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POTENTIALLY ACTIVE VOLCANIC ZONES IN CALIFORNIA

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ABSTRACT

Volcanic activity has played a dominant role in California's long geologic history. Records in rocks of many ages demonstrate that volcanic activity commenced in the Precambrian as early as 1.7 billion years ago, and has continued almost continuously into the present century. A review of the Geologic Map of California is sufficient to indicate the widespread distribution of volcanic rocks and source areas, except in the Great Valley, where the cover of soils and sedimentary rocks may mask other possible volcanic centers.

Advances in geophysics and geochemistry have demonstrated the close relationships between zones of volcanic activity and movements of tectonic blocks. Zones of volcanic activity in the Cascade Range and the Coast Range provinces in California can be explained through a subduction mechanism, whereas similar zones in the Mono Basin-Long Valley region of Mono County, the Modoc Plateau Province, and elsewhere in the Mojave Desert and Colorado Desert provinces owe their origins to the combined effects of plate tectonics and block faulting of thin continental crust.

Five active volcanic zones in California include Mount Shasta, Lassen Peak, and Medicine Lake Highland, all in the Cascade Range Province, the Mono Basin-Long Valley region of Mono County, and the Cima volcanic field in San Bernardino County. A significant number of documented eruptions has occurred in these areas in the last 2,000 years. The above named active volcanic zones and 18 other volcanic zones whose latest eruptions are known (or presumed) to be Quaternary in age, but had not erupted in the last 2,000,000 years, constitute the known potentially active volcanic zones in California.

INTRODUCTION

Volcanism has been very active and prominent almost continuously throughout California's geologic history, commencing as early as 1.7 billion years ago in the Precambrian and extending into the twentieth century. It has manifested itself through the extrusion of tremendous volumes of volcanic rocks as lava flows and fragmental deposits, and the intrusion of dikes, domes, plugs, and sills.

Time and the erosive forces of running water, moving ice and air, and of gravity have obliterated much of the evidence of volcanic activity, but thick deposits of metamorphosed volcanic rocks, of which some are greenstones and others, schists, form prominent geologic units ranging in age from early Paleozoic through late Mesozoic (an interval of some 500 million years) in the Sierra Nevada, the Klamath and Siskiyou mountains, the Coastal Ranges of California, and the Mojave Desert.

In order to illustrate in a modest way the extent of volcanic activity in California, one need only examine carefully the northeastern part of the state, which includes all of Modoc County and significant parts of Lassen, Plumas, and Siskiyou

counties. This is an area of approximately 12,000 square miles, one-thirteenth of the area of California, which is underlain by volcanic materials ranging in age from Miocene to Holocene. Much of these volcanic rock materials, totaling approximately 2,400 cubic miles, were deposited through explosive volcanic eruptions.

Very rarely indeed is volcanic activity an isolated earth process unrelated to other forces at work in the Earth's crust. On the contrary, it can be demonstrated that volcanic activity is and has throughout the Earth's long geologic history been closely associated with earthquakes, mountain building processes, and lastly and more recently, through the interaction of gigantic plates that comprise segments of the Earth's crust.

Volcanic activity in the Cascade Range and Coast Range provinces in California is best explained through the interaction between the Pacific plate and the North American plate, in which portions of the former being subducted beneath the North American plate are remelted and rise along zones of weakness to the Earth's surface to result in volcanic activity. Volcanic activity in the Basin and Range Province in California, which includes the Modoc Plateau-Warner Range area in Modoc County, the Mono Basin-Long Valley region of Mono County, and the Mojave Desert and Colorado desert regions in southeastern California, is probably due to a combination of the interaction of Earth plates and the block faulting of thin continental crust on the margin of an area undergoing extension.

ZONES OF VOLCANIC ACTIVITY IN CALIFORNIA

Another look at the Geologic Map of California tells one that the state has been mapped geologically one way or another, but it is not possible to identify all deposits of quaternary volcanic rocks since: (1) geologic process do not stop conveniently at temporal or spatial boundaries; (2) geological mapping is incomplete or even totally lacking for certain areas of the state; and (3) techniques of geochronology, although gaining stature and becoming more reliable all the time, are still not sufficiently advanced as to allow clear and reliable dating of all rocks. Because of these factors, deposits of quaternary volcanic rocks may be omitted or incorrectly dated on the map, and in some cases rocks of other ages may be labeled Quaternary.

