Mapping California's Mineral Hazards and Paleontological Resources on the State Highway System

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INTRODUCTION

WHETHER YOUR GOAL IS TO MINIMIZE EXPOSURE to mineral hazards or protect paleontological resources, geologic maps are essential to making informed decisions.

The California Geological Survey (CGS) collaborated with the California Department of Transportation (Caltrans) to conduct statewide mapping of mineral hazards and paleontological resources. The purpose of this work was to provide Caltrans with maps and data to support planning and decision making. This work required the development of new geologic mapping data for creating digital maps of paleontological resources and mineral hazards by geologic formation. The total area studied in this assessment was approximately 162,000 square miles.

Caltrans is involved in hundreds of construction projects statewide each year. These projects range from road surface rehabilitation to major highway and bridge construction and often include local city and county partners. Each project relies on the geologic maps and data.

Mineral hazards and paleontological resources along California's roadways could pose environmental or public health and safety concerns, project delays, or cost overruns. Proper handling and management of disturbed soil and rock containing mineral hazards or paleontological resources is also mandated under a variety of local, state, and federal environmental and safety laws and regulations.

"GIS screening tools enable Caltrans to quickly pinpoint issues for project design, highway maintenance, and emergency removal of geologic materials."

The ability to use digital maps and data to research and compile geologic information to determine potential mineral hazards and paleontological resources in a project area prior to construction has resulted in efficiencies that led to state cost savings of more than $200,000 annually.

MINERAL HAZARDS IN CALIFORNIA

What are mineral hazards and why does Caltrans care about them?

California is a geologically complex state with the potential for mineral hazards to occur statewide. It contains numerous types of rocks, which range from Quaternary (2.58 million years ago to present day) to Proterozoic (2.5 billion to 541 million years ago) in age (Walker and Geissman, 2022). Tectonically, it has been affected by many episodes of magmatism and metamorphism, with accompanying faulting and folding; these phenomena continue to the present. This diverse and active geologic history has resulted in a variety of potential mineral hazards throughout the state. More than 90 geologic units in the state have been identified as known or potential sources of mineral hazards.

Mineral hazards along California's roadways could pose environmental or public health and safety concerns during roadway construction and maintenance. Geographic information system (GIS) map screening tools enable Caltrans staff to quickly pinpoint issues for project design, routine highway maintenance, and emergency removal of geologic materials. With hundreds of Caltrans projects statewide each year, this results in substantial cost savings for the state.

Fibrous asbestos, Photo credit: Michael Fuller, California Geological Survey.

What are naturally occurring hazardous minerals and how do they form?

Mineral hazards are defined, in part, as minerals and elements that occur naturally in elevated, potentially harmful, concentrations in rocks, soils, and certain fluids. Mineral hazards are also features from human activities related to extraction of mineral and energy resources. Soils and rock containing mineral hazards may be harmful to the environment, the public, or construction and maintenance workers when disturbed by human activity and not handled and managed properly. Hazardous minerals and elements include, among others, naturally occurring asbestos, mercury, and arsenic.

Hazardous minerals form because of natural geologic processes such as volcanoes, geothermal springs, faults, and metamorphism. For example, the most common host rocks for asbestos mineralization are ultramafic rocks that are igneous rocks composed mainly of iron-magnesium silicate minerals, that were altered by metamorphism. Natural sources of mercury include volcanic activity and geothermal springs. Arsenic-bearing minerals may form in igneous intrusive or metamorphic rocks or in some volcanic and geothermal hot spring environments.

PALEONTOLOGY IN CALIFORNIA

What are paleontological resources and why does Caltrans care about them?

Paleontology is a natural science focused on the study of ancient life as it is preserved in the geologic record as fossils (exclusive of fossil humans). Paleontology is a sub-discipline of geology and is closely associated with evolutionary biology.

