First report of early Miocene land mammals from the Red Rock Formation, southern Coyote Mountains, Imperial County, California

THOMAS A. DEMÉRÉ
Department of Paleontology, San Diego Natural History Museum
BRIDGET BORCE
Department of Paleontology, San Diego Natural History Museum
Department of Biology, San Diego State University

ABSTRACT

PALEONTOLOGICAL FIELDWORK CONDUCTED IN the Coyote Mountains since 1985 has resulted in the recovery of significant new fossils from Neogene marine and nonmarine strata. Of particular note is the discovery and recovery of land mammal fossils from the Red Rock Formation, the stratigraphically lowest and oldest Neogene rock unit exposed in the region. The Red Rock Formation is thought to predate the initiation of strong extensional tectonics in the Salton Trough. The recovered fossils include fragmentary mandibular, dental, and postcranial remains of a small to medium-sized camelid, tentatively assigned to the protolabine taxon, *Protolabis*. This group of stem camelids has an early Miocene (late Arikareean North American Land Mammal Age) evolutionary origin, which serves to constrain the maximum geologic age of the Red Rock Formation. Although fragmentary, the camelid fossils recovered from the Red Rock Formation serve as an indication of the paleontological potential of this rock unit.

INTRODUCTION

The Coyote Mountains, located in the western part of the Salton Trough (Figure 1), have drawn the attention of geologists and paleontologists since the mid-19th century, when W.P. Blake (1857) and T.A. Conrad (1857) first reported fossils from the area. Subsequent early paleontological work in the mountains was reported by Orcutt (1890), Vaughn (1917), Kew (1914), Nomland (1916), and Hanna (1926). Since Hanna (1926) interest in the paleontology of the Coyote Mountains has occurred sporadically, with pulses of work in the 1930s (e.g., Woodring, 1931; Grant and Hertlein, 1938), 1960s (e.g., Mitchell, 1961), 1970s (e.g., Stump, 1972; Foster, 1979), 1980s (e.g., Miller and Dockum, 1983; Bell-Countryman, 1984; Quinn and Cronin, 1984; Kidwell, 1988), 1990s (e.g., Deméré, 1993; Watkins, 1990a, 1990b, 1992; Winker and Kidwell, 1996), and 2000s (e.g., Deméré, 2006; Deméré and Rugh, 2006; Redman et al., 2007; Rugh, 2014). The vast majority of this published research has focused on the extensive marine invertebrate fossil assemblages preserved in strata of the Imperial Group. These upper Miocene and lower Pliocene strata and their contained fossil record preserve evidence critical to understanding such major regional events as the formation of the proto-Gulf of California, the initial uplift of the Colorado Plateau, and the birth of the Colorado River Delta. Imperial Group strata, however, are not the only sedimentary rocks exposed in the Coyote Mountains that preserve evidence of important geologic events. Gradationally overlying Imperial Group strata are rocks of the Palm Spring Group, which document both the late Pliocene and Pleistocene migration of the ancestral Colorado River Delta across the head of the proto-gulf to form the below-sea level Salton Basin, as well as the formation of the first in a series of large, ephemeral freshwater lakes that have characterized portions of the Salton Basin since the late Pliocene.

In the Coyote Mountains, Imperial Group strata either interfinger with and gradationally overlie Miocene fanglomerates of the Split Mountain Group (Garnet Formation of Winker and Kidwell, 1999) or nonconformably overlie volcanic rocks of the middle to lower Miocene Alverson Formation and/or plutonic and metamorphic rocks of the Mesozoic and Paleozoic crystalline basement complex (Dibblee, 2003). Good exposures of the former stratigraphic relationship occur in the Fossil Canyon area near Ocotillo, while exposures of the latter stratigraphic relationship occur in the Painted Gorge area near Plaster City (Figure 1). Locally, a reddish sandstone and conglomerate unit underlies and in places interfingers with the alkaline to tholeiitic basalts of the Alverson Formation (Ruisaard, 1979; Kerr and Kidwell, 1991). These reddish sandstones and conglomerates have a complex stratigraphic nomenclatural history and have been referred to the Split Mountain Formation (Ruisaard, 1979; Bell, 1980), or the Anza Formation (Kerr, 1982; Todd, 2004), or the Red Rock Formation (Winker and