A significant amount of data, however, is readily available, and many deposits of volcanic rocks in California can be identified as being of Pleistocene and Holocene ages. Holocene is here defined to include events since the latest glacial (Tioga) stage. This is a variable time span representing, perhaps, 6,000 to 10,000 years. The traditional 1,000,000 year date for the beginning of the Pleistocene has been pushed back to 2,000,000 years, and in some cases further still. For rock units of approximately this age, I am using here, for convenience, a Plio-Pleistocene time interval. This is a convenient slot for many volcanic rock units in California which are not yet precisely dated.

Following Kilbourne and Anderson (1981), zones of volcanic activity in California can be considered in three categories: (1) active -- one in which there is current volcanic activity, or which has erupted in the last 2,000 years; (2) potentially active -- one known (or presumed) to be Quaternary in age, but the most recent eruption has not been dated as being less than 2,000 years ago; and (3) inactive -- one in which there has been no eruption in the last 2 million years.

Since our interest for this workshop lies in the active and potentially active volcanic zones in California, discussion will be confined to 23 areas in the state in which rocks of Pleistocene and especially Holocene ages occur. Frequent reference will be made to Figure 1, a map of California which shows the areas of known deposits of Quaternary volcanic rocks, and also several major tectonic features, particularly faults, as they may relate to zones of Quaternary volcanic activity.

