Evidence of the K-Pg Impact in California

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Empirical evidence and modeling indicate that the following events occurred as a result of the K-Pg impact at Chicxulub, Mexico: Impact blast, ejecta fallout, tsunami sequences, acidic aerosol generation and rain-out. We theorize that evidence of these events is preserved in the sedimentary record in California.

Paired clay-rich "melt ejecta" and Iridium-rich "fireball" layers occur globally (Pollastro and Bohor, 1993; Evans and others, 1994; Smit, 1999; Croskell and Collins, 2002). Impact-tsunami deposits are documented in the Gulf of Mexico (Yancey, 1997; Bralower and others, 1998). Elsewhere, tsunamis would likely be generated by seismically induced submarine landslides along the Atlantic and Pacific coasts (Norris and others, 2000; Busby and others, 2002), and possibly by antipodal geoid displacement (southeast Asia).

Researchers have quantified a volumetric-range for acidic aerosols generated by the K-Pg impact into Yucatan's anhydrite target rocks (D'Hondt and others, 1994; Guangqing and others, 1994; Lyons and Aherns, 2002; Kring, 2007). The estimated volume of acid is deemed sufficient to have produced, via enhanced weathering, the "spike" in sea-water strontium isotope values across the K-Pg boundary (Martin and Macdougall, 1991; MacLeod and others, 2001; Kring, 2007). These acidic solutions would likely reside in basins and lagoons until neutralized.

In California (and elsewhere), Paleocene rocks are characterized by kaolinite. Examples include: the Paleocene Simi Conglomerate, Silverado (Sutherland, 1935; Engel, 1959; Engel and others, 1959; Schoellhamer and others, 1981), and Goler (Dibblee, 1952; Cox, 1982; Cox, 1987) Formations; and basal units of the "Eocene" Ione (Allen, 1929; Creely and Force, 2007), Walker (Bartow and McDougall, 1984), and Maniobra (Crowell and Suzuki, 1959; Squires and Advocate, 1986; Ingersoll and others, 2014) Formations. Features common to these formations include laterization, pisolitic claystone, kaolinitized sediment and basement (saprolite), and lignite.

The classical interpretation is that these lateritic "paleosols" result from an extended period of weathering in a warm, humid environment (Peterson and Abbott, 1973; Peterson and Abbott, 1975; Abbott and others, 1976; Retallack, 1981; Abbott and others, 1993; Kraus, 1999). However, the laterite-bearing Silverado Formation and Simi Conglomerate are bracketed between Danian and Maastrichtian marine strata (Saul, 1983; Miller and Busch, 2016), which suggests a period of lowered sea level — and a cooler, drier climate.

We propose a model in which the observed intensive corrosion and kaolinitization of sediment and basement resulted when impact-generated acidic solutions collected in and saturated sediment-filled fluvial channels, basins, and lagoonal environments.

In this model, economic clay deposits in the Alberhill area (Sutherland, 1935; Engel, 1959; Engel and others, 1959) represent sediment and basement variably altered by ponded acidic run-off. The Claymont Clay Bed, which consists exclusively of kaolinite and angular sub-mm quartz (Schoellhamer and others, 1981), may represent a deposit from a down-range ray of the clay-rich K-Pg impact "ejecta layer."

Figure 1. *Suevite* from impact crater at Rochechouart, France; impact occurred 214 mya. Suevite is a polymict impact breccia with clastic matrix and mineral clasts in various stages of shock metamorphism; it is a diagnostic rock-type for large impact structures. (Photo: M. Schmieder)

Figure 2. Detail from Figure 1 - *Suevite* from impact crater at Rochechouart. Suevite is a polymict impact breccia with clastic matrix and mineral clasts in various stages of shock metamorphism; it is a diagnostic rock-type for large impact structures. (Photo: M. Schmieder)