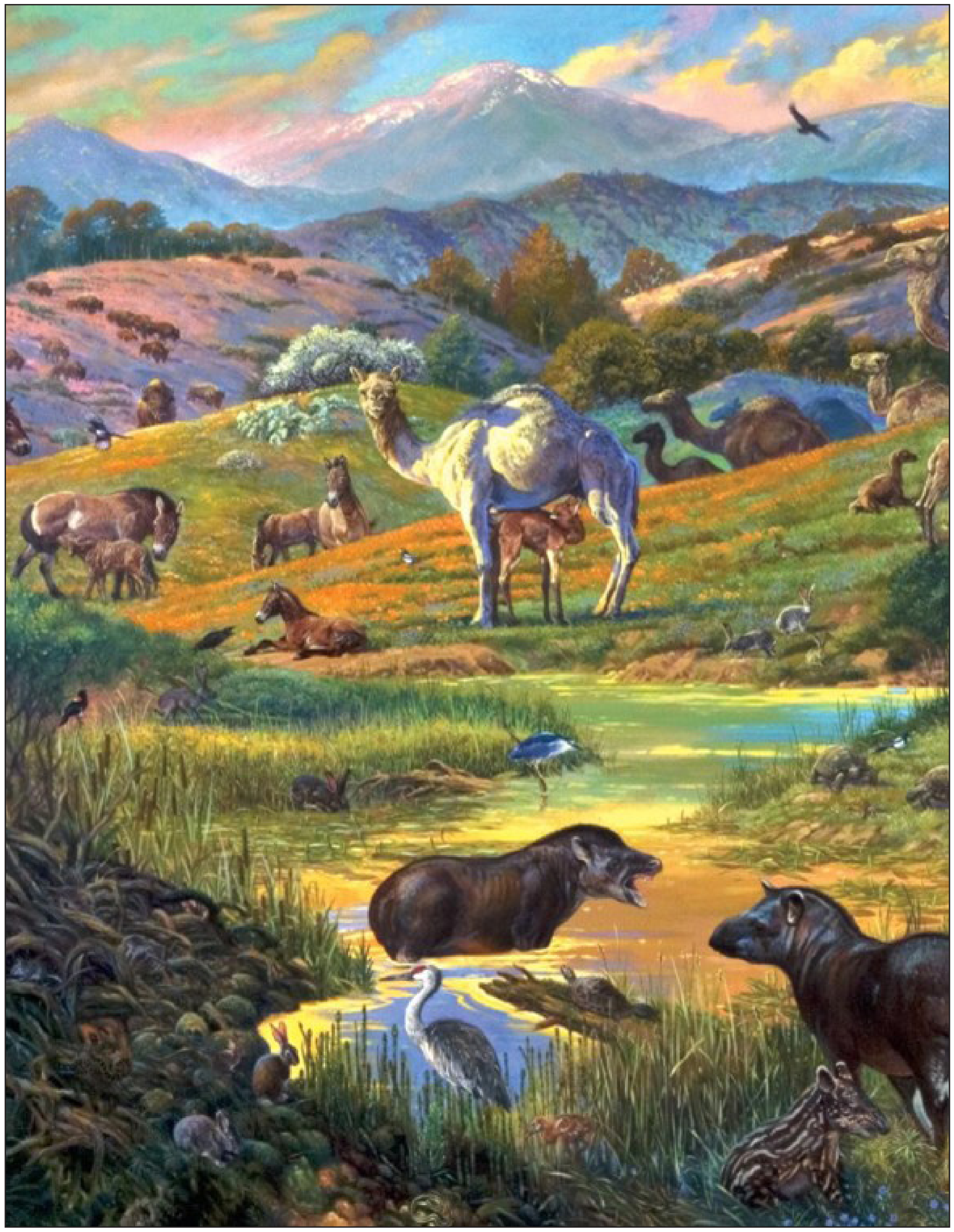
California is rich in fossil deposits that provide crucial information about the Earth's history, past climates, and ancient life forms. These fossils can offer insights into evolutionary processes, extinct species, and the environmental changes that have shaped the planet over millions of years. Fossils are non-renewable resources; once they are damaged or destroyed, they cannot be replaced. Proper protection ensures that these valuable scientific records remain intact for future research and education.