MAP OF CALIFORNIA SHOWING AREAS UNDERLAIN BY QUATERNARY VOLCANIC ROCKS—THE POTENTIALLY ACTIVE VOLCANIC ZONES

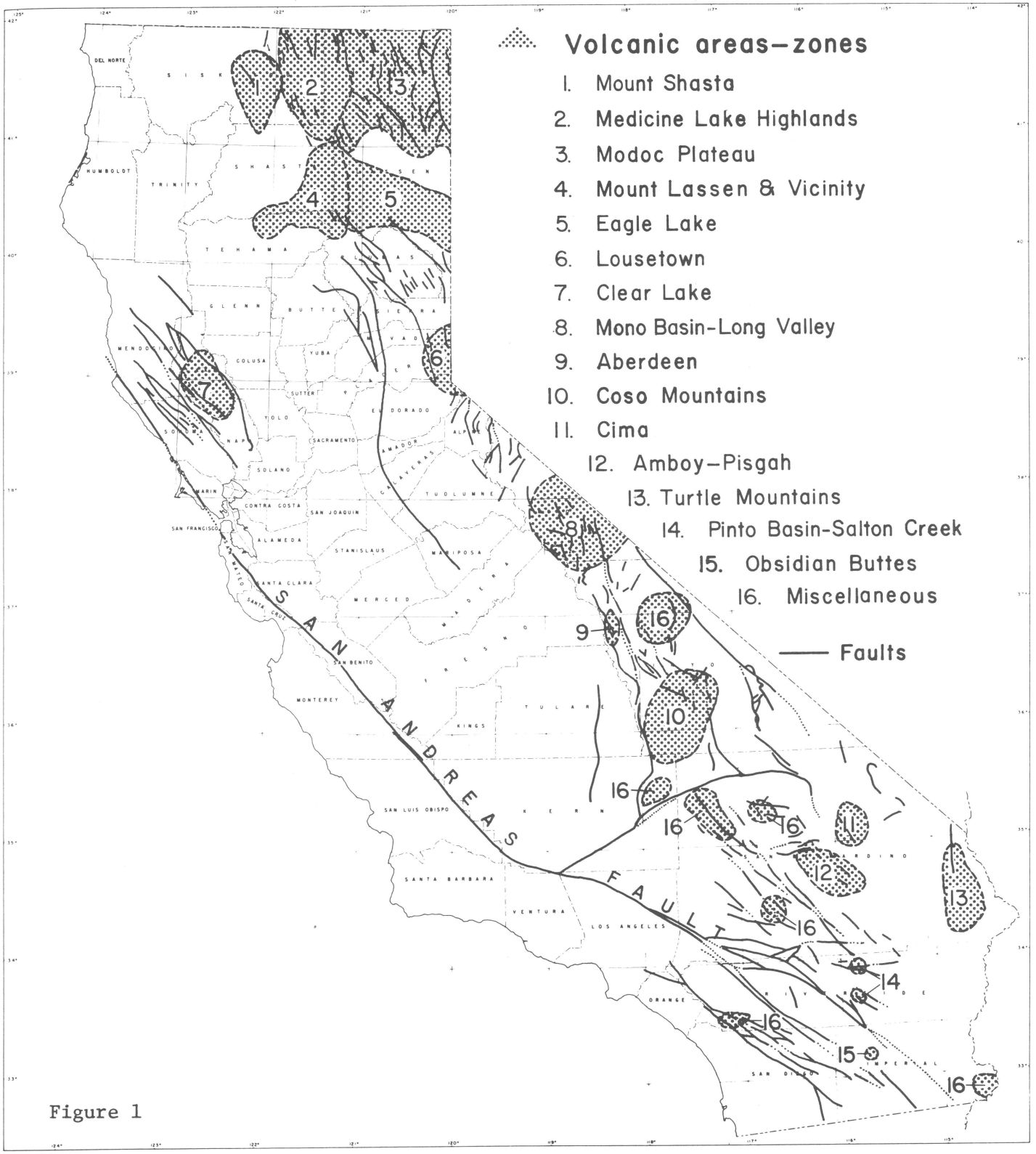

Figure 1

POTENTIALLY ACTIVE VOLCANIC ZONES IN CALIFORNIA

The following discussion will consider the potentially active volcanic zones in California, their geographic locations, types of volcanic products, and physical features, and will commence with those zones in the northern part of the state and conclude with a group of miscellaneous small zones that are largely in southeastern California.

Mount Shasta (Area 1). Mount Shasta, a complex stratocone and the largest of the Cascade volcanoes, is in the central part of Siskiyou County. It is composed of Pleistocene andesite and basalt flows, and pyroclastic deposits, and Holocene basalt and andesite flows, dacite domes and pyroclastic deposits. A major north-south fracture zone that passes through the volcano, has controlled the location of cinder cones and plug domes. Shastina, a Holocene cone high on the west flank of Mount Shasta, contains a central plug dome of dacite, and was the source of voluminous pyroclastic-flow deposits that cover many square miles on the west side of Mount Shasta and reach points beyond the town of Weed. Similar pyroclastic-flow materials issued forth from Black Butte, a composite of four dacite domes of Holocene age, and were deposited to the southwest as far as Lake Siskiyou. There are 13 Quaternary cinder cones, remnants of five Pliocene cinder cones, and Holocene flows from Shastina and Hotlum cones. Perhaps the most recent eruption in the area occurred in 1786.

Medicine Lake Highland (Area 2). Medicine Lake Highland is in eastern Siskiyou County and western Modoc County. The highland is a rampart of small volcanoes ranging from late Pleistocene to Holocene in age perched upon a low, broad-shield volcano of Pliocene and Miocene basalt and Pleistocene pyroclastic deposits. The lava flows and pyroclastic deposits of the cone were intruded by rhyolite, and collapse of the central part of the cone along a set of arcuate fractures, gave rise to a caldera which now contains Medicine Lake. Violent eruptions in Holocene time (660 A.D. $\pm$ 240 years) resulted in the mantling of the area by rhyolitic pumiceous tephra -- deposition of which was followed by the emplacement of obsidian domes and the development of cinder cones. More than 100 cinder cones developed during the Holocene volcanic episode, and at least 20 cones during the Pleistocene.

Modoc Plateau (Area 3). This area is wholly in Modoc County and includes the Warner Range. It has been the focus of intensive volcanism since the Miocene. In 1954, there was a violent mud-volcano eruption on the east side of the Warner Range near Lake City. Numerous basaltic cinder cones dot a plateau-like surface that is underlain by numerous flood basalt flows.

Mount Lassen and Vicinity (Area 4). Although Lassen is in Shasta County, the general area herein considered is largely in eastern Shasta County but includes small portions of adjacent Lassen, Plumas, and Tehama counties. The area was the site of extensive out-pourings of basalt and andesite flows during the Pliocene and Pleistocene. Later, a large stratocone named "Mount Tehama" developed as the result of subsequent volcanic activity. Much later, rhyolite and dacite intruded the flanks of Mount Tehama, flows of dacitic lava erupted from vents near Lassen Peak and, much later still, the dacite plug dome which forms Lassen Peak was emplaced. The eventual collapse of Mount Tehama formed a caldera in which one can now find hot springs and extensive fumarolic action.