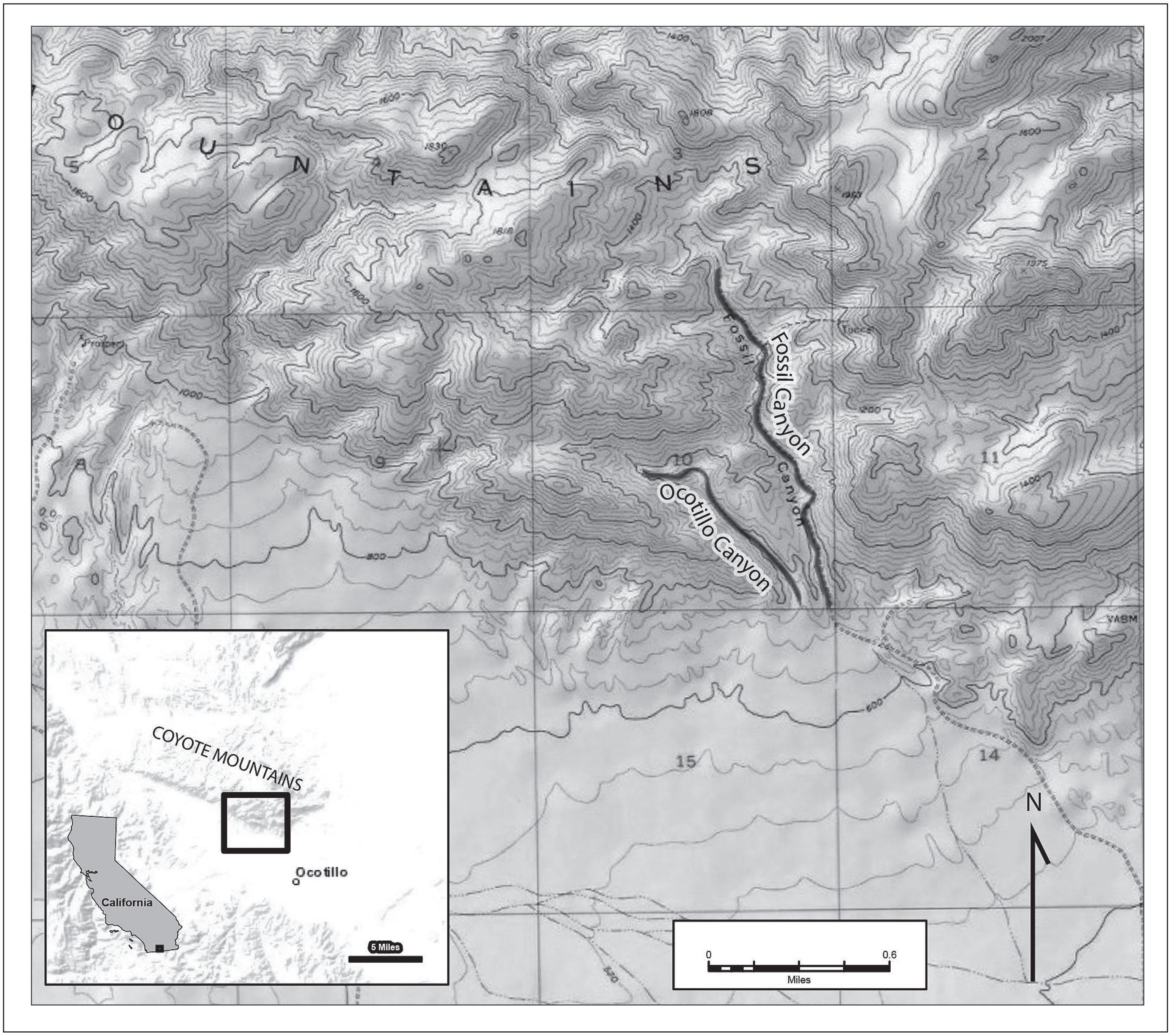

Figure 1. Index map of the southeastern Coyote Mountains showing the location of Fossil Canyon and Ocotillo Canyon. Base map: Carrizo Mountain, CA USGS 7.5' topographic quadrangle.

Kidwell, 1996). The latter formational name is used in this report following the work of Winker (1987), Winker and Kidwell (1996), and Dorsey et al. (2011).

