century. The San Francisco Bay Area also seemed to be in an active period into the last years of the twentieth century, but it too experienced a brief lull that started in the late 1990s.

South of the Big Bend. South of the Big Bend in the San Andreas Fault Zone, numerous mostly northwest–southeast trending faults are causing earthquakes and building landscapes. Included are such Peninsular Ranges as the San Jacintos and Santa Rosas and less dramatic features to the west and south all the way offshore.

The San Jacinto Fault veers south away from the San Andreas Fault in the Transverse Range. Geologists have measured more than 28 km (18 miles) of right-slip displacement that has occurred in the last few million years. The San Jacinto Mountains are being squeezed and raised between this fault on the west and branches of the

Figure 3-13 Two meters (more than 6 feet) of vertical displacement and far more horizontal displacement occurred in less than 30 seconds during the 7.3-magnitude Landers quake of 1992 in the Johnson Valley area northwest of Landers. Imagine the devastation that would result if such an event occurred below one of our urban centers. This photo was taken with the author more than a year after that earthquake.
San Andreas to the north and east. Perris Valley and Borrego Valley have been dropped down on the western side, while the impressive San Jacintos and Santa Rosas are lifted on the eastern side of this fault. These mountains are even more abruptly lifted on their eastern slopes by the Banning and other frontal faults. (The resulting scarps make for spectacular scenery, particularly from the Palm Springs desert floor up more than 3,000 m [10,000 feet] to 3,296 m [10,804 feet] Mount San Jacinto.) Back at the San Jacinto Fault, about seven earthquakes near magnitude 6 since 1890 are evidence of recent increased activity.

Farther west, the Elsinore Fault Zone is very similar to the San Jacinto Fault in age and horizontal displacement. Around the Lake Elsinore area, basins drop on this fault’s eastern side, and the Santa Ana and other mountains are being lifted on its western side. Parts of the Elsinore Basin are being pulled apart between faults, causing it to drop and fill with thick deposits of sediment. The Elsinore Fault trends southeast from there, through Temecula, Mesa Grande, and Julian. Like the San Jacinto Fault, the Elsinore Fault exhibits many classic fault features, including hot springs. Numerous lesser faults are mapped mostly parallel between and west of these two major faults, to many kms (miles) offshore.

It is interesting that the greatest vertical lifting is found in the higher eastern Peninsular Ranges; this relief tapers off in the gentler slopes toward the west, much like in the Sierra Nevada. Most major rivers also flow to the west and southwest, slicing into these uplifted terrains.

Many of the faults of the Peninsular Range that trend farther southeast toward the Imperial Valley branch off and disappear below the sediment, but interesting structural features, mostly northwest–southeast trending, abound. The San Jacinto Fault Zone branches through Borrego Valley and past Ocotillo Wells, where surface breakage was measured in the 1968 Borrego earthquake. Dramatic surface displacement was measured along the Superstition Hills Fault (a possible branch of the San Jacinto Fault) during a 1987 earthquake. The San Felipe Hills west of Anza Borrego and the Superstition Hills south of the Salton Sea contain so many tight folds that were recently bent up along major faults, they resemble the Indio and Mecca Hills along the San Andreas Fault Zone north of the Salton Sea. Similar forces have created recent folds in the young Palm Springs Formation sediments that stand out on the desert floor west of the Salton Sea.

The numerous northwest–southeast trending faults that are pulling apart the Imperial Valley produced more than twelve major earthquakes during the 1900s, including the 1979 and 1987 quakes. The magnitude 7 quake of 1940 on the right-lateral Imperial Fault near Mexicali displaced trees lined across the fault up to 5 m (15 feet). Brawley and other nearby towns were severely damaged. Rifting processes here are more similar to those pulling apart the Gulf of California than to the San Andreas Fault and other faults to the north.

Topping this was the magnitude 7.2 El Mayor-Cucapah earthquake of April 2010 that hit south of the border...
near Mexicali, doing major damage mostly on the Mexican side and even $90 million damage in the Imperial Valley especially around Calexico. NASA data showed that this earthquake shifted the ground more than ten feet in Mexico and pushed Calexico about 2.5 feet south on the California side. As aftershocks worked their way up into California along northwest-southeast trending faults through the following months, it became clear that this activity was another sign of the connection between the Elsinore, San Jacinto and other faults in southern California with those in the Gulf of California. Geologists are also speculating that this could be another clue suggesting how movement and displacement along the entire San Andreas system might be gradually shifting east during the next few million years.

**Beyond the San Andreas Fault: Faults in the Mojave**

Northeast of the San Andreas Fault system and south of the Garlock Fault, mountains of the eastern Mojave were built mostly along faults similar to the Basin and Range. The difference is that most of these normal faults are lower angle, curve toward the horizontal below the desert, and may even connect as “listric” faults. They are also older, more extensively eroded, and extend into Arizona and Nevada. There are exceptions. The Manix Fault runs along the Mojave River from Yermo toward Afton; its left-lateral movement is more similar to the Garlock Fault. Similar left-slip faults are common in the north-eastern Mojave.

However, the Garlock Fault is one of the most unusual structural features in California for a number of reasons. First, it trends northeast (nearly perpendicular to most structural features in California) away from Frazier Mountain, Tejon Pass, and the San Andreas Fault, before curving more easterly. Second, recent movement along the fault cuts off Sierra Nevada and Basin and Range landscapes, marking the northern boundary of the Mojave. Third, this is an active left-lateral fault with displacement between 10–60 km (6–40 miles). Although it is remarkably narrow (as little as 1.5 km [1 mile] wide) and only branches into two segments, it stands out on any topographic map or satellite image of California.

The 7.3-magnitude Landers quake of 1992 and the 7.1 Hector Mine earthquake of 1999 confirm the dominance of right-lateral faults in California and the importance of the eastern California shear zone. Both of these Mojave temblors and their faults were discussed in a previous section. With more than 5 m (17 feet) of displacement, we can only imagine the catastrophe that would occur if those faults had broken under a populated region.

**Sierra Nevada Structures.** The Sierra Nevada Fault Zone represents a series of parallel, vertical fault surfaces as steep as 70 degrees that are lifting the eastern wall of the Sierra Nevada and dropping basins to the east. The fault scarps have been eroded to still-impressive 30-degree slopes. Displacement from the basins to the crest is about 1,500 m (5,000 feet) in the north and 3,350 m

**Figure 3-14** It is a dramatic drop from the top of the Sierra Nevada near Mount Whitney down into the Owens Valley. This is more evidence that recent faulting has lifted the Sierra Nevada’s eastern edge and dropped the Owens Valley on the other side. Similar faults slice north–south across the Basin and Range into Nevada.
(11,000 feet) in the south. The Sierra Nevada is young; most of this mountain-building has accelerated along young and rejuvenated faults during the last 3 million years. This activity has produced some of the most spectacular landscapes on earth. The view from the Owens Valley looking west from Hwy. 395 is an example. From about 1,128 m (3,700 feet) elevation near Lone Pine, 4,418 m (14,495 foot) Mount Whitney (the highest peak in the contiguous United States) can be seen less than 21 km (13 miles) away.

The Alabama Hills represent slices of rock west of Lone Pine that were very recently lifted above the Owens Valley along branches of the Sierra Nevada Fault Zone. Even streams carving through them are older than the hills. A dramatic recent event that lifted this region higher above the Owens Valley may be the most powerful earthquake in California history. The 1872 Owens Valley, or Lone Pine, earthquake broke rocks along a 200 km (120 mile) line and lifted the Sierra Nevada block about 5 m (15 feet) higher above the Owens Valley. It destroyed Lone Pine and left thirty people dead in the sparsely populated valley.

Clearly, the Sierra Nevada is being lifted on the east along active vertical faults similar to the Basin and Range, while its gentler western slopes are relatively free of seismic events. In the south, the peculiar drainage of the Kern River is controlled by the 20 km (25 mile) long north–south trending Kern Canyon Fault and its valley. Lava flows 3.5 million years old across the fault indicate it is old and inactive. However, this fault and its canyon continue to divide the Sierra Nevada into two parallel ridges. Farther north, even the Lake Tahoe Basin is a block dropped down by faulting, with the northern Sierra Nevada branching off to the northwest and the Carson Range on the east.

Many of the vertical and horizontal joints so common in the Sierra Nevada were caused by stress from extensional and compressional forces when the rocks were buried; the weathering of these and exfoliated rocks will be covered in the next section. Though there are other interesting structural features in the Sierra Nevada, we will return to the active Basin and Range processes, where this discussion began.

Structural Features of the Basin and Range. The crustal extension previously mentioned is breaking crust along mainly right-lateral faults, with vertical movement which also causes basins to drop between mountains. One of the most dramatic illustrations of how these structural features control topography is along the classically used transect between Mount Whitney and Death Valley. That roughly 135 km (85 mile) line drops from the highest peak in California to the Owens Valley, back up to the Inyo and Argus Mountains, down to the Panamint Valley, up over the Panamint Mountains, and down to the lowest place in North America. Three major mountain ranges, three deep valleys, and the mostly parallel faults that helped form them account for repeated elevation changes of up to 3,000 m (10,000 feet). This transect defines the Basin and Range. (See Figure 2-5b showing vertical block faulting.)

The Death Valley Fault Zone trends north–northwest away from the Garlock Fault, creating outstanding fault scarps; they separate the lowest parts on the eastern edge of Death Valley from the adjacent Black Mountains. Because this fault zone is currently dropping the valley faster than faults bounding the western side, the valley tilts slightly down toward the east and the Black Mountains. As the Death Valley-Furnace Creek Fault Zone trends farther northwest, it is easily followed along the fresh and outstanding fault scarps that cut alluvial fans at the base of the Grapevine Mountains. From here, it continues through the Last Chance Mountains and to the northwest, where it marks the boundary between the White Mountains and Fish Lake Valley.

Similar faulting drops Deep Springs, Eureka, Saline, Panamint, and so many other valleys of the Basin and Range. Outstanding fault scarps also commonly surround ranges such as the White Mountains, separating them from adjacent deep valleys. Active faults above the northern Owens Valley have helped raise White Moun-
Tain Peak to 4,342 m (14,248 feet). Many of these faults are capable of generating strong earthquakes, as they have in the past.

Similar Basin and Range processes and landscapes encroach into the northeastern edge of California and the Modoc Plateau. Honey Lake Valley has been dropped below the surrounding uplifted mountains. The active Surprise Valley Fault Zone separates the Warner Range to the west from Surprise Valley and the Alkali Lakes to the east, and a series of north–south trending faults separates blocks on the Modoc Plateau. These are just some examples of the familiar structural features that have built Basin and Range landscapes.

**Tectonic Activity In and Around the Central Valley**

We end our tour of tectonic processes that build California landscapes with the Central Valley. The valley has been gradually downwarped into a long synclinal trough that has filled with thousands of meters of sediment over millions of years. Only a few structures warp or break the monotony of this valley, and oil and gas almost always accumulate in the sediments around them. The Sutter Buttes and the Stockton Fault and Arch are examples in the northern valley. Moving south, processes and landscapes more common in the Coast Ranges and Transverse Ranges begin to encroach. The Kettleman Hills represent long anticlinal folds that pop out of the western San Joaquin Valley south of Coalinga. They are examples of the many folds trending parallel to the Coast Ranges that become increasingly common to the south, such as Elk, Lost, and Buena Vista Hills, and McKittrick and Wheeler Ridges, they are all oil producers.

These folds are very young and many are growing rapidly as compressional forces similar to those building the Transverse Range impact these landscapes. Pipes and roads are buckling near many oil fields. Southwest of the valley edge, the San Emigdio Mountains were built in about the last 3 million years and they continue to grow remarkably fast—about 3 m (9 feet) per thousand years—as they migrate toward the valley. We end with the White Wolf Fault and its scarp, which separates the valley from the Transverse Range. It broke in 1952, causing the powerful and destructive 7.5-magnitude Kern County earthquake. Notable seismic activity continued in this area into the twenty-first century.

It is fitting that we have ended this section with a new and growing mountain range and another powerful earthquake. We have now reviewed some of the more important mountain-building processes and their landscapes. We cannot escape them because wherever we are in California, we are on or near the plate boundary. Most recent studies confirm that the most earthquake-free region of California is probably somewhere near Fresno, but any geologic map shows that faults begin to appear not far from there. Californians must learn to live with tectonic forces while admiring the spectacular landscapes those forces have produced. Now we will examine the external forces of denudation and the California landscapes they produce.

**EXTERNAL DENUDATIONAL PROCESSES AND LANDFORMS**

**Weathering Attacks and Contributes to California Landscapes**

As constructive tectonic (endogenic) processes push solid rocks toward the surface, weathering immediately attacks these rocks and breaks them down. These chemical and mechanical *weathering processes* are reducing California rocks into the loose regolith and soil on which most Californians live and work. Such unending weathering processes have also controlled the development of many California landscapes as weathered material is often eroded, transported, and deposited to form various California landforms which will be examined in this section.

Chemical weathering occurs in California rocks when culprits such as oxidation, weak carbonic and organic acids, and hydrolysis (occurs when reaction with water changes minerals) gradually attack rocks at and near the surface. Hydration occurs when water combines with and expands minerals, creating mechanical forces that wedge grains apart. Mechanical or physical weathering processes include expansion and contraction due to temperature changes, frost action, exfoliation, root pry, and the pressure caused by growth of salt crystals. All of these weathering processes reduce rocks to rubble. The role of each process changes with every California environment. For example, frost action is common in California’s highlands.

Most joints and fractures in rocks formed from stress when the rocks were buried deep below the surface. The joints formed from these compressional or extensional forces are often quite orderly, running in parallel and perpendicular patterns. One exception to this is exfoliation. This occurs when bedrock, once buried under pressure, is lifted and exposed by the gradual erosion or “unloading” of the rocks above. As pressure is released, blocks of rocks now at the surface are able to expand and break into onion-like sheets or slabs which are separated by curved joint patterns.

Even the largest blocks of previously unjointed granitic bedrock expand and weather into great rounded exfoliation domes. You will find them in the Sierra Nevada and many other California mountains dominated by fresh granitic outcrops. Half Dome and the domes above Tenaya Lake in Yosemite are classic examples. At Half Dome, one side of this original exfoliation dome was more extensively jointed, leaving it weaker and vul-
nerable to erosion by the glacial activity that helped scrape it away.

Regardless of the causes of the joint and fracture patterns, illustrations of the accelerated weathering within them abound. Some of the best examples are displayed in Sierra Nevada-like plutonic rocks around the state. Whether in the Sierra Nevada, Alabama Hills, Joshua Tree, outcrops near Riverside and the Peninsular Ranges down into Mexico, or in numerous other California landscapes, the process begins with the exposure of jointed rocks. Weathering attacks the weaker joint patterns where water often accumulates, isolating rectangular blocks of bedrock. Nature then attacks the corners and edges of the rectangles faster, gradually producing spheres of more rounded boulders. The most widely spaced joints produce the largest boulders.

In contrast, vertical jointing dominates in Klamath Mountains plutonic rocks and is weathered into the pinnacles at Castle Craggs State Park south of Mount Shasta.

Surfaces of rock outcrops across the state are stained in red, brown, and darker colors by oxidation when oxygen in the air or water combines with iron, magnesium, manganese, or other elements in rocks. The rusted reddish-browns of rocks in the Marble Mountain Wilderness of the Klamaths west of Scott Valley are reflected in names of local landmarks. Red Rock Canyon on Hwy. 14 north of Mojave also gets its name from beautifully stained sedimentary outcrops. The dark streams hanging down Sierra Nevada cliffs result from trickling water which often accumulates during rain and snowmelt; this water acts as a catalyst for chemical reactions that accelerate oxidation of minerals along these streaks.

In southeastern California, desert varnish has stained many otherwise undisturbed rock surfaces brown or black. Studies have shown that over hundreds of years, wind-blown clays and various metallic elements are cemented by manganese-oxidizing bacteria that survive in desert climates. When rock debris is tumbled or overturned on the desert floor, the lighter, less-stained sides are exposed.

### Differential Weathering

Weathering processes attack and decompose rocks at different rates. This differential weathering creates some of the more spectacular landscapes in California. In general, igneous and metamorphic rocks are more resistant to erosion than sedimentary rock outcrops. For instance, a block of granite or a basaltic lava flow will probably resist weathering, forming ridges next to weaker sedimentary rocks, which might form lowlands. There are many exceptions to these general rules.

For instance, the dark extrusive igneous basalt is more mafic with less silica (quartz), therefore it will weather faster than the high-silica intrusive igneous granite. Conglomerates and sandstones high in quartz usually form more resistant ridges and cliffs compared to their weaker sedimentary counterparts, such as siltstone, claystone, and shale. Regardless of rock type, the fractured, crumbled, and deformed rock formations will usually weather and erode faster than rocks exposed to less stress and deformation. Such differential weathering has produced impressive landscapes throughout California.

At Castle Craggs State Park in the Klamaths, long quartz dikes are most resistant, forming the ridges and peaks above the granitic rocks with less silica. But, even these relatively lower silica granites are, in turn, more resistant than the fragile serpentines they tower over.

Table Mountain is a lava flow in the central Sierra Nevada foothills near Jamestown. The lava rolled down a river canyon, cooled and solidified about 9 million years ago. Subsequently, weaker surfaces adjacent to the flow have been denuded so that the more resistant flow now looms above surrounding landscapes. These are known as inverted landforms. Further north you will find a very similar landform with a very similar history at another Table Mountain, this one just north of Oroville. This is the Lovejoy basalt standing out just west of Lake Oroville as a more resistant lava flow above a weaker eroding surface. Likewise, lava in the Cima Dome volcanic field in the eastern Mojave flowed into and along a valley about 630,000 years ago. Geologists can measure the rates at which the surrounding weaker weathered surface is being eroded by measuring the height of this relatively resistant lava flow above surrounding desert surfaces. Meanwhile, some 10-million-year-old lava flows at Red Rock Canyon north of Mojave have covered and are now protecting older, weaker sedimentary layers below.

**Differential Weathering in Sedimentary Rocks Shapes Landscapes.** Alternating layers of sedimentary rocks have also been differentially weathered, producing
fascinating landscapes across the state. Along I-5 near the Oregon border, exposed conglomerates in the Hornbrook Formation form the ridges, while layers of sandstone and shale form the valleys. The valleys and rivers of the Santa Cruz and other Coast Range Mountains that do not follow faults and synclinal folds often cut into more easily weathered siltstones, mudstones, and shales.