During the Holocene, perhaps not more than 1,200 years ago, violent eruptions blasted forth from an eruptive center north of Lassen Peak and produced hot pyroclastic-flows and pumiceous tephra. Shortly thereafter, a group of dacite domes, now called Chaos Crags, were emplaced in the same eruptive center.

In 1851-52, an eruption of quartz basalt lava, a few miles northeast of Lassen Peak, gave rise to a volcanic cone (called Cinder Cone) and lava flows. More recent activity in the Mount Lassen area, commencing in

1914 and culminating in 1917, was of the explosive type and is very well documented.

There are over 30 cinder cones of Plio-Pleistocene age in the area, and current activity is restricted to hot springs and fumaroles.

Eagle Lake (Area 5). This area lies almost wholly in Lassen County, and is underlain by numerous flood basalt flows of Pliocene and Holocene ages. The latest eruptions of, perhaps, Holocene age were basaltic lava flows in the vicinity of Eagle Lake. At least 30 cinder cones of Quaternary age occur in the area.

Lousetown (Area 6). This area occurs north of Lake Tahoe and is in the eastern parts of Nevada and Placer counties. It is underlain largely by flows of basalt and latite of early Pleistocene age, which are said to have a K/Ar age of 1-2 million years B.P. There were explosive eruptions in the area as evidenced by remnants of eight cinder cones.

Clear Lake (Area 7). The Clear Lake volcanic field is in southern Lake County and northeastern Sonoma County. It includes the well-known Geysers geothermal field. Flows of basalt, andesite and rhyolite, and rhyolitic tuffs of Pleistocene age occur in the area. Rocks of Holocene age include obsidian, andesite, dacite, and four cinder cones. The occurrence of sulfur and extensive mercury mineralization at Sulphur Bank; deposits of sulfur on Mount Konocti; and the high concentration of boron at Borax Lake all indicate recent volcanic activity. The hot springs, fumaroles, and steam wells at the Geysers and vicinity are clear indications that a significant source of heat, which is undoubtedly related to volcanic action, is still present in the area.

Mono Basin-Long Valley (Area 8). This area of high potential volcanic activity occurs largely in Mono County. Cenozoic volcanic rocks of Oligocene and Miocene ages (radiometrically dated as 11 to 29 million years old) include andesite, dacite, rhyolite, and welded tuff. Between 3 and 12 million years ago, discontinuous volcanic activity resulted in the eruption of andesite, basalt, rhyolite, and pyroclastic deposits. The Pleistocene was a period of almost continuous volcanic activity extending to the present. A major eruption about 700,000 years ago gave rise to the Bishop Tuff and the formation of Long Valley caldera. The Mono Basin-Long Valley region has experienced at least 30 pumiceous tephra and lava eruptions in the past 2,000 years, and all were of silicic lavas. Many hot springs and several steam wells occur at and near the Casa Diablo thermal area, and the latest eruption may have taken place beneath the waters of Mono Lake as late as 1890.

Aberdeen (Area 9). The Aberdeen volcanic field is in Owens Valley at the base of the Sierra Nevada in west-central Inyo County. It contains flows and cones of basalt of Holocene or late Pleistocene age, and a dome of perlitic rhyolite of Pleistocene age, all of which lie partly on alluvium.

Coso Mountains (Area 10). The Coso Mountains are at the southern end of Owens Valley in Inyo County. This area has been the site of explosive volcanic eruptions starting some 11 million years ago and culminating about 40,000 years ago. There are 35 rhyolite domes, 19 basaltic cinder cones, and significant deposits of pumiceous tephra lying on or near the surface of the ground. Current activity includes fumaroles and hot springs at the Coso Hot Springs thermal area.

Cima (Area 11). The Cima volcanic field, located in the northeastern part of San Bernardino County, contains basaltic cinder cones and lava flows of Pleistocene age, and lava flows as well as 27 cinder cones of Holocene age. The Holocene cones and lava flows rest on alluvium, and the youngest of the Holocene rocks has been dated at about 360 years.