The Red Rock Formation was originally named for exposures of lower Miocene non-marine strata in Red Rock Canyon in the Fish Creek Mountains. In the Coyote Mountains, the Red Rock Formation is only well-exposed in Ocotillo Canyon, just west of Fossil Canyon, and underlies and interfingers with volcanic flow rocks of the Alverson Formation (Ruisaard, 1979; Kerr and Kidwell, 1991). The superpositional relationship of the Red Rock Formation relative to the Alverson Formation indicates that the former is no younger than 14–22 Ma—the age of the Alverson Formation (Dorsey et al., 2007). As an early Miocene rock unit, the Red Rock Formation predates the onset of structurally controlled basin formation and strong extensional tectonics in the Salton Trough (Dorsey et al., 2011). This factor suggests that more intense study of the Red Rock Formation has the potential to yield new evidence about geologic conditions and events during this poorly known chapter in the geologic history of the region.

Kerr (1984) and Kerr and Kidwell (1991) discussed the sedimentology and facies relationships of strata of the Red Rock Formation as exposed in the type area in the Fish Creek Mountains and concluded that they accumulated in a braided stream depositional system with longitudinal bars, channel lags, migrating sand waves, and seif sand dunes. To date, no fossils have been reported from strata of the Red Rock Formation and as a consequence nothing is known of the organisms and ecosystems that existed in this early Miocene braided stream setting. In an effort to correct this paleontological deficiency, we report for the first time land mammal fossils from the Red Rock Formation.

GEOLOGY AND STRATIGRAPHY

The geology of the Coyote Mountains is petrologically and structurally complex. The current elevation of the range is largely the result of strike-slip faulting along the Elsinore Fault Zone, which runs NW along the southern flank of the mountains (Todd, 2004). A series of NNW and NE striking high-angle normal faults also occur in the area, where they have produced tilted fault blocks and local horsts and grabens. The oldest rocks exposed in the Coyote Mountains are rocks of the crystalline basement complex, which includes Paleozoic metasedimentary rocks and Mesozoic plutonic rocks. The metasedimentary rocks are mostly marble and quartz-mica schist, with local outcrops of amphibolite, gneiss, and quartzite (Ruisaard, 1979; Dibblee, 2003). Miller and Dockum (1983) reported the occurrence of early Ordovician conodonts from low-grade marbles exposed on the SE flank of Carrizo Mountain, in the eastern part of the mountain range. Plutonic rocks in the Coyote Mountains consist of intrusions of quartz diorite, granodiorite, and pegmatite dikes. These rocks likely share a common history with Mesozoic plutonic rocks of the Peninsular Range Batholith. Cenozoic sedimentary rocks rest noncomformably on the crystalline basement complex and include the lower Miocene Red Rock Formation, the lower to middle Miocene Alverson Formation, the upper Miocene Split Mountain Group, the Mio-Pliocene Imperial Group, and the Plio-Pleistocene Palm Spring Group (Winker and Kidwell, 1996). Locally, elevated Pleistocene terrace deposits unconformably overlie the Neogene rocks and create a stepped series of dissected pediment surfaces.

OCOTILLO CANYON

Along the southern margin of the Coyote Mountains are a series of fault controlled canyons that provide good exposures of the Neogene stratigraphic section (Figure 1). Certainly the best known and best studied of these canyons is Fossil Canyon, also called Alverson Canyon or Shell Canyon. A prominent NNW striking high angle normal fault runs along the eastern slopes of Fossil Canyon and in places juxtaposes crystalline basement rocks against NE dipping Neogene marine strata of the Imperial Group. A smaller canyon located to the west of Fossil Canyon and called Ocotillo Canyon, also is associated with a NNW striking, high angle normal fault that in this case exposes and offsets NE dipping Neogene nonmarine strata and volcanic flow rocks of the Red Rock Formation and Alverson Formation, respectively. The Red Rock Formation rests directly on crystalline basement rocks and represents the beginning of significant Neogene deposition in the Coyote Mountains area. As mapped and described by Ruisaard (1979), the Red Rock Formation in Ocotillo Canyon consists of approximately 140 meters of grayish-orange pink to moderate red, fine- to coarse-grained, arkosic sandstones and interbedded pebble to cobble conglomerates. The conglomerates typically contain clasts derived from the crystalline basement complex. However, near the major bend in Ocotillo Canyon, a stratigraphic sequence consisting of the Red Rock Formation and Alverson Formation is exposed in the steep eastern wall of the canyon. In this area, the approximate strike of bedding in the Red Rock Formation is N35°W, with an approximate dip of 20°NE. Lithologies include reddish-tan, fine-grained, laminated sandstone, reddish poorly sorted, fine- to coarse-grained arkosic sandstone with interbedded pebble to cobble conglomerate. Clasts within the conglomerates include gray feldspar, granitic rock fragments, and clear, white translucent and gray quartz. At the top of the section is a well-developed baked zone at the contact between the Red Rock Formation and the basaltic flow rocks of the Alverson Formation.

