III.4 GEOLOGY AND SOILS

This chapter describes the regulatory setting and the affected environment for geology and soils, including regional topography, geology, geologic processes, seismicity, and soils, specifically as they relate to the Proposed Land Use Plan Amendment (LUPA). Ten maps and 3 tables support this chapter in Appendix R1.4. The maps illustrate soil textures within the DRECP area's ecoregion subareas, and the tables present data, expressed in acres, for the surficial geology and soil textures in the DRECP area, as well as soil textures within Development Focus Areas (DFAs) for each alternative.

III.4.1 Regulatory Setting

Federal Land Policy and Management Act

The Federal Land Policy and Management Act (FLPMA) establishes policy and goals for the Bureau of Land Management's (BLM) administration of public lands. The intent of FLPMA is to protect and administer public lands within a multiple-use, sustained-yield program that maintains environmental quality. Its greatest areas of protection are scientific, scenic, historic, ecological, environmental, air and atmospheric, and water and archaeological resources. Under FLPMA, BLM is further charged with protecting life and ensuring safety from natural hazards.

Clean Water Act

The Clean Water Act (CWA) requires that states set standards to protect water quality through the implementation of point and nonpoint pollutant source controls. The CWA requires that all construction sites larger than one acre obtain a National Pollution Discharge Elimination System permit, which requires preparation of a site-specific Storm Water Pollution Prevention Plan. Stormwater runoff from construction may contain large loads of dissolved and undissolved organic matter, suspended sediment, and chemical pollutants in construction site soils—all of which can affect water quality. A Storm Water Pollution Prevention Plan must include a site description (including a map that identifies sources of stormwater discharges on the site), anticipated drainage patterns after major grading, and areas where major structural and nonstructural measures will be employed, including areas of disturbance near surface waters and wetlands.

III.4.2 Geology and Soils within the DRECP Area

Surficial geology, geologic processes, and soil conditions and types could all either affect or be affected by renewable energy facility siting in the DRECP area. The majority of the DRECP area covers the Mojave and Sonoran desert regions of southeastern California, with areas both within and east of the Sierra Nevada mountain range. The Mojave and Sonoran deserts comprise short, scattered mountain ranges within large desert plains. These intermountain regions include playas and basins that form terminal dry lakes, alluvial fans, major dune systems, and bajadas.

III.4.2.1 Geomorphology and Surficial Geology

Geomorphology concerns the landforms and relief patterns that make up the earth's surface. Small portions of the LUPA Decision Area extend into the mountains west and northwest, but outside of, the DRECP area: the San Bernardino and Western Transverse mountain ranges (west of the DRECP area) and the Sierra Nevada mountain range (northwest of the DRECP area). Overall, about 97% of the DRECP area is in the Mojave and Sonoran desert regions of California (71% of the DRECP area is in the Mojave Desert and 26% is in the Sonoran Desert). This discussion covers the geomorphology of both desert regions in the DRECP area.

The Mojave Desert is bounded on the west by the Sierra Nevada Mountains and on the south by the San Bernardino, Little San Bernardino, and San Gabriel mountain ranges. Within the DRECP area, the Sonoran Desert is bounded on the west by the Peninsular Ranges and on the east by the Colorado River. The large mountain ranges create the rain-shadow effect that in turn creates these arid desert regions. The geomorphology of the Mojave and Sonoran desert regions is dominated by short, isolated mountain ranges within desert plains. Major landforms include mountains, plateaus, alluvial fans, playas, basins, and dunes. Basins and ranges are common in the DRECP area.

There are at least 65 named mountain ranges in the DRECP area. Many of these mountain ranges have alluvial fans, which are the fan-shaped landforms that form around the bases of mountains (Harden 2004). Where large alluvial fans join together, a broad, gently sloped alluvial plain is formed, creating a geomorphic feature known as a bajada. The intermountain areas are characterized by numerous playas and basins, which form dry lakes known commonly as playas.

There are approximately 16 named sand dune systems in the DRECP area (CEC 2012). Among the largest are the Algodones Dunes, located in the Sonoran Desert south of the Salton Sea in Imperial County. The public uses the Kelso Dunes and the Mojave National Preserve for hiking and recreation. The 16 major dune systems in the DRECP area include:

- Olancha Dunes
- Death Valley (Mesquite) Dunes
- Dumont Dunes
- Cadiz Dunes
- Panamint Dunes
- Ibex–Saratoga Dunes
- Kelso Dunes
- Palen Sand Dunes

- Algodones Dunes/East Mesa
- Danby Dunes
- Means Dunes
- Rice Valley Dunes
- Chuckwalla Valley Dunes
- Little Dumont Dunes
- Ballarat Dunes
- Salton Sea Dunes

Surficial geology concerns the surface materials that lie above bedrock; it is an important factor in soil formation and in the type and distribution of local desert vegetation. Figure III.4-1, Regional Geology, presents generalized geologic units within the DRECP area. Table R1.4-1, Surficial Geology in the DRECP area (in Appendix R1), defines the acreage of the geologic formations across the DRECP area. The table lists 39 separate geologic units, but most would not affect development of renewable energy projects. For this analysis, the most prevalent and important geologic units are described below:

1. The majority of the ground surface of the DRECP area (over 60%) is composed of alluvium, which is unconsolidated sediment deposited by flowing water in streams or sheets. Subsequent environmental processes have variably consolidated these sediments. Alluvium, shown as sedimentary rock type in Figure III.4-1, Regional Geology, is more common in the flatter regions of the DRECP area, and less common in the more mountainous areas.
2. Young volcanic rocks (where volcanoes were active within the last 2.5 million years) make up about 143,000 acres (6% of the DRECP area). These relatively young volcanic features include:
    a. Cima, Amboy-Pisgah, and Turtle Mountain features in San Bernardino County.
    b. Pinto Basin–Salton Creek in Riverside County.
    c. Obsidian Buttes in Imperial County (Harden 2004).
3. Sand dunes make up relatively small portions of the DRECP area but still account for substantial acreage. Sand dune deposits comprise about 3% (approximately 707,000 acres) of the DRECP area.
4. The extent of landslide deposits within the DRECP area is small. The generally flat topography of the desert limits the potential for landslides.

III.4.2.1.1 Physiography and Geologic Setting

III.4.2.1.1.1 Cadiz Valley and Chocolate Mountain Ecoregion Subarea

The Cadiz Valley and Chocolate Mountains ecoregion subarea occupies the northeastern portion of the Colorado Desert. It extends from the Colorado River in the east to the Eagle

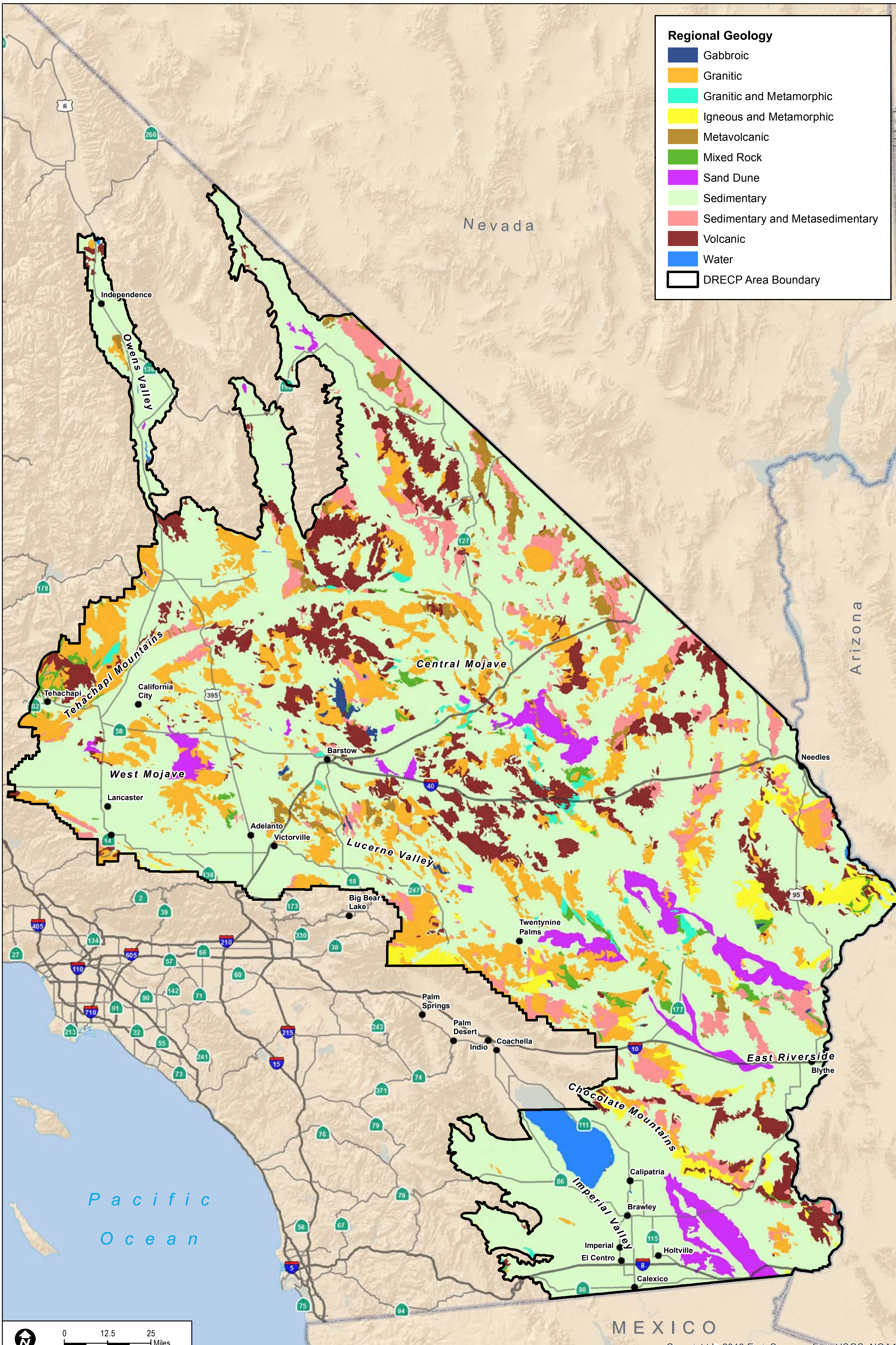
Mountains, Coxcomb Mountains, and Bullion Mountains in the west, and from the Chocolate Mountains and Orocopia Mountains in the south to the Whipple Mountains, Vidal Valley, Turtle Mountains, Cadiz Valley, and Old Woman Mountains in the north.

The geologic structure in this ecoregion subarea is complex and reflects the regional juxtaposition of large-scale tectonic forces from the transform faulting and rifting to the south along the San Andreas Fault Zone and the crustal extension to the north in the Basin and Range province. The southern mountain ranges (e.g., Chocolate Mountains and Chuckwalla Mountains), therefore, have a general northwest–southeast alignment, parallel to the San Andreas Fault Zone, while the northern mountains (e.g., Iron Mountains and McCoy Mountains) trend more north–south in keeping with the general structural trend of the Basin and Range province. The oldest rocks in the ecoregion subarea are Precambrian metamorphic rocks in the core of the Chocolate Mountains, Chuckwalla Mountains, and Big Maria Mountains.

These rocks were intruded into and altered by Mesozoic plutonic rocks. In the Chocolate Mountains, surprisingly young (~23 Ma [Ma denotes *million years before the present*]) plutonic rocks have also contributed to alteration of the older rocks in this area. Extensive sequences of volcanic rocks of roughly the same age occur in the eastern Chocolate Mountains, Palo Verde Mountains, and Black Hills. There are also younger Miocene fanglomerates and Pliocene nonmarine sedimentary rocks in these southern mountain ranges, as well as in the southeastern Whipple Mountains on the north side of Vidal Valley. The geology of the Palen Mountains and McCoy Mountains is unusual for the California desert region since it contains a thick sequence of late Mesozoic (~120 to 65 Ma) nonmarine sedimentary rocks (the McCoy Formation). The broad valleys in this ecoregion subarea have been substantially filled with Quaternary (~2.5 Ma to recent) fluvial, alluvial fan, and lacustrine deposits from adjacent mountain ranges. Several periods of deposition, uplift, and erosion are recorded in these deposits, which can be differentiated between older Quaternary alluvial fan sequences and those still being formed today. As with other desert areas, there are several dry playa lakes on the valley floors.