Lifted, contorted, and exposed, the alternating sedimentary rocks of the Transverse Ranges display repeated examples of resistant conglomerates and sandstones. They protrude as ridges and cliffs above adjacent weaker shale and other sedimentary layers. Dipping layers of more resistant rocks at Vasquez Rocks and Devils Punchbowl in the San Gabriels, Mormon Rocks in Cajon Pass, and in slopes towering above Chatsworth and Santa Barbara are just a few examples. Some of these landscapes have provided captivating scenery for television and film productions.

**Limestone Caverns.** At least small outcrops of limestone and marble are found in spots in almost every California region. However, the most renowned carbonate caves are in the west-central Sierra Nevada and at Mitchell Caverns in Mojave Desert’s Providence Mountains. In the Sierra Nevada foothills, from southern Calaveras through Tuolumne into northern Mariposa Counties, are Mercer, Moaning, and Bower Caves. Farther south, Boyden Cave is off Hwy. 180 going into Kings Canyon, while Crystal and Clough Caves are on the western edge of Sequoia National Park.

Like the others, Mojave’s Mitchell Caverns formed when underground water circulating through calcareous rocks combined with calcium carbonate to form weak carbonic acids. These acids dissolved minerals so that water could carry them away in solution, leaving the caverns. Dripping water in the underground caverns created the limestone stalactites, stalagmites, columns, and curtains that are common in such caves. When the climate became drier and water tables dropped, Mitchell Caverns were left dry and inactive as we see them today. East of I-5 in northern California, Shasta Caverns are weathered into the McCloud Limestone at Shasta Lake. Unique fossils from ancient coral reefs are found in these Permian limestones.

**Smaller-Scale Weathering Patterns.** There are smaller-scale weathering processes limited to specific California environments. They include the intricate patterns of honeycomb cavities weathered in some exposed rocks, especially along the Central California coast. This is sometimes known as tafoni. Finally, various types of frost-action features and patterned ground are common in California’s highest elevations.

**Results of Weathering.**

All of these weathering processes are responsible for producing loose regolith and soil, which has allowed life to flourish in California. Weathering also loosens the rocks that can move in landslides and other mass wasting processes on steeper slopes. Additionally, it paves the way for the processes of erosion, transportation, and deposition of materials by water, ice, wind, and coastal waves and currents. All of these erosional processes produce their own landforms as California mountains are denuded, delivering aprons of debris into the surrounding lowlands. We now turn our attention to the processes and landscapes resulting from the erosion, transportation, and deposition of this material. First, we will examine some landscapes made by mass wasting.

**Mass Wasting (Movement)**

Like many other geologic processes, some form of mass movement or wasting is found in every California region. Ancient landslides have left landscapes and clues that often allow geologists to assess future hazards. Active mass wasting processes add a little more excitement and danger to living on some California hillside slopes, but they also discourage many from moving to such locations. From the slower processes of soil creep to the faster earth flows and the life-threatening disasters caused by landslides and mud and debris flows, California represents a laboratory for these earth movements set in motion by the force of gravity.

**Slower Movement**

Soil creep is common on California hillside slopes where deep layers of loose regolith and soil are weathered from the bedrock below. Though gravity may pull the loose materials down at only around 1 cm (0.4 inches) per year, tremendous masses of debris can be delivered down...
slope over time. Trees adjust by bending back up and telephone poles, fences, and other structures lean at an angle downhill. If you notice these features on a California slope that does not receive heavy winter snows, soil creep may be the culprit. Over many years, soil creep has gradually destroyed homes and other structures built by those who did not look for its subtle clues. Irrigation, cutting and filling, and destroying vegetation cover frequently accelerate movement on such slopes.

Earth flows are common throughout California where loose surface materials have been saturated, lubricated, and made heavier by water and where stabilizing vegetation has been cleared or burned. The size of these earth flows ranges from a few square meters to entire hillside slopes. The entire flow may occur in a few days or in a few minutes. Typically, material breaks away along a crevice, leaving a horseshoe-shaped scarp. Gravity pulls the loosened lobe of material downhill, where it is deposited as the equally recognizable toe of the flow. Since these associated features can often be visually linked to the same event, they stand out on many slopes throughout California. Earth flows are especially common on cleared and heavily grazed slopes in the Coast Ranges after prolonged heavy rains.

Fast and Furious
A special type of earth flow is spontaneous liquefaction. This occurs when the supporting structure of clay soils or other loose sediment collapses, usually aided by high water tables and shaking. The material flows similar to a viscous fluid. Different types of liquefaction have been recorded, and they will occur during California’s many earthquakes. The loose fill used to extend land for development into San Francisco Bay and some areas around Marina del Rey and Venice are examples of the most vulnerable types of substrate. During the 1906 San Francisco and 1989 Loma Prieta earthquakes, Bay Area residents were reminded of the dangers of building on these earth-turned-to-jello fills.

Landslides
Perhaps the most dangerous and devastating examples of mass movement are California’s frequent landslides, when entire rock masses or parts of hillsides break off and slide downhill under the force of gravity. The abundance of freshly faulted, crumbled, and weathered rock material hanging along countless steep slopes creates landslide-prone areas across parts of California.

In the Coast Ranges. Landslides are especially common in the Coast Ranges where serpentine rocks of the Franciscan melange have been crushed and crumbled by faulting. When looming on steep slopes that have been undercut by streams or human activity, especially when saturated by heavy winter rains, these rocks become very slippery. Such slopes frequently break away and slide downhill. These slides have destroyed structures on slopes near downtown San Francisco and Telegraph Hill, and they have caused millions of dollars of damage in every other Bay Area county. Many of the deaths and injuries and the destruction of hundreds of homes and businesses during downpours in January 1982 were caused by such landslides. Though the north Coast Ranges are heavily forested, the same combination of factors may produce local conditions where landslides deliver more material down slopes than any other process, including running water.

There are many notorious Coast Ranges slides. Numerous large slides have taken about 50 homes and even left apartment buildings hanging over the sea cliff along the Daly City coast down to Mussel Rock where the San Andreas Fault emerges out of the sea. This epicenter of the great 1906 San Francisco Earthquake is the unstable site of a 1950s housing development that was doomed from the start. After recent slides, the sea continued eating away at the cliffs into 2012.

To the south, Devil’s Slide has been active for decades on the steep slopes around Hwy. 1 just south of San Francisco between Pacifica and Montara. Here, the Pilarcitos Fault has helped weaken falling rock masses. Devil’s Slide has presented dangerous threats and constant headaches to road crews because it drops directly into the sea. Slides pulling the road (first opened in 1937) down and boulders the size of cars have repeatedly closed the highway; it was closed for 158 days in 1995 and again in 2006. Typically, many millions of dollars later, CALTRANS reopens it only so it can hang precariously waiting for the next slide.

After 2007, tunnel tunnels were being cut through San Pedro Mountain, leaving what remains of the old road to bikers and clearing the way for commuters who live...
Landslides have impacted landscapes in parts of southern California’s Transverse and Peninsular Ranges for many thousands of years. About 17,000 years ago, one of the largest slides known to North America broke away from Blackhawk Mountain at the base of the northern San Bernardino Mountains. Giant blocks of limestone slid down Blackhawk Canyon and onto the desert floor on a cushion of compressed air at speeds up to 435 km (270 miles) per hour in about 80 seconds. The more than 24 sq km (10 square mile) slide is up to 30 m (100 feet) thick southeast of Lucerne Valley. Perhaps it is no coincidence that it occurred during the peak of the last Ice Age, when the area was wetter than today.

A giant slide broke off Martinez Mountain on the east side of the Santa Rosa Mountains about 15,000–20,000 years ago. After traveling about 7.5 km (4.5 miles) and dropping more than 1,800 m (about 6,000 feet), the enormous blocks of rubble were deposited on the desert floor that is now south of Palm Desert and La Quinta.

Many of the more recent and notorious southern California slides have occurred along populated steep coastal slopes from Santa Barbara and Ventura to Los Angeles and Orange Counties. Though many have devastated some of the most famous and highest-priced seaside communities in Malibu, Palos Verdes Peninsula, and Laguna, slides are not limited to those areas. After repeated drenchings from record storms in 1995, residents of the small seaside community of La Conchita southeast of Santa Barbara heard loud rumblings. The steep slope above began to break away. As residents ran from their homes to safety, an enormous chunk of the hillside above slumped down from a widening crevice, pulverizing or

Malibuan Slides

Of all the Malibu slides and slump blocks, especially along and near Pacific Coast Highway, Big Rock is one of the largest and most notorious. Big Rock Landslide is a 4.7 sq km (1.8 square mile) coast-facing block of the Santa Monica Mountains, which is falling down to the Pacific Coast Highway and the sea. After record rains in 1983, its movement was measured in cms (inches) per day as widening crevices opened, separating the head of the slide from the Santa Monicas. There was genuine concern that the slide might break away into the sea, taking the highway and scores of homes with it. Again, there was plenty of fault to be shared.

Developers were blamed for building on the slide, the county was blamed for issuing the permits, residents were blamed for the septic systems and irrigation of exotic plants that weighted and lubricated the slide, and Caltrans (California Department of Transportation) was blamed for undercutting and other road construction at the base of the slide. All of the parties readied their lawyers as one special courtroom was designed for what might have been the greatest litigation proceeding in U.S. history. A last-minute out-of-court settlement seemed to leave all the parties equally unhappy. Meanwhile, pumps were installed to pull water out of the slide, and perforated piping drained water out of its side; the slide slowed dramatically in the following years.

As this south side of the Santa Monica Mountains is lifted along the Malibu Fault Zone, Pacific Coast Highway and all who live around it and use it must look up to the freshly crumbled, weathering material lurking above. Nature sent another round of dramatic reminders of her power during the 1998 El Niño storms. More than 50 inches of rain fell on the surrounding mountains that year. So many slides were reactivated that the Pacific Coast Highway was closed for more than 20 days. Clearing and stabilizing the largest slide of about 300,000 cubic meters cost $20 million during several months of work. Some residents and road workers questioned whether this section of California Route 1 between Santa Monica and Oxford (once known as Roosevelt Highway) should have ever been built. Meanwhile, more recent slides continue to threaten this long established, legendary link between the Malibu coast and Los Angeles/Hollywood.

When will the next slide become active? This is a question that too many California hillside residents must ask.
damaging several homes below. A larger slide ten years later killed ten people in the same place.

In 1926, a much larger seaside cliff at Point Fermin on the southeastern end of the Palos Verdes Hills gave way. Rock layers that dip toward the sea and were cut by waves were probably set in motion by human activity, especially excessive watering that accumulated in the expanding layers below. Today, broken chunks of San Pedro Street and building foundations destroyed by this slide hang dramatically over the cliffs above the ocean.

The much larger Portuguese Bend Landslide was mapped in 1946; it had impacted the southwestern edge of the Palos Verdes Peninsula to the ocean for at least 37,000 years. Nevertheless, houses were being built on it by the 1950s, causing the slide to expand and accelerate. Due to water from irrigation and septic systems of more than 150 homes, and the fill and vibrations from the highway at the base of the slide, dipping rock layers began to move toward the sea cliffs.

As the center of the slide’s surface subsided and the base was raised up 1 m (3 feet) per year, material moved toward the ocean from the head of the slide at even greater rates. Power lines, pipes, roads, and structures have been repeatedly sheared, buckled, crumbled, and rebuilt in the slide, which usually accelerates after each heavy rainy season. Attempts to stabilize the slide include driving gigantic stakes through it. Buckling and sliding roads continued making news headlines in 2012 where the steep Palos Verdes Hills meet the sea.

The 1998 El Niño rains reminded some residents of southern Orange County why they should not build on unstable slopes. National media coverage concentrated on the area around the Laguna Hills, displaying graphic shots of expensive homes and condominiums teetering, then falling down steep embankments that were weakened by the storms. Because many of the developments were recently built, onlookers wondered if Californians will ever realize that those who do not learn from history are doomed to repeat it. Sure enough, devastating slides in this region were still making the news well into the 21st Century.

Farther south in La Jolla is another tragic example of the effects of uncontrolled irrigation and unwise cut and fill. The October 2007 rotational slump on Solidad Mountain was a repeat performance of similar events there since the 1960s that have damaged more than 100 homes.

Watch for Falling Rocks

Rock falls accumulate as talus slopes and talus cones at the base of California’s steepest slopes and cliffs, especially in the Sierra Nevada. After blocks are weathered and loosened, gravity tumbles them down. They create obvious hazards for the unknowing visitor searching for that perfect view or, on private lands, the unaware developer or future homeowner looking for the lot with the perfect view.

Rock falls are particularly common on such steep, glacier-carved cliffs as those in Yosemite and Kings Canyon National Parks. In 1980, three hikers were killed by rock slides near Yosemite Falls. On July 10, 1996, an exceptionally huge mass of weathered rock broke off from the cliff between Glacier and Washburn Points in Yosemite National Park. More than 25,000 tons of rock came cascading down 2,400 feet onto the valley floor at Happy Isles. One visitor was killed and more than a dozen people were injured as the impact from the slide toppled about one-quarter square mile of trees. The dust cloud kicked up by this slide was so thick that breathing was difficult for hours. When it settled, 50 acres of the valley floor were covered by 2 cm (1 inch) of granite dust. In June 1999, another deadly Yosemite rock slide made the news. Stay tuned for more rock slide drama through this century on California’s steepest slopes.

Don’t Go with the Flow

Debris flows and mudflows have also caused death and destruction throughout California history and have
shaped many California landscapes. In northern California, water from melting ice has mobilized boulders and debris on glacial moraines in the Klamaths. These debris flows carried material several kms (miles) downstream from the moraines at Swift, Canyon, and Deer Creeks and left deposits up to 100 m (300 feet) high containing large boulders. Debris and mudflows have raced down Shasta and other Cascade volcanoes when warm rains or sudden heat waves melt heavy snow packs. House-size boulders were carried with such a flow down Mud Creek from a Shasta glacier in 1924. Sudden heat from volcanic activity or eruptions is capable of causing devastating flows (called lahars) on these volcanoes.

More frequent and just as dangerous are the mud and debris flows shaping landscapes mostly in southern and eastern California’s arid and semiarid regions. These processes that build alluvial fans and bajadas will be examined in the next section.

Mud and debris flows can also occur in wetter California climates, especially where protective vegetation has been disturbed or destroyed. Another of Nature’s reminders came to Northern California residents of Rio Nido (along the Russian River) in February 1998. Record rains brought rivers of mud that devastated the community, forced evacuations, and destroyed homes.

In the fall of 2003, some of the greatest fires in California history devastated hillslopes from the Sierra Nevada to San Diego County. The following rains brought deadly mud and debris flows out of these canyons punctuating the seasonal cycles that some Californians find routine.

**That Sinking Feeling**

Subsidence of relatively level surfaces has also posed problems for many Californians. It is usually a slow process caused by settling of loose fill or the pumping of oil, gas, or water that relieves pressure from underground reservoirs. In 1995, it was reported that Treasure Island, the military’s artificial extension of Yerba Buena Island in San Francisco Bay, had subsided from about 14 feet above sea level (asl) to 9 feet asl, primarily due to the 1989 Loma Prieta earthquake. Costs to save Treasure Island were estimated at $500 million. More recent development plans have required costly seismic retrofits to stabilize the entire island during earthquakes.

Thousands of square kms (miles) of the San Joaquin Valley have subsided more than 25 cm (10 inches), mostly due to overdrafting of groundwater reservoirs. Broken pipelines and roads are examples of the problems caused as one area has dropped nearly 10 m (30 feet). These problems extend into the Delta region, where reclamation of wetlands and farming of peat soils has caused many islands to subside several feet below sea level. However, subsidence is not limited to groundwater overdrafts or the Great Valley and Delta.

Oil pumped from the Wilmington oil field east of Terminal Island near Long Beach since 1937 decreased subsurface fluid pressures and caused subsidence. Subsidence of up to 10 m (30 feet) in an area the same shape as the oil field being pumped damaged bridges and buildings. Engineers constructed higher dikes to block ocean waters from the industrial area now below sea level. Salt water was later pumped into the oil reservoir to stabilize fluid pressures and subsidence and to force out more oil.

There are few places in California immune from mass wasting processes set in motion due to the force of gravity. Even more important, however, is that nearly every California landscape is shaped or impacted by running water, the subject of the next section.

**Landforms Made by Running Water**

A view of almost any California landscape is a view of landforms carved or deposited by running water. These are also known as *fluvial landforms*. There are other processes working on California landscapes. Glaciers, winds, and waves have also eroded, transported, and

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**Figure 3-20** White Water Cascades down Sierra Nevada’s Steep Slopes. Here, the roaring Kings River cuts a V-shaped canyon deeper, as it has for centuries. Steep slopes and fast currents indicate that this young river is in the degradational stage, while smaller tributaries cut their own lesser canyons.
deposited material in parts of the state. However, none of these rival the significance of running water when considering dominant external (exogenic) forces shaping landscapes in California.

Recently uplifted mountains across California provide streams with plenty of freshly weathered material to cut and carry downstream; energized streams carve deep, narrow, V-shaped canyons with steep slopes. Their tremendous sediment loads are deposited on adjacent valley floors, filling California basins with layers of alluvium. We will begin our discussion of California landscapes made by running water in cismontane California, which is the more moist part of the state on the ocean side of the highest crests. We will then turn to drier transmontane California on the “opposite” or rainshadow sides of the highest crests, where running water shapes very different landscapes.

**Water Erodes in Cismontane California**

**Rivers Follow Paths of Least Resistance.** There are numerous examples of California rivers that have established their courses along structural weaknesses as they follow paths of least resistance. One of the best examples is the north–south path of the Kern River cutting into the Sierra Nevada along the Kern Canyon Fault. The Klamath, Mad, and Eel Rivers flow within folded and tortured rock structures in northwest California. Meanwhile, the Russian River headwaters in the north, the Salinas River farther south, and similar streams follow southeast–northwest structural features common to the Coast Ranges. The Salinas River and some of its tributaries flow within the confines of parallel, elongated structural depressions. Once established, many of these rivers cut their own deep courses.