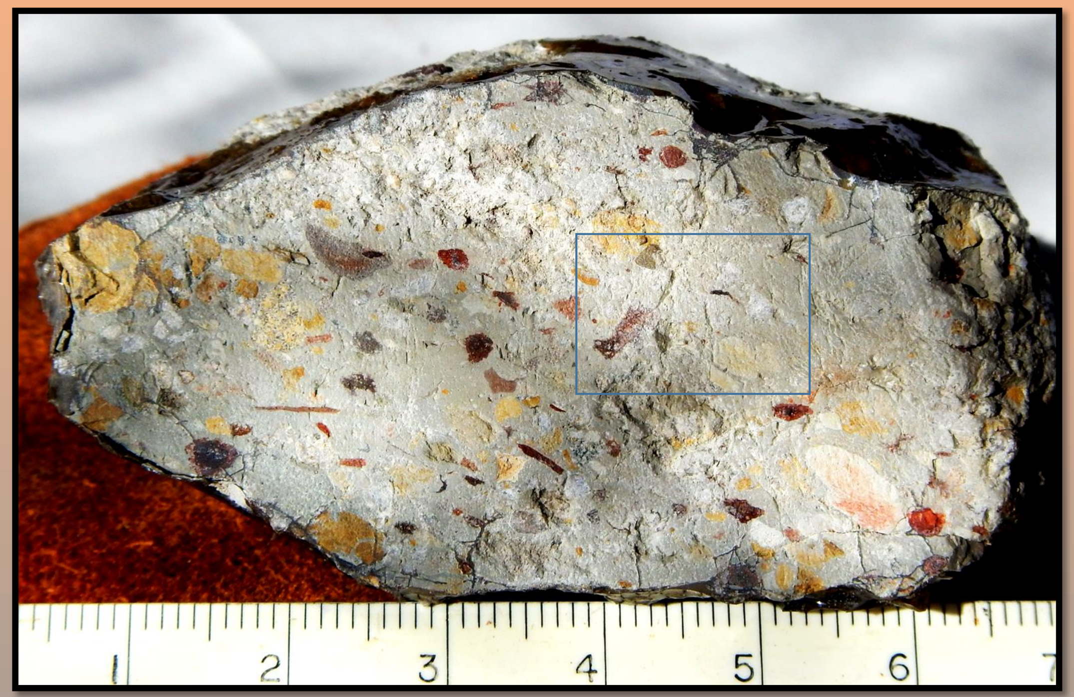

Figure 3. Suevite-textured kaolinitic claystone from the Alberhill "Bone Clay" bed in the lower Silverado Formation (lower Paleocene), Riverside County. Contains altered angular to round Clasts, shards, and droplet forms in a kaolinite matrix; also contains shattered quartz grains to 3+ mm.

Figure 4. Detail from Figure 3 - Shattered quartz grains (approx. 3 mm) in suevite-textured kaolinitic claystone, Alberhill "Bone Clay" bed, lower Silverado Formation.

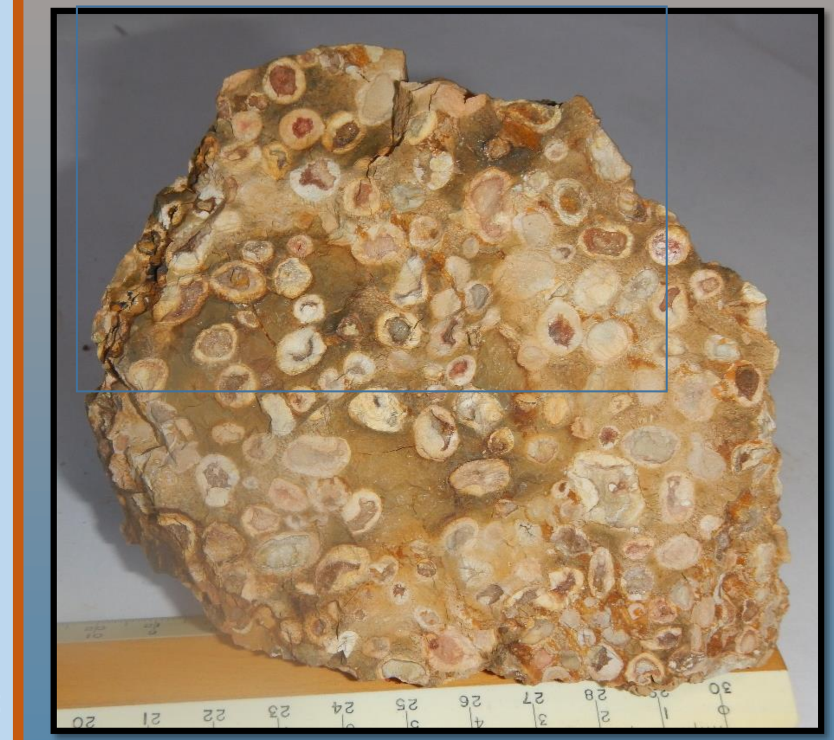

Figure 5. Clast-cored, devitrified glass-rimmed, unoxidized, accretionary impact lapilli from the "Pisolitic Claystone" bed near base of lower Silverado Formation, Alberhill, Riverside County.

