Appendix M. Paleontological Resources

1. Regional Setting

The region of the present-day Coast Ranges and Great Valley was covered by marine waters through the Mesozoic and into the Cenozoic. During this time, forearc (i.e., the deep marine region between a volcanic arc and the associated subduction zone) marine and nonmarine shale, sandstone, and conglomerate of the Cretaceous Central Valley Sequence were deposited coincident with the accretion of the Franciscan Assemblage onto the continental margin of North America during the subduction of the Farallon Plate (Bartow and Nilsen, 1990, 6)[1]. Through the Upper Cretaceous and much of the Cenozoic, unconformable marine continental shelf sedimentary rocks were deposited above the Great Valley Sequence within the actively subsiding Central Valley region. As of the Late Miocene to the Late Pliocene, most of the marine waters in the Great Valley were drained and an orogenic (i.e., mountain-building) episode occurred in the vicinity of the present-day Coast Ranges, resulting in their uplift above sea level (Weissmann et al., 2005, 169:172). Subsequently, from the Late Pliocene to Holocene, extensive deposits of terrestrial material, including alluvial fans and fluvial sediments, were deposited in the Great Valley and southern Coast Ranges (Norris and Webb, 1976, 2:3). Tectonic activity and extensive faulting continued to occur during the Quaternary period, further uplifting and deforming the Coast Ranges.

2. Current Conditions and Trends

Geology and Paleontology of the Major Fossil-Bearing Units in the Central Coast Field Office Planning Area

Geologic units listed in table 3.16-2 are described below in alphabetical order.

Avenal Sandstone. The Early to Middle Eocene Avenal sandstone is composed of massive sandstone and pebble conglomerate with interbedded siltstone and fine-grained, thinly bedded sandstone (National Geologic Map Database [NGMDB], 2015). Numerous mollusk and foraminifera localities have been recovered within the Avenal Sandstone. In addition, at least one vertebrate locality was documented within Fresno County near Coalmine Canyon in the CCFO Planning Area, which yielded unspecified vertebrate specimens (UCMP, 2015).

Briones Formation, Cierbo Formation, and Neroly Sandstone of the San Pablo Group. The Miocene San Pablo Group is exposed in the CCFO Planning Area and extends throughout Contra Costa, Alameda, Stanislaus, and Santa Clara Counties (Graymer et al., 1996). The Briones Formation is the oldest member of the San Pablo Group, which includes the overlying Cierbo and Neroly formations (Carpenter et al., 1984, 35; NGMDB, 2015). The shallow marine Briones Formation is up to 2,300 feet thick near its type section and consists of indistinctly bedded fine-grained quartz sandstone, lithic wacke, gray to brown conglomerate, interbedded silty claystone, and resistant shell conglomerate (Chetelat, 1995, 8; Graymer et al., 1996; NGMDB, 2015). The Briones Formation has yielded an abundant and diverse fauna, including an extinct hippopotamus-like herbivorous mammal and taxa of reptile, fish, bird, shark, bivalve, gastropod, crustacean, echinoid, and brittle stars (UCMP, 2015).

The Miocene Cierbo Formation is up to 650 feet thick and consists of poorly to moderately consolidated white to pale yellow brown quartz sandstone interbedded with thin pebble conglomerate lenses and brown shale deposits (Carpenter et al., 1984, 35). The Cierbo Formation has yielded unnamed vertebrate fossils

[1] References for citations within this Appendix M are located in RMPA/EIS Section 7 under Paleontological Resources.

as well as abundant fossil specimens of invertebrate fauna, including mollusk, sea urchin, stony coral (Graymer et al., 1996; UCMP, 2015).

The Neroly Formation is up to 1,800 feet thick and is characterized by distinctive blue-gray sandstone derived from andesitic eruptions to the east (Bartow, 1985, A5; Throckmorton, 1988, 33). Numerous marine and terrestrial invertebrate, vertebrate, and plant fossils of have been recovered from within the Neroly Formation including well-preserved taxa of wolf, skunk, proboscidean, pronghorn, primitive beaver, and primitive New World mouse (Graymer et al., 1996; Throckmorton, 1988, 34). Additional fossil remains recovered within the Neroly Formation include horse, ground squirrel, eagle ray, gastropod, bivalve, scaphopod, coral, crab, sea urchin, and plants (UCMP, 2015).