**Young, Energetic Streams Degrade.** High-energy white-water streams continue to slice deep, narrow canyons and gorges into youthful topography of the Klamaths, Cascade volcanoes, Sierra Nevada, Transverse, Peninsular and parts of the Coast Ranges, and even through many of California’s dry desert ranges. The Klamath Mountains—with their adjacent narrow ridges and canyons connected by steep slopes—are the most impressively rugged. Scott Valley is the only flatland to interrupt this Klamath topography that challenges the hardest traveler.

You might expect thick forests of the northern Coast Ranges to quell the erosion caused by permanent streams. However, frequent landslides in weak serpentinite rock formations can deliver freshly broken material to the sometimes raging torrents below. Less predictable seasonal streams more common to the southern Coast Ranges often drain bare slopes ravaged by summer and fall brush fires; they carry away the tons of loose and exposed soil and regolith and slice deeper in their brief but muddy winter rages.

Similar conditions are common during the brief winter storms which follow intense drought and fire seasons in Southern California’s Transverse and Peninsular Ranges. In addition to fires, other natural and human events in the mountains of coastal California provide vulnerable, fresh sediment waiting to be carved and carried away by water.

Even the more consistent rivers and tributary streams of the Sierra Nevada are cutting deep V-shaped notches into resistant granite slopes. They accomplish most of their work during spring snow melts. Standing next to raging rivers like the Kings following a heavy snow season, one can hear the sounds of boulders the
size of trucks crashing below these powerful currents. Degradational streams rule on these steep slopes. A variety of other landscapes are forming as California rivers cut through recently uplifted terrain.

Numerous California streams have continued to stubbornly flow and cut in place as renewed mountain building lifts surrounding landscapes. These antecedent streams include the Santa Margarita River northeast of Oceanside and the Santa Ana River, which is slicing through very recent uplift in the northern Santa Ana Mountains. Antecedent streams in the Transverse Ranges include the Ventura River north of San Ventura and Malibu Creek, which has carved a spectacular north–south gouge into the east–west trending Santa Monica Mountains.

Several streams in the Coast Ranges first follow the northwest–southeast trend of inland valleys, then suddenly veer and cut through direct gorges to the coast. Alameda Creek through Niles Canyon east of Fremont, the Pajaro River across the San Andreas Rift Zone to Monterey Bay, and the Gulyama River east of Santa Maria are examples. Even Lone Pine Creek flowing east from the Sierra Nevada continues to slice in place through the recently uplifted Alabama Hills.

Some of California’s more interesting landscapes result when deep notches are carved by rejuvenated streams into recently uplifted terraces. Especially prominent river terraces represent former valley floors lifted above the Smith, Klamath, Trinity, and Eel Rivers. Weaver Creek near Weaverville has cut a fresh channel up to 120 m (400 feet) deep since the Pleistocene Epoch.

San Diego’s Coast
Along the coast of San Diego County, more than a dozen marine terraces represent platforms now overlooking the Pacific. Recently rejuvenated streams have since sliced deep notches into those terraces as waters race west to the ocean. At the end of the last Ice Age, sea levels rose up to 90 m (300 feet). These streams abruptly slowed at their higher base levels, depositing their sediment loads into San Diego’s famous coastal baymouth bars and the lagoons behind them. Similar coastal processes formed landscapes at the mouths of other California canyons. But, the combination of these features is most conspicuous next to I-5 in northern San Diego County as you travel up on the marine terraces, but repeatedly cross the canyons that cut into them.

Farther inland in the Peninsular Ranges, streams alternately flow gently through broad valleys on the surface of faulted block benches, then cascade and slice over bench edges through deep notches down to the next lower block to the west.

Making Deposits
Just as these streams are eroding and transporting material, the sediment they must deposit on surrounding valleys or shorelines forms very different landscapes. As soon as the fast-moving streams blast out of steep mountain canyons, their velocities slow on the subdued relief of valley floors, and they deposit course alluvium. The first materials to be deposited at the base of these mountains are the coarsest gravels, rocks, and even boulders that may overflow channels onto roads and into developments during heavy rainstorms. Such repeated events over centuries pile up fan-shaped structures at canyon mouths, especially in drier areas of southern and eastern California. In wetter regions, substantial year-round stream flow cuts and carries such material farther downstream. As the slowing streams flow farther out over valley floors or to the ocean, they deposit the finer sand, silt, and clay particles that make up most of California’s flood plains.

These broader flood plains contain more lethargic, meandering aggradational streams that have deposited the fine fertile sediments in California’s most productive farmlands. In the Central Valley, the Sacramento and San Joaquin Rivers and their many tributaries laid thick deposits as broad areas of the valley were flooded from heavy Sierra Nevada snow melts. Fertile soils of the Salinas Valley, Los Angeles Basin, and dozens of other California valleys were formed from similar deposits.

Fluvial Processes and Landforms Common to California’s Dry Climates
Ironically, some of the most dramatic landscapes carved and deposited by running water are found in California’s drier regions. Here, persistent drought has left slopes barren and vulnerable to the rare heavy rainstorm. In transmontane California, sporadic and unreliable precipitation episodes can dump one year’s average rainfall

Taming the Colorado

For centuries, the aggrading Colorado River dumped sediments toward the Gulf of California. This formed the delta that diverted the river away from the Imperial Valley and into Mexico. In the early 1900s, those who tried to divert a portion of the Colorado back toward the Imperial Valley were reminded of the power of running water. Their canals and diversion projects silted up from 1902-1904 until a great flood in January 1905 turned the entire river toward the Imperial Valley to fill the Salton Sea. The Colorado was not controlled until February 1907, after it had eroded deep channels in the Alamo and New Rivers, causing damage along an 80 km (50 mile) stretch to the Salton Sea. The Salton Sea remained as a sump, accepting mineral and chemical-laden agricultural runoff from surrounding farms.
within hours, and such events can occur any time of year, particularly during summer in California’s south-eastern deserts. On coastal slopes, especially in southern California, isolated landscapes are left even more barren for brief periods after summer and fall wildfires. Equally dramatic events erode and deposit tons of loose debris, regolith, and soil exposed by fires to winter rains, creating landforms similar to those described below.

Much of the spectacular scenery of the Basin and Range and the rainshadow slopes of southern California’s recently lifted mountains has been etched by these processes. Weathering continues to produce abundant loose materials waiting for very rare heavy rainstorms. Once the infrequent downpour, often generated by an isolated summer thunderstorm, forms over a drainage basin, these loose materials combine with water and rush from the steep slopes into rills and gullies. Then, they are channeled into deeper canyons and normally dry washes. The momentum of these viscous mud and debris flows can carry truck-sized boulders out of narrow canyons only to dump them on the desert floor below.

A typical event may last only a few hours, but a series of these catastrophes over centuries has carved intricate patterns of rills and gullies onto desert slopes. The events have deposited impressive alluvial fans at the mouths of canyons—fans made of successive debris and mudflows.

From Young Alluvial Fans to Old-Age Desert Landscapes. Some of the most conspicuous fans are at the bases of slopes surrounding the Owens Valley, especially at the base of the White Mountains and then moving east and south, such as on slopes around Death Valley. Visitors to these landscapes who are unaware of the consequences of sudden, violent rainstorms have been swept away by flows that roar out of canyons, damaging or burying everything in their paths. These processes and landscapes are witnessed throughout the Basin and Range and in steep terrains of southern deserts, into Mexico.

Similar events have deposited alluvial fans at the base of southern California coastal mountains, especially during heavy winter storms that follow the drought season’s wildfires. Heavily populated alluvial fans and the catastrophic events that shape them are common at the base of mountains surrounding the Los Angeles Basin and nearby valleys. Residents in canyons and on these fans

Accelerated Erosion

Accelerated erosion is destroying soil and producing higher sediment yields in streams and rivers in parts of California. Whether the cause is overgrazing, overfarming, burning, clear cutting, or extensive off-road vehicle use, deep rills and gullies and badlands topography are cutting into once productive soils across the state. These careless land-use practices may produce quick profits. However, even the briefest landscape survey reveals how the long-term productivity of these lands and the economies they support could eventually be destroyed.

Some examples of accelerated erosion include slopes within the Coast Ranges and around the Oxnard Plain. Areas of off-road destruction near Gorman and in Ballinger Canyon on the northern boundary of Santa Barbara and Ventura Counties are just a few of the many other examples. Clearly, the processes and landscapes of running water not only dominate California physical landscapes, but they are being substantially modified by Californians.
live in constant danger of becoming the next victims, especially after fires ravage the slopes above.

With time, adjacent alluvial fans may continue to build until they coalesce into gently sloping bajadas (the more subdued surfaces of pediment [alluvial deposits] which slope from the base of the mountains to the playas or valleys below). In the absence of recent mountain building, the rugged topography gradually yields and is denuded into the very sediment it produced. In older landscapes, only inselbergs (tiny remnants of eroded mountains) may protrude above vast, expanding old-age desert plains. Geographically, we have moved from the fresh gouges and fans typical of the steeper Basin and Range to the mostly gentler topography typical of the older aggrading landscapes of the Mojave.

**Desert Playas.** Salt playas and saline lakes are common throughout transmontane California. They are found in desert basins where abundant Ice Age waters evaporated and where recent wetting and evaporation have left salts behind. Interior drainage is the rule in California’s desert valleys as brief floods and shallow groundwaters are trapped with the minerals they have carried. During the Ice Age, the Owens and other rivers had up to ten times more water than when they were discovered by American explorers; a series of streams and lakes may have flowed from the Owens to Death Valley through the Mojave Desert to the Colorado River. The water is almost gone, but the salt playas remain. Their hard clay and crusty, bright, salty surfaces are not only testimony to today’s hot, dry climate, but their minerals are often mined (a topic covered in Chapter 2). Names like Badwater in Death Valley and Soda Lake near Baker give clues to the nature of these basins so important to California’s desert landscapes. The salts originate not only from weathered rocks in mountains surrounding the playas, but have also accumulated from trace amounts deposited by winds and clouds from the Pacific Ocean.

**Badlands.** Classic badlands have been cut by water in some of California’s driest regions. The combination of steep slopes, loose materials, sporadic precipitation, and a lack of protective vegetation leave surfaces vulnerable to erosion by water. Intricate repetitive patterns of thousands of rills and gullies have been cut into the delicate volcanic ash around Ubehebe Crater and in the mudstones at Zabriskie Point in Death Valley during rare downpours. There are many other examples of badlands in southern California deserts, including the Borrego Badlands, best viewed from Font’s Point. Even marginal areas such as the hills along Hwy. 60 between Riverside/Moreno Valley and Banning/Beaumont have been appropriately named “The Badlands.” It is not surprising that streams and dry washes are choked with sediment when heavy rain finally falls in these places.

Many dry slopes exhibit parallel retreat which produces the rugged, steep landscapes common to California deserts. Excellent examples can be found in a quick survey of the landscapes above Needles, which gave this desert town its appropriate name.

**California’s Glacial Landscapes**

During the Pleistocene Ice Age, ice accumulated on California’s high mountain crests. Large glaciers advanced and cut deeper valleys into the Sierra Nevada, Klamath, and Cascade Mountains. While continental ice sheets extended from Canada into the central United States, only these local mountain/valley (alpine) glaciers carved into California highlands. Periods of cooling (glaciations or glacial) allowed the expansion of massive glaciers to lower elevations; during warmer, drier periods (deglaciations or interglacials), California’s ice fields retreated or completely melted away.

Today, we live in an interglacial period. Scientists are using many methods to study these glacial advances. For instance, they date glacial till (debris eroded, transported, and deposited by glaciers) and other evidence which is sometimes sandwiched between lava flows and other geologic events.

The El Portal tills may have been deposited by the most extensive ice caps and glaciers about 750,000 years ago during the “Nebraskan” glacial. The last glacial stage (“Wisconsin”) was not as expansive as it peaked about 18,000–20,000 years ago and ended about 10,000 years ago.
ago, but it left the most recent glacial landscapes. Alternate cool and warm periods since the last ice age have caused the expansion and then the complete ablation of numerous tiny ice patches remaining in California. Today, there are about sixty tiny glaciers remaining in the Sierra Nevada. There are also patches of ice in the Klamaths and California’s Cascades (including about five small glaciers on Mount Shasta’s slopes). The largest ice fields include the Palisade Glacier west of Big Pine and Lyell Glacier between Yosemite Valley and June Lakes. However, the spectacular erosional and depositional glacial features represent landmarks left by cooler, wetter periods in California’s very recent geologic past.

**Why and Where the Glaciers Grow**

Accumulation of glacial ice in California is enhanced by cooler temperatures and increased precipitation. We would expect the following combination of most favorable geographic conditions to encourage the growth of glaciers: the highest mountain ranges with the most extensive high-altitude surface areas, more northerly locations, and north–south trending barriers facing the Pacific to block moisture from eastward-moving Pacific storms. It is not surprising that the Sierra Nevada exhibits the most impressive glacial features in or near California.

Individual mountains, such as Shasta, may be farther north and nearly as tall as the Sierra Nevada, but they do not represent such massive barriers; consequently, they are not capable of accumulating as much ice during glacial periods. The Klamath Mountains are neither as tall or extensive as the Sierra Nevada; their impressive glacial features are still no match for a Yosemite, Kings Canyon, or the moraines of the eastern Sierra Nevada. The Coast Ranges are not nearly as tall, and they are located adjacent to ocean waters; marine air masses with moderate winter temperatures frequently produce snow levels above their peaks. Although nearly as high, the White-Inyo Range (several miles east of the Sierra Nevada), is not as massive and is located on the rainshadow side of its bigger brother. Though glacial landscapes are found in parts of each of these ranges, the Sierra Nevada Mountains have the best combination of conditions in California to encourage growth of alpine glaciers.

The farthest south we see any evidence of alpine glacial landscapes in California is in the San Bernardino Mountains, where there is evidence of only tiny Pleistocene Epoch glaciers. Only a few miles south, the San Jacinto Mountains—high enough, but incapable of capturing and holding as much ice and snow due to less extensive high alpine terrain—exhibit no glacial landscapes. All other mountains to the south are too low, dry, and warm to support glacial activity.

**Glacial Scenery in California**

In the highlands of northern and central California we find spectacular erosional scars which remain from extensive glaciation. As compacted ice and snow (firm) accumulated in those highlands, it began to move downhill under gravity’s force. Rocks were repeatedly plucked away from those highlands until bowl-shaped depressions (cirques) formed at the base of many peaks and ridges. This erosion transformed so many rounded highlands into a series of individual sharp peaks (horns) and sawtooth ridges (aretes).

During warmer, drier periods, melting ice filled the cirques and other depressions with glacial lakes (tarns). During cooler, wetter periods, the ice rivers advanced downhill, scraping away and plucking at bedrock surfaces. Where two glaciers merged and combined forces or where bedrock weakened, they eroded faster, creating glacial stairways. Imbedded coarser material carved grooves in the bedrock as the glaciers moved through; more widespread scouring polished other rock surfaces like sandpaper on wood.

Smaller tributary glaciers fed ice and debris to the massive trunk valley glaciers which carved much deeper U-shaped troughs from once V-shaped stream canyons. When the glaciers finally retreated and the ice melted, the smaller tributaries became hanging valleys, complete with waterfalls plunging abruptly over the vertical cliffs on the sides of the main valleys. Milky glacial meltwater carried the fine glacial flour (scoured by ice against bedrock) and filled the chains of paternoster lakes remaining behind on the now U-shaped valley floors.

Nearly all of the jagged exposed bedrock and rugged mountains of the high Sierra and Klamaths contain classic examples of ice-eroded landscapes. At June Lakes in the eastern Sierra Nevada, the Rush Creek glacier forms the most impressive example, with most of the erosional and depositional features.

**Figure 3-24 Looking North into the Trinity Alps toward the Klamath Mountains.** The Trinity Alps exhibit aretes, cirques, U-shaped valleys, moraines, and other typical glacial features.
rolled downslope only to be split by Reversed Peak. The smaller fork split to the east, carving into the valley where Gulf and June Lakes are today. The larger fork carved a deeper valley to the north, where Silver and Grant Lakes currently pour into Rush Creek. With the ice gone, today’s Reversed Creek drains, oddly, directly toward the Sierra Nevada from June and Gulf Lakes. It then turns north around Reversed Peak, finally flowing through the more deeply carved canyon into Silver and Grant Lakes and into Rush Creek and then Mono Lake.

Like giant conveyor belts, the glaciers once transported glacial till (unsorted rock debris eroded into and carried by the ice). The till was deposited and accumulated in huge piles called moraines, or it was left behind in the form of erratic boulders and other debris as the glaciers receded. As a shoe would push mounds of soft sand ahead and to the side, the valley glaciers built hills of lateral moraines to their sides and terminal moraines at their toes, especially as they poured into valleys beyond the mouths of canyons. Though they are found throughout the Sierra Nevada and Klamaths, the moraines are most spectacular in the eastern Sierra Nevada, where they are hundreds of meters high. Fallen Leaf Lake south of Lake Tahoe is dammed by a moraine, as is Convict Lake southeast of Mammoth. West of Bishop, McGee Creek, Pine Creek, and other streams up and down the eastern Sierra Nevada flow east out of canyons containing impressive moraines.

**Yosemite**

One of the world’s most spectacular and classic examples of a glacially carved U-shaped valley is the Yosemite Valley. Where the Merced River now cascades down its glacial stairway (including Nevada and Vernal Falls) in Little Yosemite Valley and merges with Tenaya Canyon, enormous glaciers once ground into Yosemite Valley. The principal glacier receded for the last time only about 10,000 years ago, but the El Portal Glacier of about 750,000 years ago was the largest of them all. Growing to 1,800 m (6,000 feet) thick and 60 km (37 miles) long, it cut Yosemite Valley more than 600 m (2,000 feet) below its present level. This valley glacier extended past El Portal, where it deposited a terminal moraine. The lesser and final “Wisconsin” Glacier left a wall-to-wall lake behind its terminal moraine at Bridalveil Meadow. Typical of many California glacial lakes, it has since filled with sediment and supports one of today’s meadows.