Figure 6. Detail from Figure 5. Clast-cored, devitrified glass-rimmed, unoxidized, accretionary impact lapilli from the "Pisolitic Claystone" bed near base of lower Silverado Formation.

Figure 7. Comparison: clast-cored, devitrified glass-rimmed, unoxidized, accretionary impact lapilli from the Figures 5 and 6 -- compared to typical, red, oxidized, "Pisolitic Claystone" from lower Silverado Formation, Alberhill, Riverside County.

Figure 8. Typical red oxidized "Pisolitic Claystone" bed from near base of lower Silverado Formation, Alberhill, Riverside County.

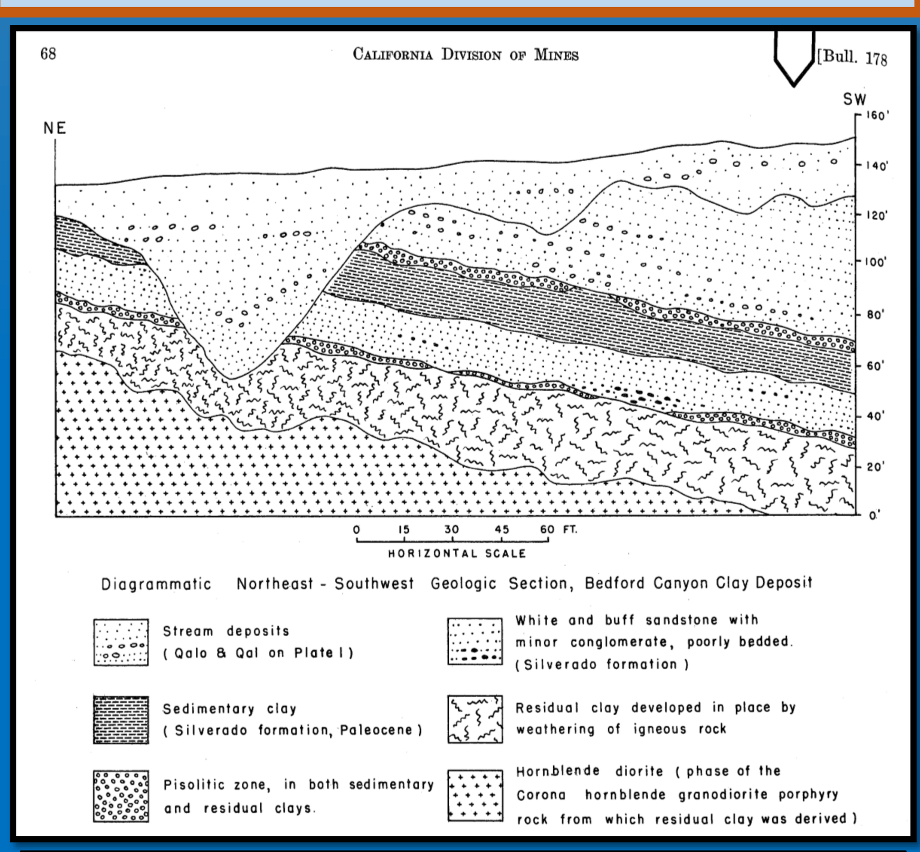

Figure 9. Diagrammatic Cross Section, lower Silverado Formation, Riverside County (CaDivMines Bul. 178, 1961).