Paleontological resources include fossil remains or ichnofossils, of Pleistocene or older (>11.7 Ka) typically extinct organisms exclusive of human remains. This includes the localities where fossils originated and the rock formations in which they were preserved. When taken together, they provide evidence of past life and behavior and the environmental conditions at the time of preservation. The defining character of fossils or fossil deposits are generally regarded as older than 11,700 years, the generally accepted temporal boundary marking the end of the last Late Pleistocene glacial event and the beginning of the current period of the Holocene (~11.7 Ka years ago). Paleontological resources have educational, cultural, and scientific value and may be legally protected.

Particularly important are fossils found in situ (undisturbed) that have not been subjected to disturbance after their burial and fossilization. As such, they aid in stratigraphic correlation, particularly those offering data for the interpretation of tectonic events, geomorphological evolution, paleoclimatology, the relationships between aquatic and terrestrial species, and evolution in general.

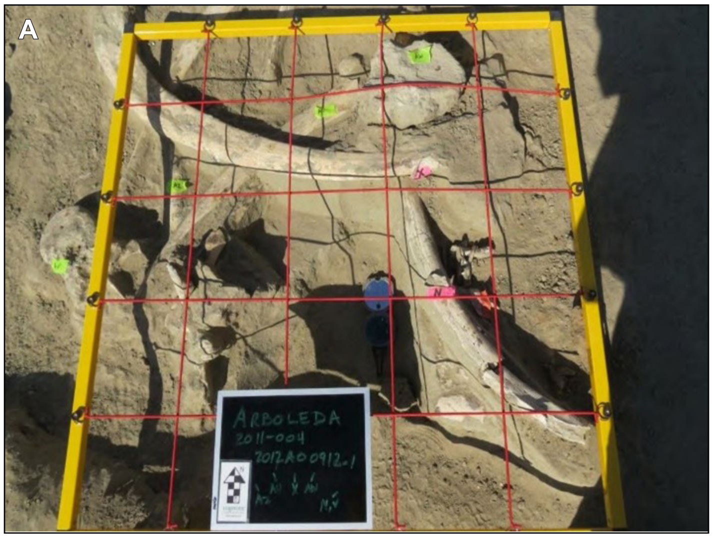
An example is the discovery of fossilized Columbian mammoth (Mammuthus columbi) bones from the Pleistocene epoch (2.58 million to 11,700 years ago) that were uncovered by Caltrans during construction work on State Route 99 (SR-99) in Merced County. The mammoth bones, including a juvenile mammoth skull and the skull, femur, and tusk of a mammoth estimated to be 49 years old at the time of death, were donated by Caltrans to the University of Merced. The mammoth bones are on permanent display on the second floor of the University library. Additionally, silhouettes of mammoths walking on the SR-99 overpasses for the 176 exit (Plainsburg Road) and 179 exit (Le Grand Road) were installed for public education and art near where the mammoth was discovered in Merced County.

Terrestrial vertebrate fossils (i.e., mammoths) are often assigned greater significance than other fossils because they are rarer than other types of fossils. This is primarily because the best conditions for fossil preservation include little or no disturbance after death and quick burial in oxygen depleted, fine-grained, sediments. These conditions are relatively rare in terrestrial settings (e.g., because of pyroclastic flows and flashflood events). This has ramifications on the amount of scientific study needed to adequately characterize an individual species and therefore affects how relative sensitivities are assigned to formations and rock units.



