15

EIGHTH ANNUAL FALL FIELD FROLIC

FOLLOW THE FORTY-NINERS TO THE MOTHER LODE

GEOLOGY AND EARTH SCIENCE
FIELD TRIP
CALIFORNIA STATE UNIVERSITY,
NORTHRIDGE

AUG. 29 - SEPT. 1, 1990

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Following is a summary of the major features of the geology of Calaveras County and adjoining parts of Tuolumne County. You will have plenty of time to read it, should you choose to do so, en route to the first stop. It has been taken from Clark, W. B., and Lydon, P. A., 1962, Mines and mineral resources of Calaveras County, California: California Division of Mines and Geology County Report 2, p. 11-17. The chart on page 17 is the key to almost everything that you will see on this trip. I hope that you have a good time and learn a lot.

GEOLOGY

General Features

The rocks in Calaveras County can be divided into two major assemblages—the "Bedrock series", consisting of steeply dipping metamorphic rocks of Paleozoic and Mesozoic age, and intrusive rocks of Mesozoic age; and the "Superjacent series", the overlying nearly flat beds of sedimentary and volcanic rocks of Tertiary age.

The metamorphic rocks occupy broad belts trending north-northwestward in the central and western portions of the county. They are by far the most abundant rocks in the county and cover slightly more than two-thirds of the total area. They consist of schist, slate, and limestone of the Calaveras formation (Carboniferous and Permian?); schist, greenstone, and slate of the Amador group (Middle or Upper Jurassic); slate of the Mariposa formation (Upper Jurassic); and amphibolite and chloritic schist, greenstone, and phyllite of undetermined age. Granitic rocks, exposed chiefly in the narrow eastern portion, range in composition from granite to gabbro, granodiorite being the most abundant type. Smaller amounts of basic and ultrabasic intrusive rocks, largely altered to serpentine, are found in narrow, northwestward-trending lenses in the west-central portion of the county.

The Tertiary rocks consist of quartz sand, clay, and auriferous quartzose gravel of the Ione formation (Eocene); rhyolitic ash and tuff of the Valley Springs formation (Miocene); and andesitic detritus of the Mehrten formation (Mio-Pliocene). Small patches of basalt of Quaternary age are found in the eastern portion of the county. Recent sand and gravel lie in and adjacent to the present stream beds. Small glacial moraines are found in the eastern part of Calaveras County.

Geologic Structure

The Sierran bedrock complex in Calaveras County is characterized by a series of northwestward-trending beds of metamorphic rocks that have been intensely folded and faulted and invaded by a series of intrusive igneous rocks, chiefly granitic. Interpretation of the geologic structure in the metamorphic rocks often is extremely difficult because of its complexity, the destruction of bedding by shearing, and the absence of key horizons. Taliaferro, in separating the Amador group, has been able to work out the intricate structure in the bedrock in the vicinity of the Cosumnes River to the north in El Dorado and Amador Counties (Taliaferro, 1943, p. 285, 306). Eric, Stromquist, and Swinney (1955, pp. 22-30) have mapped the structure both west and east of the Mother Lode in the vicinity of Angels Camp and Sonora. Clark (1954, pp. 11-14) has studied the geologic structure of the Calaveras formation in the Calaveritas quadrangle, and Taliaferro and Solari (1944) have mapped structures in the Copperopolis area.

The metamorphic rocks are characterized by beds and foliation that strike northwest, parallel to the trend of the Sierra Nevada; vertical or steep easterly and north-easterly dips; and overturned, nearly isoclinal folds. The repetition of beds, particularly those of the Mariposa slate and greenstone west of the Mother Lode, results from this folding. The Mother Lode vein system extends across Calaveras County in a northweastward direction. It is a major fault zone in which there has been reverse movement, but the amount of displacement is largely unknown. Gold-bearing quartz veins have been deposited within the fissures. Ultrabasic intrusions west of the Mother Lode are largely serpentinized and trend northwest, reflecting the major structural trend of the region. The acidic batholithic masses were intruded after the beds had been folded (Taliaferro, 1943, p. 285) and probably after many of the displacements in the Mother Lode fault zone.

Major faulting along the east flank of the Sierra Nevada has had a profound influence on the later geologic history of Calaveras County. Faulting occurred on the east flank during the end of the Pliocene epoch and at the beginning of the Pleistocene epoch. The Sierra Navada was elevated and became asymmetrical in form, with a broad, gently dipping western slope and short, steeply dipping eastern slope (Hinds, 1952, p. 18).