III.4.2.1.1.2 Imperial Borrego Valley Ecoregion Subarea

The Imperial Borrego Valley ecoregion subarea encompasses the majority of the Salton Basin between the Chocolate Mountains and San Andreas Fault Zone in the east and the eastern flanks of the Peninsular Ranges in the west. The Salton Sea forms a substantial part of the northern portion of this ecoregion subarea, while the Anza-Borrego Desert State Park and the Ocotillo Wells State Vehicular Recreation Park encompass large areas of the western portion.



Sources: ESRI (2014); CEC (2013); BLM (2013); CDFW (2013); USFWS (2013); CA Geological Survey (2011)

FIGURE III.4-1

Regional Geology

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The central portion of this ecoregion subarea is characterized by low-relief topography associated with the Pleistocene to Holocene (~37 to 0.5 thousand years before the present) Lake Cahuilla. In the east lies the Algodones Dune field; in the west the Vallecito and Coyote mountains separate the Borrego Badlands, Carrizo and Vallecito Badlands, and the Yuha Basin, respectively. These western valleys contain deformed sequences of late Miocene (~6 Ma) through middle Pleistocene (~0.7 Ma) marine to nonmarine sedimentary rocks. These rocks record the opening and flooding of the proto-Gulf of California during the late Miocene (~7 to 6 Ma) and the initiation and westward progradation of the ancestral Colorado River Delta during the Pliocene (~4.5 to 2.5 Ma). They also show the cyclical formation and desiccation of large perennial lakes formed by periodic changes in the flow of the Colorado River during the Pleistocene and Holocene (~2.5 Ma to 0.4 thousand years before the present). Today, as much as 2,000 square miles of the ecoregion subarea lie below sea level, protected from marine waters of the modern Gulf of California by the sediment "dam" formed by the Colorado River Delta.

III.4.2.1.1.3 Kingston and Funeral Mountains Ecoregion Subarea

The Kingston and Funeral Mountains ecoregion subarea encompasses the northeastern portion of the DRECP area and is a western extension of the Basin and Range province into California. It extends from the California-Nevada border in the east to Amargosa Mountains, Silurian Valley, and Old Dad Mountains in the west, and from Ivanpah Valley and the Kelso Dune Field in the south to the Grapevine Mountains and Funeral Mountains in the north. As a western extension of the Basin and Range province, this ecoregion subarea is characterized by a series of northwest-trending mountain ranges and intervening valleys, each bounded by frontal faults that have uplifted the ranges and downdropped the basins. This general geologic structure also continues into the adjacent Panamint and Death Valley ecoregion subarea and the Mojave and Silurian Valley ecoregion subarea.

The geology of the mountain ranges in this ecoregion subarea is somewhat more complex than in other parts of the DRECP area. This area includes very ancient, marine sedimentary rock units of Proterozoic (~>1000 Ma) and Paleozoic (~540 to 250 Ma) age that have not been subjected to the intense metamorphic conditions that have altered similar aged rocks farther west in the Mojave Desert. The geologic history of the valley areas, however, is similar to that of other areas in the Mojave Desert and primarily reflects internal drainage systems with streams and alluvial fans flowing off uplands to fill adjacent basins. As is often the case, these internal drainage systems culminated during the Pleistocene, forming local pluvial lakes that in some cases became interconnected, especially along the Amargosa River drainage.

III.4.2.1.1.4 Mojave and Silurian Valley Ecoregion Subarea

The Mojave and Silurian Valley ecoregion subarea encompasses much of the central portion of the Mojave Desert from Silurian Valley and Soda Valley in the east to the Rand Mountains, Gravel Hills, and Calico Mountains in the west, and from the Manix Basin in the south to Pilot Knob Valley, the Granite Mountains, and the Avawatz Mountains in the north. Topographically, the region is similar to the adjacent Kingston and Funeral Mountains ecoregion subarea.

The ecoregion subarea is characterized by a series of generally northwest-trending mountain ranges and intervening valleys, each bounded by frontal faults that have uplifted the ranges and downdropped the basins. However, east–west trending mountain ranges to the north (e.g., Rand Mountains, Granite Mountains, and Avawatz Mountains) cut across this general northwest structural grain and are largely the result of tectonic forces from the Garlock Fault.

III.4.2.1.1.5 Owens River Valley Ecoregion Subarea

The Owens River Valley ecoregion subarea is the smallest ecoregion subarea in the DRECP area and is confined to the floor of Owens Valley between Little Lake on the south and Tinemaha Reservoir on the north. The Owens River traverses the valley from north to south and flows from its headwaters in the Sierra Nevada Mountains and Inyo Mountains into Owens Lake. Since 1913, a majority of this flow has been diverted to the Los Angeles Basin via the Los Angeles Aqueduct. Owens Valley lies in the western part of the Basin and Range province and is a downdropped basin between the White and Inyo mountains to the east and the Sierra Nevada Mountains to the west.

The Owens Valley floor itself is relatively flat for much of its length and width, but is punctuated in places by resistant igneous rocks of both plutonic and volcanic origin. At the Alabama Hills in the center of the valley, the Central Owens Valley Fault has offset Cretaceous-age plutonic rocks of the Sierra Nevada Batholith and older Mesozoic metasedimentary rocks. Farther north in the valley, a series of well-preserved Pleistocene cinder cones and volcanic flows is located on either side of the valley floor. Owens Lake occupies the southern portion of Owens Valley and is today a mere shadow of its Pleistocene, pluvial self. Younger and older Pleistocene lacustrine deposits in this area attest to the former size of Owens Lake, which at it maximum inundation was over 300 feet deep. There are extensive accumulations of Pleistocene and Holocene volcanic rocks in the Coso Range east of Owens Valley.

III.4.2.1.1.6 Panamint Death Valley Ecoregion Subarea

The Panamint Death Valley ecoregion subarea encompasses the western corner of the Basin and Range province and consists of a north–south trending series of down-dropped basins (e.g., Death Valley and Panamint Valley) separated by block-faulted mountain ranges (e.g., the Amargosa Range, Panamint Range, and Argus Mountains). For the most part, the uplifted mountain ranges are excluded from this ecoregion subarea, which primarily includes only the elongate valley floors of Death Valley, Panamint Valley, and Searles Valley. The major uplands regions are located to the south and include the Owls Head Mountains, Quail Mountains, Slate Range, Spangler Hills, and El Paso Mountains.

The general east–west trending Garlock Fault controls the topography along the southern boundary of this ecoregion subarea. The oldest rocks are erosional remnants of Precambrian metamorphic rocks in the southern Panamint Range. There are limited amounts of Paleozoic marine sedimentary rocks on the northern part of the Slate Range and in the eastern portion of the El Paso Mountains. Plutonic igneous rocks of Mesozoic age are widely exposed in the Owls Head Mountains, the Slate Range, the southern Argus Range, and the Spangler Hills. There are localized remnants of Mesozoic roof pendants, altered by intrusion of younger Mesozoic plutonic rocks, in the southern Panamint Range. Cenozoic volcanic rocks are concentrated over a broad area in the Quail Mountains and the southern Panamint Range, while Cenozoic sedimentary rocks have a more patchy distribution, primarily along the Garlock Fault. Paleocene-age rocks of the Goler Formation are confined to the El Paso Mountains.

Much younger Quaternary-age sediments fill the broad basins of Searles Valley, Panamint Valley, and Death Valley, and there are several dry lake beds on the floors of these valleys today.

III.4.2.1.1.7 Pinto Lucerne Valley and Eastern Slopes Ecoregion Subarea

The Pinto Lucerne Valley and Eastern Slopes ecoregion subarea encompasses the southern portion of the Mojave Desert from the Bullion Mountains in the east to the Mojave River in the west, and from the San Bernardino and Cottonwood mountains in the south to the Newberry Mountains and Stoddard Valley in the north. The northern part of this ecoregion subarea conforms geologically to other parts of the western Mojave Desert, and consists of a series of northwest-trending mountain ranges bounded by parallel striking faults. In contrast, the southern portion of this ecoregion subarea has more in common with the transverse ranges that begin in the Santa Ynez Mountains in Santa Barbara County and extend eastward as a series of east–west trending mountain ranges that terminate in the Little San Bernardino Mountains, Pinto Mountains, and Eagle Mountains.

The geology of these transverse-trending mountains is dominated by Mesozoic plutonic rocks and well-metamorphosed Precambrian rocks. The mountain ranges in the north also expose large masses of Mesozoic plutonic rocks. The smaller mountain ranges and buried peaks at the north end of Apple Valley and Lucerne Valley are notable exceptions; they expose thick sequences of resistant, Mesozoic volcanic rocks. There are similar rocks in the Ord Mountains and Rodman Mountains. There are limited Cenozoic sedimentary rocks in this ecoregion subarea in isolated fault blocks of the Newberry Mountains and along the northern flanks of Stoddard Valley.

Like other ecoregion subareas, there are extensive fluvial and lacustrine deposits of Pleistocene age that form deep valley fills in the many large and small valleys. There are especially thick valley fills in Apple Valley, Lucerne Valley, Johnson Valley, and, in the south, Pinto Basin.

III.4.2.1.1.8 Piute Valley and Sacramento Mountains Ecoregion Subarea

The Piute Valley and Sacramento Mountains ecoregion subarea spans the approximate boundary between the Colorado Desert and Mojave Desert. It extends from the Colorado River and Piute Valley in the east to the Turtle Mountains, Old Woman Mountains, and Piute Mountains in the west, and from the Whipple Mountains and Chemehuevi Valley in the south to the Dead Mountains and Piute Valley in the north. Topographically, this ecoregion subarea contains extensive aprons of active alluvial fans that extend from widely separated uplands into the adjacent valleys. The Sacramento Mountains trend northwest–southeast across the ecoregion subarea and create a prominent divide between Chemehuevi Valley to the south and Piute Valley to the north.

The oldest rocks are in the core of the Sacramento Mountains and in the Chemehuevi Mountains to the southeast and consist of Precambrian metamorphic and igneous rocks that are in close fault contact with much younger Cenozoic-age volcanic rocks. There is an outlier of Mesozoic plutonic rocks in the northern part of the Turtle Mountains. Sedimentary rocks are largely confined to the broad and extensive alluvial fan and fluvial sequences that have been filling low-lying areas of this region since at least early Pleistocene time.

III.4.2.1.1.9 Providence and Bullion Mountains Ecoregion Subarea

The Providence and Bullion Mountains ecoregion subarea encompasses the southeastern portion of the Mojave Desert. It extends from Lanfair Valley and the Old Woman Mountains in the east to the Cady Mountains and Bullion Mountains in the west, and from the Cadiz Valley and Sheep Hole Mountains in the south to the New York Mountains, Providence Mountains, and Bristol Mountains in the north. Topographically, the ecoregion subarea is similar to other areas in the eastern Mojave Desert and contains a series of generally northwest-trending mountain ranges and intervening valleys bounded by frontal faults that have uplifted the ranges and down-dropped the basins. However, there are both several north–south trending mountain ranges (e.g., the Providence Mountains and Old Woman Mountains) and a succession of broad alluvium-filled valleys (e.g., Lanfair Valley, Clipper Valley, Bristol Valley, and Cadiz Valley) in this ecoregion subarea.

There are crystalline basement rocks of Precambrian age, intruded by Mesozoic plutonic rocks, in the cores of the eastern mountain ranges including the Old Woman Mountains, Piute Mountains, Clipper Mountains, and Granite Mountains; mountain ranges in the west are primarily composed of extensive accumulations of Cenozoic volcanic rocks. Examples of these volcanic rocks include Miocene lava flows preserved in the northern Bullion Mountains, as well as very young (late Pleistocene; ~25 thousand years before present) lava flows and cinder cones (e.g., Pisgah Crater) in the Lavic Lake Volcanic Field south of Newberry Springs. Cenozoic sedimentary rocks occur sporadically in this ecoregion subarea, with notable exposures in the Cady Mountains. Large playa lake beds (e.g., Bristol Lake and Dale Lake) cover several of the valley floors and represent Ice Age relicts of once-larger Pleistocene pluvial lakes.