Scrapes and gouges on Yosemite’s rocks are mere details compared to the spectacular cliffs, hanging valleys,
and waterfalls left behind by its glaciers. The spectacular shear cliffs of El Capitan rise 884 m (2,898 feet) above the valley. Numerous joints and fractures on the side of Half Dome made the rocks vulnerable to erosional forces of the valley glaciers that carried them away. Ribbon Falls is the highest single falls in the valley at 492 m (1,612 feet), but it dries to a trickle for much of the year. Yosemite Creek plunges over 435 m (1,430 foot) high Upper Yosemite Falls, then crashes and cascades onto the rocks only to spill over 98 m (320 foot) Lower Yosemite Falls. The upper falls is one of the highest in the world; after a wet year, the entire falls has few rivals. The many falls and hanging valleys were once capped by tributary glaciers which could never cut rock as fast as the gigantic trunk glaciers into which they merged. These spectacular glacial landscapes do not begin or end with Yosemite. Just to the north is Hetch Hetchy Valley, exhibiting strikingly similar glacial landscapes, except they were flooded by the reservoir.

**Glacial Landscapes Beyond Yosemite.** To the south, the south fork of the Kings River now flows through Kings Canyon. This is one of the deepest canyons carved in the Sierra Nevada and is strikingly similar to Yosemite Valley. Splendid glacial landscapes with classic horns, aretes, and U-shaped valleys are common throughout Sequoia National Park’s high country. Glacial activity diminished rapidly south of the Kaweah River and the line between Visalia and Olancha. The 11 km (7 mile) long Kern Canyon Glacier was the most southerly of any major California glacier, advancing just south of this line, down to about 1,750 m (5,700 feet) asl.

The Klamaths were also heavily glaciated with up to sixty glaciers from west of Red Bluff to the Oregon border during several Pleistocene Epoch glacial stages. Typical and dramatic glacial features are common in the granitic bedrock of Klamath’s high country. The most remarkable landscapes are similar to the Sierra Nevada in the Siskiyou and Salmon Mountains, the Trinity Alps, and the most impressive glacial features of the Marble Mountain Wilderness. The Trinity Alps glaciers extended as much as 18 km (11 miles) long down to 750 m (2,450 feet) asl. Conspicuous glacial deposits and erratic boulders abound in Trinity’s Coffee, Deer, Swift, and Canyon Creeks. Today, patches of ice up to only 2 hectares (5 acres) remain by the end of summer near the Thompson and Sawtooth Mountains.

Small glaciers formed only near California’s highest Basin and Range peaks. This more subtle glacial topography dots highlands and a few canyons of the White Mountains. Because this region was in the rainshadow of the magnificent Sierra Nevada ice fields, the greatest Pleistocene Epoch changes brought cooler and wetter conditions. Many of today’s intermittent streams and rivers became perennial as inland lakes filled with water and were connected by those streams well into the Mojave Desert. The Owens River flowed with ten times more water and Death Valley partially filled with Manly Lake up to 275 m (900 feet) deep during the wettest periods. Some researchers believe that a waterway may have flowed all the way from Lake Russell and western Nevada through the Mojave and to the Colorado River, into the Gulf of California.

Just as glaciers have left scars on some of California’s modern landscapes, so wind has been working to erode, transport, and deposit materials. These landscapes are the focus of the next section.

**California Landforms Made by Wind**

Of all the denudational processes and landscapes, wind is one of the least important in California and in the world. This relative statement can be misleading unless we consider the enormous tonnage of fresh material being eroded, transported, and deposited around California by all natural processes.

There are two general settings where wind becomes a more important agent in landscape evolution in California. Where waves are pushing sand onto California beaches, changes in tide levels and other adverse conditions may create disturbed sites where permanent plant cover is not established. Along these vulnerable, isolated coastal strips, wind can carry loose sand great distances. Additionally, in some of California’s rainshadow deserts, precipitation is too sporadic to support protective plant cover. Again, wind may erode, transport, and deposit
Sand is coughed out of coastal streams and rivers, then worked along the coast by waves. Here, it is deposited as sand–spit barriers, sometimes considered baymouth bars that protect Bolinas Lagoon from pounding ocean waves near Stinson Beach. The quiet lagoon is now filling with mud carried and deposited by surrounding streams.

Material; these processes polish desert rocks and create their own desert landscapes.

Wind Leaves Its Marks on Desert Landscapes
Throughout California deserts, patches of desert pavement have formed as weathering breaks particles into finer clays, silts, and sands which can be blown away by the wind. Additionally, clay surfaces alternately expand when wetted and contract when dried, pushing coarser pebbles toward the surface. The accumulated coarser particles are jammed together in a surface matrix which cannot be blown away by the wind. A poorly developed soil may form below this natural pavement.

Deflation denudes desert surfaces and forms blowouts and areas where sandy surfaces are carried away from the bases and roots of anchoring plants. Devils Cornfield in Death Valley dramatically displays plants and their roots protruding above the windblown sand; numerous plants died because they could not hold on after losing their footing. New sources of windblown sand are continually weathered from exposed desert mountains and plains in California.

Dunes in the Basin and Range. In the Basin and Range, sand dunes may accumulate where formerly free-moving wind and sand is finally blocked by mountain barriers. The sand is deposited in topographic traps or forced up the bases of mountains. The most impressive dunes are in or near the Death Valley area. The tallest dunes of up to 210 m (700 feet) are in the southern Eureka Valley. At the southeastern edge of Death Valley, the Dumont Dunes are 128 m (420 feet) high.

The dune fields within Panamint and Death Valley are not nearly as tall, but represent captivating lessons in natural history. Erratic winds keep the Star and other dunes shifting and changing shapes while they remain in the same place. Smaller dunes in northern Death Valley are more stabilized by mesquite, which taps into the shallow groundwater. All of these Basin and Range dunes share some striking similarities.

Low dunes have even accumulated in Saline Valley and south of Owens Lake. Following the draining of Owens Valley water to Los Angeles, thick, health-threatening alkali dust clouds rise and are swept around and away from the valley when winds are strong. More recent legal agreements with the City of Los Angeles (reviewed in Chapter 6) are designed to improve these conditions.

Mojave Dunes. In the Mojave Desert, Devils Playground contains the tallest and largest dune field. Sand was transported to the area by the Mojave River, then blown by previously prevailing winds over thousands of years. Kelso Dunes (up to 168 m [550 feet] tall and 6.4 km [4 miles] long) are the highest. Like most California dunes, they are composed mainly of lighter quartz and feldspars, but some heavy metals such as iron have oxidized, leaving a rusty stain to these dunes.

Southern Desert Dunes. Far to the south, prevailing winds out of San Gorgonio (Banning) Pass blow sand, brought by the Whitewater River, from northwest to southeast across the Coachella and Imperial Valleys. The San Gorgonio Pass/Whitewater area exhibits some of the best ventifacts (stones and other objects shaped by windblown sand) in the state. Efforts to stabilize the shifting sand with trees, fences, and urban sprawl have helped. Still, high winds can blast sand against heavily abraded surfaces and create treacherous travel conditions. Active dunes occasionally threaten and actually consume parts of housing developments, such as in Cathedral City. Meanwhile, isolated classic barchan dunes migrate up to 30 m (100 feet) per year from near the Borrego Badlands area east toward the Salton Sea.

The Algodones Dunes (also known as Glamis Dunes or Sand Hills) are in Imperial Sand Dunes Recreation Area. Located on the southeast corner of California, they are the most expansive dunes in North America. Ridges of sand up to 80 m (250 feet) high trend perpendicular to the prevailing northwest winds. These winds have pushed this 72 km (45 mile) long dune field southeast into Mexico. Roads have been covered and

Figure 3-27 Sand is coughed out of coastal streams and rivers, then worked along the coast by waves. Here, it is deposited as sand–spit barriers, sometimes considered baymouth bars that protect Bolinas Lagoon from pounding ocean waves near Stinson Beach. The quiet lagoon is now filling with mud carried and deposited by surrounding streams.
canals filled with this blowing sand. At least portions of each of these dune fields have been altered by human activity. Ironically, these activities include aggressive attempts to stabilize them and to rectify the results of disturbances from off-road recreational vehicles.

**Coastal Dunes**

Similar problems are common to California’s coastal dune fields, but there are also many differences. First, the sand in most of California’s coastal dunes starts as weathered material from California’s mountains that is transported by rivers and streams to the ocean. Once it is coughed out on the shoreline, usually during heavy winter and spring storms, constant wave action begins to work the sand along the coast, usually from north to south. Where weaker waves deposit sand (often in bays and protected inlets), the wind can now blow the sand inland or against the sides of protective promontories, where it is saved from further attack from the waves.

Because prevailing winds blow onshore along most of the California coast, accumulated sand dunes often migrate inland unless there is sufficient dune vegetation to anchor them down. Often, ice plant and other vegetation is introduced on these dunes to restabilize them after the native vegetation has been trampled or destroyed. Victims of migrating dunes include roads, farms, housing projects, and water reservoirs consumed by the sand.

The processes that shape California’s coastlines are reviewed in more detail in Chapter 12.

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**SUMMARY**

Where tectonic processes have slowed or ceased, weathering and erosion eventually will destroy mountains and level landscapes. In California, where there are abundant fresh outcrops and steep slopes, denudational processes work quickly and often dramatically. However, at this time in geologic history, California is situated on a remarkably active plate boundary, and the tectonic forces are winning the seesaw battle. Good examples are the many California mountain ranges growing faster than they are being destroyed. Most geologists agree that these mountain-building forces will continue to dominate over denudational forces in most of California into the near geologic future.

California exhibits spectacular diversity in its physical landscapes and in the geologic processes that shape them. The topographic features produced by these processes impact weather and climate, plants and animals, and hydrology throughout the state. Californians, willingly or not, also recognize their connections to these landscapes and processes. The cycles of change in our physical world are causing dramatic changes in our human landscapes and our everyday lives. These are topics for the following chapters.

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**SOME KEY TERMS AND TOPICS**

- accelerated erosion
- alluvial fans
- Big Bend
- denudation
- erosional processes
- fluvial processes/landforms
- glacial landscapes
- Ice Age
- liquefaction
- marine terraces
- mass wasting
- modern volcanic regions
- mountain building
- North American plate
- Pacific plate
- San Andreas Fault Zone
- tectonic processes
- volcanic activity
- weathering processes
- wind (landforms made by)

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**ADDITIONAL KEY TERMS AND TOPICS**

- basaltic lava flows
- composite volcanoes
- constructional processes
- differential weathering
- dunes
- earthquake intervals
- exfoliation
- folding
- Garlock Fault
- geomorphology
- geothermal energy
- great earthquakes
- hot springs
- interglacial period
- left-lateral fault
- limestone caverns
- right-lateral fault
- rock displacement
- stretching/pulling apart
- subduction
- synclinal troughs
- tectonic landforms
- thrust fault (blind)
- topography
- transform fault
- vertical faults
Can you find another place on Earth the size of California displaying such diversity of climates? If the title that best summarizes weather in parts of southern California is “Waiting for the Rain”, the narrative for parts of northwestern California might be “Waiting for the Rain to End” in winter, or at least, “Waiting for the Sun”. Depending on the classification system used, you may find examples similar to nearly every major climate group, except for tropical climates, somewhere in California. We could devote this entire book to California’s weather events and climate zones and still not cover them all.

Just as California’s climates significantly influence the shaping of its landscapes, the varieties of geologic features and plant communities in the state (discussed in Chapters 2, 3, and 5) have significant influence on California’s weather and climate. Though recognition of these and other connections is important, there are three major, more general geographic factors that have the greatest influence on California’s weather and climate. These controlling factors are latitude (distance north from the equator), ocean air mass versus continental air mass influence (usually an east–west component, but strongly influenced by situation in relation to mountain barriers), and elevation above sea level. We begin our discussion with these three more general, dominant controls on California’s weather and climate.

We will then consider many other factors that affect weather and climate and cause the numerous exceptions to our generalities. For example, gradual climate change has always played a role in shaping California landscapes, beginning long before humans arrived. However, changes in microclimates caused by people are relatively fast and dramatic. Today, there is increasing evidence that humans are changing California climates on a much grander scale. Because every Californian is impacted by these climate changes (drought, flood, heat, cold), every Californian has a stake in the results. Here is your opportunity to reconnect to the sky above and to recognize it power and relevance in your life.
LATITUDE

Like the other two major geographic factors influencing California’s weather and climate, latitude significantly influences radiation, temperature, precipitation, humidity, and myriad other elements. When all other factors are equal—such as distance from the ocean, situation in relation to mountain barriers, and elevation—cooler temperatures and increased precipitation will be found as we travel north in California, farther from the equator. This is partly because sun angle and intensity decrease as we travel north during any time of the year across California’s nearly 9½ degrees of latitude. However, this also leaves different regions of California vulnerable to air masses and weather patterns more common to their particular latitudes. Consequently, moving north across the state will result in more than just a general decrease in land and water surface temperatures. Figure 4-2 illustrates how temperatures change with latitude.

Solar Radiation and Temperatures Change with Latitude

We start at the very northern border of the state (42 degrees latitude). Here, the angle of the sun from the southern horizon at solar noon (noon sun angle) ranges from a
low of 24½ degrees on December 21 (winter solstice), to 48 degrees during the vernal (spring) and autumnal equinox, to a high of 71½ degrees from the horizon on June 21 (summer solstice). Note the dramatic change of sun angle and resulting intensity changes throughout the year. Additionally, dramatic change in the length of day and night—from very long summer days to very long winter nights—accompanies this annual cycle.

Near to and during the summer solstice, residents near the state’s northern border, even with daylight savings time, see morning’s twilight return by 5 A.M. After the long summer day, noticeable evening twilight remains after 10 P.M. The length of short winter daylight hours and long nights is just as dramatic, but reversed from summer, during the winter solstice.

The southern edge of the state is barely more than 32½ degrees latitude. Here, the winter noon sun is about 34 degrees from the southern horizon; it rises to nearly 57½ degrees during the vernal and autumnal equinox and to an annual high of almost 81 degrees at solar noon during the summer solstice.

The nearly ten-degree difference in sun angle between northern and southern California results in increased solar radiation intensities toward the south, and it is partially responsible for differences in California’s climate zones.

Still more dramatic are the seasonal changes in the length of day and night and the 47 degree annual change in sun angle at any one location. This encourages weather patterns, air masses, and temperature regimes to dramatically shift north across the state during summer and drop south during winter.

Almost all elements of weather and climate depend on sunlight for their original source of energy, and the differences in sunlight intensity have profound impacts, especially on temperature. As southern California experiences higher insolation (the amount of radiation received at the surface) rates than northern California, the average temperatures warm more than 10°F as we travel from the northern to the southern California coast. Average (mean monthly) temperatures in San Diego near the Mexican border range from about 13°C (55°F) in January to 22°C (71°F) in August; in Crescent City near the Oregon border, they range from about 7°C (44°F) in January to 13°C (56°F) in August. Therefore, California’s high range in latitude and solar insolation translates into a high range of temperatures from north to south, even along its mild coastline. These latitudinal temperature differences are greatly exaggerated in transmontane California; as we investigate weather stations far inland, that north–south temperature difference may double.

Precipitation Changes with Latitude
Another result of this latitude range is a great variation in precipitation. Again, when all other factors, including distance from the ocean, situation in relation to mountain barriers, and elevation, are similar, precipitation increases as we travel north. This is because we travel away from the subtropical high pressure (which dominates around 30 degrees latitude) as we move north, and closer to the subpolar Aleutian low pressure and polar front.

Global Circulation: California’s Situation
A very generalized view of our atmosphere’s circulation patterns begins near the equator. This is where surfaces warmed by solar radiation transfer heat to the air above, which is usually free to expand and rise. These rising air masses spread out away from the tropics at the top of our
Many factors are responsible for temperature variations throughout the state. Besides latitude and variations in solar radiation, the effects of ocean versus continental air masses and elevation play important roles.

**Figure 4-2 Temperature Patterns.** Many factors are responsible for temperature variations throughout the state. Besides latitude and variations in solar radiation, the effects of ocean versus continental air masses and elevation play important roles.
In this section we will discuss one of the most basic and important concepts necessary to the understanding of California’s weather.

**Less-Dense, Low-Pressure Air Rises: Clouds and Stormy Weather**

Vertical air motion is the cause of almost all periods of precipitation, fair weather, or drought in California (see Figure 4-3). We begin with the rising air which is responsible for stormy weather and precipitation. When air masses, or parcels, become less dense than their surroundings, they begin to rise. This makes sense when we recognize that less-dense air parcels contain fewer molecules per given volume than their neighboring air masses.

Because the less-dense air parcels are lighter (like pieces of less-dense wood in a body of water), the surrounding fluid buoys them upward. We refer to this as low atmospheric pressure because there are fewer molecules per volume to exert air pressure on any surface. Therefore, less-dense air is associated with low pressure and rising air parcels. (Two common events that cause low pressure to form in California are [1]: diverging air aloft draws surface air upward, causing winter-like storms, or [2] air is heated at the surface in inland valleys and deserts during hot summer afternoons, causing it to expand and become less dense.)

When such air parcels rise into more rarefied (thinner), high-altitude air, they encounter weaker forces pushing in from the outside. As a result, they expand like balloons. As these air parcels rise and expand, they push surrounding air away. Therefore, they cool at the dry adiabatic lapse rate of 10°C per 1,000 m (5.5°F per 1,000 feet). Stated too simply, as air cools, it loses its ability to hold water vapor (H₂O in the gaseous state). This cooling causes relative humidities to increase as the air approaches saturation, (or its dew point), which is when condensation takes place. (Relative humidity measures the amount of H₂O in the air compared to the amount of H₂O that can remain as vapor at a given temperature.) The dew point is reached when relative humidities approach 100 percent, and H₂O condenses faster than it evaporates. At this point, billions of the gaseous H₂O molecules combine to form liquid water drops, and fog or clouds form.

Consequently, less-dense, low-pressure air masses will rise, often cooling to their dew points (if there is sufficient moisture) as condensation occurs. When the clouds form, higher-energy water vapors condense to form lower-energy liquid water drops, releasing latent heat into the rising column of air. This latent heat of condensation added within the developing clouds causes the air pockets to expand and rise even faster. As air is drawn up from near the surface, a volume of even less-dense, lower-pressure air is left below. We now have a chain of events that drive the engine of a storm. When these updrafts are strong enough, tremendous amounts of moisture are brought into the clouds, only to condense into larger liquid water drops. They eventually freeze into giant ice crystals that begin falling to the ground. Precipitation results.