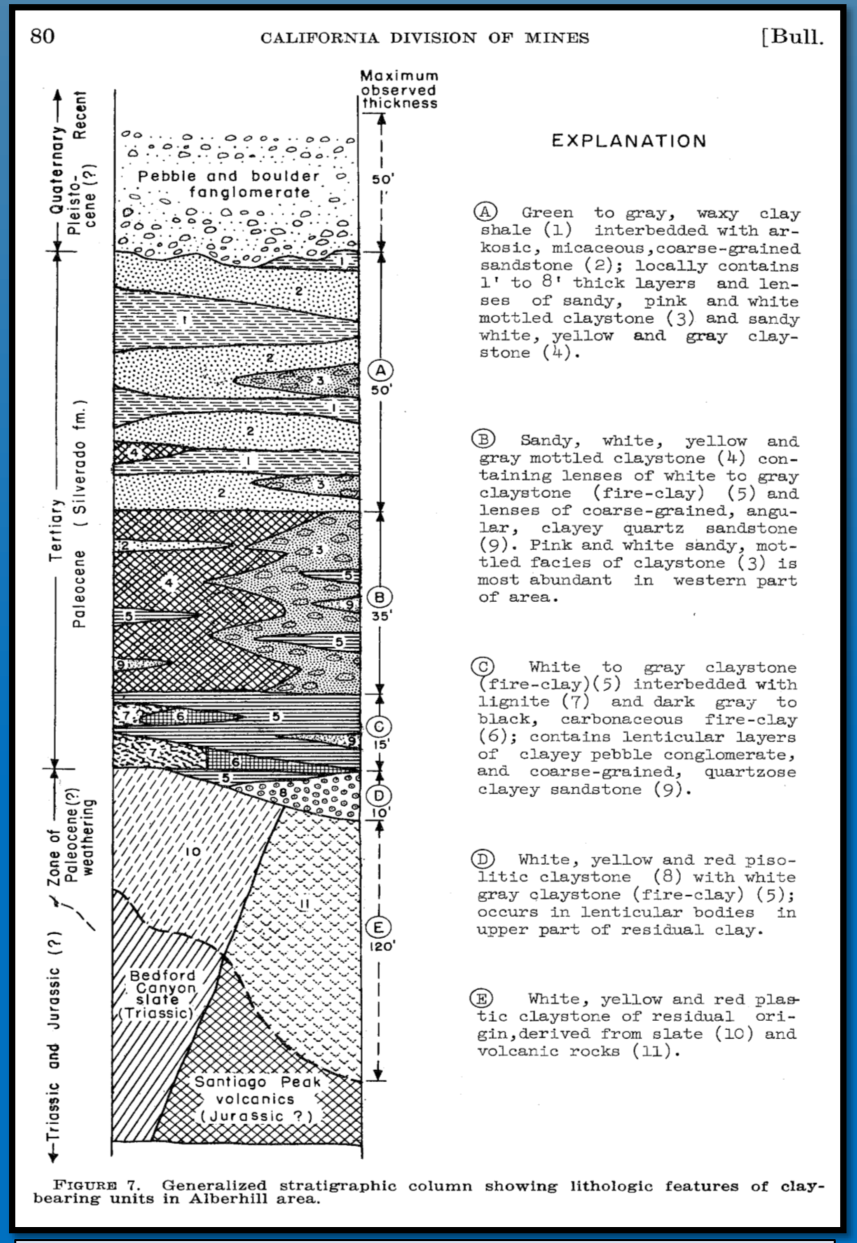

Figure 10. Generalized Stratigraphic Column, Alberhill Clay-bearing units, lower Silverado Formation, Riverside County (CaDivMines Bul. 146, 1959).

Figure 11. Photomicrograph of Claymont Clay Bed, lower Silverado Formation, Orange County, California. Note angular, sub-mm quartz grains in pisolites and matrix (USGS PP 420-D, 1981).

Figure 12 a & b. Claymont Clay Bed - kaolinitic claystone of the lower Silverado Formation, Orange County, California. Face approximately 2 m high. b - Detail from a, Claymont Clay Bed, lower Silverado Formation, Orange County. Diagonal dimension approximately 1 m.

Figure 13 a & b. Serrano Clay Bed - kaolinitic sandstone of the lower Silverado Formation, Orange County, California. Face approximately 3 m high. b - Detail from a, Serrano Clay Bed, lower Silverado Formation, Orange County (view approximately 1 m x 1 m).