III.4.2.1.1.10 West Mojave and Eastern Slopes Ecoregion Subarea

The West Mojave and Eastern Slopes ecoregion subarea encompasses the western portion of the Mojave Desert from the Mojave River west through El Mirage Valley and the Antelope Valley to nearly Quails Lake, and from the San Andreas Fault Zone along the eastern flanks of the San Gabriel Mountains north to the southeastern slopes of the southernmost Sierra Nevada Mountains. It further extends north into Indian Wells Valley around the western end of the El Paso Mountains. The main, western Mojave Desert portion of this ecoregion subarea is characterized by broad expanses of low relief alluvial plains punctuated by isolated buttes, ridges, and hills. These upland areas are mostly composed of nonfossil-bearing Mesozoic-age plutonic igneous rocks (e.g., Antelope Buttes, Rosamond Hill, Soledad Mountain, Bissell Hills, Castle Butte, Shadow Mountains, and Kramer Hills) that represent the weathered “peaks” of a deeply eroded and ancient landscape that has mostly been buried beneath the younger Pleistocene basin filling alluvial and lacustrine deposits.

A series of northwest trending faults has deformed portions of the ancient basement plutonic rocks. To a varying extent, these faults are also responsible for the spotty preservation of a series of middle and late Cenozoic nonmarine sedimentary rock units in areas like Rosamond Hill and the Bissell Hills (Fiss Fanglomerate and Gem Hill Formation), Castle Butte (Tropico Group), and Kramer Hills (Tropico Group). Local faulting is also responsible for the uplift and dissection of Pleistocene older alluvial fan deposits adjacent to the Mojave River drainage, as well as in several inter-basin valleys like Hinkley Valley, Harper Valley, and Fremont Valley. Larger-scale faulting related to the San Andreas Fault Zone and the Garlock Fault is associated with the uplift and dissection of Pleistocene alluvial fans along the flanks of the San Gabriel, Tehachapi, and southern Sierra Nevada mountains.

There are localized playa lake deposits (e.g., Rosamond Dry Lake and Rogers Dry Lake) in low-lying areas away from the mountains; they are Pleistocene and Holocene remnants of much larger pluvial lakes (e.g., Lake Thompson) that characterized the region during the Pleistocene glacial periods. The Mojave River is a prominent element in the eastern portion of this ecoregion subarea and is responsible for depositing a relatively thick sequence of Pleistocene-through-Holocene-age fluvial sediments.

III.4.2.1.2 Geologic Processes

Three fundamental geomorphic processes shape the surficial geology of desert systems and the transportation and deposition of substrates (Miller et al. 2009):

1. Aeolian processes describe wind-transported materials.
2. Fluvial, alluvial, and lacustrine processes describe water-transported materials.
3. Mass-wasting processes describe gravity-transported materials.

Surficial deposits vary according to several factors related to these depositional processes including particle size, cohesiveness, bulk density, lateral and vertical heterogeneity, and the degree of sorting (Miller et al. 2009). Descriptions of these geomorphic processes and their corresponding deposits follow. In addition to the fundamental primary geomorphic processes that this section describes, several secondary processes (such as weathering and bioturbation) influence geomorphic development (Miller et al. 2009). This section focuses on the primary geomorphic processes and does not describe the secondary processes.

In the Mojave Desert, alluvial fans are formed through flowing water that entrains debris from mountain foothills (Miller et al. 2009). Sand dunes and sheets are formed through aeolian, or wind, processes. Playas and valley washes are formed through fluvial, lacustrine, and aeolian processes. Hillslope materials are formed through mass-wasting processes, and wetland deposits are formed through fluvial and aeolian processes. Surficial deposits vary according to several factors including particle size, cohesiveness, bulk density, lateral and vertical heterogeneity, and the degree of sorting (Miller et al. 2009).

Aeolian Processes

The erosion, transport, and deposition of wind-blown sediments shape the desert landscape, affecting desert pavement, sand sheets, and dune systems (Miller et al. 2009).

Aeolian systems are determined by the interactions of three main factors: sediment supply, sediment availability (i.e., its ability to be transported by the wind), and wind transport capacity (Kocurek and Lancaster 1999). Miller (Miller et al. 2009) describes aeolian-driven soil formation as a process that "proceeds by progressive infiltration of fine-grained dust, chemical deposition, and weathering within sediment deposits." This process results in soil layering that strongly affects the water permeability and moisture-holding capacities of desert soils. This layering, or soil profile, is more pronounced in older soils. One by-product of aeolian processes is desert pavement, which is described in more detail in Section III.4.2.2.4.

Sand dune systems form where winds are consistently strong enough to lift just above the ground and push (or "saltate") fine sand grains across the dune surface, especially where there is little or no vegetation to stabilize the loose soil. Sandy alluvium in dry washes and alluvial fans are examples of sources for these materials, and strong winds generally transport the sands to areas with topographic irregularity, such as at the mountain front, where decreasing winds deposit sand (Harden 2004). Except in high-force winds, wind does not typically suspend and transport sand high into the air. The sand forming the Algodones Dunes in the southeastern portion of the DRECP area, for example, originated in the sandy delta of the Colorado River. The dunes currently extend about 43 miles from the southeast portion of the Salton Sea to the U.S.–Mexico border and can be over 300 feet high (Harden 2004).

Fluvial, Alluvial, and Lacustrine Processes

Water exerts a stronger but more intermittent force on desert surface sediments than wind. The majority of the surficial geology of the DRECP area is alluvium (shown as sedimentary in Figure III.4-1, Regional Geology), which is from flowing water that, over geological time, carries materials from the mountains and deposits them at their base, creating broad alluvial fans of unconsolidated sediment.

Desert fluvial processes generally relate to the drainage system of distant hill slopes and channels. These processes are generally short-lived, severe events related to thunderstorms in the distant hills, which can create fast-moving debris flows and cause flash flooding on alluvial fans. Generally, the size of an alluvial fan is proportional to the size of its drainage network upslope (Harden 2004).

Lacustrine processes are most prominent in desert dry lakes or playas, which are generally low spots in drainage basins that capture fine grain sediments and surface water. These low points may also be influenced by shallow or emergent groundwater. Such areas are technically base-level plains in desert drainage basins (Cooke and Warren 1973). Playas are large flat areas dominated by fine-grained sediments (e.g., clay and evaporite minerals). These fine-grained sediments make playas relatively impermeable. Surface water is removed by infiltration and evaporation. Groundwater is removed by evaporation, evapotranspiration (or evaporation and transpiration by vegetation), and by groundwater outflow into neighboring basins if fluid pathways exist. During wet periods, surface water accumulates, causing sedimentation onto playa or lakebed surfaces. Overall, the hydrologic characteristics of a playa are affected by climate, basin floor conditions, soil and vegetation, and water salinity, which affects evaporation rates.

Mass-Wasting Processes

Mass wasting refers to the downslope movement, under the direct influence of gravity, of rock, rock and mineral fragments, and soil (Nelson 2012). Mass-wasting processes include creep, slides, and debris flows. Slides are the sudden downslope movements of rock and sediment. Debris flows are dense, fluid mixtures of rock, sediment, and water. While mass wasting in the DRECP area occurs primarily as rock falls and rockslides on steep slopes, larger events could also potentially occur. Large events are often connected to either existing faults or new seismic activity. Intense monsoonal rains and earthquakes are the primary causes of rock falls and rockslides on steep mountain slopes in the DRECP area. Creep, on the other hand, is a slow, continuous downslope movement primarily caused by freeze/thaw or wet/dry cycles (California Department of Conservation 2007); creep therefore occurs only in small areas at high elevations.

III.4.2.2 Soils

Soil types can directly affect the site suitability for renewable energy projects. Soil types also can be indicators of the potential for valuable habitat, as explained in Chapter III.7 (Biological Resources), but this chapter focuses on the nonbiological values. Table R1.4-2 (in Appendix R1) presents a complete list of the acreage for various soil textures for the DRECP area. Table III.4-1 summarizes soil types within the DRECP area.

Table III.4-1
Soil Types and Textures within the DRECP Area

Soil Type	Definition	Textures	Acres
Clay	A stiff, sticky (when wet) fine-grained soil, often forming an impermeable layer in a soil profile.	Clay, silty clay, clay loam	589,000
Sand	A loose granular soil resulting from the erosion of siliceous and other rocks and usually containing only small amounts of organic matter	Fine to coarse sand; cobbly or gravelly sand; Loamy sand	8,340,000
Loam	A fertile soil of clay, silt, and sand containing organic components formed by decomposition of microorganisms and plant biomass	Fine, gravelly, sandy, or silty	8,457,000

Table III.4-1
Soil Types and Textures within the DRECP Area

Soil Type	Definition	Textures	Acres
Bedrock	Solid rock on the surface or underlying loose deposits such as soil or alluvium.	Unweathered bedrock	4,190,000
		Weathered bedrock	822,000
Unknown	n/a	Not Mapped	188,000
		Total	**22,585,000**

Source: USDA 2006.
Note: The following general rounding rules were applied to calculated values: values greater than 1,000 were rounded to the nearest 1,000; values less than 1,000 and greater than 100 were rounded to the nearest 100; values of 100 or less were rounded to the nearest 10, and therefore totals may not sum due to rounding. In cases where subtotals are provided, the subtotals and the totals are individually rounded. The totals are not a sum of the rounded subtotals; therefore, the subtotals may not sum to the total within the table.

Soil types and textures for each ecoregion subarea are presented in Tables R1.4-3 through R1.4-12, in Appendix R1.

In addition to soil types, soil conditions are important characteristics of the desert environment and geologic setting of the DRECP area. They include desert pavement, erosive (e.g., carbonate, high-silt) soils, corrosive soils (saline), and expansive (high-clay) soils. The following paragraphs describe each soil condition. Biotic soil crusts are addressed in Section III.4.2.2.4, Biological Soil Crusts, as well as in Section III.7.3.3, Soil Biota.

III.4.2.2.1 Soils Prone to Erosion

Wind and water erosion are the primary generating forces for surface features in desert climates. Surface features prone to erosion from wind and water include steep slopes, playas, bajadas, washes, alluvial fans, and sand dunes. Erosion occurs when wind or water detach and entrain soil components of all sizes. Multiple factors influence the quantity of soil loss from wind and water erosion including soil texture, soil structure, vegetation cover, permeability, land use, and topography.

Soil texture is the primary factor in determining soil's erodibility. Soil textures dominated by silt or very fine sand are the most highly erodible by wind because soil particles are not bound together by electrochemical bonds as they are in clays; they are therefore easily detached (not too heavy). Aggregated soils that are more closely bound together with high amounts of soil organic matter are less erodible since their aggregates are larger and can better resist erosional action from wind and water. Highly permeable soils are the most resistant to erosion since a greater proportion of rainfall seeps into them, thereby diminishing runoff. The amount of vegetation cover and land use also influence a soil's susceptibility to wind or water erosion.