Paleontology

Artiodactyla

Camelidae

cf. *Protolabis* sp.

Referred specimens: SDNHM 140180 (Figure 2); partial left dentary with dp3-4 and unerupted m1. SDNHM 140352; associated left calcaneum and astragalus

Locality and Stratigraphic Horizon: SDNHM Locality 5961, Ocotillo Canyon, Coyote Mountains, Imperial County, California, USA. Collected November 2002 and May 2009 from the upper part of the Red Rock Formation, approximately 20 feet stratigraphically below basalt in the Alverson Formation.

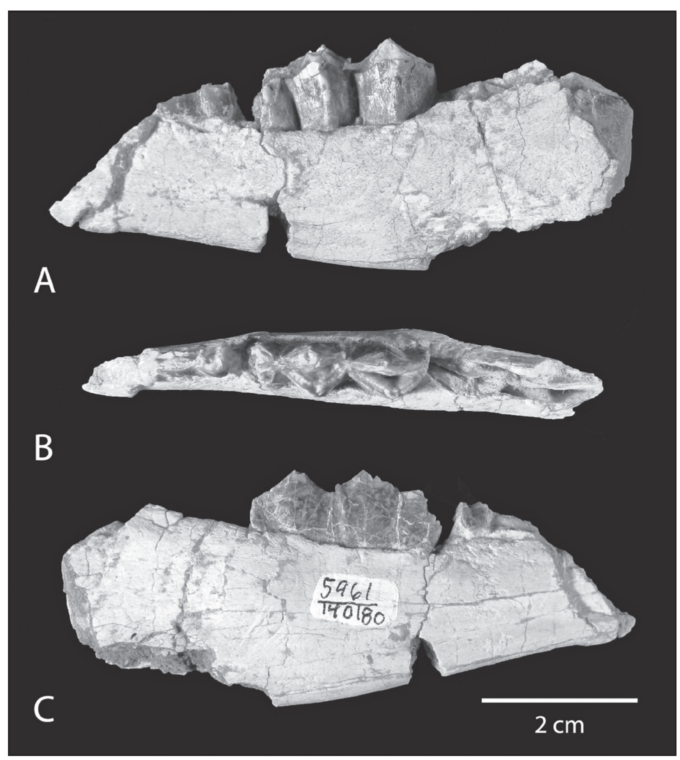

Figure 2. cf. ***Protolabis*** sp., partial left dentary with dp3-4 and unerupted m1 (SDNHM 140180) recovered from SDNHM Locality 5961. A. labial view; B. occlusal view; C. lingual view.

Description

Dentary: The partial left dentary (SDNHM 140180) is represented by the central portion of the horizontal ramus containing a partial dp3, a complete dp4, and an unerupted m1 (Figure 2). The preserved ramus measures 73.10 mm in greatest length, and is 18.06 mm in height and 10.14 mm in width as measured at the level of dp4. The anterior and posterior breaks are sharp and unabraded. The dentary is relatively small and gracile and reflects a rather small subadult individual.

dp3: The dp3 is fragmentary and preserves a nearly complete posterior crest with well-worn hypoconid and broken entoconid (Figure 2). The posterior fossettid is enlarged due to wear. The posterolingual corner of the crown is developed into a weak entostylid. The posterior border of the crown has a small facet, suggesting that the dp4 was in direct contact with the dp3. The anterior crest of the crown is largely missing, although the labial enamel surface of the primary cusp is intact. The crown measures 11.14 mm in length and the posterior lobe measures 4.74 in maximum width.