Domengine Formation. The Middle Eocene age Domengine Formation is intermittently exposed throughout the CCFO Planning Area. The deposit is composed of massive, greenish-grey, medium-grained calcareous sandstone and well-indurated brown conglomeritic sandstone, with medium- to coarse-grained sand and well-rounded pebbles and cobbles (Oakeshott, 1958, 58-89). The Domengine Formation includes the white to light gray pebbly sandstone of the Yokut Sandstone member that forms the base of the unit and unconformably overlies older units, including rocks of the Great Valley Sequence (Prothero, 1991, 45-46). In central and northern California, the Domengine Formation has yielded hundreds of invertebrate and microfossil localities as well as one vertebrate locality in Fresno County, which yielded specimens of shark and bony fish (UCMP, 2015).

Etchegoin Formation. The Pliocene Etchegoin Formation is exposed in the CCFO Planning Area along the western margin of the San Joaquin Valley and into the eastern foothills of the Coast Ranges from Monterey County to San Benito County (NGMDB, 2015). Near the type section, the Etchegoin Formation overlies the Santa Margarita and Monterey Formations and is in turn overlain by the Tulare Formation. The Etchegoin Formation is composed of weakly lithified, light gray, well-bedded sandstone with interbeds of gray silty shale (Dibblee, 2005). The unit has also yielded vertebrate specimens of whale, shark, dolphin, beaver, otter, mammoth, deer, mastodon, rhinoceros, fox, and horse, as well as an abundant molluscan fauna (NGMDB, 2015; UCMP, 2015).

Franciscan Assemblage. The Franciscan Assemblage includes over 55,000 feet of greywacke, shale, greenstone, and bluestone metasedimentary rocks as well as ophiolite sequences, which were originally deposited on an ancient seafloor during the Jurassic to Cretaceous (Norris and Webb, 1976, 252:254). Rocks of the Franciscan Assemblage are exposed throughout the Coast Ranges and have yielded invertebrate and vertebrate specimens from numerous localities throughout the CCFO Planning Area in Alameda, Monterey, San Francisco, San Joaquin, San Mateo, Santa Clara, and Stanislaus Counties. Recovered fossils from the Franciscan Assemblage include the large marine reptiles, *Plesiosaurus* and *Ichthyosaurus*, as well as numerous burrow traces and invertebrate and plant fossils (UCMP, 2015).

Irvington Gravels. The Pliocene to Pleistocene age Irvington Gravels are exposed in Alameda County within the CCFO Planning Area and consist of poorly to well-consolidated, distinctly bedded pebbles and cobbles, gray pebbly sand, and gray, coarse-grained, cross-bedded sand (Helley and Graymer, 1997). The UCMP online database (2015) lists four vertebrate localities for the Irvington Gravels, which yielded hundreds of fossil specimens, including taxa of horse, camel, ground sloth, mammoth, dire wolf, fox, coyote, saber-toothed cat, rabbit, rodent, as well as the type specimen for *Tetrameryx irvingtonensis* (pronghorn).

Jacalitos Formation. The shallow marine to nonmarine Jacalitos Formation of Miocene to Pliocene age is exposed in the CCFO Planning Area within Fresno, Monterey, and San Benito Counties. The unit consists of fluvial and nearshore quartzitic and andesitic sandstone, siltstone, and conglomerate (NGMDB, 2015). Several invertebrate and vertebrate localities have been recovered from within the Jacalitos Formation, which yielded specimens of horse, echinoderm, mollusk, and brachiopod (UCMP, 2015).

Kreyenhagen Formation. The Eocene Kreyenhagen Formation conformably overlies the Domengine Formation and is exposed in Contra Costa, Fresno, San Benito, Monterey, Stanislaus, and Merced Counties within the CCFO Planning Area (UCMP, 2015). The unit consists of deep marine sediments composed of white diatomaceous shale, porcelaneous mudstone, and brown argillaceous shale with subordinate interbeds of siltstone and limestone (NGMDB, 2015; Bartow, 1990, 5:7). The Tumey Sandstone Lentil member (previously recognized as the Tumey Formation) forms the stratigraphic top of the Kreyenhagen Formation and is composed of a gray to brown, friable to cemented, locally pebbly lithic sandstone with dominate volcanic clasts (Bartow, 1996). Numerous invertebrate, microfossil, and vertebrate localities have been recovered from within the Kreyenhagen Formation, which yielded unspecified vertebrate remains as well as echinoderm, mollusk, foraminifera, and diatom fossils (UCMP, 2015).