This is why California weather forecasters, especially in winter, often associate a dropping barometer measurement (barometers measure air pressure) with an approaching low-pressure system. This low pressure may bring with it less-...
IMPORTANT LESSONS (continued)

dense rising air masses, cloudier skies, unsettled weather, and possible storminess.

More-Dense, High-Pressure Air Sinks: Fair Weather

The opposite of the previous conditions occurs in high-pressure systems. When air parcels become more dense than their surroundings, there are more molecules exerting pressure per volume, and so the air pressure increases. However, these dense, heavy air masses will sink like more-dense bowling balls in pools of water. Whether they start out cool or warm, if they are denser and heavier than their surroundings, they sink. As they sink, they encounter greater air pressures pushing in from the surrounding lower-altitude air. These stronger forces push the air parcels together from the outside and squeeze their molecules closer together.

This squeezing force heats the air parcels by compression at that same adiabatic rate of $10^{\circ}$C per 1,000 m (5.5$^{\circ}$F per 1,000 feet) as the agitated, colliding molecules are forced ever closer together. A similar effect is witnessed when we use a hand pump to force air into a tire or ball. The work we do on the pump compresses and agitates air, generating heat. We can feel the heat from some of these forces at the base of the pump. In the fast-moving molecules of warmer air more H$_2$O may remain in the gaseous state (since warmer air has greater capacity to hold water vapor), and condensation of clouds is unlikely in the lower relative humidities produced by this heating by compression. Fair weather results.

It is commonly believed that hot air rises. We can now make that statement more accurate. It is true that the agitated molecules in hot air want to expand and rise, and they will, if allowed. This happens frequently in tropical air when sun-heated surfaces then heat a shallow layer of air above them. This moist, super-heated afternoon air is often free to expand and rise and expand even more. It eventually cools to its dew point, creating cumulus clouds, afternoon thunderstorms, and precipitation. With a few exceptions, such a weather event is unlikely to occur in California where unmodified tropical air is rare.

Most California heat waves are created by large domes of heavy, dense, high-pressure air aloft that sink toward the surface. As these air parcels are heated by compression, they want to expand and rise, but they are stopped by heavy, dense air parcels falling around them and squeezing them together. The dry intense heat waves that visit California are usually caused by giant high-pressure systems that move “aloft” over parts of the state. Their sinking and compressively heated air masses can hold much more water vapor than they contain, so relative humidities are usually very low during these episodes. Fair, dry weather rules below these high-pressure “ridges”, though fog or low stratus clouds can be trapped near the surface below the inversion and high pressure capping it.

When the dome of high pressure finally weakens or moves away, compressional heating will cease as the air is liberated to rise. The result is usually cooler weather with higher relative humidities and more cloudiness. (Remember that temperature is the other variable that can change pressure. Very cold, surface air masses are usually quite dense and also represent high pressure. This produces cold, stable, clear winter days. Again, it is important to associate stormy or fair weather with low or high pressure, but not necessarily with cold or warm temperatures.)

It follows that high pressure must be more dominant in drier southern California than to the north, and it must dominate all of California during its dry summers. Why? The culprit is the atmosphere’s general circulation pattern. We are now prepared to continue our discussion of the role latitude plays in the state’s weather and climate.

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**Figure 4-4** Summer afternoon heating on mountain slopes in northern California causes moist air to rise, expand, and cool. The flat bottoms of cumulus clouds show where the air reached its dew point. The puffy tops form when latent heat given off within the clouds causes them to boil up. They dissipated after sunset.
troposphere just as rising air from a kitchen stove spreads out when it hits the ceiling. As these upper air currents diverge and move toward the poles, they are cooling. They are also forced to converge into smaller volumes aloft as their air molecules are packed closer together. They never make it far to the north. At about 30 degrees, they form the heavy and dense air masses of subtropical high pressure. As the air sinks out of these high-pressure systems from aloft, stable, fair weather is the rule at the surface (see Figure 4-5).

Therefore, we expect fair weather with less precipitation to dominate as we move south in California, closer to 30 degrees and the subtropical high. Because the southern edge of California is south of 33 degrees, we expect the driest conditions there, but what causes the heavy precipitation farther north?

Remember that the air sinking at about 30 degrees must spread out when it reaches the surface. Some of it moves back to the Equatorial Low (as the trade winds) to fill that void, only to be warmed and lifted again. However, some of it also spreads north toward the Arctic, only to be turned to its right (due to the coriolis effect) as the prevailing westerlies. This middle latitude current is destined to collide with much colder, denser northern air masses at the surface. On the average, this collision occurs at about 60 degrees north. However, the boundary between relatively warm, middle latitude air and colder polar air migrates, depending on the time of year and the movement of air masses. When the two air masses meet, the warmer, less dense air from the westerlies glides over or is scooped aloft by the heavier, cold polar air, which remains near the surface. The warmer air now rises from the surface within less-dense low pressure on the warm side of this frontal boundary.

These polar fronts (often associated with the subpolar lows) usually produce stormy weather as air is forced to rise above the collision boundary. Again, the rising air expands and cools to its dew point, causing clouds and precipitation to form. Traveling north in California, we move closer to the average location of the Aleutian Subpolar Low and the polar front, so there is more precipitation. However, the boundary of these air masses and associated frontal systems migrates across several degrees of latitude during the seasons.

Because general pressure systems are dragged north with the vertical rays of summer sun, the subtropical high (known as the East Pacific or Hawaiian High) also moves north and strengthens, shielding California from storminess during the summer. Months later, when the winter sun shifts south, so do the pressure systems. By mid-winter, the protective East Pacific High weakens and moves south, opening the door to the disturbances and polar frontal systems near the Aleutian Subpolar Low. This is why all areas of California, except for a few spots in the southeastern deserts, experience peak precipitation in winter, usually during January or February; this is the time of year when these frontal systems sweep through, especially in the northern part of the state. Southern California often experiences just the tail end of the storms that more frequently batter the north. This is also why most annual precipitation records in California are more conveniently recorded from July 1 through June 30. The rainy season develops, peaks, and dissipates in the middle of the annual record, while the break occurs in the middle of the drought season.

In summary, contrasts between winter rain and summer drought and the wet north and dry south are mainly a function of latitude and the average locations and migrations of dominant high- and low-pressure systems in and around California.

**Ocean Air Mass Versus Continental Air Mass Influence**

Now we are ready to explore the second vital factor that controls California's weather and climate—the dominance of moist ocean, or marine air masses versus dry continental air masses. This is usually a function of distance from the ocean and proximity to mountain range slopes that face either toward the ocean or the dry continent. In California, this is often, but certainly not always, an east–west component.
Because local weather conditions often result from the dominance and movement of air masses, we must pause to define them. Air masses represent homogeneous masses of air with distinct characteristics (such as temperature and humidity) that are derived from where they formed. The most general classification distinguishes warm (usually low latitude) from cold (usually high latitude) and wet (often maritime) from dry (often continental) air masses. As they move over different surfaces, they are modified; they often meet along fronts.

**Temperatures in Marine and Continental Air Masses**

There are several reasons why land surfaces heat up faster and become hotter than water surfaces when both are exposed to equal amounts of sunlight or heat energy. Because they are better conductors of heat, land surfaces also cool off faster and get colder than water during periods of heat loss. This is one reason why inland locations experience dramatic changes in diurnal (daily) and seasonal temperatures compared to their coastal counterparts in California.

Another reason why coastal areas experience milder temperatures is that air masses near the coast tend to be more moist, keeping daytime and summer temperatures cooler, while forming an insulating blanket that traps and counterradiates heat at night and in winter. In the drier air common inland, intense solar radiation causes very hot days and summers, while allowing rapid radiation loss of surface heat into space and quick cooling during nights and winters.

Therefore, there is a direct correlation in California between the distance from and exposure to moist coastal air masses and the range of temperatures. High relative humidities and frequent fog and low clouds common along the coast contrast with drier, clearer air inland, especially during summer. Mild temperatures along the coast also contrast with extremes in temperatures farther inland. These contrasts are remarkably enhanced by mountain barriers.

In California, mountain barriers may separate some of the greatest temperature contrasts within such short distances anywhere in the world. Heavy, moist pools of marine air are often trapped in basins against the ocean, or windward, sides of mountain ranges along the California coast, resulting in moderate temperatures. In contrast, areas on inland, or leeward, sides of those mountain ranges facing toward the drier continent experience extreme temperatures in the dry air; such conditions are more characteristic of continental interiors hundreds of miles inland. The ridges of California’s numerous mountain ranges often separate moist, moderate, coastal air masses from the dry, harsh climates extending behind them. This helps define the differences between cismontane (coastal slopes and valleys) and transmontane (the inland sides of the mountains) California.

**Marine and Continental Air Masses Influence Precipitation**

Enormous contrasts in precipitation also occur between coastal/windward locations and the inland/leeward sides of major mountain barriers (see Figure 4-8). First, since the source of almost all moisture in California is from the Pacific Ocean, we might expect precipitation totals to gradually diminish as we move farther inland. Add the mountain barriers, and there are striking differences. As winter storms carry moist, unstable air from the Pacific, they generally sweep from west to east across California.
When the air masses encounter major mountain barriers such as the Klamaths or Cascade, the Coast Ranges or Sierra Nevada, or the Transverse or Peninsular Ranges, the air is forced to rise on the windward mountain slopes. The air in these strong updrafts quickly expands and cools to its dew point. Recall that rising air produces the 

\textit{thickest clouds and heaviest precipitation}. In California, the air mass is forced to rise along these windward slopes where the greatest precipitation totals are common. This is called \textit{orographic precipitation}.

Thus, some locations on west-facing slopes in northwestern California receive more than 250 cm (100 inches) of precipitation per year. Some western Sierra Nevada locations average accumulations of more than 3 m (10 feet) of snow pack by the end of the winter season, while total winter snowfalls are much greater.

In contrast, on the leeward sides of California’s major mountain barriers, prevailing winds must sink back down to reach the inland deserts. Recall that \textit{sinking air is heated by compression at 10°C per 1,000 m (5.5°F per 1,000 feet)} and the oversimplified explanation that warmer air is capable of holding more water vapor (\textit{H}_2\textit{O} in the gaseous state). Therefore, in the sinking air on leeward slopes, ice crystals and water drops tend to evaporate, relative humidities decrease, cloud formation is less likely, and precipitation is rare. These areas are called \textit{rainshadows} and California exhibits some classic examples.

The driest place in California (and one of the driest in the world) is Death Valley, where average annual precipitation is less than 5 cm (2 inches). Here, a series of mountain ranges, starting with the Coast Ranges and then the Sierra Nevada, block the encroachment of moist air from the Pacific. Once an air mass finally invades the region, it must sink below sea level toward the valley floor, causing compression, heating, and drying. This is why Death Valley is often left only partly cloudy or clear and dry during some of California’s wettest and most powerful winter storm events. Numerous southeastern California desert locations are nearly as dry; all are on rainshadow sides of major mountain barriers.

\section*{ELEVATION}

\textbf{Temperatures Change with Elevation}

The third and perhaps simplest major factor controlling California’s weather and climate is elevation above sea level. With some major exceptions, which we will explore, air temperatures become cooler at higher elevations. This is a result of the more rarefied (thinner) air at higher altitudes that is not only farther from surface heat sources but is not compressed as much as lower-altitude air. High-altitude air simply doesn’t contain as much heat energy. The average environmental lapse rate is about 6.5°C per 1,000 m (3.5°F per 1,000 feet). This is the average rate of temperature change within a column of air that is \textit{not} moving vertically; rather, we are moving through it, making measurements at different altitudes.

Therefore, the following California temperatures are typical of those recorded at the same time on a spring or fall afternoon.

- 21°C (70°F) at Redding, 8°C (47°F) at 2,000 m (6,500 feet) a few kms (miles) northwest in the Klamath Mountains

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure_4-8}
\caption{\textbf{Windward and Leeward Climates.} As winter storms move across California from the Pacific Ocean, moist air is forced to rise over windward slopes of coastal ranges and the Sierra Nevada. Condensation, clouds, and precipitation are common. Drier air must sink down leeward slopes, producing rainshadow climates.}
\end{figure}
Local Low-Level Temperature Inversions.

The once stable layers of air to break the inversion. Dense air pockets that settle into low spots. Eventually, especially in winter. Many night and morning travelers settle into valleys and canyons on clear, calm nights, especially in winter. These cold, dense air pockets that settle into low spots. Eventually, morning sunlight warms the surface, or winds may mix the once stable layers of air to break the inversion.

Local parcels of cold, denser air drain downward and into the cool forest. The trouble is that the air below tends to be cooler, especially after crossing mountain barriers. Finally, precipitation decreases as we move east, especially after crossing those mountain barriers to their rainshadow sides.

When combining these factors, we see why, for stations at similar elevations above sea level, we record the mildest temperatures near the coast. The greatest temperature ranges are experienced in eastern California; the hottest summer temperatures are recorded in southeastern California, the coldest winter temperatures in northeastern California. Finally, we find the wettest locations in the northwest and the driest in the southeast.

- 29°C (80°F) in Fresno, 11°C (52°F) at 2,450 m (8,000 feet) several kms (miles) east in the Sierra Nevada
- 38°C (100°F) in Palm Springs, 18°C (65°F) at 3,000 m (10,000 feet) only 10 km (6 miles) west in the San Jacinto Mountains

One of the most dramatic elevation gains and corresponding temperature changes in such a short distance anywhere in the world can be experienced during a ride on the Palm Springs Tramway from the desert floor up the fault scarps of the eastern San Jacinto Mountains and into the cool forest.

There are at least three interesting and important exceptions to this generalized rule of temperature decrease at higher elevations in California. First, because air is rarified (thinner) at higher elevations, solar radiation is less filtered and more intense. Summer days may turn surprisingly warm after hot surfaces are exposed to direct sunlight at high elevations. However, that same rarified air is a poor insulator, allowing heat to quickly radiate out after sunset, making way for very cold nights, especially during winter. This is why California mountain locations experience greater diurnal and seasonal ranges in temperatures compared to lower elevations, especially when skies are clear.

**Local Low-Level Temperature Inversions**

Perhaps more important exceptions to our rule of temperature decrease at higher elevations are temperature inversions. A temperature inversion occurs when cooler air, which is denser, settles below a layer of warmer air, reversing “normal” conditions (see Figure 4-9). California’s mountains and valleys experience two types of inversions. One type is the simple, low-level inversion. Local parcels of cold, denser air drain downward and settle into valleys and canyons on clear, calm nights, especially in winter. Many night and morning travelers across California’s ridges and valleys notice the cold, dense air pockets that settle into low spots. Eventually, morning sunlight warms the surface, or winds may mix the once stable layers of air to break the inversion.

These local inversions are important to California farmers who plant on fields and slopes in areas with near-freezing temperatures. Frost-sensitive crops must be planted in the thermal belts just above the local canyons, basins, and valleys where cold, dense air settles on long winter nights. Many a California farmer has exploited these slightly higher thermal belts to increase growing seasons. These conditions also affect the distribution of natural plant communities with varying resistance to temperature extremes. Native plants less resistant to extreme cold may be absent where cold pockets of air can settle on long winter nights.

**Widespread Upper-Level Inversions**

Regional upper-level inversions cover much larger areas and affect the major population centers of California (see Figure 4-11). Remember that California is often situated beneath a large dome of high pressure (particularly in southern California and especially in summer). These sinking air masses are often clear and dry aloft. As the air cascades down to lower altitudes, it is heated by compression. The trouble is that the air below tends to be cooler, especially when coastal air masses dominate at the surface. Frequently (usually in summer), coastal valleys are invaded by this cooler, moist, denser air from the ocean. This relatively cooler air has settled near the surface and is
trapped below the warmer, drier air sinking from the dominant high pressure aloft. With very little mixing between the two layers, very stable conditions exist.

Unfortunately, California’s major population centers pour tons of pollutants into the already hazy, stagnant air near the surface. Because the pollutants rarely mix with the upper atmosphere during these inversion episodes, people are forced to live with and breathe unhealthy air. When upper-level high pressure strengthens, the relatively cooler ocean air is squeezed closer to the surface, resulting in shallower inversions and even less mixing.

These conditions can sometimes create a pressure-cooker effect, producing the most stagnant air and the smoggiest days. Though afternoon temperatures may be heated to 38°C (100°F) in inland valleys, air on top of the inversion may be just slightly warmer. The valleys then bake in summer heat and smog. These conditions are common in the Central Valley in summer. On some of the hottest summer afternoons, surface temperatures may rise high enough (becoming much hotter than the air above) so that the air expands, rises, and breaks through the inversion. The haze and smog is then funneled up heated mountain slopes and through canyons, pulling better air quality from the coast into inland valleys.

Inversions commonly cause afternoon temperatures in summer to get hotter in the mountains than in the coastal plains near sea level. Summer afternoon temperatures are often higher in such southern California mountain locations as Palomar, Julian, Idyllwild, Big Bear, Lake Arrowhead, Wrightwood, Mount Wilson, and Mount Pinos than in coastal stations to the west and south near sea level. During these periods, it is likely that mountain communities are looking down on a blanket of thick haze and smog trapped in the cooler surface air that flatlanders know as the marine layer.

Similar summer inversions are common in central and northern California, including the San Francisco Bay Area. Summer afternoon temperatures on nearby peaks and even in Sierra Nevada resorts commonly soar above those of the cooler, foggy coastal locations near sea level. Passengers can easily identify an inversion when their plane pops out of the thick marine layer’s haze and into nearly unlimited visibilities in the warmer, drier air above.

**Back to the Average Temperatures**

Despite our noted exceptions, we know that California’s mountain communities are usually cooler than the flatlands below, particularly during winter. Proof is in the impressive snow packs which accumulate at higher elevations from northern to southern California during winter. It is also proven when stations in or near the high elevations typically have cooler average temperatures.

**Figure 4-10** The sun sets into a soupy marine layer typical of California’s coastal valleys. Haze, fog, and low clouds are common in the cool, dense surface air that has drifted off the Pacific Ocean and remains near its dew point. Clear skies rule above the inversion, except for some scattered cirrus clouds.