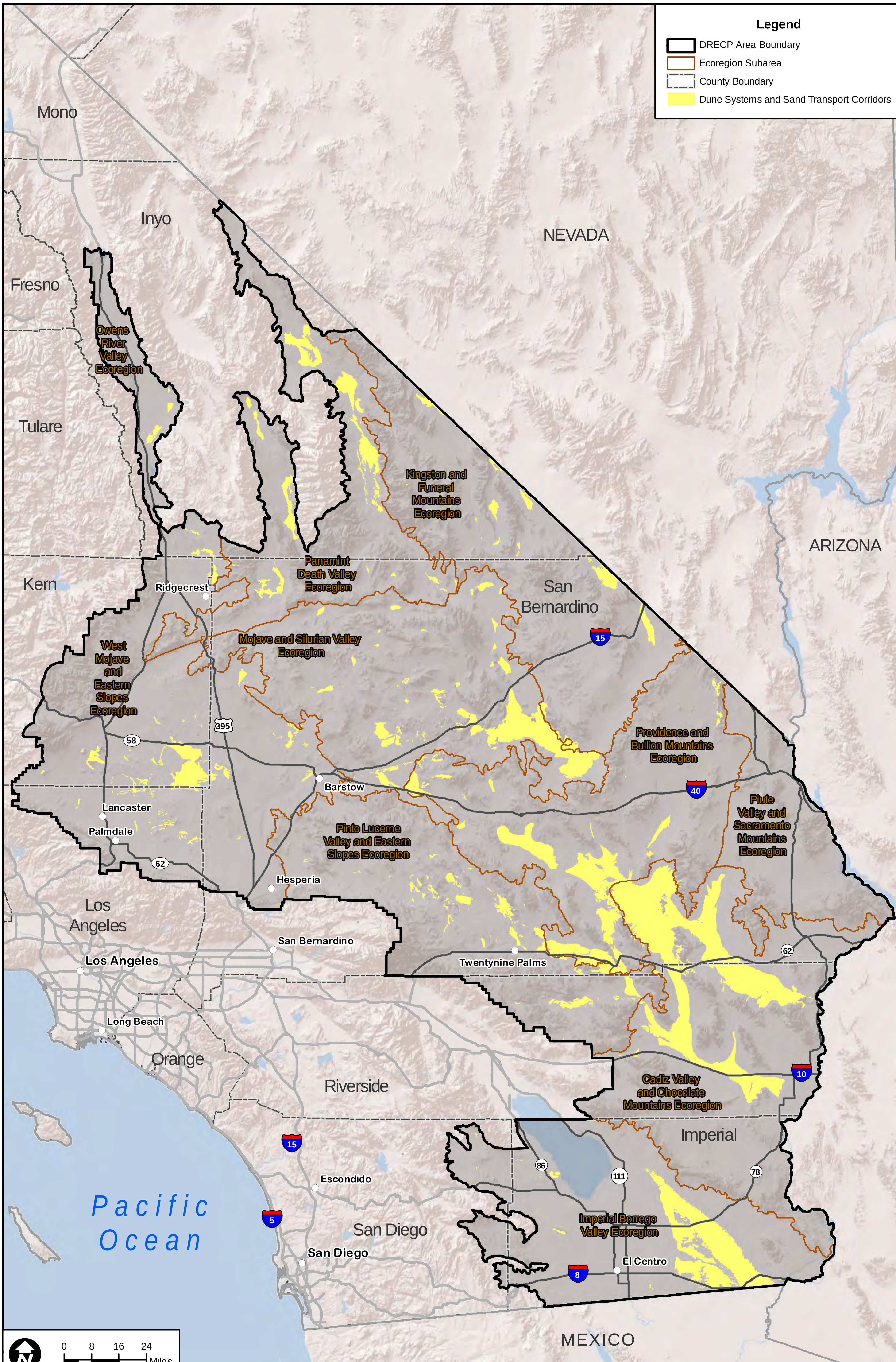
III.4.2.2.1.1 Dune Systems and Sand Transport Corridors

The Chuckwalla Valley of the Mojave Desert, located along Interstate 10 between Blythe and Desert Center, is an example of a sand transport corridor. This valley supports sand dune habitats that depend upon delivery of fine sand from aeolian and fluvial processes. These sand dunes have an active layer of mobile sand, and exist in a state of dynamic equilibrium as they continuously lose sand downwind and gain sand upwind. Dunes move within sand transport corridors. At Palen Dunes in the Chuckwalla Valley, dune migration rates were as high as 50 meters per year, totaling 1,373 meters in 27 years (1984-2011), predominantly in a southern direction (Potter and Li 2014). The overall size of active dune fields increased significantly from 1984-2011.

Active sand dunes, such as Palen Dunes, Dumont Dunes, Algodones Dunes, and Kelso Dunes, also provide important habitat for species (e.g., the Mojave fringe-toed lizard) that rely on a regular supply of wind-blown sand. Based on land-cover mapping of North American warm desert dunes and sand flats, there are about 1,781,000 acres of sand dune systems within the DRECP area (Data Basin 2014[a]). See Figure III.4-2, Dune Systems and Sand Transport Corridors within the DRECP Area, for the distribution of sand transport corridors.

The DRECP's Biological Goals and Objectives identify 23 dry lakes within the DRECP area as important sand sources (CEC 2012). These dry lakebeds, which provide wildlife habitat and sand sources for sand transport corridors and dune systems, include:

- Rosamond Dry Lake
- Silurian Lake
- Cuddeback Lake
- Bristol Lake
- Melville Lake
- Coyote Lake
- Danby Lake
- Silver Dry Lake
- Palen Lake
- Ford Dry Lake
- China Lake
- Bagdad Lake
- Harper Dry Lake
- Twentynine Palms
- Dale Lake
- Searles Lake
- Cronese Lake
- Kelso Wash/Dry Lake
- Cadiz Lake
- Leach Lake
- Mesquite Lake
- Lavic Lake
- Bicycle Lake



Sources: ESRI (2014); CEC (2013); DATABASIN (2014b)

FIGURE III.4-2

Dune Systems and Sand Transport Corridors within the DRECP Area

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III.4.2.2.2 Corrosive Soils (Saline, Gypsic, and Sodic Soil)

Depending on its chemical composition, soil may be corrosive to buried steel, concrete, other construction materials, and on-site equipment. Soil corrosion can potentially create geologic hazards that could undermine the long-term integrity of renewable energy project infrastructure. Soil resistivity is the ability of soil to allow electrons to move through it. A low resistivity means that a soil is a good electron conductor and thus a stronger corrosive agent. A soil with resistivity between 2,000 to 5,000 Ohm-centimeters is considered "moderately corrosive" to ungalvanized steel, while soils with a resistivity between 5,000 to 10,000 Ohm-centimeters are considered "mildly corrosive." The predominant soil type in the DRECP area is alluvium, which has a resistivity ranging from 1,428 to 10,000 Ohm-centimeters (USDOT 2009).

Corrosive desert soils have high contents of chloride, sodium, or sulfate minerals. Soils with high amounts of sulfate minerals, such as gypsum, are harmful to concrete, particularly when soil moisture is acidic (low pH). High chloride concentrations from saline minerals can corrode metals. Many of the soils that develop on or near playas contain unusually high quantities of saline and sodic minerals, which are left behind from stormwater evaporation. Certain playas (e.g., Searles Lake) produce commercially valuable corrosive minerals such as trona, which is corrosive to steel.

Vegetation in the desert is specifically adapted to its soil characteristics. Playas are fairly devoid of vegetation due to their highly alkaline soils. Wetland habitats known as "North American warm desert alkaline scrub and herb playa and wet flat" are widespread in the DRECP area. The presence of playas indicates potentially corrosive soil. Using these two vegetation types to help identify likely corrosive soils, there are an estimated 509,000 acres of potentially corrosive soil within the DRECP area (Data Basin 2014b). See Figure III.4-3, Potentially Corrosive Soils within the DRECP Area.

III.4.2.2.3 Expansive Soils

Expansive soil volumes can change significantly with variations in soil moisture content. Expansive soils are typically fine grained, with a high percentage of clay that expands and contracts as soil moisture content fluctuates. Clay soil expansion and contraction can damage building foundations, concrete flatwork, and asphalt or concrete pavements through uplift and swelling. As shown in Table III.4-1, there are nearly 589,000 acres of predominantly clay soil within the DRECP area. See Figure R1.4-1 through Figure R1.4-10 in Appendix R1 for soil textures, by ecoregion subarea. See also Tables R1.4-3 through R1.4-12, in Appendix R1.

III.4.2.2.4 Desert Pavement

Desert pavement is composed of close-packed angular or rounded rock fragments with an often dark varnish cover. These layers cover fine-grained silt and clay particles beneath the rock pavement surface. The interstitial and underlying material can be highly calcareous with low permeability. Desert pavements form in the most arid parts of the DRECP area where average annual rainfall is less than 8 inches. These areas typically support a sparse seasonal cover of ephemeral plants and few, if any, perennial plant species. Desert pavement generally overlies older alluvium formations within the DRECP area. Topographically, pavements tend to form on abandoned or relic areas along the middle elevations of alluvial fans, where stormflow runs along distinct down-cut channels between raised areas of desert pavement. The tightly packed pebbles and the underlying silt and clay surface of desert pavement inhibit infiltration of precipitation and promote runoff, which funnels water into adjacent small channels. Aeolian processes facilitate the formation of desert pavements. If desert pavement is damaged by vehicle traffic or grading, it loses its armoring function and can increase the likelihood of soil erosion from surface runoff.

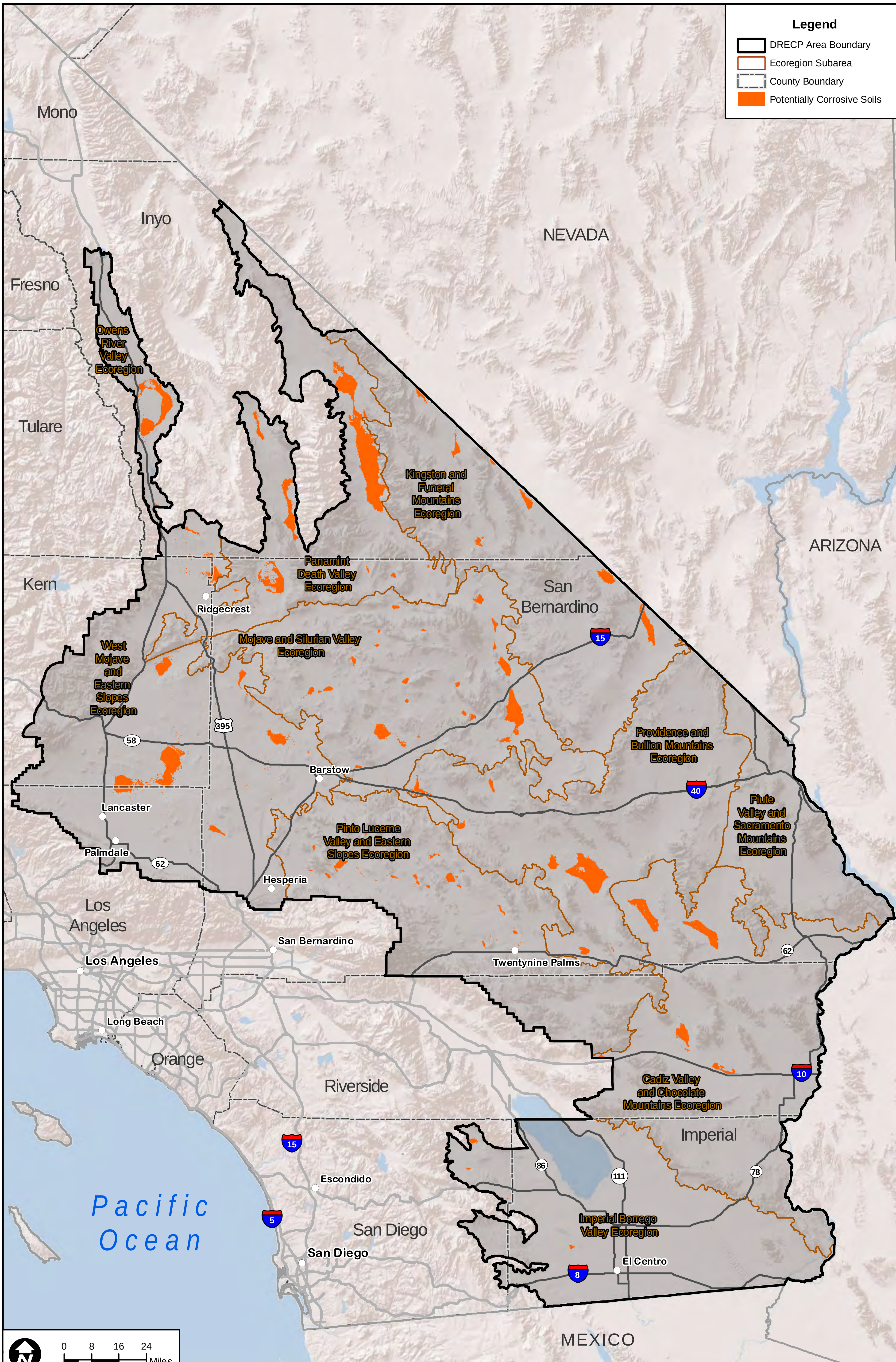
III.4.3 Faulting and Seismicity

Earthquakes happen when large masses of subsurface rock move against each other along fractures called faults. The shaking from earthquakes can be significant, and can be felt many miles from their actual epicenters, depending on the type of earthquake and the characteristics of underlying soils and geology (BLM 2008).

Earthquakes can cause property damage and loss of life. Seismic hazards include ground shaking, landslides and rockfalls, liquefaction, and ground ruptures (surface faulting). Most widespread damage and loss of life results from ground shaking, because it can cause structure failures and collapses, even at great distances from the fault rupture (U.S. Geological Survey [USGS] 2012). Specific potential seismic hazards in the DRECP area are described in Section III.4.4.