Laguna Seca Formation. The Late Paleocene to Early Eocene Laguna Seca Formation is exposed in the CCFO Planning Area and is unconformable with the underlying Moreno Formation and overlying Domengine Formation. The unit is composed of well-lithified, light gray to tan, massive fine-grained micaceous sandstone and siltstone, local red mudstone, and white kaolinitic sandstone (Bartow, 1996). In addition to well-preserved fossil plant material, the Laguna Seca Formation has yielded several Paleocene to Eocene age invertebrate localities from paralic deposits in the CCFO Planning Area (UCMP, 2015; Paleobiology Database, 2015).

Livermore Gravels. The Pliocene to Pleistocene age Livermore Gravels are exposed within Alameda County and consist of loosely consolidated, massive to poorly bedded, gray to greenish-brown cobble conglomerate with a coarse arkosic matrix; conglomeritic sandstone; coarse-grained sandstone; and subordinate, interbedded greenish-blue siltstone and claystone (Helley and Graymer, 1997, 8). At least five vertebrate fossil localities within the Livermore Gravels have been recorded by the UCMP (2015) from various localities in central Alameda County, including specimens of bison, mammoth, horse, rodent, and turtle, and bird.

Lodo Formation. The Late Paleocene to Early Eocene age Lodo Formation is exposed within the CCFO Planning Area in Fresno, Merced, and San Benito Counties and is composed of bluish-gray, deep marine mudstone and claystone (Bartow, 1990, 6). The Lodo Formation contains abundant foraminifera microfossils as well as numerous mollusk invertebrate localities and at least one vertebrate locality within Fresno County, which yielded a specimen of Chimaera (cartilaginous fish) (UCMP, 2015).

Lompico Formation. The Middle Miocene Lompico Formation is exposed within the CCFO Planning Area in Santa Cruz County where it conformably underlies the Monterey Group. The Lompico Formation is up to 500 feet thick and is composed of yellowish-gray, massive to thickly bedded, medium- to fine-grained, moderately to well-sorted calcareous arkosic sandstone and a thin granitic basal conglomerate (Clark, 1981, 18). According to the UCMP (2015), the Lompico Formation has yielded numerous invertebrate localities of molluscan fauna from Santa Cruz County as well as one vertebrate locality, which yielded a specimen of whale.

Markley Formation. The late Eocene Markley Formation is exposed in Contra Costa and San Mateo Counties and is composed of interbedded, shallow marine to terrestrial, argillaceous shale, mudstone, and sandstone (NGMDB, 2015). The Markley Formation has yielded an abundant microfossil assemblage and invertebrate fauna, including specimens of gastropod, bivalve, foraminifera, radiolarian, and diatom (Squires, 1988, 107). In addition, at least five vertebrate localities have been recorded within the Markley Formation, which yielded fossil specimens of bony fish (UCMP, 2015).

Martinez Formation. The Paleocene to Eocene age Martinez Formation is locally exposed throughout the CCFO Planning Area. The fossiliferous marine unit consists of sandstone, pebble conglomerate, and siltstone and has yielded reptilian and other unspecified vertebrate specimens from localities in Contra Costa County. In addition, the Martinez Formation has yielded numerous invertebrate localities in San Mateo, Fresno, and Merced Counties (UCMP, 2015).

Merced Formation. The Pliocene to Pleistocene age Merced Formation is exposed within the CCFO Planning Area in Santa Clara, San Mateo, and San Francisco Counties. The Merced Formation is composed of up to 5,000 feet of marine to nonmarine grayish-brown medium- to fine-grained sandstone and silty clay, with subordinate interbedded pebble conglomerate and local tuffaceous deposits (NGMDB, 2015). According to the UCMP (2015), the Merced Formation has yielded abundant microfossils, plants, mollusk, and echinoderm specimens as well as at least 24 vertebrate localities, which yielded fossil specimens of bird, shark, fish, mammoth, horse, ground sloth, deer, camel, whale, dolphin, seal, and mastodon.