Figure 14 a & b. Comparison: on right, Serrano Clay Bed kaolinitic sandstone (lower Silverado Formation, Orange County); compared with, on the left, kaolinitic sandstone of basal bed on the Maniobra Formation in the Mojave Desert (Riverside County). B - Detail, on right, Serrano Clay Bed of the Silverado Formation; compared with basal bed on the Maniobra Formation on the left (view 2 cm x 2 cm).

Evidence for Reassignment of Kaolinite- and Quartz-Rich Strata of the Basal Tertiary Section in California to the Lower Paleocene

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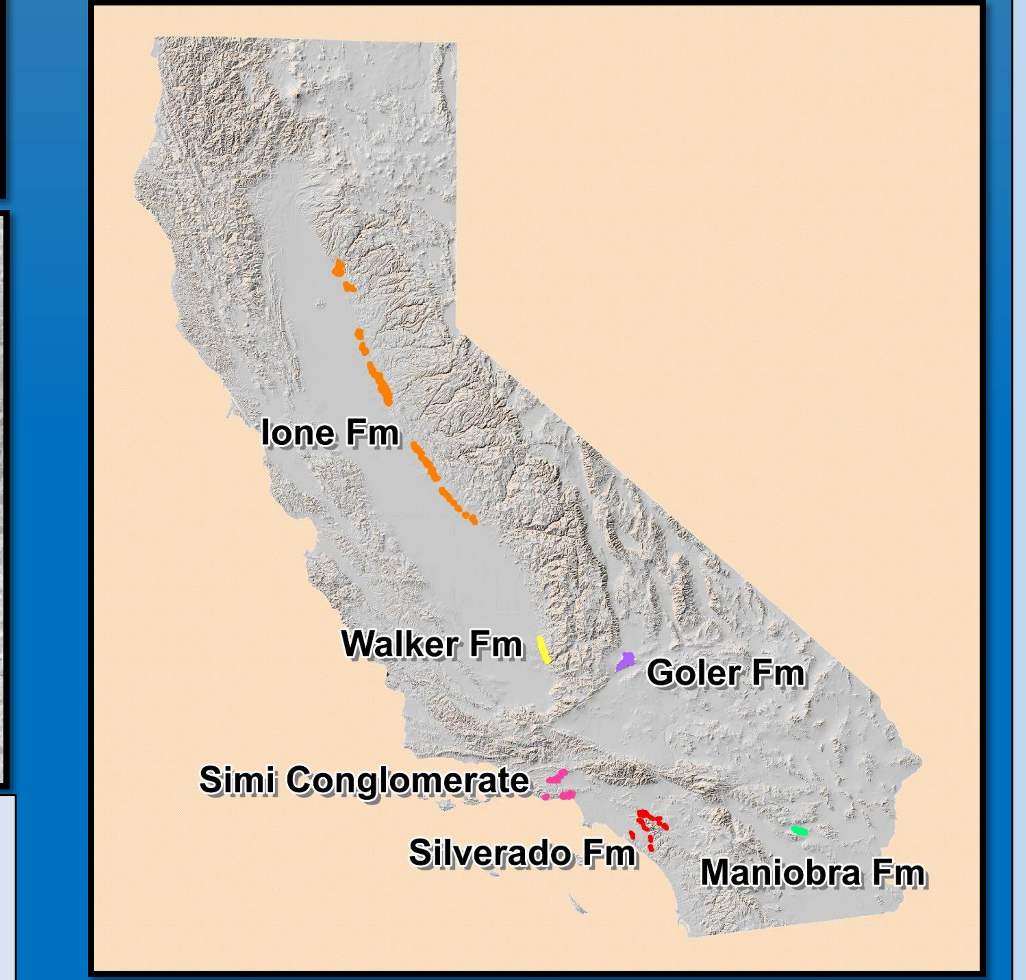
Most assignments of a mid- to late-Paleocene age for the lower, nonmarine portion Silverado Formation are derived from a 1984 paper by Gaponoff published in Palynology. The mid- to late-Paleocene age was based on the presence of two species: *Momipites tenuipolus* Anderson, and *Plicatopolis triradiata* (Nichols) Frederiksen and Christopher. Gaponoff states these two species were "restricted to the late Paleocene in North America." Nichols (1973) was cited as a guide to that age; subsequently, Nichols (1992) identified the former species as a characteristic form in the lower Paleocene of the Powder River Basin. The latter species, also originally dated as late Paleocene (Frederiksen and Christopher, 1978), was subsequently found to occur in the early Paleocene in Maryland and Virginia (Frederiksen, 1984). Thus, we can interpret an early Paleocene age for the lower Silverado Formation.