There are approximately 1,000 known earthquake faults within the DRECP area, as shown in Figure III.4-4, Earthquake Faults within the DRECP area. The faults with the potential to generate the largest earthquakes are the San Andreas and San Jacinto faults, which are located in the Imperial Borrego Valley ecoregion subarea. The San Andreas Fault also extends through the West Mojave and Eastern Slopes ecoregion subarea.

The assessment of risk from earthquakes is complex and usually expressed as zones of probability of exceeding a certain amount of ground motion. The highest hazard risk within the DRECP area occurs along the San Andreas and San Jacinto faults, along the western boundary of the DRECP area, and within Imperial Valley. Figures III.4-5 through Figure III.4-12 show existing earthquake faults by ecoregion subarea. Not all ecoregion subareas have earthquake faults. Figure III.4-13, Peak Horizontal Ground Acceleration within the DRECP Area, shows the peak accelerations with a 10% chance of being exceeded within the next 50 years.



Sources: ESRI (2014); CEC (2013); DATABASIN (2014b)

FIGURE III.4-3

Potentially Corrosive Soils within the DRECP Area

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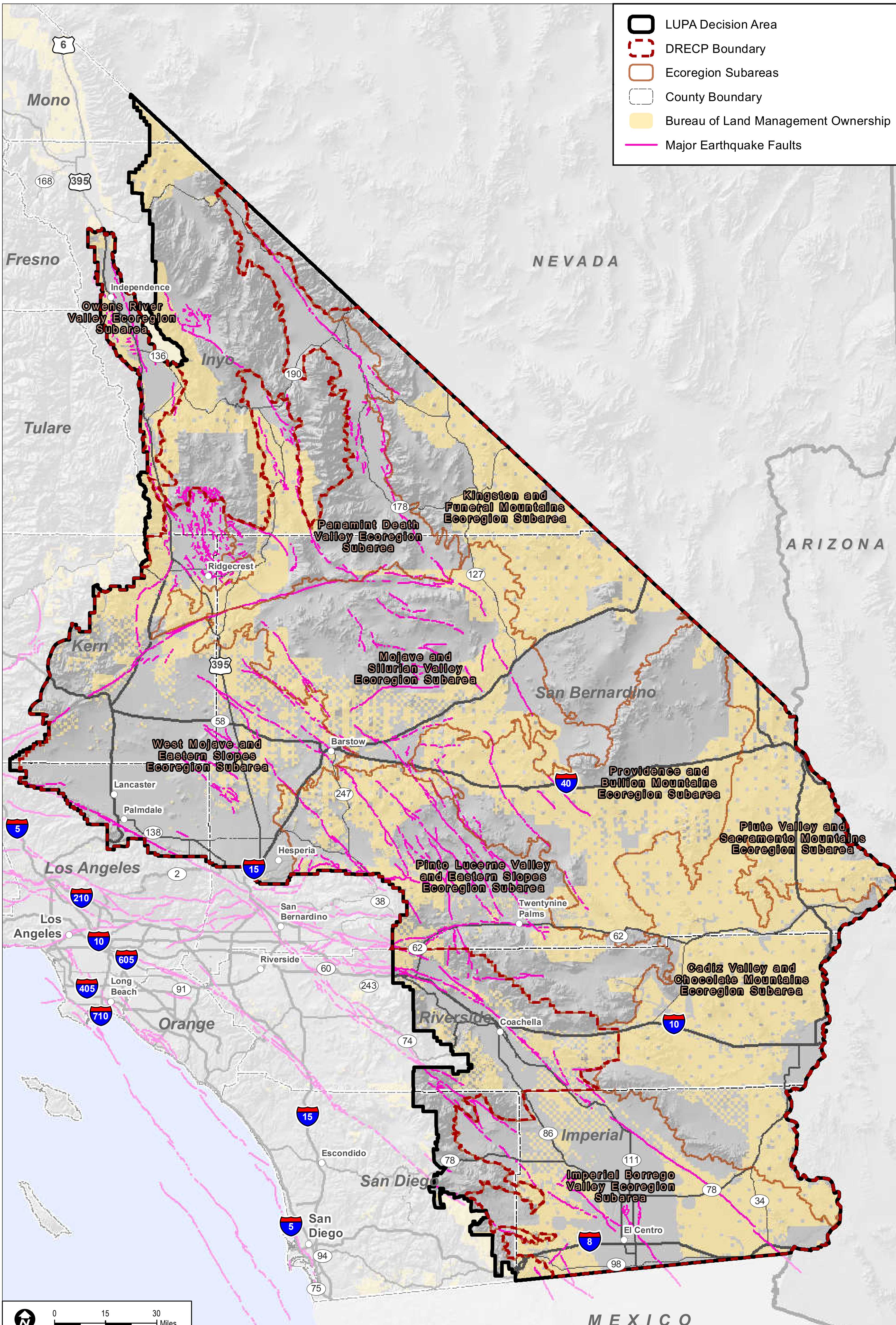

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-4

Earthquake Faults within the DRECP Plan Area

DRECP Proposed LUPA and Final EIS

October 2015

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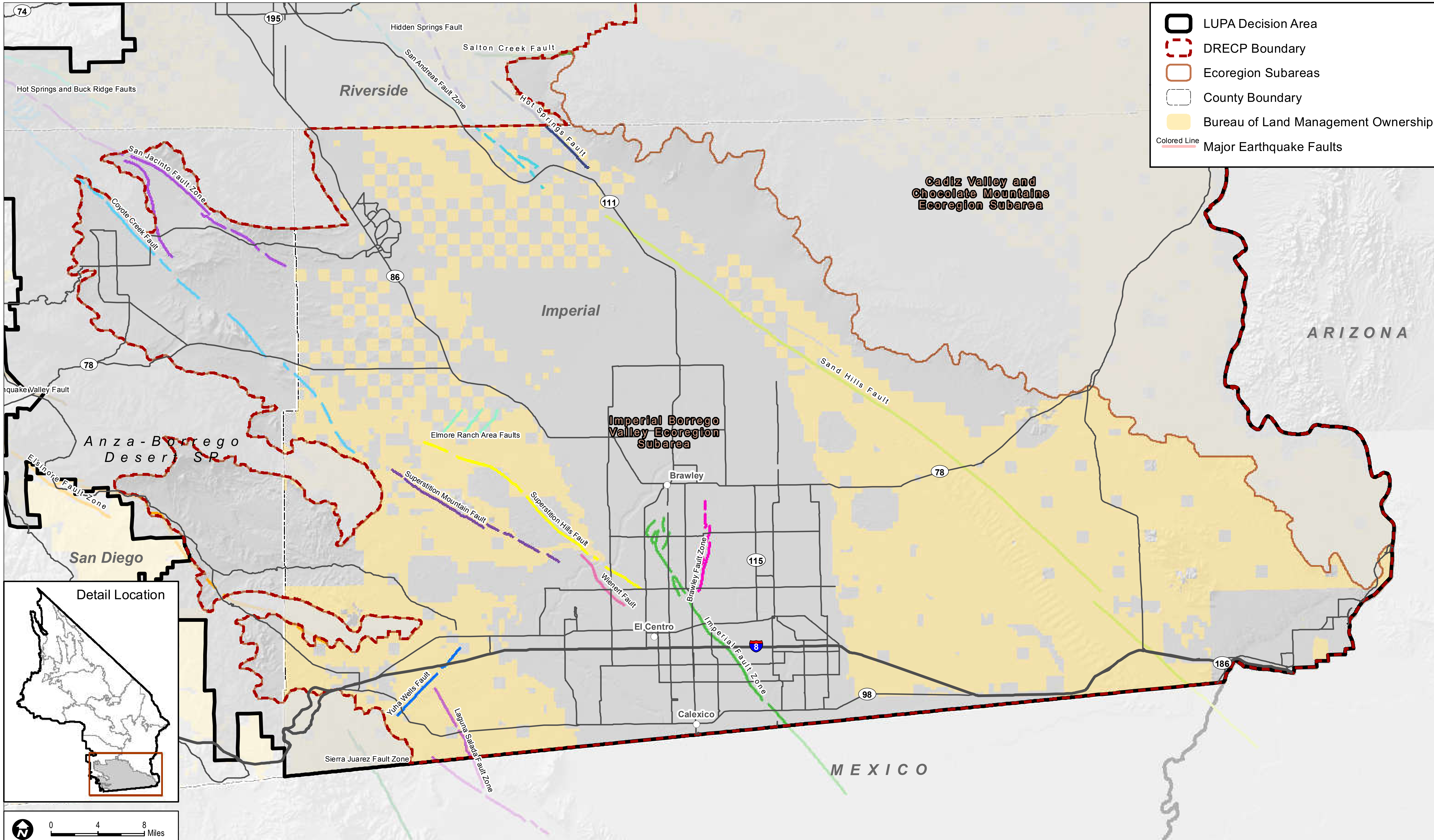

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-5

Earthquake Faults within the Imperial Borrego Valley Ecoregion Subarea

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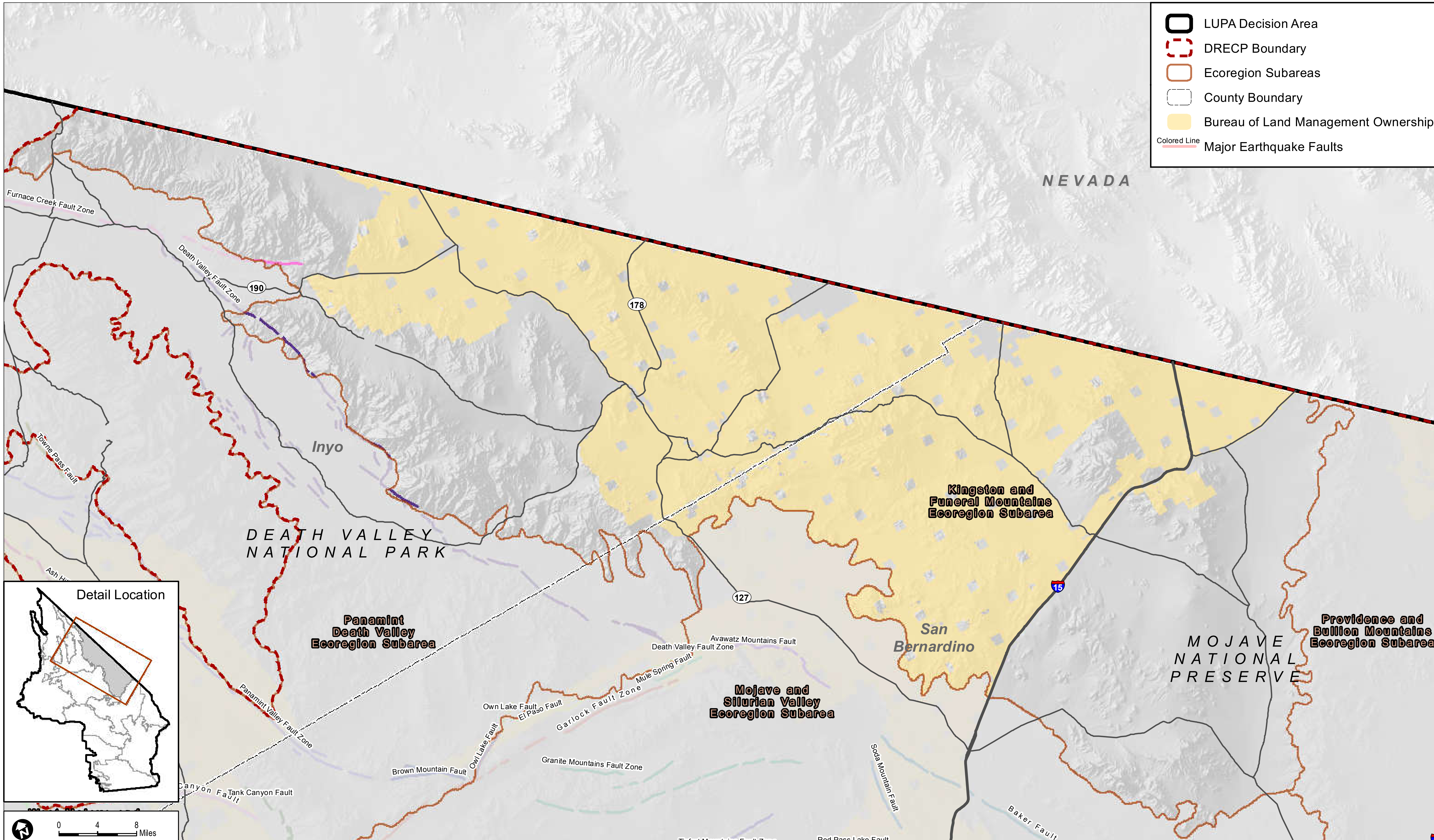