Monterey Group. The Monterey Group (also referred to as the Monterey Formation) is intermittently exposed throughout the CCFO Planning Area. The Monterey Group is up to approximately 5,000 feet thick and is dominated by finely laminated fine-grained diatomaceous and siliceous mudrocks; limestone and dolomite; calcareous and phosphatic mudrocks; chert and porcelanite; and subordinate tuff, sandstone, and conglomerate (Bramlette, 1946, 1:3; MacKinnon, 1989, 13:16). Numerous vertebrate localities have been documented from within the Monterey Group in California, including specimens of large sea turtles, whales, dolphins, sea lions, shark bones and teeth, desmostylians, sea cows, fish, birds, rare terrestrial vertebrates, and many other fauna (Bramlette, 1946, 9:10; Harden, 1998, 395:397; Koch et al., 2004, 7:10; Murphey et al., 2007, 45:70). Typically, specimens from the Monterey Group have been recovered within diatomite and shale deposits at depth and at the surface; however, limestone and sandstone beds also have yielded abundant remains (UCMP, 2015). In many cases, fossil specimens recovered from within the Monterey Group, such as whale, Chondrichthyes (cartilaginous fish), and bony fish, are remarkably well preserved and have previously yielded fully articulated specimens (Koch et al., 2004, 1). In addition, the Monterey Group has yielded numerous species of scientifically significant invertebrates, foraminifera, and plants, such as kelps and other large soft-bodied seaweeds.

Oro Loma Formation. The Miocene to Pliocene Oro Loma Formation is exposed within Alameda, Stanislaus, Merced, and San Joaquin Counties in the CCFO Planning Area and unconformably overlies the Briones Group (Graymer et al., 1996; NGMDB, 2015). The Oro Loma Formation is up to 300 feet thick and consists of unconsolidated to moderately consolidated red siltstone, sandstone, and pebble conglomerate interbedded with greenish-gray claystone. The Oro Loma Formation has yielded several fossil localities within the eastern Diablo Range, which yielded specimens of horse and camel (Kelly and Stewart, 2008, 2; Paleobiology Database, 2015; UCMP, 2015).

Panoche and Moreno Formations of the Cretaceous Great Valley Sequence. The Panoche and Moreno Formations are members of the Great Valley Sequence, which is extensively exposed throughout the CCFO Planning Area. The current Panoche-Coalinga ACEC was originally established as the Moreno Paleontological ACEC to protect its scientifically-significant paleontological resources. The Great Valley Sequence records a thick (10,000- to 30,000-foot) accumulation of Jurassic to Paleogene marine mudstone and sandstone deposited within a forearc basin flanked by the Sierra Nevada Batholith to the east and the Franciscan Complex to the west (Harden, 1998, 242:249). In the Diablo Range, the Cretaceous Panoche Formation rests unconformably on the Coast Range ophiolite and represents the base of the Great Valley Sequence. The Panoche Formation is up to 3,000 feet thick and consists of laterally variable deposits of gray to brown, moderately to well-bedded, and well-indurated mudstone and siltstone beds with local sandstone and boulder conglomerate lenses (Dibblee and Minch, 2007b and 2007d). The overlying Moreno Formation is up to 1,300 feet thick and was deposited conformably on the Panoche Formation during the Late Cretaceous to Paleocene epochs (Throckmorton, 1988, 5). The Moreno Formation consists of fine-grained sediments and is composed of commonly laminated, gray to brown micaceous shale with subordinate selenite gypsum, limestone lenses, and fine- to medium-grained grayish-tan arkose (Throckmorton, 1988, 9:12).