dp4: The dp4 is tri-lobed, distinctly seleodont, and except for damage to the anterior cusp is complete (Figure 2). The lingual surface is marked by a prominent metastylid and weakly developed entostylid. The entoconid has a very weak median ridge. There is no median ridge developed on the lingual surface of the metaconid. There are no anterior or posterior cingula present. With greater wear, the median fossettid likely would have reached the lingual surface behind the prominent metastylid. The broken anterior lobe preserves a small anterior fossettid, but the labial and lingual anterocondis are both missing due to breakage. A small piece of enamel adhering to the posterior margin of dp3 is likely a remnant of the anterior margin of the anterior lobe. As preserved, the dp4 measures 23.45 mm in length, although the actual length of the tooth was likely closer to 26 mm. The maximum width of the posterior lobe is 7.08 mm, while the median lobe measures 7.01 mm and the anterior lobe 5.61 mm.

m1: The m1 is unerupted and unworn (Figure 2). The crown is visible within the alveolar crypt and is narrowly elongate and bilobed, with the inner and outer cusps separated by deeply inset fossettids. Based on the relative positions of the metaconid and entoconid, there is likely a distinct metastylid. There is no evidence of an entostylid, although the posterior margin of the crown appears to be slightly broken. There is no evidence of median ridges on the metaconid or entoconid. However, this may be a function of how the tooth is preserved in its alveolar crypt. The maximum length of the crown is 24.70 mm, while the estimated width of both the anterior and posterior cusps is ~6 mm.

Calcaneum: The left calcaneum (SDNHM 140352) is damaged (due to weathering) and is missing the proximal portion of the sustentaculum, as well as the distal terminus of the calcaneal tuber. The dorsal margin of the calcaneal tuber has lost the cortical bone layer. As preserved, the calcaneum measures 45.58 mm in greatest length. The calcaneal tuber measures 35.14 mm in greatest length and 7.25 mm in minimum width.

Astragalus: The left astragalus is very fragmentary and is missing the lateral margin and major portions of the distal trochlea. The maximum length as preserved measures 20.72 mm and the maximum preserved width is 13.30 mm. The fossil preserves enough features to confirm the characteristic artiodactyl "double pulley" morphology.

Taxonomy

Unfortunately the presence of a deciduous dentition in SDNHM 140180 makes it difficult to definitively diagnose the dentary to the species level, or for that matter to a taxonomic level below the family Camelidae. However, several features taken together suggest that the specimen is likely a protolabine camelid and provisionally a taxon of *Protolabis*. Length and width measurements of dp3 and dp4, as well as the length/width ratio of dp4 fall within the morphometric range of *Protolabis* (Honey and Taylor, 1978). In addition, the general morphology of dp3 and dp4 in SDNHM 140180 is compatible with features described for deciduous teeth of *Protolabis* by Loring and Wood (1969) and Honey and Taylor (1978), including the presence of a prominent metastylid and an anterolingually placed median fossettid on dp4. In addition, Honey (2007) has recently suggested that the two, coeval protolabine taxa *Protolabis* and *Michenia* might actually represent sexually dimorphic pairs of a single camelid genus of small to medium-sized ungulate browsers.

DISCUSSION

The camelid fossils described in this study represent the first identifiable land mammal fossils known from the Red Rock Formation. Although the fossils are fragmentary and do not preserve sufficient anatomical detail to allow for taxonomic identification to the species level, the fossils do document the occurrence of land mammal fossils in the Red Rock Formation and indicate the likelihood that additional well-preserved vertebrate fossils will be discovered with increased paleontological prospecting. The eventual recovery of additional, identifiable vertebrate fossils will provide new information critical to better understanding the biochronology, biostratigraphy, and paleoecology of the Red Rock Formation. This information can, in turn, be used to better understand the early Miocene paleoenvironments and paleoclimate of the Salton Trough.