Camels, tapirs, horses, and early llamas roamed southern California 20,000 years ago. None of those species—not even the horses—survived there after the end of the Ice Age. Mural painted by William Stout for the permanent exhibition Fossil Mysteries at the San Diego Natural History Museum. Photo by Barret Oliver, Courtesy of the San Diego Natural History Museum.

The Society of Vertebrate Paleontology (SVP, 2010) defines scientifically significant paleontological resources as "fossils and fossiliferous deposits, here defined as consisting of identifiable vertebrate fossils, large or small, uncommon invertebrate, plant, and trace fossils, and other data that provide taphonomic, taxonomic, phylogenetic, paleoecologic, stratigraphic, and/or biochronologic information."



A. Columbian mammoth (Mammuthus columbi) field documentation, Highway 99, Madera County.

B. Caltrans construction activity in Pleistocene deposits, Madera County. White streaks seen during grading are often fossilized bones being pulverized.

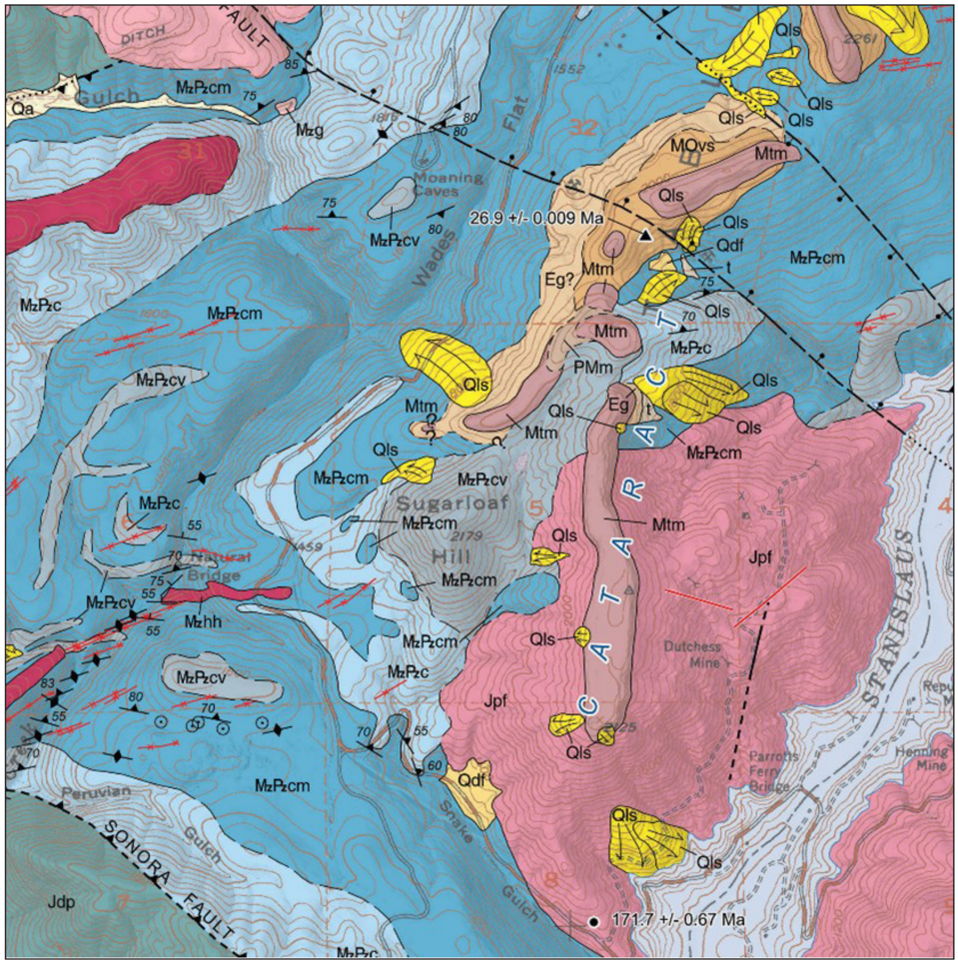
C. Columbian mammoth fossils being exposed for plaster jacketing.