The nonmarine Simi Conglomerate is mineralogically and lithologically similar to the lower Silverado Formation (Schoellhamer and others, 1981; Cox, 1982). Both lie unconformably on Cretaceous marine strata. An "unnamed" pre-Martinez (Danian) marine faunal assemblage in the upper Las Virgenes Sandstone lies stratigraphically above the Simi Conglomerate (Saul, 1983). We infer that the Simi Conglomerate and the lower Silverado Formation are litho- and chrono-stratigraphically equivalent—and early Paleocene in age.

Constraining the kaolinitic, pisolite-bearing Simi Conglomerate and lower Silverado Formation to the early Paleocene implies a need to reconsider the age of similar rocks elsewhere in California. For example, the Simi Conglomerate and lower Silverado Formation bear compelling mineralogic and lithostratigraphic similarities to basal units of the less well constrained "Eocene" Ione (Allen, 1929; Creely and Force, 2007;) and Walker Formations (Bartow and McDougall, 1984) in central California. Hand samples from a basal, 0-2 meter-thick kaolinitic sandstone of the largely Eocene Maniobra Formation (Crowell and Suzuki, 1959; Squires and Advocate, 1986; Ingersoll and others, 2014) in the Mojave Desert are indistinguishable from samples from the Serrano Clay Bed in the lower Silverado Formation in Orange County. All five formations contain bed(s) comprised exclusively of quartz and kaolinite; all lie unconformably upon Cretaceous-age strata or older basement. Similar kaolinite-quartz rocks of Paleocene age are found in San Diego County and Baja California (Peterson and Abbott, 1973; Peterson and Abbott, 1975; Abbott and others, 1976; Abbott and others, 1993).

Lower Paleocene kaolinite-bearing strata in California may record evidence of the K-Pg impact event (Busch and Miller, 2016).



References:

Abbott, P.L., Hanson, A.D., Thomson, C.N., Logue, D.L., Bradshaw, K.D., Pollard, W.J., Seeliger, T.E., 1993, Geology of the Paleocene Sepultura Formation, Mesa de la Sepultura, Baja California: Ciencias Marinas, v. 19, No. 1, p. 75-93.

Abbott, P.L., Minch, J.A., and Peterson, G.L., 1976, Pre-Eocene paleosol south of Tijuana, Baja California, Mexico: Journal of Sedimentary Petrology, v. 46, p. 355-361.

Allen, Victor T., 1929, The Ione Formation of California: Bulletin of the Department of Geological Sciences [University of California], v. 18, no. 14, p. 347-448.

Bartow, A.J., and McDougall, K., 1984, Tertiary stratigraphy of the southeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1529-J, 44p.

Bourgeois, J., Hansen, T.A., Wiberg, P.L., and Kauffman, E.G., 1988, A tsunami deposit at the Cretaceous-Tertiary boundary in Texas: Science, v. 241, p. 567–580.

Bralower, T.J., Paull, C.M., and Leckie, R.M., 1998, The Cretaceous-Tertiary boundary cocktail: Chicxulub impact triggers margin collapse and extensive sediment gravity flows: Geology, v. 26, p. 331–334.

Busby, C.J., Yip, G., Blikra, L., and Renne, P., 2002, Coastal landsliding and catastrophic sedimentation triggered by Cretaceous-Tertiary bolide impact: a Pacific margin example?: Geology, v. 30, no. 8, p. 867-890.

Busch, L.L., and Miller, R.V., 2016 Evidence of the K-Pg Impact in California: *abstract,* GSA Cordilleran Section abstracts with program, v. 48, No. 4, A5-1.

Cox, Brett F., 1982, Stratigraphy, sedimentology, and structure of the Goler Formation, El Paso Mountains, California; implications for Paleogene Tectonism on the Garlock Fault Zone: Dissertation, University of California, Riverside, 266 p., 2 plates.