An abundant Cretaceous age flora and fauna has been recorded within the deposits of the Great Valley Sequence (UCMP, 2015). Numerous localities have been recorded within the Panoche and Moreno Formations, which have yielded marine and terrestrial fossils, including specimens of foraminifera,

diatoms, bivalves, ammonites, shark, fish, sea turtle, large marine reptiles, dinosaurs, fossilized wood of conifer and flowering plant taxa, and foliated conifer branches (Elder and Miller, 1993, 9-16; Haggart and Ward, 1984, 622:625; Long et al., 1946; Page, 1967, 1968, 197, 1973, 1979, 1980, 1981; San Joaquin Valley Geology, 2018; U.S. Geological Survey, 1963;). The remains of numerous large reptiles have been recovered within the Moreno Formation from within the Diablo Range, including mosasaur, plesiosaur, and dinosaur (Hilton, 2003; Paleobiology Database, 2015). In the Panoche Hills, the nearly fully articulated holotype specimen of the plesiosaur *Morenosaurus stocki* was recovered from within the Moreno Formation and is currently on display in the Natural History Museum of Los Angeles. Additionally, foliated branch fragments of the Moreno conifer (*Margeriella cretacea*) are exceptionally well preserved within the Moreno Formation (Page, 1973). Additional plant taxa identified from fossilized wood recovered from within the Moreno Formation include taxa palm, elm, sycamore, and magnolia (Page, 1967, 1968, 1970, 1973, 1979, 1980, 1981; San Joaquin Valley Geology, 2018; US Geological Survey, 1963).

Paso Robles Formation. The Late Pliocene to Early Pleistocene nonmarine Paso Robles Formation extends from the Salinas Valley through the southern border of the CCFO Planning Area and is composed of grayish-red sandstone, claystone, limestone, and conglomerate with clasts of white siliceous shale and chert derived from the underlying Monterey Formation (NGMDB, 2015; Tennyson, 1992). The fluvial-lacustrine unit is more than 3,000 feet thick and is composed primarily of gravel and sand channel and floodplain deposits, and with subordinate silt, clay, and limestone representing short-lived lakes. The Paso Robles Formation has numerous localities in the CCFO Planning Area, including several localities identified in the Salinas Valley and in Monterey County that yielded fossil specimens of horse tooth, rodent bones, seal, gastropod, and ostracode (Addicott and Galehouse, 1973, 510; UCMP, 2015; Woodring and Bramlette, 1950, 96).

Purisima Formation. The Early to Middle Pliocene age Purisima Formation is exposed within the CCFO Planning Area in San Mateo, Santa Clara, and Santa Cruz Counties and consists of basal marine deposits composed of poorly consolidated, laterally variable, claystone, siltstone, and fine-grained sandstone that coarsen up into terrestrial sandstone and conglomerate (NGMDB, 2015). Numerous vertebrate and invertebrate localities have been documented within the Purisima Formation, including hundreds of specimens of birds, shark, bony fish, reptile, pinniped, dolphin, whale, sea cow, horse, rodent, crustacean, echinoderms, bivalve, gastropod, and foraminifera (UCMP, 2015).

Quaternary Older Alluvium. Quaternary age alluvial deposits are exposed throughout the CCFO Planning Area and are composed of variable lithology derived from diverse sources (Graymer et al., 1996; Jennings, 1958; Jennings and Strand, 1958; Koenig, 1963; Strand and Koenig, 1965; UCMP, 2015). The deposits typically consist of unconsolidated to moderately consolidated, moderately dissected, locally variable compositions of silt, sand, gravel, and larger clasts deposited as alluvial fan and channel deposits, fluvio-lacustrine deposits, terrace deposits, and landslides. Quaternary alluvial, fluvial, and lacustrine deposits of Pleistocene age have proven to yield significant vertebrate fossil localities throughout the California Coast Ranges and the Central Valley. Recovered specimens include terrestrial mammals such as mammoth, horse, camel, bison, cat, bird, rodent, and reptile (UCMP, 2015). Some Pleistocene-age alluvial deposits are composed of coarse-grained material, which is not typically conducive to the preservation of fossils (e.g., alluvial fan deposits). For example, coarse-grained surficial Quaternary deposits derived from the local plutonic igneous rocks are unlikely to contain fossils; however, older, finer-grained alluvial sediments may contain significant paleontological resources.

San Benito Gravels. The Pliocene to Pleistocene age San Benito Gravels are exposed in San Benito County and consist of moderately consolidated conglomerate, sandstone, and argillaceous shale (NGMDB, 2015). At least eight vertebrate localities have been identified in the San Benito Gravels, which have yielded several fossil specimens of horse and mammoth (UCMP, 2015).