D. Columbian mammoth fossils jacketed and ready for transport to curation.

E. Part of the Columbian mammoth exhibit at the University of Merced library. Caltrans Photos

California's geologic record is diverse with vertebrate, invertebrate, plant, and trace fossils found throughout the state, primarily in sedimentary rocks and in some metasedimentary rocks and volcanic ash deposits. These non-renewable resources are essential to helping us understand current and past aspects of our world, such as the radiation, diversification and extinction of life, regional and local environments, climate and sea level change, plate tectonics, animal behavior and adaptation, soil characteristics, and mineral resources.

Significance may also be stated for a particular rock unit, predicated on research of potential fossils suspected to occur in that unit. Such significance is often stated as "sensitivity" or "potential." In most cases, decisions about how to manage paleontological resources must be based on this potential because the actual situation cannot be known until construction excavation for a project is underway. Caltrans uses the following three-part scale (Caltrans, 2025).



Portion of a CGS geologic map used by Caltrans (example from the Columbia 7.5-minute Quadrangle, available at https://www.conservation.ca.gov/cgs/rgm/preliminary)

- High Potential - Rock units likely to contain significant vertebrate, invertebrate, or plant fossils, including sedimentary formations known for significant paleontological resources or lithologically suitable for the preservation of fossils.
- Low Potential - Sedimentary rock units with some chance for containing fossils, generally not needing monitoring unless significant paleontological resources are found, in which case a qualified paleontologist must assess their significance.
- No Potential - Intrusive igneous rocks, most extrusive igneous rocks, and moderately to highly metamorphosed rocks, which are unlikely to contain significant paleontological resources.

APPROACH AND METHODS

Why are mapping projects undertaken and what is their scope?

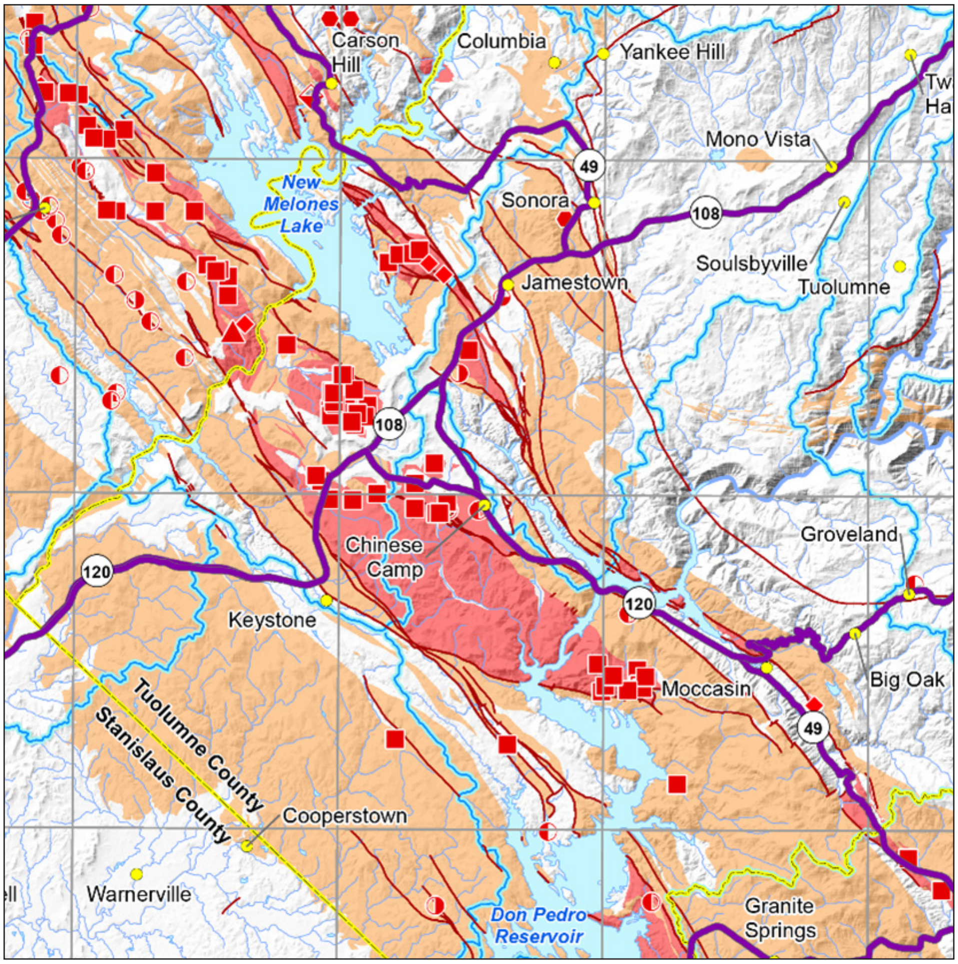
The purpose of the mineral hazards assessment and paleontological resource mapping was to assist Caltrans staff in their determination of where mineral hazards and paleontological resources may be present in each of the Caltrans 12 geographic districts; the intended audience includes engineers, geologists, planners, construction and maintenance crews, and managers, among others.