Cox, Brett F., 1987, Stratigraphy, depositional environments, and paleotectonics of the Paleocene and Eocene Goler Formation, El Paso Mountains, California – geologic summary and road log, *in* Cox, B.F., (ed.), Basin analysis and paleontology of the Paleocene and Eocene Goler Formation, El Paso Mountains, California: SEPM Book 57, p. 1-29.

Creely, Scott, and Force, E.R., 2007, Type region of the Ione Formation (Eocene), central California: stratigraphy, paleogeography, and relation to the Auriferous Gravels: U.S. Geological Survey Open File Report 2006-1378, 65 p.

Croskell, M.S., and Collins, G.C., 2002, Formation of the Double K/T boundary layer in North America: 33rd Annual Lunar and Planetary Science Conference, abstract no.1103,2 p.

Crowell, J.C., and Suzuki, T., 1959, Eocene Stratigraphy paleontology, Orocopia Mountains, southeastern California: Geological Society of America Bulletin, v. 70, p. 581-592.

D'Hondt, Steven, Pilson, M.E., Sigurdson, H., Hanson A.K., and Carey, S., 1994, Surface-water acidification and extinction at the Cretaceous-Tertiary boundary: Geology, v. 22, p. 983-986.

Dibblee, T.W., 1952, Geology of the Saltdale Quadrangle, California: California Division of Mines Bulletin 160, p. 8-66, 3 Plates.

Engel, Rene, 1959, Geology of the Lake Elsinore Quadrangle California: California Division of Mines Bulletin 146, p. 59-154, 7 Plates.

Engel, Rene, Gay, Thomas E., Jr., and Rogers, B.L., 1959, Mineral deposits of the Lake Elsinore Quadrangle California: California Division of Mines Bulletin 146, p. 9-58, 3 Plates.

Evans, N.J., Gregoire, D.C., Goodfellow, W.D., Miles, N., and Veizer, J., 1994, The Cretaceous-Tertiary fireball layer, ejecta layer and coal seam: Platinum-group element content and minerology of size fraction: Meteoritics, v. 29, p. 223-235.

Frederiksen, N.O., 1984, Lower Tertiary pollen biostratigraphy, Maryland and Virginia, *in* Frederiksen, N.O., and Krafft, K., (eds.), Cretaceous and Tertiary stratigraphy, paleontology, and structure, southwestern Maryland and northeastern Virginia: American Association of Stratigraphic Palynologists Field Trip Volume and Guidebook.

Frederiksen, N.O., and Christopher, R.A., 1978, Taxonomy and biostratigraphy of Late Cretaceous and Paleogene triatriate pollen from South Carolina: Palynology, v. 2, p. 113-145.

Gaponoff, S.L., 1984, Palynology of the Silverado Formation (Late Paleocene), Riverside and Orange counties, California: Palynology, v. 8. P. 71-106.

Guangqing Chen, Tyburczy, J.A., and Aherns, T.J., 1994, Shock-induced devolatilization of calcium sulfate and implications for K-T extinctions: Earth and Planetary Science Letters, v. 128, p. 615-628.

Ingersoll, R.V., Pratt, M.J., Davos, P.M., Caracciolo, L., Day, P.J., Hayne, P.O., Petrizzo, D.A., Gingrich, D.A., Cavazza, W., Critelli, S., Diamond, D.S., Coffey, K.T., Stang, D.M., Reith, R.C., and Hendrix, E.D., 2014, Paleotectonics of a complex Miocene half graben formed above a detachment fault; the Diligencia Basin, Orocopia Mountains, southern California: Lithosphere, v. 6, no. 3, p. 157-176.

Kraus, Mary J., 1999, Paleosols in clastic sedimentary rocks: their geologic applications: Earth Science Reviews, v. 47, p. 41-70.

Kring, D.A., 2007, The Chicxulub impact event and its environmental consequences at the Cretaceous-Tertiary Boundary: Palaeogeography, Palaeoclimatology, Palaeoecology v. 255, p. 4–21

Lyons, J.R., and Aherns T.J., 2002, Terrestrial acidification at the K/T boundary, *in* V.L. Davison, Y. Horie, and T. Sekine, (eds.), High-pressure shock compression of solids: Springer-Verlag-New York, Inc. 2002, p. 181-197.