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-6

Earthquake Faults within the Kingston and Funeral Mountains Ecoregion Subarea

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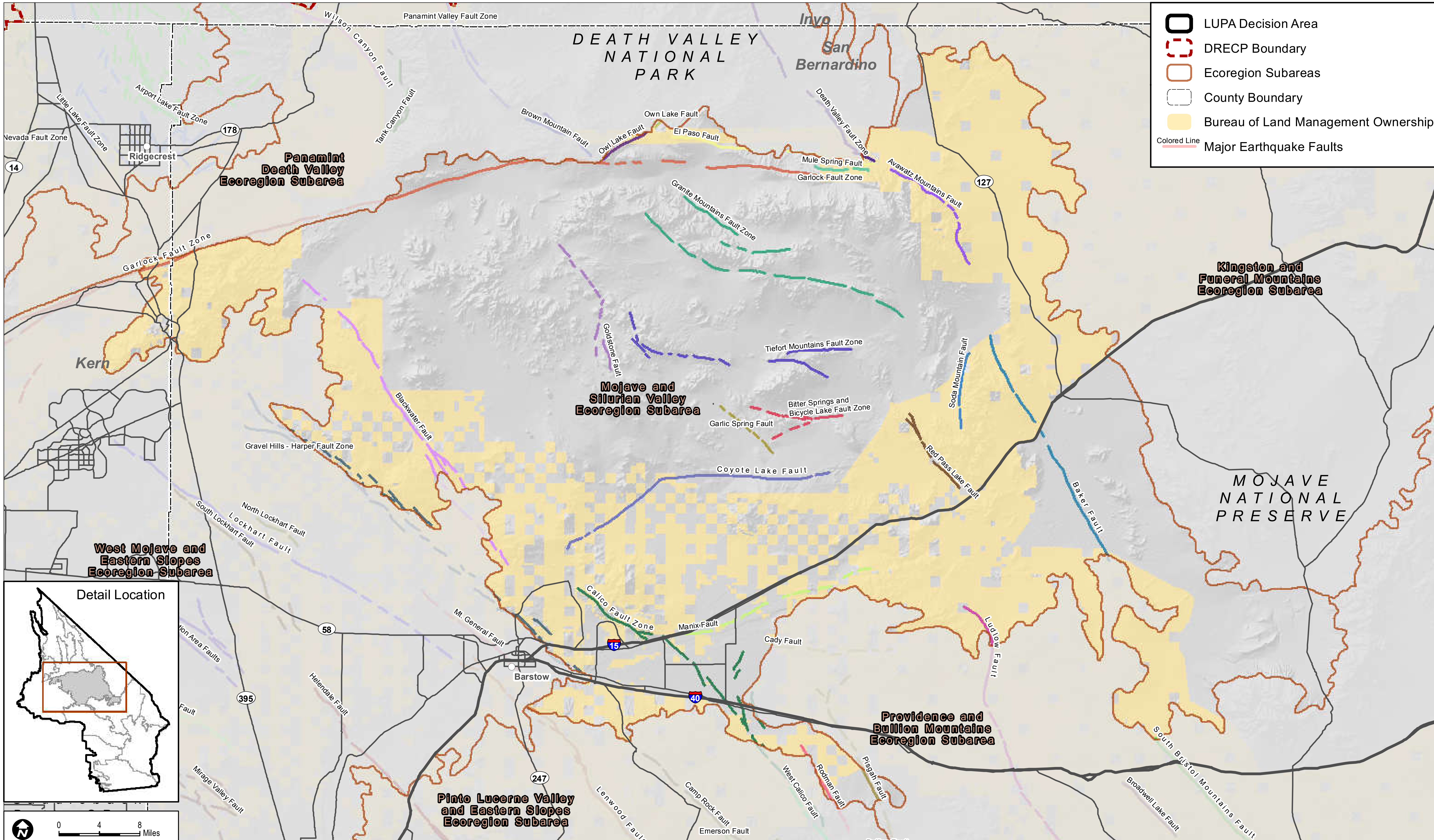

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-7

Earthquake Faults within the Mojave and Silurian Valley Ecoregion Subarea

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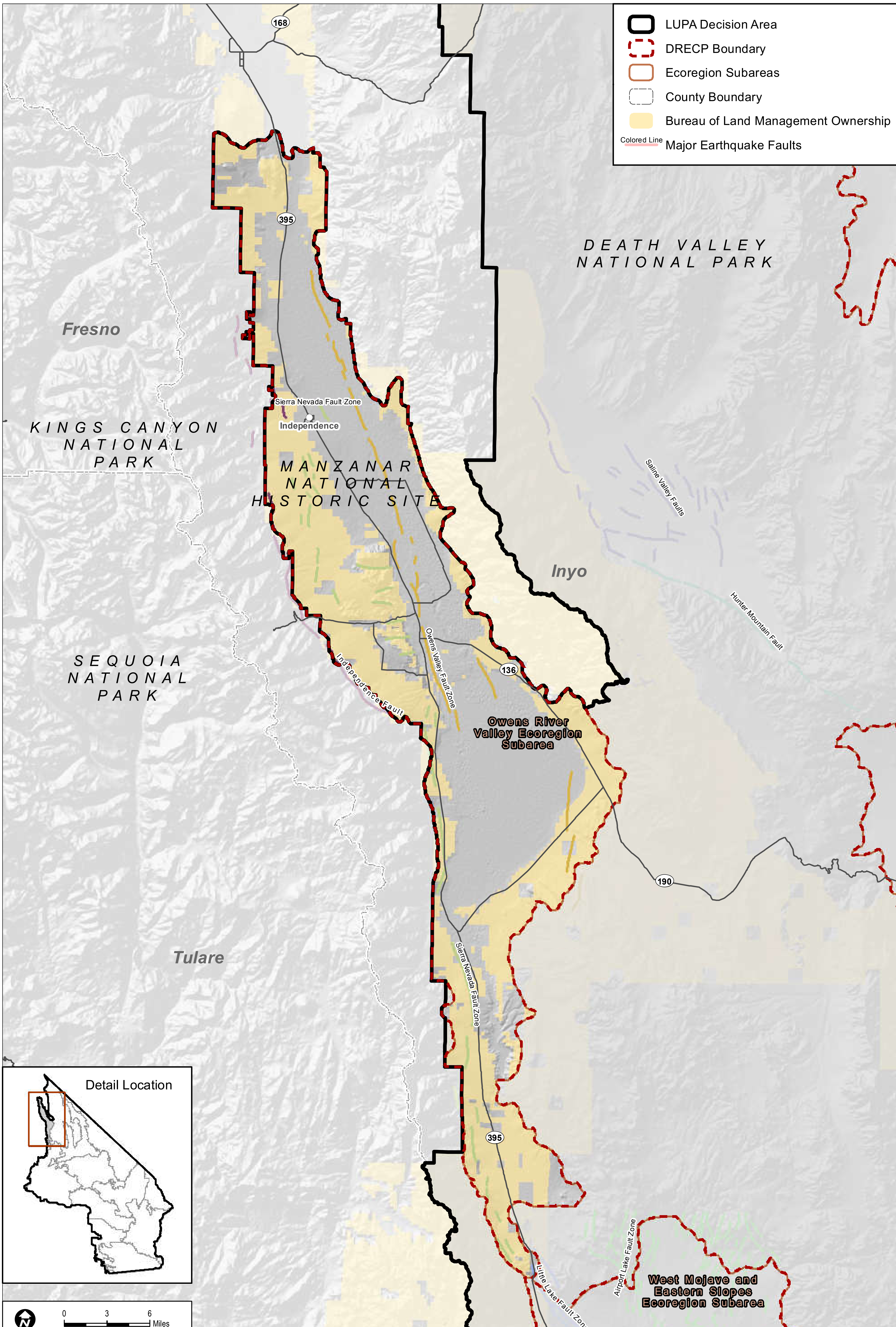

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-8

Earthquake Faults within the Owens River Valley Ecoregion Subarea

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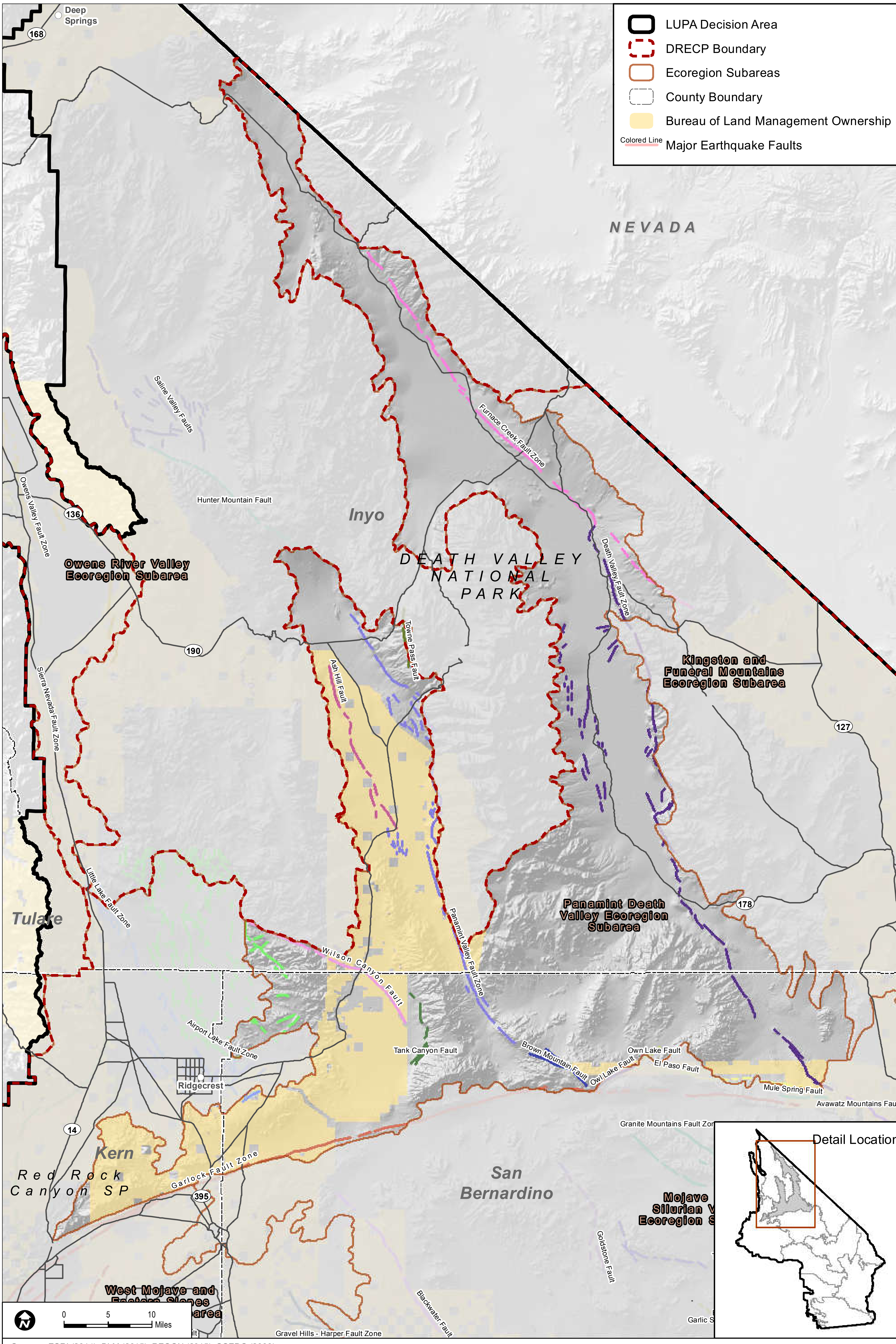