Correlating geologic formations with hazardous minerals and paleontological resources, and stitching together geologic maps from various researchers, was an immense undertaking by professional geologists, paleontologists, and university students. At times, staff conducting field investigations were required to resolve conflicts between maps.

The data and information generated during the project are used by Caltrans staff as a screening tool to improve planning of activities that involve new road projects, routine maintenance of roadways, and emergency removal of debris deposited on roads by natural processes.

Mapping of mineral hazards

The main approach of the assessment was to develop baseline information concerning the potential for mineral hazards statewide, which might adversely affect construction,



Representative mineral hazards map. Example from Caltrans District 10.

use, and maintenance of state and federal highways under Caltrans jurisdiction. The work focused on natural and man-made minerals-related features.

Geologic features investigated included geologic units (bedrock and some minor areas of unconsolidated sediments), faults, areas of highly mineralized rock, oil and natural-gas seeps, and thermal springs and fumaroles.

Geologic features investigated included: 1) geologic units that may contain naturally-occurring asbestos or elevated concentrations of regulated metals (Ag, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Tl, V, Zn) and metalloids (As, Sb, Se); 2) faults, which can serve as conduits for the movement of hazardous element-bearing fluids; and 3) areas of highly mineralized rock.

The features from human activities are related to extraction of mineral and energy resources. Specifically, these include: 1) mines and prospects, which can be sources of anomalous concentrations of metals and ore-processing chemicals; 2) oil and natural-gas seeps; 3) thermal springs and fumaroles; and 4) oil, natural-gas, and geothermal wells.

The CGS conducted fieldwork in each of the 12 Caltrans districts to directly observe and verify geologic features that were previously documented on geologic maps by other geologists. To a much lesser extent, observation and verification included mining areas, petroleum features, and geothermal features. Finally, fieldwork included observation and documentation of new localities of mineral hazards of potential interest to Caltrans. Most of the state and federal highways were driven in reconnaissance during this project. Most field observations were made along highway corridors.

What types of products did the CGS create for Caltrans?

An array of paper and digital products were prepared to accommodate the needs and background of Caltrans staff concerning mineral hazards in California that might affect Caltrans activities. These include:

- District Reports – individual reports for each of the 12 Caltrans districts. These included detailed information on the types of mineral hazards investigated, their characteristics and distribution in each district.
- District Maps – sets of 1:250,000-scale (one-inch equals approximately four miles) maps that display for each district the geologic features and features related to human activities described above.
- Geochemical Summaries – compiled tabular summaries and

DID YOU KNOW?