Rock Units

Calaveras formation (Carboniferous and Permian in part). The Calaveras formation is a suite of undifferentiated metamorphic rocks that underlies extensive areas in the central and east-central portions of the county. The rocks of the group are quartz-mica schist, graphitic schist, low-grade carbonaceous slate, fine-grained quartzite, highly contorted and poorly bedded recrystallized chert, and recrystallized limestone and dolomite. Present in smaller amounts are sheared conglomerate, chlorite and talc schist, and massive greenstone. In places, tectonic breccia consisting of quartzite fragments in a matrix of graphitic schist is common. Beds of the Calaveras formation generally have a north to northwest strike and dip steeply to the east. In the Murphys-Calaveritas area, they strike westward and dip steeply to the north.

On the basis of fossils found in limestone, the Calaveras has been classified as Carboniferous in age, although recent investigators believe that part of the group may be of Permian age (Taliaferro, 1943, p. 280).

Amador group (Middle to Upper Jurassic). The Amador group consists of metamorphosed sedimentary and volcanic rocks in north- to northwest-trending beds west of the Mother Lode in western Calaveras County. The group is divided into two formations—the Cosumnes, which lies unconformably on the Calaveras formation, and the overlying Logtown Ridge. On the geologic map (pl. A), the Amador group is included with undifferentiated metamorphic rocks.

The Cosumnes formation is composed of sheared tuffaceous siltstone and sandstone, gray to black clay slate, thinly bedded tuff, small amounts of quartzite and chert, and a thick basal conglomerate containing pebbles and boulders of chert, quartz, schist, and volcanic rocks in a sandy or gritty matrix.

The overlying Logtown Ridge formation consists predominantly of blocky metamorphic rocks derived from pyroclastic rocks. The most characteristic rocks are massive greenstone derived from augite andesite, and basaltic and andesite agglomerate. Both commonly contain large phenocrysts of augite and plagioclase in a fine-grained groundmass. Also present are bedded tuffs, agglomerates, and smaller amounts of conglomerate and dark clay slate.

Mariposa formation (Upper Jurassic). The Mariposa formation is principally in two northwest-trending belts, 1 to 2 miles wide, in the west and west-central portions of Calaveras County. The formation consists predominantly of dark gray to black carbonaceous clay slate. Present in smaller amounts, most commonly in the Angels Camp area, are dark gray sandy tuff and tuffaceous graywacke. In places there is a sheared conglomerate containing pebbles and cobbles of chert, quartz, schist, and volcanic rock. In the northern part of the county, this formation contains the Mother Lode gold belt; but south of San Andreas, the Mother Lode is east of the Mariposa formation.

Undifferentiated metamorphic rocks (Jurassic and/or Carboniferous (?) in part). This group of metamorphosed sedimentary and volcanic rocks of pre-Cretaceous age forms extensive northwest-trending belts in and near the Mother Lode gold belt. This group has been tentatively correlated with the Amador group (Eric, Stromquist, and Swinney, 1955, p. 15). The metasedimentary rocks consist of phyllite, quartz-mica schist, phyllonite, and stretched conglomerate. The metavolcanic rocks are green schist, derived from basaltic and andesitic breccia and tuff, and smaller amounts of sericite schist. On the geologic map (pl. A), the Amador group also is included under this designation.

Serpentine and associated rocks (Jurassic). Northwest-trending lensoid serpentine bodies are found along the Mother Lode belt in the Angels Camp-Carson Hill area, east and northeast of Copperopolis, and between Valley Springs and San Andreas. The serpentine ranges from green to black in color and may be massive or highly foliated and slickensided. Associated with the serpentine are minor amounts of gabbro, pyroxenite, talc schist, and, in the area of Carson Hill, appreciable amounts of mariposite-ankerite rock. Locally it may contain veinlets of chrysotile. Also in some places small pods and kidneys of chromite are present. Areas underlain by serpentine commonly are covered with a thick growth of manzanita.

Granitic rocks (Upper Jurassic or Cretaceous). This group of rocks includes granite, granodiorite, quartz diorite, diorite, and gabbro. Hornblende granodiorite is by far the most abundant type. The entire eastern portion of the county is underlain by granodiorite, and there are smaller bodies at Rich Gulch, Jesus Maria, Mokelumne Hill, and east of San Andreas. Small bodies of

Photo 4. Tertiary channel gravels exposed in roadcut on the Valley Springs-San Andreas road.

diorite are present in various areas in the county, especially between Railroad Flat and Mountain Ranch. Several gabbroic bodies are in granodiorite in narrow northwest-trending belts at Angels Camp, about 8 miles west of Angels Camp, and in the eastern part of the county. Diorite gneiss and quartz diorite are closely associated with granodiorite and other intrusive rocks in the eastern portion of the county. These rocks are locally abundant in the vicinity of Garnet Hill and to the west and along the Stanislaus River northeast of Calaveras Big Trees State Park.