**Figure 4-11** Widespread Upper-Level Inversions. Particularly during summer, high-pressure air sinks over California. A regional inversion develops along coastal areas when the cooler, dense sea breeze is trapped below descending warmer, drier air. Haze, fog, and smog are common in coastal valleys when the marine layer is shallow and trapped by surrounding mountains.
Sierra (such as Truckee and Bodie) so frequently record the night’s coldest temperatures in the United States outside Alaska. Average annual temperatures along a line across central California range from near 15°C (60°F) near sea level to below freezing at the highest mountain locations (an average annual difference of more than 16°C [30°F]). The year-round, frost-free locations in California are strung along the southern and central California coast or in a few inland locations near the Mexican border, all at or near sea level. In contrast, some of the highest elevations in northern and central California may experience frost any time of year.

Precipitation Varies with Elevation
Precipitation also varies dramatically with elevation in California. We noted earlier that air masses must rise, expand, and cool (often to their dew points) as they move over mountains. This orographic effect results in increased clouds and precipitation at higher elevations; the effect is most dramatic on windward slopes. Annual precipitation increases by about 5–10 cm per 100 m (2–4 inches per 330 feet) elevation gain. This trend continues to about 2,440 m (8,000 feet) where Sierra Nevada precipitation totals average 153 cm (60 inches). Precipitation is even greater along many northwestern California mountain slopes. Consequently, higher elevations are not only cooler, but they receive more moisture. More precipitation on mountain slopes with lower evaporation rates (due to cooler temperatures and forest cover) means more water available for the soil and plants. This is usually true on all but the highest mountain slopes in California.

At extremely high elevations (above about 2,500 m [8,000 feet]), and often at or above tree lines, precipitation decreases with elevation gain. Rising air masses have already dumped much of their moisture on lower and middle slopes. Furthermore, the cold, rarefied air does not contain as much moisture when it reaches very high elevations. Drier conditions are amplified by the extreme evapotranspiration rates on slopes exposed to intense sun, high winds, and dry air even following snowstorms. This may leave little water on the exposed, highest slopes above tree lines during summer, after most runoff drains down to the forest below.

We have explained how the three major factors of latitude, coastal influence, and elevation impact California’s weather and climate. We now turn our attention to a variety of more specific and often related topics.

**SEASONAL CYCLES**

Contrary to popular myths spread beyond the state’s boundaries, California weather patterns are subject to pronounced seasonal changes. Most notable are winter’s heavy mountain snows and drenching valley rains that yield to summer’s prolonged drought. What forces are responsible for these and other seasonal cycles, and how do they impact California?

**Summer Patterns**

**The East Pacific High Dominates Summer Weather**
Earlier in this chapter, we learned about the East Pacific High’s powerful influence over California’s weather and climate. Besides blocking so many storms from sweeping into California, it is also at least indirectly responsible for our prevailing winds, sea breezes, stable air, ocean currents, temperatures, and many other weather elements and events, especially during summer. As summer approaches, the East Pacific High strengthens and bulges northward, becoming the dominant weather maker for the Eastern Pacific and California.

Usually centered hundreds of kms (miles) west of California, it forms as upper level winds converge, and the air becomes dense and heavy aloft. It is often enhanced during the summer when eastern Pacific surface water temperatures remain cooler than the heated surfaces of the North American continent. Summer air above these cooler waters often becomes cooler and denser, forming higher pressure.

Like all other high-pressure systems, winds flow out of it and into adjacent lower-pressure systems. Then, the coriolis force pulls the air to its right as it pours out of this Northern Hemisphere subtropical high pressure. (The coriolis effect is produced as a fluid moves across the rotating earth.) The results are winds that blow out of the high pressure, but they are turned in a clockwise direction away from its center. Because this is the opposite direction from Earth’s rotation in the Northern Hemisphere, we call these high-pressure systems “anticyclones.” (Low-pressure systems are considered “cyclones.”)

**California’s Cold Ocean Current.** As the wind turns clockwise out of our prevailing East Pacific High, it pushes ocean currents with it. (Wind is most responsible for generating ocean currents and waves on our planet.) Because California is usually situated on the east side of this high pressure, prevailing winds curve down our coast from the northwest. Friction from these winds sets our ocean current in motion. However, the ocean is also a fluid that, once set in motion, will be turned to its right by the coriolis effect. These processes create the California Current, which flows from north to south down the coast (see Figure 4-12).

At California’s latitude, this is considered a cold ocean current, especially during summer. Because summer air that flows out of the East Pacific High is often drawn into the hot thermal low-pressure conditions in the deserts, it must pass over the California Current before moving onshore. These winds are chilled by the current, especially in
The cool ocean breeze, at or near its dew point, brings the advection fog and low stratus clouds that have condensed over the cold California Current. It moves in with low specific humidities (the total amount of water in the air), but high relative humidities, because the chilled air cannot sustain what little water vapor it contains. This dense, stable air will remain near the surface as it moves into coastal and inland valleys and against coastal slopes. On summer afternoons, the air is heated as it moves inland, the fog and low clouds burn off, and relative humidities decrease.

California’s cold ocean currents are often further chilled by upwelling. Particularly where the coastline bends more east–west, such as along the Southern California Bight (south of Point Arguello/Point Conception), prevailing northwest winds can set surface water flowing south, away from the coast. As this surface water is pushed away, cooler nutrient-rich water flows up from the depths to replace it. Summer water temperatures are typically in the upper teens Celsius (60s F) off southern California, where occasional pockets of warm water make it above 21°C (70°F) for only brief periods. Northern and central California waters are several degrees colder. This makes for great fishing in the nutrient rich cold water, which holds more dissolved gases, but uncomfortably cold swimming conditions are the rule.

This also enhances the summer pressure gradient and the resulting sea breezes along the coast. High pressure intensifies in the dense, cooler air offshore. Because air wants to blow out of that high pressure and into the heated, expanding air of the thermal low over the deserts and Central Valley, summer sea breezes dominate coastal California. Especially during the afternoon, when superheated desert air is rapidly expanding and often rising, a strong sea breeze is pulled inland toward the less dense, thermal low pressure.

California summers lack precipitation not only because the East Pacific High acts as a protective barrier to storms, but also because of the cold ocean currents generated by its winds that chill the air before sea breezes move on shore. If California were on the west side of the ocean and its subtropical high (such as in the eastern United States and Asia), a warm coastal current would flow from the south. The summer sea breezes would then be warm, humid, and unstable. Unstable marine tropical (mT) air masses would produce hot, muggy summers with frequent thundershowers and occasional tropical storms. Instead, California’s refreshing summer sea breezes are dense and stable; because this chilled air can’t sustain much water in the vapor state, condensation, coastal fog, and stratus are common. Summer precipitation is rare.

**Fluctuating Highs.** Fluctuations in the strength and location of the East Pacific High are most responsible for changes in summer weather. When the high strengthens and bulges eastward over California or combines with another high-pressure system to the east, air masses cascade directly on California. Extreme summer heat waves result from the compressional heating in inland areas. Along the coast, the marine layer is pressed closer to the surface, creating shallow inversions and choking coastal cities in the smog and heat below. A thin, shallow strip of fog may hug only the beaches. Even stronger high pressure centered farther inland is rare in summer, but can squeeze the marine layer offshore, leaving coastal basins and even beaches baking in dry record heat.

When the high pressure weakens or migrates far out to sea, the marine layer thickens and stronger sea breezes penetrate far into inland valleys. These cooling breezes bring advection fog and low clouds so thick that it may not burn off in the afternoons and can even produce morning drizzle. During these weather patterns, the low stratus thickens each night as it pours into inland valleys and pushes up against coastal slopes in marine layers up to 2,000 m (6,000 feet) thick until weather conditions change.
Similar weather conditions may result (especially in late spring and early summer) when the high pressure spins winds from north to south along the California coast to Point Conception. The winds are forced to veer out to sea at this topographic boundary, only to gradually turn back toward the coast near San Diego. A large counterclockwise eddy (swirling current) may develop just off the coast, circulating and sending a thick marine layer up the coast from south to north into the California Bight. These Catalina Eddies may bring thick, low stratus to blanket southern California coastal valleys while much of the rest of California remains clear.

**Surprise Summer Storms**

A different summer weather pattern is produced especially in southern California when another high-pressure system bulges toward California from the east. Converging air aloft often produces high pressure that forms near and around western Texas. The sinking air spinning out of this summertime high also turns clockwise, picking up tropical moisture from the south in Mexico and flinging it north into New Mexico and Arizona. When this moisture-laden air begins to expand and rise in the intense summer afternoon heat of the deserts and plateaus of Arizona, it reaches its dew point, producing giant cumulonimbus clouds. Spectacular tropical-like thunderstorms erupt mostly during afternoons and evenings. Arizonans refer to this as their "monsoon season" because most stations in New Mexico and Arizona receive more precipitation in late summer than any other time of year.

More rarely, this upper-level high pressure will bulge westward and settle near the Four Corners region. This sets up upper level winds from the southeast over southern California that carry moisture from Mexico and the Gulf of California across the Colorado River and Mexico can border into southeastern California. Specific humidity (total moisture) in this subtropical air is high. The rising desert heat within the thermal low finally contains enough moisture to explode into afternoon thunderstorms similar to Arizona’s monsoon season.

Though usually isolated, these storms can dump an average year’s rainfall on one desert location in less than an hour. Dangerous severe weather and flash floods may hit one desert location while residents only a few miles away view the bright side of the cumulonimbus clouds in the hot desert sun. These summer events become more common closer to the Colorado River, the only area in California where meager precipitation totals peak during late summer.

Even more rarely, when the high pressure pushes farther west, moisture pours into all southern California desert and mountain areas from the southeast and up the spine of the Sierra Nevada. Resulting thunderstorms are more widespread and may even slip over the mountains and drift into southern coastal areas. More commonly, coastal residents are limited to viewing the sides of these towering cumulus as they build over nearby mountain slopes during summer afternoons. The cooler, stable marine air from the eastern Pacific that dominates during summer in coastal valleys contains less total water vapor (lower specific humidities), and it usually does not rise, inhibiting storm development. Even more rarely, dissipating tropical disturbances may be pulled into this southerly flow from the west coast of Mexico, resulting in more widespread cloudiness and showers that contrast with California’s summer drought.

Only in California’s southeastern deserts and mountains and in the Sierra Nevada do these rare summer events significantly influence climates. Building clouds cast afternoon shade and higher humidities cut evapo-
transpiration rates at the exact time when plants need the relief most in these areas. Even the most isolated and brief summer shower is welcome relief from an otherwise long, hot summer. The more rare spectacular electrical displays, hailstorms, downpours, and ominous flash floods are peculiar oddities against a background of otherwise relentless summer heat and drought.

Unfortunately, these downpours are usually so isolated, they contribute very little total moisture to any region (even southeastern California) on an annual basis. Summer drought is so dependable, some California farmers take advantage by planting crops that fail when there is prolonged moisture. Controlled irrigation is then timed to the life cycles of special crops, such as cotton, to make them more productive. These California farmers don’t worry about competition from regions that receive summer rains.

Fall Patterns

Autumn is the season when temperature and pressure patterns begin to change suddenly and dramatically across the state (see Figure 4-14). First, the high sun angles and intense solar radiation of summer shift south. The East Pacific High weakens and follows. Second, colder air masses and storms from the Aleutian Low and North Pacific begin to trail into northern sections of California. Third, the first cold air masses of the season move inland into the Great Basin and settle on cooling surfaces inland. Ocean temperatures will take longer to cool and the pressure gradient may reverse from summer, trending from higher pressure inland to lower pressure over the coastal waters. Eventually, this cold, dense inland air builds the first strong Great Basin High of the season over or near Nevada.

As the cold, heavy air sinks and flows clockwise from the Great Basin High pressure center, an offshore (land) breeze develops across California to the coast. This air is eventually heated by compression as it sinks toward the coast. This is why San Francisco and other coastal cities often experience their highest temperatures of the year in September or October, but it is along the southern California coast south of the Transverse Ranges where these conditions are amplified.

After the descending air masses move across the deserts out of the Great Basin High, they must first pass over the mountains and then cascade down coastal slopes and canyons, where they are squeezed into coastal valleys. This reversal of average wind conditions sends winds cascading toward the coast, leaving coastal valleys on the leeward sides of mountains and passes, where there is intense compressional heating. These hot, dry Santa Ana winds blow the smog and haze toward the coast and often out to sea.

The winds often shift from the north to northeast to easterly within a few days as the high pressure drifts farther east and inland of Nevada. It is ironic that when much of the country feels that first chill of fall and winter air masses from the north, southern California may experience Santa Ana winds blowing hot air from the north. Temperatures in southern coastal areas may rise above 38°C (100°F) into November during Santa Ana winds. Even in mid-winter, Santa Anas have boosted temperatures to 32°C (90°F) when much of the rest of the United States had freezing temperatures.

If the heated Santa Anas and down-slope winds in other parts of the state are responsible for attracting so many chilled easterners to California, they are also famous for fanning some of the most terrifying and destructive fires in the world. The fire season peaks on the heels of the prolonged summer heat and drought so characteristic of California’s Mediterranean climate. Many coastal areas from central California to Mexico may experience

Hurricanes—An Unlikely Disaster

There are at least two reasons why California has never experienced a hurricane in recorded history, and only a few tropical storms have visited even the southern part of the state. First, mainly easterly trade winds normally blow tropical disturbances that form off the west coast of Mexico away from the mainland and into the Pacific. Second, when a renegade tropical disturbance finally wanders far to the north toward California, it must travel great distances across the relatively cold waters along the Baja California coast. Because the evaporation of tropical waters of at least 26°C (79°F) provides the latent heat required for these storms to form and strengthen, they dissipate long before reaching California. Only clouds and some showers are left if a storm’s remains drift into the state. Rare tropical disturbances moving north along the warm Gulf of California are also weakened as they must travel mainly over land to reach California.

During late September 1997, powerful hurricanes formed over exceptionally warm El Niño waters off the west coast of Mexico. One of the most powerful hurricanes ever recorded in the eastern Pacific (Linda) drifted up the Baja coast, headed for southern California. In disbelief, the National Weather Service, public officials, and the media began preparing. The storm could have brought near hurricane-force winds, torrential rains, and severe flooding even as it weakened. Instead, Hurricane Linda made a last-minute left turn into the Pacific. As usual, southern California only received residual showers from the dying storm.

As the cold, heavy air sinks and flows clockwise from the Great Basin High pressure center, an offshore
summers when no rain falls between May and October. The annual battle of the air masses usually arrives at the end of this drought season, just when soils and plants are driest. Since the first Santa Anas and other down-slope winds often arrive before the first significant rainfall of the season, the months of September–December bring some of the most hazardous fire seasons in the world to California.

When these strong, gusty down-slope winds are heated by compression up to 38°C (100°F) and relative humidities drop below 10 percent, fires in dry grasslands, scrub, chaparral, and other woodlands are almost impossible to stop. Could you write a better script to pave the way for a disastrous fire season?

Along the Santa Barbara coast, sundowner winds may descend the southern base of the Santa Ynez Mountains as north or even cool northwesterly winds blow across most of California. These winds may be forced to sink down the south slopes of the east–west trending Transverse Ranges. Here, they are heated by compression before reaching the east–west oriented coastal valleys and can become a local version of the hot, dry Santa Anas. These very brief and local warm, dry episodes may invade valleys throughout the Santa Barbara area and even into the Ventura/Oxnard Plain. They can provide surprising breaks to normally cooler sea breezes directly off the North Pacific.

Meanwhile, in California’s mountains and transmontane valleys, deciduous trees turn color and the chill in the air announces winter is not far away.

Winter’s Storms

The winter season brings great changes in the general circulation patterns responsible for California’s weather. As the sun angle dips ever lower and the days shorten, the East Pacific High continues to weaken and migrate south. Aloft, along the boundary where short columns of cold, heavy air from the north meet the taller columns of warmer, expanding air, a strong pressure gradient produces the polar front jet stream. This high-velocity core of wind meanders from west to east within the troughs and ridges known as the upper-level Rossby waves. All of this occurs many thousands of meters (tens of thousands of feet) above the boundary between the shorter (cold) and taller (warmer) air masses at the surface. These
upper-level waves and the jet stream frequently dip south over California during winter, along with the air mass collisions near the surface that may cause storminess.

Pools of polar air masses occasionally slip south during winter months in troughs of the Rossby waves, sometimes bringing weather from the Aleutian Low. When the cold, dense air invades south, warmer lighter air is lifted over it. Abundant vertical mixing, condensation, clouds, and precipitation result, producing a glaring contrast to the stable fair weather of summer.

When Stubborn Patterns Set In
Occasionally, the winter troughs and ridges stop migrating across California. When these upper-level waves stall, surface weather remains stationary and records are often set. In 1977, a ridge of high pressure stalled over California. This blocking high sent storms far to the north. There was literally no snow pack in the Sierra Nevada at the end of the driest rainy season in California’s history. A similar series of high-pressure ridges stationed over California from the late 1980s to the early 1990s brought the longest drought in California history—six years. Both droughts devastated the state’s water supply, agricultural industry, and other portions of the economy. The first few years of the twenty-first century brought one of the worst droughts to ever hit southern California, including the driest year on record for stations such as Los Angeles. Then, following a wet 2010-2011 season, many parts of the state especially in northern and central California were recording one of their driest Decembers in 2011, a drought that lingered into 2012 in spite of some late-season spring rains.

Antithetically, when the east side of an upper-level trough is stationed over California, warm and cold air masses clash. As the warmer air is lifted in these storms, an accelerating jet stream aloft evacuates it and pulls more air up from the surface. The great floods of 1983, 1993, 1995, and 1997 and the record 1998 El Niño rains were at least partially caused by the repeated formation of deep troughs just off the coast. The result: a jet stream aloft and clashing air masses and their storms at the surface swept over California. By early 2005, similar patterns brought near record Sierra Nevada snows and one of the wettest 15 consecutive days in the history of Los Angeles and surrounding locations. These stationary weather patterns are not new to California.

More than a century ago, two years of drought, dwindling water supplies, and devastating fires came to an abrupt end after the summer of 1889. Storms began battering California in early November. More than 660 cm (260 inches) of snow fell on Donner Pass in the Sierra Nevada by the end of that December. By January 6, 1890, more than 7 m (24 feet) of snow had accumulated in Truckee.