Amboy-Pisgah (Area 12). This area is in the central part of San Bernardino County and centers principally about Pisgah Crater and Amboy Crater, which are separated by some 40 miles of arid lands. Holocene basaltic cinder cones and lava flows, and Pliocene andesitic and basaltic dikes, lava flows, plugs and sills occur in the region.

Because of the fresh appearance of their lavas, Amboy and Pisgah craters are thought to be less than 2,000 years old.

Turtle Mountains (Area 13). The Turtle Mountains, which contain flows of Pleistocene basalt lying on late Tertiary volcanic rocks, are in the southeastern part of San Bernardino County. The late Tertiary volcanic rocks contain layers of pyroclastic deposits and perlitic rhyolite flows, which indicate that the area has been the focus of explosive volcanic eruptions.

Pinto Basin-Salton Creek (Area 14). Remnants of Pleistocene or Holocene basaltic flows and pyroclastic deposits lie on alluvium in the Pinto Basin and Salton Creek areas in central Riverside County.

Obsidian Buttes (Area 15). This area, in Imperial County near the southern end of Salton Sea, contains obsidian domes and pumiceous tephra deposits of late Pleistocene age amid alluvium and lacustrine sediments. The area contains hot springs, carbon dioxide springs and wells, and mud volcanoes. Several thermal wells encountered hot brines.

Miscellaneous (Area 16). Scattered throughout the Basin and Ranges Province in Inyo, Imperial, Kern, Riverside, San Bernardino, and San Diego counties are a number of bodies of volcanic rocks, consisting principally of flows of andesite and basalt, and pyroclastic materials, all ranging in age from late Pliocene to Holocene. Included among the bodies are: lavas in the El Paso Mountains in eastern Kern County; basaltic flow remnants on pyroclastic deposits in the Fort Irwin area and at Opal Mountain, northeast and northwest of Barstow respectively; small remnants of a probable Pleistocene basalt flow northeast of Ogilby, Imperial County; and possible Pleistocene basalt flows on pyroclastic deposits near Murrieta, Riverside County.

An extensive area in central Inyo County contains flows and pyroclastic deposits of Pliocene and/or Pleistocene age, as well as a Holocene basaltic cinder cone and rhyolitic ash deposits.

CONCLUSIONS

The above listed areas contain the known, potentially active volcanic zones in California wherein hazardous conditions are most likely to occur. However, one cannot be absolutely certain that this list is complete, for, as was stated earlier, there is a likelihood (remote as it may be) that there are isolated bodies of Holocene volcanic rocks that have been erroneously included among older volcanic units. These improperly identified bodies might just as well be sites for future volcanic activity as are any of the five zones that are considered among the most active in the state.

DISCUSSION

McBirney: I notice that the Sutter Buttes were not mentioned in your talk. Do you consider them too old, and if so, what is the youngest age that has been obtained there?

Chesterman: I didn't mention them as being active because they are rather old. I believe their youngest age is about 1.4 million years old.

Question: What is the approximate age of the volcanic tubes at Cambria, north of Morro Bay?

Chesterman: Any volcanism in that part of the state is likely to be either late Miocene or early Pliocene in age. As one proceeds from the southern part of the California Coastal Ranges northward, the age of volcanic rocks becomes progressively younger. Volcanic rocks in the Morro Bay area are of late Miocene/early Pliocene age while to the north, in Lake County, some volcanic rocks are as young as very late Pleistocene, or about 11,000 years old.

Question: Just how active is the Surprise Valley area? I heard about a mud volcano being in that area. Could you explain that?

Chesterman: Mud volcanoes erupted in Surprise Valley at hot springs near Lake City, Modoc County in 1951 and 1953. There is extensive faulting in the area, and although the springs owe their high temperature of about 65°C and part of their water supply and mineral content to past volcanism, it seems unlikely that their mud-volcano activity of comparatively recent date is a forerunner of future volcanic activity.

Question: How about the Aberdeen area?

Chesterman: The Aberdeen volcanic area is located in Inyo County along a frontal fault zone of the Sierra Nevada. It is an area where rocks of both rhyolitic and basaltic compositions erupted from nearby vents. The basaltic eruptions formed cinder cones and lava flows while the rhyolitic eruptions have given rise to domes of perlitic rhyolitic and tuffs. A late Pleistocene or early Holocene age has been determined for one of the cinder cones.

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