Ione formation (Eocene). The Ione formation consists of nearly flat lying beds in the low foothills of northwestern Calaveras County in the Camanche-Valley Springs area. In this county, it is predominantly clayey quartzose sand and interbedded lenses of clay. The Ione sand consists chiefly of medium to coarse angular grains of quartz with small amounts of feldspar, quartz and chert pebbles, interspersed grains of pearly white anauxite, and heavy minerals of which zircon, magnetite, and ilmenite are most abundant. The clay consists largely of kaolinite and a minor amount of anauxite. It is light colored, generally white to yellowish white, but in places tints of gray, pink, and red are common.

Auriferous gravels (Tertiary). The auriferous gravels were deposited in stream channels during the Tertiary period and range from Eocene to Miocene in age. They are in isolated patches, which are remnants of the early channels, and in more extensive deposits that are pre-

Photo 5. Rhyolite tuff of the Valley Springs formation exposed in roadcut near Mokelumne Hill. Photo by Mary Hill.

served by a thick cover of volcanic rocks. The Eocene channel deposits are characterized by a high percentage of pebbles, cobbles, and boulders of white quartz, and by concentrations of placer gold at or near bedrock. The later Tertiary channel deposits, known as the intervolcanic deposits, are characterized by abundant rhyolite and andesite pebbles and are relatively lean in gold as compared with the older Eocene deposits.

The principal gravel deposits of the Tertiary channels in Calaveras County are found between Mokelumne Hill and San Andreas, from Railroad Flat to Sheep Ranch, between Murphys and Angels Camp, in the vicinity of Mountain Ranch and Calaveritas, and in an area just west of San Andreas. Extensive, shallow deposits of Tertiary gravel also are found in a broad north-trending belt between Camanche, Burson, and Jenny Lind. This gravel, which consists largely of quartz and metamorphic rocks, may represent material deposited along the shoreline of the Ione sea by Eocene streams draining the low hills to the east.

Photo 6. Tuolumne Table Mountain as viewed from O'Byrnes Ferry bridge. Camera facing east.

Valley Springs formation (Miocene(?)). The Valley Springs formation forms extensive beds in the northwest portion of the county, notably in the vicinity of Valley Springs. Beds are less extensively exposed in the Angels Camp area and on some of the interstream ridges in the Douglas Flat, Sheep Ranch, and Railroad Flat areas. The formation consists predominantly of nearly flat lying beds of white, vitreous rhyolite tuff. Interbedded with the tuff are gravel and breccia, and the lower part of the formation contains clay, silt, and sand.

In the western part of the county, this formation rests unconformably on sand and clay of the Ione formation, but to the east it lies on auriferous channel gravel or Sierran bedrock.

Undifferentiated volcanic rocks. Two small patches of basalt are exposed on a spur east of Devils Nose, 8 airline miles northwest of West Point. The basalt is younger than the rhyolite (Valley Springs formation) and older than the andesite (Mehrten formation).

Mehrten formation (Miocene and Pliocene). The Mehrten formation is found throughout Calaveras County. In the western part of the county, it generally overlies the Valley Springs formation, but in the eastern portion of the county, it is in extensive beds on the interstream ridges, where it rests on crystalline rocks of the Sierran bedrock complex (granite and Calaveras group).

The Mehrten formation consists of deposits of detritus originating near the crest of the Sierra Nevada during a post-Valley Springs volcanic epoch that was characterized by flows of andesitic lava and the eruption of ash. The deposits consist predominantly of andesitic agglomerate of mud-flow origin and smaller amounts of andesitic sandstone, siltstone, conglomerate, and tuff.

Latite of Table Mountain (Plio-Pleistocene). Extending across part of the southwestern section of the county is a flat-topped, sinuous, steep-sided hill known as Table Mountain. It consists of an erosion-resistant porphyritic augite latite that contains phenocrysts of plagioclase, augite, and olivine in a fine-grained groundmass. The latite occupies a former channel of the Stanislaus River known as the Cataract Channel and overlies Tertiary river gravel.