Though Central Pacific mobilized thousands of workers

Figure 4.16 This infrared satellite image shows a powerful Pacific storm pounding California with its characteristic counterclockwise circulation. Brighter colors represent thicker, taller clouds usually associated with heavier precipitation. You can see the Pineapple Express: warm air streaming up from Hawaii especially into southern California. Just off the north coast, cold air circulates down from north to south on the back side of the storm.

Figure 4.17 This 500-mb upper-level chart was layered on a satellite image at San Francisco State University’s Web site. Notice that California is under the east side of a large, upper-level, low-pressure trough. The jet stream and moist winds accelerate above, causing air to rise and stormy winter weather.
and heavy equipment to keep tracks open, westbound trains were stalled for weeks; 200 stranded passengers died of influenza and pneumonia within one week. Western Union workers dug down 6m (20 feet) to reach the tops of poles connecting the snapped Trans-Sierra telegraph lines. Emerald Bay residents on Lake Tahoe recorded fresh snowfall every day from December 2–January 30 as nearly endless storms battered the Sierra Nevada in January and February 1890.

**Each Winter Storm is Different**

Because these winter storms may have different origins, pull in a variety of air masses, and play vital roles in shaping California’s physical and human landscapes, they deserve more attention here.

Winter storms that move from west to east out of the North Pacific (or northwest to southeast out of the Gulf of Alaska) are most common in California. Because winds spin into these surface low-pressure systems in a counterclockwise direction (the same as Earth’s rotation in the Northern Hemisphere), they are called cyclones. The storms that invade California in winter are called **middle-latitude wave cyclones**; they are large and complex, some with diameters exceeding 1,000 miles (1,600 km).

As a storm approaches the California coast from the west, southerly winds pour warm, moist air up into the storm’s east side. Often, the warm air encounters cooler air as it moves north. When the warm, less dense air is forced to gradually glide over the colder dense air, cooling causes condensation, forming mostly thick stratus clouds and often a warm front. Steady light rain and drizzle is common over a wide area of the eastern edge of the cyclone, and snow levels are usually high. As the rising air in the storm center moves toward the coast north of or directly over California, it usually has a vigorous cold front in tow.

These trailing cold fronts form in the counterclockwise spiral as cold air spins in from the north and northwest behind the middle-latitude cyclone. This denser cold air remains near the surface as it invades California and quickly lifts any warmer, lighter air in its path. The rapid lifting forms a narrow, often fast-moving but more violent cold front with vertically developed cumulus and cumulonimbus clouds. Short-duration, heavy showers and lower snow levels may also result. After most cold fronts pass, the crisp, colder, stable air eventually settles in and skies begin to clear.

When middle-latitude cyclones and their trailing cold fronts finally pass through California, they bring dramatic weather changes. Southerly winds deliver warm, moist air in ahead of the front, followed by heavy showers and erratic winds as the cold front passes. A quick shift of the wind to westerly, northwesterly, or northerly announces the passage of the front and is followed by only scattered showers of instability as the cool, crisp air finally moves in behind the storm. This is also when mountain snow levels are lowest.

Somewhat similar storms carry much warmer and moister air masses into California from the southwest. Sometimes traveling from near Hawaii to California, usually in late winter or spring, these storms pick up tremendous amounts of moisture and dump it on California’s coastal slopes. Some historical floods, including the great floods of 1969, were caused by a series of these storms. Even when storms originate farther north in the Pacific, they frequently strengthen as their typical counterclockwise circulation draws this energy and moisture up from the south. This stream of moisture is often properly named the “Pineapple Express” and has resulted in some of the wettest periods in California history.

Presentations at the annual California Extreme Precipitation Symposium (such as in 2011) have highlighted recent research, shedding light on the nature and significance of these “atmospheric rivers” (or ARs). Our Pacific Atmospheric Rivers that set up just east of our rainy season’s low pressure troughs previously mentioned are long, relatively narrow regions of horizontal air flow capable of transporting enormous amounts of water vapor from the southwest into the state. When these ARs flow up against California mountain ranges to the east of these storms, heavy precipitation can be dumped within the moist, rising air. Drought seasons have changed to flood seasons within a week as these weather patterns have resulted in some of the wettest months and years ever recorded in California.

At the other extreme, the colder and drier Inside Sliders occasionally slip directly south into inland California, often after moving over Washington and Oregon.
Winter's Radiation Fog

In the long, cold, clear, calm winter nights between storms, radiation (tule) fog often forms in inland valleys. This is very different from summertime’s coastal advection fog. When cold, dense air settles on moistened valley floors that have radiated heat energy into space, low-lying air finally cools to its dew point and condensation occurs near the surface. We are all familiar with the dew that forms on cold surfaces at night; this radiation fog might be considered an extension of that process into the air that has also finally cooled to its dew point. Radiation or tule fog often burns off in the next morning’s sunlight, especially in southern California’s inland valleys.

However, in the Central Valley during especially long winter nights, the tule fog may form and thicken until visibilities are near zero. Often, when most of California is experiencing clear winter weather, the blanket of fog in the Central Valley is so thick that it does not burn off even during afternoons. The winter sun is often not intense enough; it makes a brief appearance and stays low on the horizon. These fog episodes may last for days, when high and low temperatures near such cities as Stockton, Modesto, and Fresno never change from a few degrees above freezing in blankets of fog hundreds of meters thick.

The persistent fog creates extremely hazardous driving conditions, especially along such highways as I-5 and Hwy. 99. Accidents have involved multiple injuries, deaths, and more than 100 vehicles at a time. This fog has also been found to impact the mental health of some Central Valley residents. Radiation fog does not form in California’s inland valleys during summer, when warmer air masses maintain H₂O in the vapor state.

Because these storms are so cold and have already swept onto land, they usually do not produce as much precipitation, but they may usher record cold air into California from the north. These Inside Sliders occasionally produce impressive but relatively dry snowfalls in the Cascades, Sierra Nevada, and Basin and Range and even into southern California mountains as they slide south along troughs through transmontane California and the backsides of the mountains. The term “Tonopah Low” is often applied when they settle over western Nevada.

Though the winter season brings the rainy season, we now recognize that this rainy season is usually characterized by alternating periods of mild weather interrupted by periodic storms of many different types and intensities. Milder weather usually dominates and lasts longer to the south, while stormier weather usually arrives earlier and stays longer farther north.

Spring Changes in the Air

As spring approaches, the sun rises higher each day, solar radiation becomes more intense, and the East Pacific High begins to strengthen and bulge farther north. Gradually, the jet stream and the waves of storms are pushed north and become less frequent in California while high pressure builds a little stronger.

Recent studies have shown that infrequent, but stubborn, late-season storms may combine with the increased spring surface heating to produce rare violent weather, even tornadoes, in California flatlands. Tornadoes are rare in California because of the dominant stable air masses. There is also the absence of extremely warm, moist tropical air to do battle with bitter cold, arctic air. The warmer maritime tropical (mT) air masses are modified because they must pass over the cold California current before reaching the state. Continental polar (cP) and arctic air masses are normally blocked and modified by mountain barriers before they reach California. However, a few water spouts and tornadoes form each year in freak storms that bring unusually unstable air to the state. You may hear about one of these tornadoes that might touch down in the Central Valley, Los Angeles Basin, or nearby coastal or inland valleys. They do not rival in power or frequency the ominous tornadoes of the central United States.

While inland areas begin to heat very rapidly in the spring sun, the East Pacific High builds over ocean water still cool from winter. This sets up a strong temperature and pressure gradient as closely spaced isotherms and isobars trend nearly parallel to the coast and roughly northwest-southeast across California. The cooler, denser air flows off the ocean from the high pressure and pours into the hot, expanding air of the developing thermal low pressure inland. Strong sea breezes and thick, stable marine layers with low stratus and fog keep coastal valleys cool, often into June, except for a few interruptions from early season heat waves. Southern Californians sometimes refer to this as “June gloom.”

Soils often become saturated only by late winter and early spring in California, following the cool rainy season. This paves the way for an explosion of new plant growth from mountain slopes to coastal hills and from valley grasslands to the deserts. Depending on temperatures and the amount and timing of precipitation, spring delivers some of the most beautiful wildflower displays in the world to parts of California. Meanwhile, as winter’s mountain snows melt, reservoirs fill with precious water for California’s farms and thirsty residents. By late spring, weather patterns have ushered
Advection (coastal) fog in the marine layer is a more gentle and more predictable player in California’s weather and climate. Along the coast, it has been romanticized, loved, and hated. Its fingers roll into coastal valleys; it pushes against, surrounds, then cascades down coastal hills. It is nearly a constant factor in summer coastal weather forecasts, especially toward the north.

We previously noted how this fog forms in the chilled air moving across the cold California current. It is not surprising that the fog becomes more persistent to the north, where colder water temperatures more commonly cool the air to its dew point. Frequently, especially along the northern California coast, the cool sea breeze brings fog, which replaces air that would have been warmed on a sunny summer day.

Even in southern California, when summer afternoon temperatures approach 38°C (100°F) in the San Fernando Valley, the shallow, cool sea breeze and fog may hold temperatures below 21°C (70°F) just 16 km (10 miles) across the narrow Santa Monica Mountains barrier, along the Malibu coast. Similar summer temperature contrasts occur between the cool, often foggy Laguna coast and the hot valleys on the inland side of the Laguna Hills. Similar contrasts are also common in parts of northern and central California. The string of cities and valleys connected by Hwy. 101 north of San Francisco is often isolated in searing summer heat, while cool fog blankets coastal locations on the other side of the mountains less than 32 km (20 miles) to the west.

Advection fog can be relentless when it piles against Big Sur’s coastal hills, or pours into the Salinas Valley from Monterey Bay, or envelopes Fort Bragg, Eureka, and Crescent City in a dull, gray mist. It is most impressive as it funnels through the Golden Gate (the only major, complete gap in the Coast Ranges) past San Francisco, across the bay, and sometimes even into the Carquinez Strait toward the Central Valley. Because San Francisco’s peninsula juts directly into the Golden Gate, the City is famous for getting in the fog’s way as it races inland through and around San Francisco, over the bay, and past Alcatraz. It pushes up and against the Oakland/Berkeley Hills. Though they are located on the east side of the bay, these cities get a direct hit from the sea breeze and fog funneled through the Golden Gate; their summer afternoons often remain as cool as San Francisco’s.

In northern and southern California, as it moves toward the normally hot, drier inland valleys during the afternoon, the mixture of fog or low stratus thins, then evaporates in the warmer air. Later, when the land cools after sunset, it marches and spreads into inland valleys, only to be burned back toward the coast by the next morning’s summer sun. These diurnal advances and retreats lay the framework for the monotonous “late night and early morning low clouds and fog—otherwise mostly sunny” weather forecasts repeated throughout the summer in California’s largest coastal population centers.

This marine layer and its fog and stratus delivers the cool, mild summers famous along California’s coast. Particularly along the north coast, it cuts evapotranspiration rates and provides moisture for plants and animals during the summer drought. Fog drip to the soil from trees catching this moisture has been measured at more than 25 cm (10 inches) per year along the northwest coast and even along the Oakland/Berkeley Hills. Without this advection fog, many plant communities along the California coast (including the coast redwood forest) could not survive.

Summer’s cool marine layers and its advection fogs are also indirectly responsible for the culturally famous California tan and some of the highest skin cancer rates in the
in high pressure and set the stage for California’s summer drought season. The annual cycle continues.

**AIR POLLUTION**

**Southern California and the Los Angeles Basin**

A combination of natural factors often concentrates California’s air pollution into local basins. We’ve already examined some of these factors. The classic example is in the Los Angeles Basin, especially where it extends into the San Fernando, San Gabriel, and Pomona/Walnut Valleys and finally farther east into the inland valleys surrounding San Bernardino and Riverside. The pollutants come from the cars, factories, and daily activities of more than 15 million people.

On many days, especially in summer, air sinks down from the dominant high-pressure cell aloft. As it heats by compression, it forms a warm, dry lid of less dense air above the basin. Below this lid is the persistent marine layer, that relatively cooler and denser layer near the surface. This produces one of the most stable columns of air in our troposphere; the cooler, denser air remains low, and the warmer air stays above. There is very little mixing or communication between the two layers. This condition is called an inversion. The pollutants from human activities—what we call smog (smoke plus fog)—are trapped in the denser layer of air below.

Because this dense surface air is the marine layer, the sea breeze pushes it and the smog away from the coast and into inland valleys on most days, especially during summer. Eventually, the sea breeze and its smog is blocked by the high mountains that ring the basin, mostly the San Gabriels and San Bernardinos. On many days, the smog cannot escape up through the inversion, and it cannot move farther inland because of the mountain barriers. Prevailing winds keep it from moving back out toward the coast, and it remains trapped in the valleys.

Other natural factors may now join the drama. Remember that the high pressure aloft is associated with fair weather. Below it, there is little chance of rain that

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**Figure 4-20** Looking down toward Santa Barbara and the distant Channel Islands, you can see patches of coastal fog drifting along the coast. This advection fog condenses over cold water currents and hugs the coast as local eddies keep it moving in patterns.
Most of the state’s more than 38 million people are concentrated within valleys with stagnant air, and they are often forced to breathe the variety of toxic pollutants produced by industries, transportation, and other activities. Most air pollutants are so toxic, they must be measured in parts per million (ppm), some in even smaller fractions.

Ozone (a molecule with three oxygen atoms) is a photochemical air pollutant. Concentrations far less than 1 ppm can cause eye, nose, and throat irritation; it also irritates and impairs breathing, eats away at paint, rubber, and paper surfaces, and damages plants. Severe fatigue and other serious symptoms become evident at concentrations above 1 ppm.

Ozone can be produced in California cities when nitrogen dioxide (NO₂) is exposed to sunlight. Nitrogen dioxide, belched mostly from automobiles and power plants, is a brownish gas that impairs breathing and damages the lungs. In sunlight, atomic oxygen liberated from NO₂ combines with an oxygen molecule (O₂) to produce ozone (O₃). Remaining nitric oxide (NO) molecules react with hydrocarbons to form a host of other air pollutants.

Carbon monoxide (CO) is produced by incomplete combustion. It is an invisible gas that reduces the blood’s oxygen content and can eventually cause carbon monoxide poisoning. There are several other air pollutants that Californians must endure. They range from complicated peroxyacetyl nitrates (PAN) to simpler sulfur oxides. Though acid fog episodes have been recorded in the state, acid precipitation has not been as problematic as in the northeastern United States or European locations; prevailing winds bring cleaner clouds and precipitation from the Pacific.

Particulates of all kinds are produced from natural (such as dust, salt, and smoke) and human (such as trucks, tractors, and trains) sources in the state. Anyone who has experienced the thick, dark smoke expelled behind a malfunctioning diesel engine understands the problem carbon particles represent in our cities. These particulates not only reduce visibility, but they may invade deep into the lungs and cause a range of dangerous and deadly respiratory problems. These soot clouds are most noticeable downwind of major cities in the state’s inland valleys.

Following nearly 10 years of research, the state Air Resources Board finally declared diesel soot a cancer-causing pollutant in 1998. Officials immediately faced a more challenging problem: how to require cleaner diesel engines without creating unnecessary hardships for diesel users. Decreasing combustion and building cleaner, more efficient engines are vital steps to remedying the particulate problems that cause air pollution.

Controversy erupts when pollution control efforts focus on specific polluters, as illustrated by the trucking and shipping industries’ reactions to regulations designed to increase the efficiency of California’s trucks and cut diesel exhaust on our highways and in our ports. As these industries resist pollution controls, repeated scientific studies demonstrate that hundreds of thousands of people (particularly more vulnerable children) in California suffer from respiratory diseases and other health problems caused especially by breathing in finer particulates that easily enter their lungs. Most of these victims live near freeways and port facilities. Pollution control efforts and the controversies will carry through the twenty-first century.

Another controversy erupted at the end of the twentieth century when studies revealed that recreational watercraft spewed more than 750 tons of hydrocarbons and nitrogen oxides into California’s air during the average weekend. That represents about 50 percent more pollution than all the cars on California roads produce during a weekend. Local air district boards and the state Air Resources Board had finally found an explanation for the stubborn air pollution levels common near and downwind from these recreational areas. Efforts to require cleaner-burning Jet Skis and other recreational watercraft have been met with opposition from manufacturers and some consumers.
smog that sloshes up mountain slopes from cities below during hot summer afternoons.

**Other California Valleys Trap Smog**

It is clear that most California beach cities get the first fresh blast of sea breeze during most of the year, especially during summer, and their air quality is acceptable most of the time. However, it is a different story for California inland valleys downwind from major pollution sources. San Diego County’s inland valleys are good examples of pollution havens. Years ago, the city of San Diego’s population soared well over one million. As it and its neighbors continue to grow, commuters and industries spew out air pollution. Most of it drifts east, accumulating in pockets many miles inland from the coast, trapped against mountain barriers.

The San Jose area and Santa Clara Valley are also examples of air pollution reservoirs. The sea breeze pours around mountain barriers, through the Golden Gate, and pushes south over great Bay Area cities (all the cities around the bay) until it reaches the most populated—San Jose. Here, the air and its pollutants are often trapped by the surrounding hills and a familiar summer inversion. Inland valleys of the East Bay into Livermore may suffer from similar conditions as do some inland valleys of the North Bay.

In the 1990s, the Bay Area was taken off a national list (published by the U.S. Environmental Protection Agency) of metropolitan areas with major air pollution problems, and residents boasted about having some of the cleanest air of any major American population center. Unfortunately, ozone levels increased again in 1998, and the area was placed back on the EPA list of cities with polluted air. The culprits included more frequent inversions and a growing population and economy that put more cars on Bay Area freeways. Bay Area residents and officials, like their counterparts in Los Angeles, have learned that persistence is required in the battle against air pollution. By 2012, the Bay Area’s average air quality remained considerably better than the L.A. area and it had improved over the last few decades. Still, each year’s weather patterns help determine whether pollutants such as ozone and particulate matter concentrations exceed stricter federal standards at each of their monitoring stations.