Medical geology is an earth science specialty that concerns how geologic materials and earth processes affect human health. Geologic materials such as rocks, soils, dusts, and volcanic emissions can contain naturally elevated levels of elements, minerals, other compounds, or microbes that harm or benefit human health. They can also contain human-related chemical, mineral, or pathogen contaminants. Medical geologists work with earth, biological, physical, and health scientists to help improve public health.

prepared maps of geochemical data from several sources.

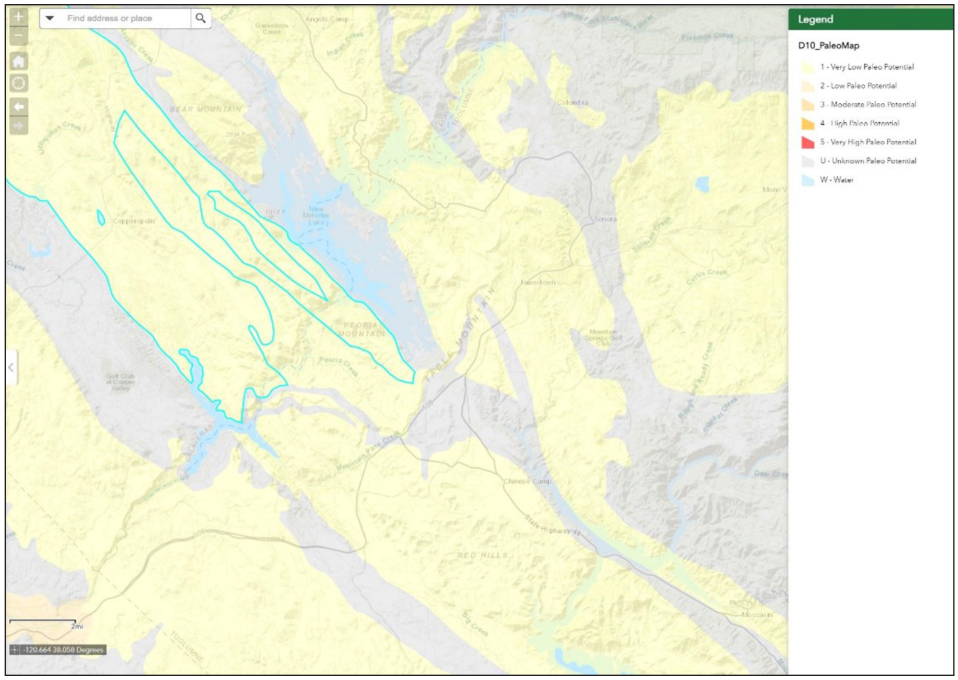
› GIS Products – many “feature classes” (digital thematic map layers) were developed during this project. The final phase of the project was integration of these into a statewide master geodatabase.

Mapping of paleontological resources

The paleontological GIS mapping utilized a group of university geology student interns with oversight by Caltrans geologists/paleontologists. The paleontological GIS mapping was beneficial for both the students and Caltrans. The students were able to work on an important project from start to finish, something they could add to their resume, and Caltrans ended up with a useful, cost-saving tool. Also, CGS geologists provided digitized geologic maps, digital mapping of formations involved in landslides, and interpretation of geologic formations.

How are paleontological resource maps and mineral hazard maps derived from geologic maps?

Geologic maps show the distribution of various geologic formations. Based on these maps and information on previously recorded fossil finds, geologic formations can be characterized as High Potential, Low Potential, or No Potential for paleontological resources. Because paleontological resources usually are irregularly dispersed throughout a geologic formation, both vertically as well as laterally, the location of fossils within a particular formation cannot be pre-determined. Comparing a Caltrans project site to a resource map showing the potential of formations to produce fossils is the first step in assessing the potential for paleontological resources to be present on a project site. More precise



Representative paleontological resource map showing areas of low paleontological potential. Areas of high potential, if shown, would appear bright red or orange. Example from Caltrans District 10.

determinations of the potential presence of paleontological resources can be made by studying more detailed geologic maps and conducting onsite field surveys.