Santa Cruz Mudstone. The Late Miocene Santa Cruz Mudstone is exposed within the CCFO Planning Area in Santa Cruz County where it conformably overlies the Santa Margarita Formation. The Santa Cruz

Mudstone is composed of yellowish-brown, thickly bedded to laminated, blocky siliceous mudstone (Clark, 1981). The Santa Cruz Mudstone has yielded pollen, foraminifera, and mollusks from Santa Cruz County as well as a number of rare vertebrate localities, which yielded fossil specimens of fish scales and a sea cow rib (Clark, 1981). In addition, the UCMP online database (2015) identifies two localities that record occurrences of bony fish and shark.

Santa Margarita Formation. The Late Miocene age Santa Margarita Formation is intermittently exposed throughout the CCFO Planning Area in Fresno, Monterey, Santa Cruz, San Benito, and Santa Clara Counties (Jennings, 1958; NGMDB, 2015; UCMP, 2015). The Santa Margarita Formation conformably overlies the Monterey Formation in the Diablo Range and consists of deep to shallow marine deposits composed of buff, poorly indurated sandstone and biogenic shale and terrestrial sandy conglomerate. The Santa Margarita Formation has yielded abundant fossil specimens of mastodon, artiodactyl, horse, rabbit, walrus, sea cow, pinniped, shark, fish, reptile, bird, bivalve, gastropod, bryzoa, and echinoderm (UCMP, 2015).

Tehama Formation. The Pliocene age Tehama Formation is exposed in Contra Costa County and is composed of fluvially deposited, green-gray to tan quartzitic and tuffaceous sandstone, with lenticular siltstone deposits and crossbedded cobble conglomerate (Blake et al., 2000, 2; UCMP, 2015). Numerous vertebrate localities have been documented within the Tehama Formation outside of the CCFO Planning Area in adjacent counties, including specimens of mastodon, mammoth, horse, artiodactyl, dog, shrew, sloth, rodent, fish, and reptile (UCMP, 2015).

Temblor Formation. The Oligocene to Early Miocene Temblor Formation is exposed throughout the southeastern CCFO Planning Area and was named for exposures northwest of McKittrick in northwestern Kern County (NGMDB, 2015). The Temblor Formation is up to 500 feet and is composed of interbedded terrestrial and marine sandstone and shale deposits, including light gray to tan arkose, gray to red pebbly sandstone, and gray red claystone (Bridges and Castle, 2003, 275:285; Graham et al., 1989, 713:716). The Temblor Formation has yielded abundant fossils resources from more than 700 localities in central California. Of those localities, 38 yielded hundreds of vertebrate specimens including sea cows, gomphothere, mastodon, extinct horse, pinnipeds, fish, and sharks, among other taxa (UCMP, 2015).

Tulare Formation. The Late Pliocene to Early Pleistocene Tulare Formation is exposed in Fresno, Stanislaus, San Joaquin, and Alameda Counties within the CCFO Planning Area. The unit is approximately 1,700 to 3,500 feet thick and is composed of moderately lithified, thickly bedded, white to tan marl, massive gray claystone, and local gypsum and other fresh water evaporates (Bartow, 1990, 6; Dibblee and Minch, 2007b, 2007d). Numerous vertebrate localities have been recovered from within the fine-grained sediments of the Tulare Formation within the CCFO Planning Area within Alameda and San Joaquin Counties, which yielded specimens of horse, bird, shark, fish, and rodent. In addition, the remains of several well-preserved plants, including taxa of giant sequoia, pine, manzanita, fir, and walnut, were recovered in Stanislaus County (UCMP, 2015).

Vaqueros Formation. The early Miocene age Vaqueros Formation is intermittently exposed throughout the CCFO Planning Area. The Vaqueros Formation is a brown-gray, massive to thickly bedded marine sandstone, with interbedded siltstone, shale, and subordinate nonmarine conglomerate (NGMDB, 2015). The deposit has yielded numerous vertebrate fossils in Monterey and San Benito Counties including specimens of whale, hippopotamus, and shark (UCMP, 2015).