Meanwhile, the combination of population growth and agricultural activity in the Central Valley has created one of the worst air pollution problems in the United States, especially in the San Joaquin Valley. As that same summer sea breeze pushes into the valley from the Bay Area, it gathers pollutants. The breeze pushes south and is trapped by the inversion and the surrounding mountains in the southern San Joaquin Valley. The big cities of the valley, such as Fresno and Bakersfield, add to the residue spewed by the agricultural industry. During the hottest summer days, when the air tries to rise and break through the inversion, the pollutants have been traced up the western slopes and canyons of the Sierra Nevada. Here, they inhibit plant growth and have damaged forest species such as Sequoia seedlings. Officials in Sequoia/Kings Canyon have measured the worst air pollution of any national park. This is nothing new to California; entire forests have been destroyed by air pollution creeping up the slopes and canyons of the San Gabriel and San Bernardino Mountains from the Los Angeles Basin during hot summer afternoons.

Even the Coachella and Imperial Valleys trap dangerous air pollutants. The mixture of urban and agricultural activities produces a host of pollutants much like the Central Valley’s until hot afternoon temperatures break the inversion and vent the cooked stew.

**California’s Climates**

Before we examine California’s plants and animals, we should take a closer look at the different climates around the state and the factors that contribute to and control them. We will use our understanding of California weather patterns to explain why these climates exist and how they evolved.

Climate classification has always been a difficult and controversial job, especially in California. First, particular types of climate data and classifications serve specific needs. Biologists, farmers, hydrologists, tourists, architects, city planners, utility workers, and so many others are interested in different elements of weather and climate in California.

Second, it is especially crucial in a state like California to establish the scale of climate study. The larger regional climates (macroclimates) cover and connect the most general, somewhat homogeneous, climatic regions of the state. Local climates cover smaller areas and envi-
environments, such as hillside slopes, canyons, river valleys, basins, and mesas. Microclimates are the miniature environments found near the ground at specific sites next to rocks, trees, buildings, or other features that impact climate on the smallest scale.

We will use the Köppen system of regional climate classification because it is the most widely used and understood, and it uses conveniently recorded values showing annual trends of temperature and precipitation. The boundaries of these climate groups may also roughly coincide with major vegetation types, a subject of Chapter 5. The Köppen system uses a shorthand code of letters to place regions into major climate groups, then subgroups with smaller subdivisions, all based on seasonal temperature and precipitation patterns.

No Tropical Climates in California
There are no “A” (tropical rainy) climates in California because every location experiences seasons with the temperature of at least one winter month averaging (a monthly mean) below 18°C (64.4°F). Maritime tropical air masses (mT) are greatly modified before reaching California, so they only affect local areas for brief periods. Tropical air flowing from the southwest is chilled by cold ocean currents before reaching California. This air can even be cooled until it takes on characteristics of maritime polar (mP) air masses. Meanwhile, air from the south or southeast must pass over great land masses and even mountain barriers before reaching the state. It is often modified so that it resembles dry, hot (cT) air masses.

The Driest Climates: California Deserts
A variety of “B” (dry) climates exist trending toward southeastern California, where cT (dry, hot continental) air masses dominate in the summer and even some cP (dry, cold continental) air masses invade and settle in during winter. These are regions where potential evapotranspiration rates exceed precipitation during the year (there is no water surplus) and no major permanent streams originate. Located near the dominant subtropical high and behind major mountain barriers that create great rain shadows, these are the driest places in California and North America. Any moist air mass encroaching into these regions is drastically modified and dried by the time it sinks into these low desert valleys.

In the southern San Joaquin Valley and throughout southeastern California, BWh (true hot desert climates) exist where precipitation is less than one half of potential evapotranspiration, and the average temperature of even the coldest month is above freezing. A hotter division of this climate (BWhh) exists where average maximum temperatures exceed 38°C (100°F) for at least 3 months. These very hot deserts are found in lower desert valleys from Death Valley to the Colorado River and in the Coachella and Imperial Valleys.

Interestingly, a few of these locations are the only places in California that often experience peak precipitation (though with meager totals) in late summer rather than winter. (The causes and dynamics of these summer thunderstorms have already been reviewed.) Regardless, summer afternoon temperatures may soar over 49°C (120°F); the hottest temperature ever recorded in California and North America was nearly 57°C (134°F) in Death Valley.

Semiarid California
Bordering the driest climates and scattered within southern California’s inland valleys and along its extreme southern coastal strip are the semiarid steppe (BS) climates. Here, precipitation is more than one half of (but still less than) potential evapotranspiration rates. This is an intermediate climate between the true deserts and more humid climate groups. Therefore, these landscapes often support grasslands and are somewhat wetter and often cooler than California’s true deserts.
These include the higher elevation rainshadow, semiarid deserts of transmontane California, ranging from the higher elevations of the Mojave, north into the Owens Valley and other parts of the Basin and Range. Precipitation is greater and temperatures are cooler than the hot, dry deserts below them; evapotranspiration rates are not as extreme. The BSh climate’s coldest month averages above freezing, or the mean annual temperature is over 18°C (64.4°F). Still higher terrain exhibits BSk (cool desert) climates, where the average temperature of the coldest month is below freezing, or the mean annual temperature is below 18°C (64.4°F); these often trend into the colder, wetter, higher elevation mountain climates.

In inland valleys of cismontane southern California (including the southern San Joaquin), BSh climates experience occasional invasions of moist air, but summers are usually hot and dry. They are bordered by cooler and wetter Mediterranean climates. Along the coast from Orange County south, the BShn is a foggy, coastal, semiarid zone. With annual precipitation around 25 cm (10 inches), it is drier than the classic Mediterranean coastal climate to the north. However, coastal stratus and fog are common, especially in summer as the ocean air moderates temperatures and cuts evapotranspiration rates.

**Mediterranean Climates**

Most renowned and widespread in California are Mediterranean climates. They are categorized under the mild, mesothermal middle-latitude “C” climates, where the average coldest month (mean monthly) temperatures drop below 18°C (64.4°F), but remain above −3°C (26.6°F) and where precipitation is often greater than evapotranspiration. In California, all of these are more specifically “Cs” climates, or mild humid climates, where intense summer droughts give way to winter rainy seasons. In some years in southern California, more than 5 months may pass without measurable precipitation. These climates dominate cismontane California at lower and middle elevations from the coast up the mountain slopes, from the Oregon border to southern California. These environments typically experience severe fire seasons from summer well into fall.

When the East Pacific High builds north in late spring and dominates through the summer, it protects cismontane California from storminess and precipitation. The clockwise winds spiraling out of this high pressure then push the cold California ocean current down the coast. As these prevailing winds are pulled inland toward California’s hot thermal low, they must first pass over this current, where they are chilled. The cool, dense sea breeze that moves onshore may carry plenty of low stratus and fog, but it is very stable.

This further inhibits the formation of storms or any type of unsettled weather. The monotonous “late night and early morning low clouds and fog—otherwise mostly sunny” forecast is typical of these Mediterranean coastal climates, especially during summer. During winter, the East Pacific High weakens and migrates south. At this time, the polar front jet stream slips south and low pressure disturbances invade from the North Pacific. California’s winter rainy season results.

Hot summers rule in Csa climates of the inland valleys; the average temperature of the warmest month is
greater than 22°C (72°F). These regions are far enough inland or protected by small topographic barriers so that summer's cooling sea breezes are weaker and modified by the time they arrive. These often border the Csb (cooler summer) climates of higher elevations or coastal zones, where the warmest month averages less than 22°C (72°F). More distinctive are the Csbn climates along the immediate coast, where persistent coastal fog and stratus clouds keep summers even cooler. Recall that this is due to the cold California ocean current that keeps coastal air masses chilled and near their dew points during summer.

**Mountain Climates**

Classified as “D”s are the microthermal (snowy forest) climates, where the average temperature of the coldest month is less than −3°C (26.6°F). These are only found at higher elevations in the Klamaths, Cascades, Sierra Nevada, and near southern California’s higher ridges and peaks. Heavy snow is common and substantial snow packs accumulate during the winter storm season, due to orographic effects. However, studies have shown that most of the annual precipitation falls only within several days during winter’s most severe storms.

During summer, rare North Pacific storms might sneak into the north. Isolated afternoon thunderstorms (especially toward the south) may also provide brief relief from summer drought. However, they do not produce significant or reliable precipitation compared to winter storms. This is an interesting and rare variation from the more common “D” climates around the world, which usually have winter dry seasons or no dry season at all. The average warmest month in Dsb climates is less than 22°C (72°F); summers are not hot. At still higher elevations, the Dsc climates average fewer than four warm season months with temperatures above 10°C (50°F).

Finally, California’s “EH” climates are the highland climates similar to the worldwide arctic or alpine class, often known as tundra climates. Average temperatures of the warmest month are less than 10°C (50°F) and winters are bitter cold. Winter’s high winds and temperatures below −18°C (0°F) make these hostile places. These climates are only found on California’s highest peaks and ridges above the tree line. Once winter and spring snows finally melt, the water frequently drains into forests of lower elevations, making way for short, harsh growing seasons, where weather swings between extreme conditions in the rarefied air. Brief frost or violent thunderstorms may interrupt the summer drought at any time.

◆ **CALIFORNIA’S CHANGING CLIMATES**

From the warm tropical climates of millions of years past to the cooler Ice Age, which ended more than 10,000 years ago, what we now call California has experienced dramatic climate changes. Even during the last 150 years of record-keeping, there have been impressive annual variations in temperatures, while fluctuations between intense flood and drought have been even more remarkable.

In recent years, these fluctuations have become more pronounced as anomalous weather patterns become the rule and “normal” seasonal patterns less reliable. As additional years of records accumulate, we might expect the chances of breaking records to decrease. However, there is a lengthening list of recent anomalous weather patterns and events. We can start with the longest drought during the six years from the late 1980s to early 1990s and the record-breaking downpours, floods, and snowfalls of 1995, 1997, and 1998, some that included open ski resorts well into July. These events caught the attention of farmers, insurance companies, biologists, flood-control officials, water departments, the tourist industry, and, of course, climatologists. There are many more examples. Here is a brief summary (in chronological order) of some of the more recent events up to 2012 just to make a point.

Two weeks of torrential rains flooded northern California valleys in early 1997. The rains stopped early that year, leaving many parts of the state dry after mid-February; it did not rain in Los Angeles from mid-February until fall. It was the longest period without measurable rain in that city’s history. This was immediately followed by the 1998 El Niño downpours. Several stations up and down the California coast (including San Francisco, Santa Barbara, and UCLA) recorded their wettest years in history. Several northern California communities received well over 100 inches of rain, while well over 50 inches of rain poured over the Santa Monica Mountains in southern California. Even Death Valley experienced the wettest season on record in 1997–1998. The first years of the twenty-first century brought one of the worst droughts in southern California history, including the driest year on record for many locations. Then, 2005 started with near-record snow in California mountains and one of the wettest 15 consecutive days in southern California history. By April 2005, several southern California communities had recorded their second-wettest season in history, including L.A., with over 36 inches of rain. Following the persistent rains and impressive snowpacks of 2011, December of that year was one of the driest on record in many California cities; by January 2012, the only snow on the ground in many high country locations like Mammoth Mountain was coming out of snowmaking machines on the ski slopes. Skiing through July one year and no snow on the ground in January on another, record drought followed by record floods: by now you get the point; recently, the records just keep on breaking. We will apply some basic geographic concepts to better understand these changes in Chapter 12.
EL NIÑO/SOUTHERN OSCILLATION

Many scientists blame El Niño for some of California’s unusual weather events, and certainly for the 1998 episode. During average years, rising air in the Intertropical Convergence Zone (ITCZ) near the equator pulls the trade winds into the Equatorial Low. South of the equator, the Southeast Trades push the cooler waters from the Humboldt Current from south to north up and along the coast of South America and then along the equator toward the western Pacific. Likewise, the Northeast Trades (north of the equator) also push the remnants of the California current toward the equator and then into the tropical West Pacific.

During rare years, around December, air pressure rises in the West Pacific, the Equatorial Low weakens, and the trade winds subside. This is called the Southern Oscillation. The combined effects on the ocean and the atmosphere are often referred to as El Niño/Southern Oscillation (ENSO). Westward flowing ocean currents near the equatorial Pacific also slow and back up, and the cooler Humboldt and California currents may begin to wane. Large pools of warmer water form in the eastern tropical Pacific and begin backing toward Central and South America, baking in the sun (see Figure 4-25).

Sea levels rise in the warmer-than-normal water of the eastern tropical Pacific, and large masses of exceptionally warm moist air form over the water during these El Niño events. The amplified contrast between this super warm water and air and the colder water and air of the North Pacific often brings the jet stream farther south, sometimes directly over California. When a series of winter storms forms in the Pacific, they are often guided toward California by that enhanced jet stream. Moving toward the coast, they frequently tap the heat energy and moisture from these unusually warm tropical air masses, pulling them up into their counterclockwise circulations. Now strengthened, the storms carry this tropical air in ahead of them to California, where heavy downpours are produced as they sweep through the state.

Although many factors must come together for such storms to target California, the floods of 1983, 1993, 1995, and 1998 did occur during enhanced El Niño events. During those winters, satellite images dramatically showed pools of warm, moist air flowing into California from the heated tropical Pacific, ahead of almost every major storm. This “pineapple connection,” often carried in by a subtropical jet stream, produced record downpours in California.

The 1998 ENSO was the best predicted and arguably the most substantial of all previous events. Meteorologists, climatologists, and oceanographers were already predicting it and its effects during early summer, 1997, before it fully developed. In an unprecedented show of solidarity, these scientists warned of the possible downpours. Their predictions became reality with the wettest February in Los Angeles history and the wettest season ever recorded in many communities from northern California to Orange County, including all-time records in San Francisco and Santa Barbara. Several California mountain communities added impressive snowfalls to that record. Scientists had progressed all the way from being surprised by the 1983 ENSO to predicting the 1998 event. The millions of dollars spent to prepare the state saved both lives and many more millions of dollars in private and public property damage.

El Niño does not always mean flooding in California, but it is repeatedly and more frequently blamed for many weather anomalies in the state. In contrast, a La Niña is recognized during years when eastern Pacific waters are unusually cooler than normal. As expected, this opposite of El Niño often results in very different weather patterns, including drought in southern California as torrential rains ravage the western Pacific. By the end of the 1990s, a substantial La Niña had replaced the historic El Niño of 1998. In contrast to 1998, Los Angeles received less than 4 inches of rain by mid-February 1999. Drought had returned to southern California in an unpredictable cycle that can change in a day.

Recent research indicates that ENSO is one of the most important weather makers on our planet. It is blamed for weather anomalies (such as a decrease in hurricanes in the Atlantic) thousands of miles from Pacific waters. It certainly deserves the attention given to it by scientists all over the world. Numerous other cycles and variables are gaining attention. One example is the Pacific Decadal Oscillation (PDO), which brings cooler water to the California coast that may last for decades.

Figure 4-24 This old photo from 1983 (displayed near the end of the rebuilt pier) shows the devastated Santa Monica Pier after waves more than 30 feet high came ashore with a storm surge. This and the 1997-98 season were the most powerful El Niño years recorded up to 2012.
El Niño/Southern Oscillation (ENSO) occurs when unusually warm water accumulates in the eastern tropical Pacific Ocean. El Niño and La Niña cycles may have dramatic impacts on California’s weather.

Figure 4-25 El Niño/Southern Oscillation. El Niño/Southern Oscillation (ENSO) occurs when unusually warm water accumulates in the eastern tropical Pacific Ocean. El Niño and La Niña cycles may have dramatic impacts on California’s weather.
DIVERSITY AND CHANGE DOMINATE CALIFORNIA WEATHER PATTERNS

In an article in the 2009 California Geographer, Guy King analyzed 30 years of NOAA data compiled from 257 official weather stations distributed throughout the state, but none of them at highest elevations above about 8,400 feet. Confirming the concepts covered in this chapter, you can see why southeastern low deserts and Death Valley experienced the hottest summers and highest annual means. And you can see why locations in and east of the Sierra Nevada (such as Bodie) were the coldest. The hottest and coldest temperatures ever officially recorded in the state were in Death Valley at 57°C (134°F) and Boca north of Tahoe at -42°C (-43.6°F), but stations surrounding these measure temperatures close to these extremes each year. We have also noted the incredible variations in annual average precipitation that range up to 100 inches (254cm) from place to place in the state with even greater variations in different locations from year to year.

Superficial assumptions about California’s unchanging, mild climates are blown away when these sometimes radical spatial and temporal variations are explored. These conditions make California an ideal state for the study of so many extratropical weather events and climates. Before we use this information to make connections and explore the biogeography of California, we can interpret climate data for selected weather stations around the state.

CLIMOGRAHS REVEAL CLUES TO CALIFORNIA’S MANY CLIMATES

Climographs are used to show annual variations and trends in temperature and precipitation for selected weather stations in California (see Figure 4-27a, b, c). These graphics present California climate data in an organized and easy-to-understand fashion, ready for interpretation. The commonly used Köppen classification system shows the distribution of California’s diverse climates (see Figure 4-28). The following climate graphs of selected California weather stations were compiled by Rob O’Keefe.
Figure 4-27a All graphs compiled by Rob O’Keefe.
Figure 4-27b  All graphs compiled by Rob O'Keefe.
Figure 4-27c  All graphs compiled by Rob O’Keefe.
Figure 4.28 Köppen Climate Map of California.
Chapter Four  California’s Weather and Climate

◆ SOME KEY TERMS AND TOPICS ◆

advection (coastal) fog  Great Basin High  rainshadow
Aleutian Subpolar Low  jet stream  Rossby waves
California Current  lapse rate  Santa Ana winds
catalina eddy  marine layer  smog
dew point  middle-latitude wave cyclone  temperature inversion
East Pacific (Hawaiian) High  orographic precipitation  thermal low
El Niño/Southern Oscillation (ENSO)  radiation (tule) fog

◆ ADDITIONAL KEY TERMS AND TOPICS ◆

adiabatic lapse rate  environmental lapse rate  pressure gradient
air pollution  fire season/hazard  radiation
atmospheric pressure  global circulation  sea breeze
climate change  humidity  snow level, depth
climate classification  land breeze  solar radiation
climographs  latitude factors  stable air
compressional heating  marine air mass  temperature
condensation  microclimates  temperature range
continental air mass  mountain barriers  tropical storms
coriolis effect  pineapple connection  unstable air
downslope winds  precipitation  upwelling
elevation factors

First Snow Hope Valley  by Patty Kellner