Camelids have had a long geological history in North America and, in fact, the entire clade had its evolutionary first appearance on this continent during the middle Eocene (Uintan NALMA; 46.2–42 Ma). It is noteworthy that fossils of one of the earliest stem camelids, *Poebrodon californicus*, have been recovered from middle Eocene strata of the Santiago Formation as exposed in Carlsbad and Oceanside (Golz, 1976). Camelids remained a North American endemic lineage until the late Miocene (Turolian ELMA; 9.0–5.3 Ma), when a northern dispersal event brought the first camelids to Eurasia (Honey et al., 1998). The period of greatest camelid diversity in North America occurred during the early through middle Miocene (late Arikareean to Barstovian NALMAs; 19.2–13.6 Ma). In some early and middle Miocene mammalian faunas, camelids were the most common large herbivores, where they were represented by a diversity of small to medium-sized animals (Honey et al., 1998). Camelids remained a conspicuous element of North American land mammal assemblages through the late Miocene (Hemphillian NALMA; 10.3–4.9 Ma), with a decrease in diversity during the Pliocene (Blancan NALMA; 4.9–1.8 Ma) until their extirpation from North American at the end of the Pleistocene (Rancholabrean NALMA, 240–10 ka).

The earliest protolabine camelids are known from the early Miocene (late Arikareean NALMA; 23–19 Ma) of the great basin and central plains (Honey et al., 1998) and the lineage extended through the middle Miocene into the late Miocene (Clarendonian NALMA; 13.6–10.3 Ma). Protolabines were relatively long-legged (compared to miolabines) camelids with moderately hypsodont cheek teeth, and are considered to have been ground-level feeders (browsers) in contrast to the tree-browsing and giraffe-like, later diverging aepycamelines (Janis, 1982). The relatively diverse protolabine lineage of stem camelids occupied the woodland savannah habitats that dominated certain regions of North America during the early Miocene (Janis, 1982). Given the taxonomic diversity and broad biogeographic range (i.e., central California, Great Basin, and Great Plains) of protolabines, it is not surprising that fossil remains of this camelid lineage have been found in the Coyote Mountains.

The recovery of camelid fossils from the Red Rock Formation has biochronological implications and suggests that this rock unit possibly is no older than the late late Arikareean NALMA (i.e., no older than ~19 Ma). This tentative age correlation, in turn, has implications for constraining the timing for initiation of strong extensional tectonics in the Salton Trough. However, it needs to be emphasized that this biochronological evidence is weak and in need of testing by the collection of additional vertebrate fossil remains and possible radiometric dating.

SUMMARY

Paleontological fieldwork in the southern part of the Coyote Mountains has resulted in the recovery, for the first time, of land mammal fossils from Neogene fluvial deposits of the Red Rock Formation. The fossils represent a small- to medium-sized camelid that is tentatively referred to the protolabine taxon, *Protolabis*. Protolabine camelids were conspicuous members of woodland savannah mammalian assemblages of the early Miocene of central California, the Great Basin, and the Great Plains. The recovery of land mammal fossil remains in the Red Rock Formation has the potential to yield important new information about the early Miocene paleoenvironment, paleoclimate, and paleoecology of the Salton Trough.

ACKNOWLEDGEMENTS

The fossils reported in this study were collected by dedicated field paleontologists presently and formerly employed in the Department of Paleontology at the San Diego Natural History Museum, especially Richard A. Cerutti, Patrick L. Sena, and the late Stephen L. Walsh. Field work and fossil collection activities were conducted under BLM paleontological investigation permit CA-10-00-009P. It is important to emphasize that vertebrate fossils cannot be collected in the Coyote Mountains (a federally designated wilderness area) without an approved paleontological investigation permit from the BLM El Centro field office.

BIBLIOGRAPHY

Bell, P.J. 1980. Environments of Deposition, Pliocene Imperial Formation, Southeast Coyote Mountains, Imperial County, California. Department of Geological Sciences, San Diego State University, unpublished Master's thesis, 80 p.

Bell-Countryman, P. 1984. Environments of deposition, Pliocene Imperial Formation southern Coyote Mountains, Imperial County, California. In, C.A. Rigsby (ed.), The Imperial Basin—Tectonics, Sedimentation, and Thermal Aspects, Pacific Section SEPM: 45–70.

Blake, W.P. 1857. Geological report. U.S. Pacific Railroad Exploration. U.S. 33rd Congress, 2nd session, Senate Executive Document 78 and House Executive Document 91, vol. 5, 390 p.

Conrad, T.A. 1857. Report of Mr. T. A. Conrad on the fossil shells collected in California by W. P. Blake, geologist of the expedition under the command of Lieutenant R. S. Williamson, U.S. Topographical Engineers, 1853. In, W.P. Blake, Geological report. U.S. Pacific Railroad Exploration. U.S. 33rd Congress, 2nd session, Senate Executive Document 78 and House Executive Document 91, vol. 5, Appendix 2: 325–326.