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-9

Earthquake Faults within the Panamint Death Valley Ecoregion Subarea

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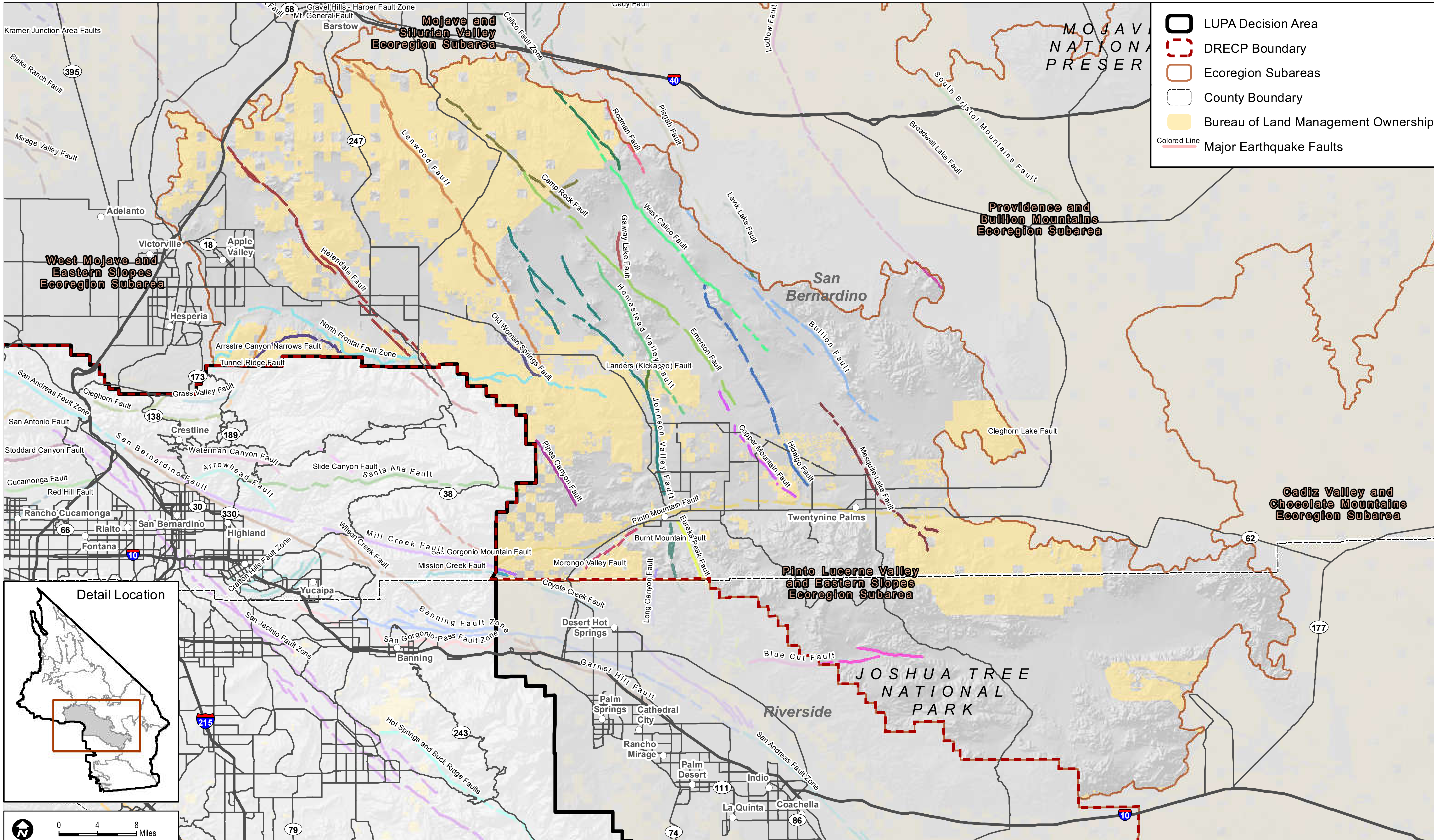

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-10

Earthquake Faults within the Pinto Lucerne Valley and Eastern Slopes Ecoregion Subarea

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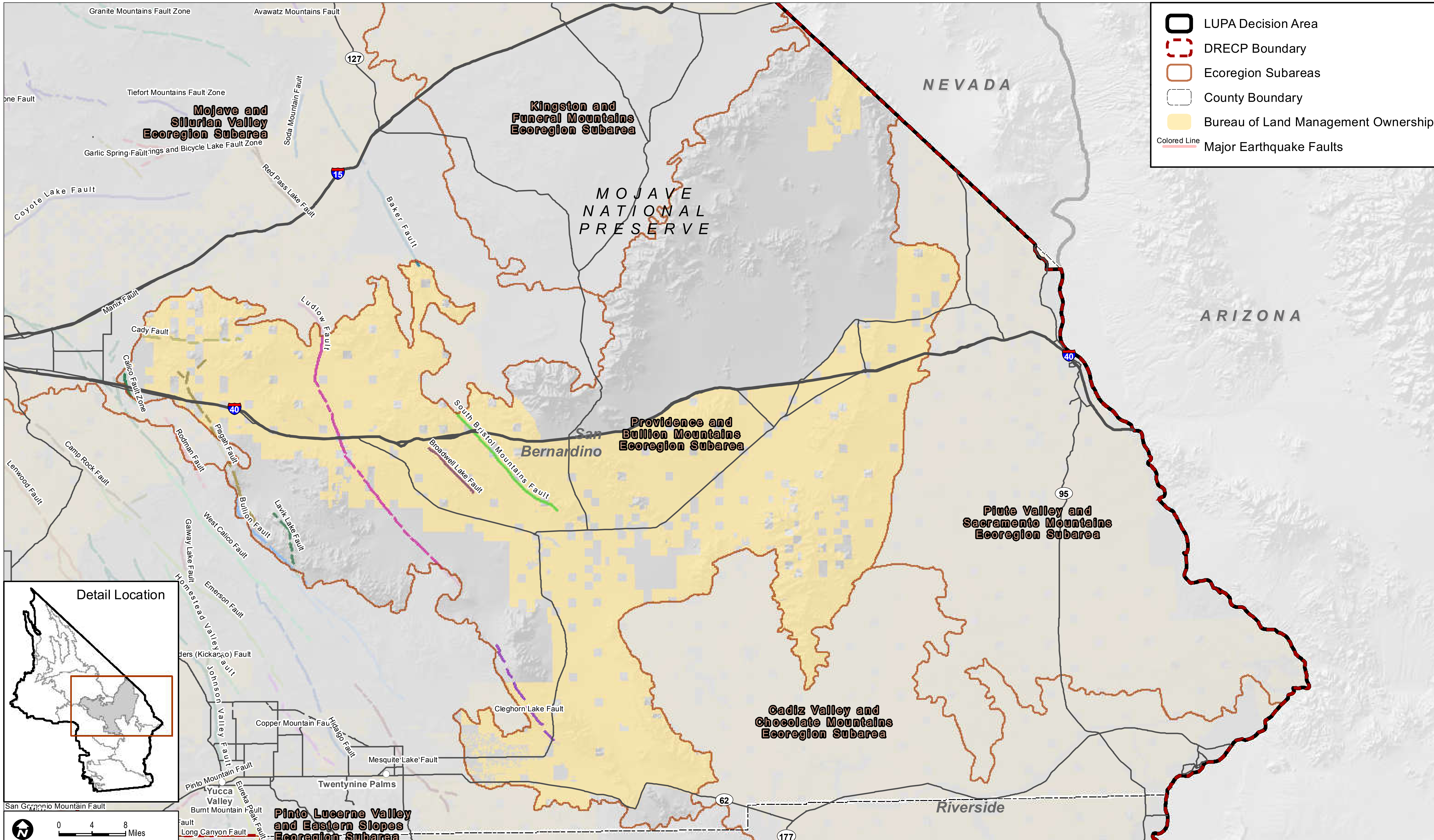

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-11

Earthquake Faults within the Providence and Bullion Mountains Ecoregion Subarea

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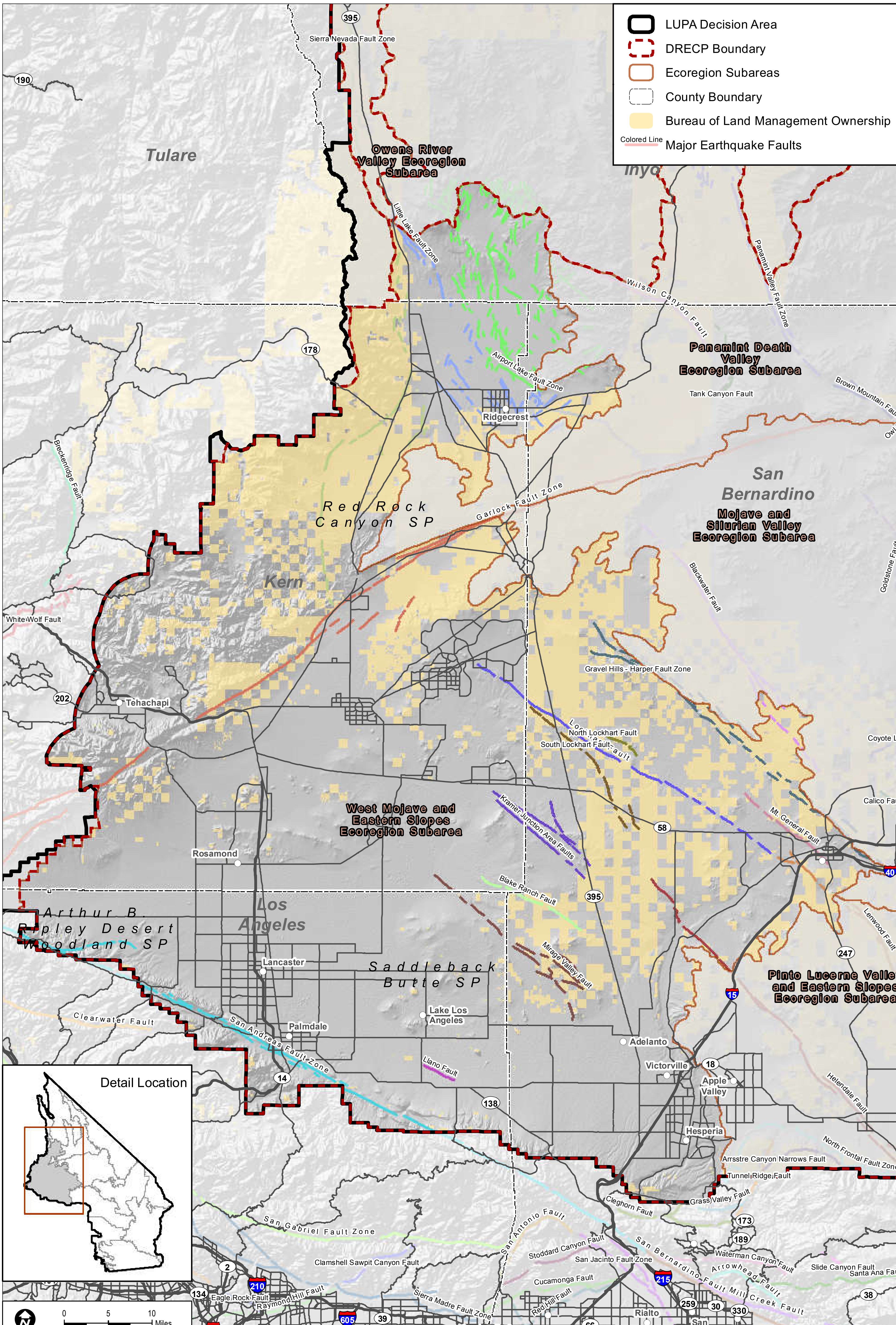

Sources: ESRI (2014); BLM (2015); RECON (2015); SCEDC (2000)