MacLeod, K.G., Huber, B.T., and Fullagar, P.D., 2001, Evidence for a small (∼0.000030) but resolvable increase in seawater 87Sr/86Sr ratios across the Cretaceous-Tertiary boundary: Geology, v. 29 no. 4, p. 303-306.

Martin, E.E., and Macdougall, J.D., 1991, Seawater Sr isotopes at the Cretaceous/Tertiary boundary: Earth and Planetary Science Letters, v. 104 (2-4), p. 166-180.

Miller, R.V., and Busch, L.L., 2016, Evidence for reassignment of kaolinite- and quartz-rich strata of the basal Tertiary section in California to the lower Paleocene: *abstract,* GSA Cordilleran Section abstracts with program, v. 48, No. 4, A27-5.

Nichols, D.J., 1973, North American and European species of *Momipites ("Engelhardtia")* and related genera: Geoscience and Man, v. 7, p. 103-117.

Nichols, D.J., and Brown, J.L., 1992, Palynostratigraphy of the Tullock Member (lower Paleocene) of the Fort Union Formation in the Powder River Basin, Montana and Wyoming; U.S. Geological Survey Bulletin 1917-F, 35 p., 10 plates.

Norris, R.D., Firth, J., Blusztajn, J.S., and Ravizza, G., 2000, Mass failure of the North Atlantic margin triggered by the Cretaceous-Paleogene bolide impact: Geology, v. 28, p. 1119–1122.

Peterson, G.L., and Abbott, P.L., 1973, Weathering of the pre-Eocene terrane along coastal southwestern California and northern Baja California: *in* Ross, A. and Dowlen, R. (eds.), Studies on the geology and geological hazards of the Greater San Diego Area, California: San Diego Association of Geologists and Association of Engineering Geologists Field Trip Guidebook, p. 19-22.

Peterson, G.L., and Abbott, P.L., 1975, Paleocene age of lateritic paleosol, western San Diego County, California: *in* Ross, A. and Dowlen, R. (eds.), Studies on the geology of Camp Pendleton and western San Diego County, California: San Diego Association of Geologists Field Trip Guidebook, p. 60–64.

Pollastro, R.M., and Bohor, B.F., 1993, Origin and clay-mineral genesis of the Cretaceous-Tertiary boundary unit, western interior of North America: Clays and Clay Minerals v. 41, no. 1, p. 7-25.

Retallack, Greg, 1981, Fossil soils; indicators of ancient terrestrial environments, *in* Niklas, K.J. (ed.), Paleobotany, Paleoecology, and Evolution, v.1, p. 55-102: Praeger Publishers, New York.

Saul, L.R., 1983, Notes on Paleogene turritellas, venericardias, and molluscan stages of the Simi Valley area, California: *in* Squires, R.R., and Filewicz, M.V., (eds.), Cenozoic geology of the Simi Valley area, southern California: Pacific Section, S.E.P.M., Fall Field Trip Volume and Guidebook, p. 71-80.

Schoellhamer, J.E., Vedder, J.G., Yerkes, R.F., and Kinney, D.M., 1981, Geology of the northern Santa Ana Mountains, California: U.S. Geological Survey Professional Paper 420-D, 109 pages, 4 plates.

Smit, J., 1999, The global stratigraphy of the Cretaceous-Tertiary boundary impact ejecta: Annual Review of Earth and Planetary Sciences, v. 27, p. 75–113.

Squires, R.L., and Advocate, D.M., 1986, New Early Eocene mollusk from the Orocopia Mountains, southern California: Journal of Paleontology, v. 60, p. 851-864.

Sutherland, J.C., 1935, Geological investigation of the clays of Riverside and Orange counties, southern California: California Journal of Mines and Geology-31st Report of the State Mineralogist, p. 51-87, 1 Plate.

Yancey, T.E., 1997, Tsunamites and bolide impact: Cretaceous-Tertiary boundary deposits, northern shelf of the Gulf of Mexico: Geological Society of America Abstracts with Programs, v. 29, no. 6, p. A142.