Deméré, T. A. 1993. Fossil mammals from the Imperial Formation (upper Miocene-lower Pliocene), Coyote Mountains, Imperial County, California. In, R.E. Reynolds and J. Reynolds (eds.), Ashes, Faults, and Basins. San Bernardino County Museum Association Special Publication 93-1: 82–85.

Deméré, T.A. 2006. The Imperial Sea: Marine Geology and Paleontology. In, G.T. Jefferson and L. Lindsay (eds.), Fossil Treasures of the Anza-Borrego Desert. Sunbelt Publications, San Diego, chapter 2: 29–41.

Deméré, T.A., and N.S. Rugh. 2006. Invertebrates of the Imperial Valley. In, G.T. Jefferson and L. Lindsay (eds.), Fossil Treasures of the Anza-Borrego Desert, Sunbelt Publications, San Diego, California, chapter 3: 43–70.

Dibblee, T.W. 2003, Geology of the Coyote Mountains, Imperial and San Diego Counties, San Diego. In, M.L. Murbach and M.W. Hart (eds.), Geology of the Elsinore Fault Zone, San Diego Region: San Diego Association of Geologists, San Diego, South Coast Geological Society, Santa Ana, California, p.117–123.

Dorsey, R.J., A. Fluette, K. McDougall, B.A. Housen, S.U. Janecke, G.J. Axen, and C.R. Shirvell. 2007. Chronology of Miocene-Pliocene deposits at Split

Mountain Gorge, southern California: A record of regional tectonics and Colorado River evolution. Geology 35: 57–60.

Dorsey, R.J., B.A. Housen, S.U. Janecke, C.M. Fanning, and A.L.F. Spears. 2011. Stratigraphic record of basin development within the San Andreas fault system: Late Cenozoic Fish Creek-Vallecito basin, southern California. Geological Society of America Bulletin 123: 771–793.

Foster, A.B. 1979. Environmental variation in a fossil scleractinian coral. Lethaia. 12:245–264.

Golz, D.J. 1976. Eocene Artiodactyla of southern California. Natural History Museum of Los Angeles County Science Bulletin 26:1–85.

Grant, U.S. and L.G. Hertlein. 1938. The West American Cenozoic Echinoidea. Publications of the University of California at Los Angeles in Mathematical and Physical Sciences 2: 1–225.

Hanna, G.D. 1926. Paleontology of Coyote Mountains, Imperial County, California. California Academy of Sciences Proceedings, series 4, 14: 51–186.

Honey, J.G. 2007. The Camelidae. In, D.R. Prothero and S. Foss (eds.), The Evolution of Artiodactyls. Johns Hopkins University Press, p. 177–188.

Honey, J.G. and B.E. Taylor. 1978. A generic revision of the Protolabidini (Mammalia: Camelidae), with a description of two new protolabidines. American Museum of Natural History Bulletin 161:367–426.

Honey, J.G., J.A. Harrison, D.R. Prothero, and M.S. Stevens. 1998. Camelidae. In, C.M. Janis, K.M. Scott, and L.L. Jacobs (eds.), Tertiary Mammals of North America. Cambridge University Press, Cambridge and New York, p. 439–462.

Janis C. 1982. Evolution of horned ungulates: ecology and paleoecology. Biological reviews 57: 261–318.

Kerr, D.R. 1982. Early Neogene Continental Sedimentation, Western Salton Trough, California. Department of Geological Sciences, San Diego State University, unpublished Master's thesis, 150 p.

Kerr, D.R. 1984. Early Neogene continental sedimentation in the Vallecito and Fish Creek Mountains, western Salton Trough, California. Sedimentary Geology 38: 217–246.

Kerr, D.R., and S.M. Kidwell. 1991, Late Cenozoic sedimentation and tectonics, western Salton Trough, California. In, M.J. Walawender and B.B. Hanan (eds.), Geological Excursions in Southern California and Mexico: San Diego, California, Department of Geological Sciences, San Diego State University, p. 397–416.

Kew, W.S.W. 1914. Tertiary echinoids of the Carrizo Creek region in the Colorado Desert. University of California Publications in Geological Sciences Bulletin 8: 39–60.