FIGURE III.4-12

Earthquake Faults within the West Mojave and Eastern Slopes Ecoregion Subarea

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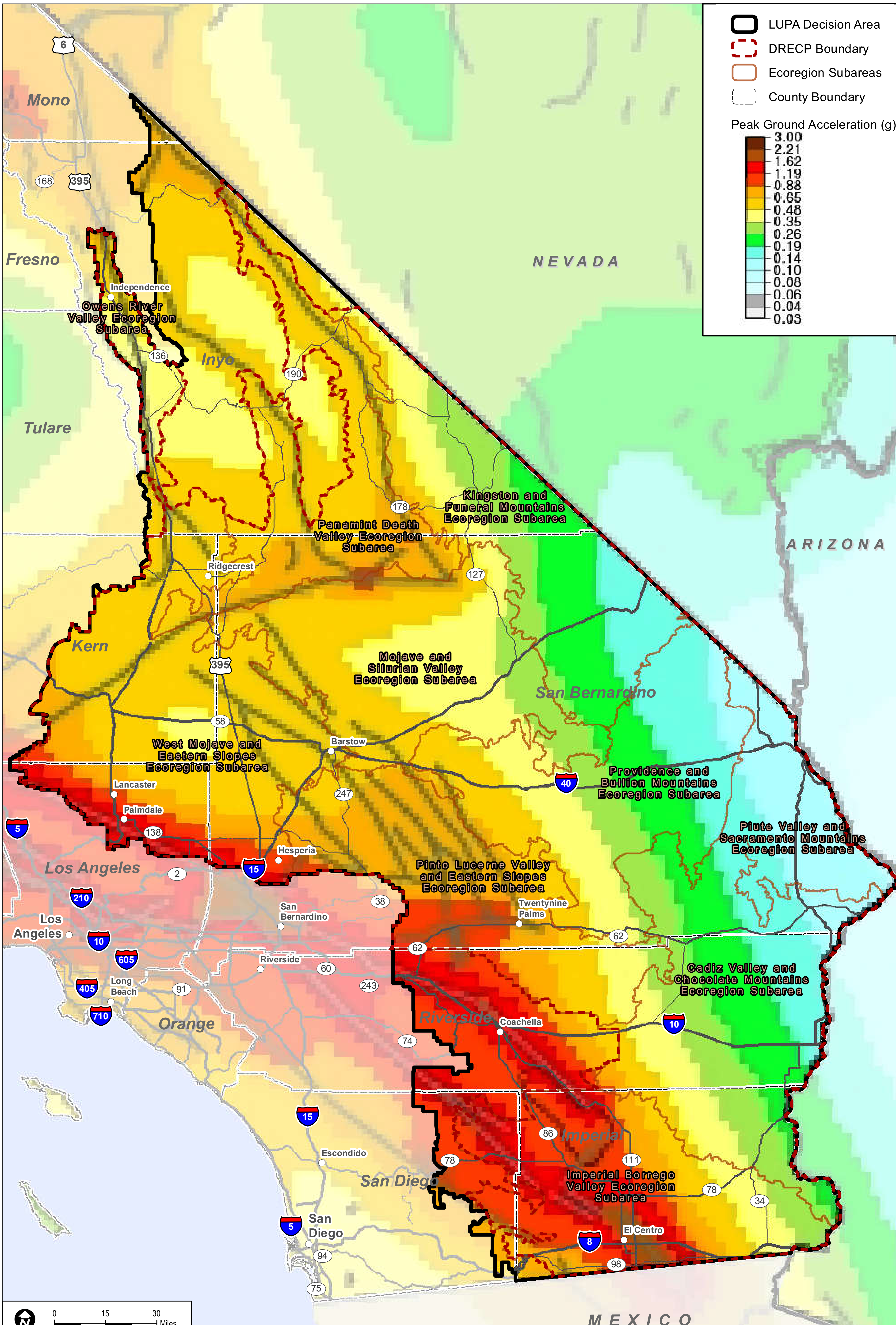

Sources: ESRI (2014); CEC (2013); BLM (2013); CDFW (2013); USFWS (2013); U.S. Geological Survey National Seismic Hazard Maps (2008)

FIGURE III.4-13

Peak Horizontal Ground Acceleration within the DRECP Plan Area (Lands with a 10% probability of exceedance within 50 years)

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One common method to measure earthquake magnitude is the Richter scale, a logarithmic scale that measures the amplitudes of the waves of motion 100 kilometers from the epicenter of an earthquake. Table III.4-2, Largest Faults within the DRECP area, lists the largest faults based upon the probable Richter magnitude they could generate. The table presents the fault name, magnitude of earthquake capable of being generated, the ecoregion subarea in which it is located, and the length of each fault. Also in the table is whether the fault is within an Alquist-Priolo Fault Zone. According to the Alquist-Priolo Earthquake Fault Zoning Act (1972), fault zones are distinguished from faults based on the potential for surface fault rupture and whether the fault is active. The USGS Earthquake Glossary defines active faults as those that have moved within the last 11,000 years (USGS 2014).

Table III.4-2
Largest Faults within the DRECP Area

Fault	Probable Richter magnitude	Ecoregion Subarea(s)	Length of Fault per Ecoregion (miles)
San Andreas Fault	6.8 – 8.0	Imperial Borrego Valley	7.3
		West Mojave and Eastern Slopes	52.5
Furnace Creek Fault	6.8 – 7.6	Panamint Death Valley	34.0
Garlock Fault	6.8 – 7.6	Mojave and Silurian Valley	38.8
		Panamint Death Valley	20.7
		West Mojave and Eastern Slopes	60.3
Owens Valley Fault	6.5 – 8.2	Owens River Valley	31.7
Coyote Creek Fault	6.5 – 7.5	Imperial Borrego Valley	24.8
Elsinore Fault	6.5 – 7.5	Imperial Borrego Valley	4.4
Laguna Salada Fault	6.5 – 7.5	Imperial Borrego Valley	7.0
Pinto Mountain Fault	6.5 – 7.5	Pinto Lucerne Valley and Eastern Slopes	31.5
San Jacinto Fault	6.5 – 7.5	Imperial Borrego Valley	25.3
Panamint Valley	6.5 – 7.5	Panamint Death Valley	42.5
Lenwood Fault	6.5 – 7.4	Mojave and Silurian Valley	1.3
		Pinto Lucerne Valley and Eastern Slopes	37.8
		West Mojave and Eastern Slopes	5.0
Lockhart Fault	6.5 – 7.4	West Mojave and Eastern Slopes	3.9
Death Valley Fault	6.5 – 7.3	Kingston and Funeral Mountains	11.4
		Panamint Death Valley	47.7
Emerson Fault	6.5 – 7.3	Pinto Lucerne Valley and Eastern Slopes	30.3
Helendale Fault	6.5 – 7.3	Pinto Lucerne Valley and Eastern Slopes	28.9
		West Mojave and Eastern Slopes	1.8
Johnson Valley Fault	6.5 – 7.3	Pinto Lucerne Valley and Eastern Slopes	37.6
Gravel Hills – Harper Fault	6.5 – 7.2	Mojave and Silurian Valley	8.0
		West Mojave and Eastern Slopes	18.1

Table III.4-2
Largest Faults within the DRECP Area

Fault	Probable Richter magnitude	Ecoregion Subarea(s)	Length of Fault per Ecoregion (miles)
Blackwater Fault	6.5 – 7.1	Mojave and Silurian Valley	13.0
		West Mojave and Eastern Slopes	0.3
Bullion Fault	6.5 – 7.1	Pinto Lucerne Valley and Eastern Slopes	10.9
		Providence and Bullion Mountain	9.4
Calico Fault	6.5 – 7.1	Mojave and Silurian Valley	20.2
		Pinto Lucerne Valley and Eastern Slopes	6.4
		Providence and Bullion Mountain	2.8
West Calico Fault	6.5 – 7.1	Pinto Lucerne Valley and Eastern Slopes	21.0

Alquist-Priolo Fault Zones
Historic/Holocene and Minimum Probably Magnitude >= 6.5
Sources: Southern California Earthquake Data Center 2012; California Geologic Survey 2007

III.4.4 Other Geologic Hazards

This section addresses several different types of hazards. Of the geologic hazards that could affect renewable energy projects, two could result from fault movement: ground shaking and liquefaction. Other hazards that could occur in the DRECP area include subsidence and volcanic activity.

III.4.4.1 Ground Shaking

Earthquakes are the principal geologic activities affecting public safety and structures throughout most of California. The ground shaking from earthquakes creates various secondary hazards including:

- Differential ground settlement.
- Soil liquefaction, rock and mudslides, ground lurching, and avalanches.
- Ground displacement along the fault.
- Floods from dam or levee failures.
- Fires.
- Disruptions to water, sewer, gas, electricity, transportation, and communication services.

The intensity of ground shaking during an earthquake is dependent upon (1) the distance between a project area and the epicenter (point at the earth's surface directly above the initial movement of the fault at depth) of the earthquake, (2) the magnitude or size of the earthquake, (3) the depth at which the earthquake occurs, and (4) the underlying geologic conditions. A commonly used benchmark for intensity is peak horizontal ground acceleration, which is the maximum peak horizontal acceleration experienced from an earthquake expressed in percent of the acceleration due to gravity (%g). CGS has calculated earthquake probabilities by projecting occurrence rates for earthquakes based on earthquake history and fault slip rates. Figure III.4-13, Peak Horizontal Ground Acceleration within the DRECP area, shows the maximum predicted peak horizontal ground acceleration with a 10% probability of exceedance within 50 years for the DRECP area. Table III.4-3, Earthquakes within the DRECP area with a Magnitude 6.0 or Higher, lists large earthquakes that have occurred within the DRECP area over the last 75 years.

Table III.4-3
Earthquakes within the DRECP Area with a Magnitude 6.0 or Higher

Earthquake Name	Date	Magnitude	Location
Hector Mine Earthquake	October 16,1999	7.1	North of Twentynine Palms
Landers Earthquake	June 28,1992	7.3	Yucca Valley
Superstition Hills Earthquake	November 24, 1987	6.6	West of Brawley
Borrego Mountain Earthquake	April 9, 1968	7.0	East of Borrego Springs
Imperial Valley Earthquake	May 18, 1940	6.9	North of Calexico
Walker Pass Earthquake	March 15, 1946	6.0	West of Ridgecrest
Manix Earthquake	April 10, 1947	6.5	East of Newberry Springs
Imperial Valley Earthquake	October 15, 1979	6.4	West of El Centro
1954 San Jacinto Fault	March 19, 1954	6.4	East of Borrego Springs
San Jacinto Fault	March 25, 1937	6.0	Northeast of Borrego Springs

Source: SCEC (2014)

III.4.4.2 Liquefaction

Liquefaction can occur in sandy soils and silty soils of low plasticity that are water-saturated, in areas where the groundwater table is within approximately 50 feet of the ground surface (CGS 2008). Earthquake shaking causes the soil to weaken, resulting in its inability to stick together; the soil therefore behaves as a liquid. Liquefaction can result in a loss of the soils' ability to support a load such as a building foundation, lateral spreading, subsidence, and buoyancy effects. Susceptibility to liquefaction is a function of the sediment density, water content, soil thickness, and the peak ground acceleration of an earthquake at the location. In the 1989 Loma Prieta earthquake in the San Francisco Bay Area, liquefaction in the city's Marina District caused many large buildings to slide off their foundations, and also caused underground natural gas line ruptures that in turn caused major fires.

III.4.4.3 Subsidence

Land subsidence normally results from fluid withdrawal from groundwater pumping, oil extraction, or geothermal generation. (Logfren 1973). Fluid removal can create subsurface voids from ground surface sinking and soil permeability loss. Subsidence from shifting earth plates can also occur over large areas. Subsidence from fluid extraction can occur near geothermal areas (Logfren 1973). In the western portion of the DRECP area, groundwater levels in some basins have declined more than 100 feet from predevelopment conditions. Land subsidence could therefore occur within the DRECP area. See Chapter III.6, Section III.6.3.4, Subsidence from Groundwater Pumping, for further discussion of subsidence.

III.4.4.4 Volcanic Activity

As shown in Table R1.4-1 (Surficial Geology in the DRECP Area, Appendix R1), the DRECP area includes 60,252 acres of young (Holocene) volcanic materials on the land surface. See Figure III.4-1, Regional Geology, for the locations of this volcanic rock type.

There are several areas of potential volcanic hazards within the DRECP area. According to USGS, areas designated as “Moderate Threat Volcanoes” (defined as posing a risk to aviation and a low to very-low threat to people and property), include Ubehebe Craters in Death Valley National Park and Coso Volcanic Field in Inyo County (USGS 2005). The DRECP area includes two features deemed “High Threat Volcanoes” (defined as posing significant risks to aviation and proximate to smaller population centers and power and transportation infrastructure). These high-risk features are the Salton Buttes in Imperial County and the Lavic Lake Volcanic Field in San Bernardino County