> **“California’s geologic record is diverse with vertebrate, invertebrate, plant, and trace fossils . . .”**

Occurrences of paleontological resources are known to be correlated with mapped geologic units (i.e., formations). The paleontological sensitivity or potential is a GIS layer created from geologic maps and assigns a rating to each geological unit, representing the potential abundance and significance of paleontological resources that occur in that geological unit. The rating is considered a first approximation of the potential presence of paleontological resources, subject to change based on ground verification.

The geologic units are assigned a class based on the relative abundance of significant paleontological resources and their sensitivity to adverse impacts. This classification is applied to the geologic formation, member, or other mapped unit. The classification is not intended to be applied to specific paleontological localities or small areas within units. The overall abundance of scientifically important localities is intended to be the major determinant for the assigned classification.

To complete resource identification efforts, the Caltrans project environmental staff need mapping of sufficient detail to correlate the potential project footprint with detailed geologic maps and paleontological databases. The required level of detail available may vary from project to project and will be determined by the complexity of the project and the complexity of the geology of the project area. Caltrans staff review the paleontological GIS layers to determine if there are known or reasonably anticipated paleontological resources within the project area. If so, it must be further determined if project excavation may impact the resource.

The CGS conducted fieldwork in each of the 12 Caltrans districts to directly observe and verify mapped geologic features or add refinements to the maps. The focus was on natural bedrock units as potential sources of geologic hazards. The fieldwork included observation and documentation of new localities of mineral hazards of potential interest to Caltrans.

As part of the district studies, the CGS developed a geologic map of each district at 1:750,000-scale (one-inch equals approximately twelve miles), using the Geologic Map of California as the base. Additionally, the CGS developed mineral hazard maps at 1:250,000-scale that display for each district the natural geologic features and features related to human activities.

CONCLUSION

Before Caltrans can do any soil disturbing work, potential mineral hazards and paleontological resources must be evaluated along with several other evaluations that include biological and cultural resources. These evaluations not only protect the resource through possible avoidance, but also provide for worker safety, proper soil and rock handling, management and disposal, and proper monitoring for and salvage of paleontological resources. Researching and mapping of mineral hazards and paleontological resources can be a labor and time-consuming process, even with the voluminous datasets and reports available on the internet.

Caltrans defines efficiencies as steps that may result in cost avoidance or a reduction in support or capital costs. Past practice involved review of multiple databases and site-specific history to determine if a particular project would require additional study. Now, using the GIS tool, these evaluations can be performed efficiently with geological maps and source references that can be added to evaluation memorandums and reports. Additionally, labor spent in the field verifying potential concerns can now be focused or eliminated altogether.

> **“. . . the improved process has resulted in efficiencies that led to state cost savings of more than $200,000 annually.”**

The GIS tool provides substantial time savings for this effort. It does this by allowing the analyst to perform a comprehensive survey of the potential of paleontological resources and mineral hazards from a single GIS database, as opposed to checking multiple sources of information. Cost savings are also realized by using the internal Caltrans GIS tool rather than contracting with external consultants. Cost savings are calculated as a measure of staff hours saved per environmental document review. Using the improved process has resulted in efficiencies that led to state cost savings of more than $200,000 annually.

The value of these evaluations cannot be overstated for the protection provided from mineral hazards to the public and for worker safety; proper soil and rock handling and management; and for the preservation of non-renewable paleontological resources that provide valuable insight to our current and past world conditions and ecological processes.

The CGS has conducted studies and produced mineral hazard maps and reports at statewide and regional scales. These maps and reports are intended to educate about mineral hazards and to help in mitigation of those hazards.

For information about mineral hazards and to request published mineral hazards reports visit the CGS Mineral Resources website at: https://www.conservation.ca.gov/cgs/minerals/mineral-hazards

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