Kidwell, S.M. 1988. Taphonomic comparison of passive and active continental margins: Neogene shell beds of the Atlantic Coastal Plain and northern Gulf of California. Palaeogeography, Palaeoclimatology, Palaeoecology 63: 201–223.

Loring, S.H. and A.E. Wood. 1969. Deciduous premolars of some North American Tertiary camels (family Camelidae). Journal of Paleontology 43:1199–1209.

Miller, R. and M. Dockum. 1983. Ordovician conodonts from metamorphosed carbonates of the Salton Trough, California. Geology 11: 410–412.

Mitchell, E.D., Jr. 1961. A new walrus from the Imperial Pliocene of southern California: with notes on odobenid and otariid humeri. Los Angeles County Museum Contributions in Science 44: 1–28.

Nomland, J.O. 1916. Corals from the Cretaceous and Tertiary of California and Oregon. University of California Publications in Geological Sciences 9: 59–76.

Orcutt, C.R. 1890. Geology of the Colorado Desert. California Mining Bureau Report 10: 899–919.

Quinn, H.A., and T.M. Cronin. 1984, Micropaleontology and depositional environments of the Imperial and Palm Springs Formations, Imperial Valley, California. In, C.A. Rigsby (ed.), The Imperial Basin—Tectonics, Sedimentation, and Thermal Aspects: Pacific Section, Society for Sedimentary Geology (SEPM), Los Angeles, p. 71–85.

Redman, CM., L.R. Leighton, S.A. Schellenberg, C.N. Gale, J.L. Nielsen, D.L.Dressler, and M.K. Klinger. 2007. Influence of spatiotemporal scale on the interpretation of paleocommunity structure: lateral variation in the Imperial Formation of California. Palaios 22: 630–641.

Rugh, N.S. 2014. Imperial Group invertebrate fossils Part 2: the Kidwell Collection. In, R.E. Reynolds (ed.), Not a Drop Left to Drink, California State University Desert Studies Center, 2014 Desert Symposium. Pp. 138–143.

Ruisaard, C.I. 1979. Stratigraphy of the Miocene Alverson Fomation, Imperial County, California. Department of Geological Sciences, San Diego State University, unpublished Master's thesis, 136 p.

Stump, T.E. 1972. Stratigraphy and paleontology of the Imperial Formation in the western Colorado Desert. Department of Geological Sciences, San Diego State University, unpublished Master's thesis, 128 pp.

Todd, V.R. 2004. Preliminary geologic map of the El Cajon 30' x 60' quadrangle, southern California. USGS Open-File Report 2004-1361.

Vaughan, T.W. 1917. The reef-coral fauna of Carrizo Creek, Imperial County, and its significance. United States Geological Survey Professional Paper 98: 355–386.

Watkins, R. 1990a. Paleoecology of a Pliocene rocky shoreline, Salton trough region, California. Palaios 5: 167–175.

Watkins, R. 1990b. Pliocene channel deposits of oyster shells in the Salton Trough region, California. Palaeogeography, Palaeoclimatology, Palaeoecology 79: 249–262.

Watkins, R. 1992. Sedimentology and paleoecology of Pliocene shallow marine conglomerates, Salton Trough region, California. Palaeogeography, Palaeoclimatology, Palaeoecology 95: 319–333.

Winker, C.D. 1987. Neogene stratigraphy of the Fish Creek-Vallecito section, Southern California: implications for early history of the northern Gulf of California and Colorado Delta. Department of Geosciences, University of Arizona, unpublished Ph.D. dissertation, 494 pp.

Winker, C.D. and S.M. Kidwell. 1996. Stratigraphy of a marine rift basin: Neogene of the western Salton Trough, California. In, P. L. Abbott and J. D. Cooper (eds.), Field Conference Guide 1996. Pacific Section AAPG GB 73, Pacific Section SEPM book 80: 295–336.

Woodring, W.P. 1931. Distribution and age of the Tertiary deposits of the Colorado Desert. Carnegie Institute of Washington Publication 418: 1–25.

GEOLOGY OF THE COYOTE MOUNTAINS

SOUTHERN CALIFORNIA

Published in conjunction with the

2015 Field Trip of the

San Diego Association of Geologists

November 6-8, 2015

RANDALL WAGNER, *Editor*

SAN DIEGO ASSOCIATION OF GEOLOGISTS

Distributed by Sunbelt Publications

www.sunbeltbooks.com