Glacial moraines (Pleistocene). Small remnants of glacial moraines are found in the high eastern portion of Calaveras County at Big Meadow, Mattley Meadow, and an area north of Camp Tamarack. The moraines contain unsorted and unconsolidated rough boulders and angular rock fragments mixed with sand and other detritus, and were deposited during the Pleistocene glaciation.

Alluvium (Recent). Recent alluvium consists of silt, sand, and gravel adjacent to and in the present stream channels. It also includes placer and hydraulic mining debris.

Geologic History

The oldest rocks in Calaveras County are metamorphosed sedimentary and volcanic rocks of the Calaveras formation. These for the most part represent marine sediments that were deposited as sand, mud, limestone and marl during the Carboniferous and Permian periods about 350 million years ago. Deposition of calcareous material during the late Paleozoic era gave rise to valuable limestone deposits. Submarine volcanic products and chemically deposited manganese-bearing siliceous sediments were also associated with the late Paleozoic sedimentation. Near the end of the Paleozoic era, crustal movements partially destroyed the Paleozoic sea basin and created a mountain chain of unknown extent.

Between the end of the Paleozoic era and the Middle Jurassic period, another sea advanced over what is now Calaveras County. Near the end of the Upper Jurassic period, marine sedimentation, submarine vulcanism, and marine sedimentation, gave rise to the Cosumnes, Logtown Ridge, and Mariposa formations, respectively. Some small manganese deposits were associated with the submarine vulcanism.

In late Upper Jurassic time, about 125 million years ago, mountain building processes known as the Nevadan Orogeny began to elevate the Sierra Nevada. This effected an almost complete withdrawal of the Mesozoic sea from the Sierra Nevada area. The nearly flat-lying Jurassic sedimentary beds were folded into a complicated series of northwest-trending folds, faulted, and the rocks themselves were metamorphosed. The ancestral Sierra Nevada thus created was a fold-mountain range. Prior to destruction of the Mesozoic sea basin, igneous rocks of peridotitic composition were intruded into the marine sedimentary rocks. These intrusives are now largely altered to serpentine. Chromium mineralization was introduced with the peridotites which later gave rise to chromite deposits.

Toward the end of Jurassic time, granitic rocks of the Sierra Nevada batholith were intruded into the folded crust; after cooling and solidification of the granite, fractures and fracture systems developed. The introduction of mineralized solutions along these and earlier fractures led to the pyrometasomatic deposition of tungsten and hydrothermal deposition of gold, copper, lead, and zinc. A very long period of erosion followed during the early part of the Cretaceous period. The elevation of the Jurassic Sierra Nevada was greatly reduced, and broad river valleys developed. For 20 or 30 millions of years, erosion stripped away the rocks lying above the gold deposits, un-roofed the Sierran granitic rocks and cut deeply into the gold-bearing veins themselves.

During Upper Cretaceous time, a sea advanced eastward over a narrow belt of the ancestral Sierra Nevada marginal to the Great Valley. Marine sedimentation at that time resulted in thin, fossiliferous beds that were laid down on the bedrock along this western belt. Patches of these Upper Cretaceous deposits, gently tilted westward, are found from place to place along the western edge of the present Sierra Nevada except in Calaveras County.

Continued erosion reduced the topography of the ancestral Sierra Nevada, and by early Tertiary time (60 million years ago) the temperate climate which characterized the Jurassic and Lower Cretaceous periods had changed to sub-tropical. The resultant warm humid climate caused chemical decay of the bedrock which proceeded slowly but deeply. The finer products of this decay, chiefly clay and quartz sand, were removed by running water and deposited along the eastern margin of the Eocene sea which lapped onto the western flanks of the ancestral Sierra Nevada in a manner similar to that of the Upper Cretaceous sea during the preceding period. The abundant semi-tropical flora which flourished in the area at that time contributed carbonaceous matter which gave rise to the development of lignite.

The heavier and coarser products of decay during the Eocene, notably gold and quartz pebbles, eroded from the late Jurassic-Cretaceous gold-quartz veins, were deposited and concentrated in stream channels as placer deposits. These Eocene placer deposits were extremely rich in gold and were characterized by an abundance of quartz pebbles and a lack of volcanic debris.

Near the close of the Eocene epoch, vulcanism broke out in the Sierra Nevada which was destined to have a profound effect upon the economic geology of the placer gold deposits. Volcanic activity began with rhyolitic ash falls over areas at lower elevations as well as rhyolitic ash falls and rhyolite flows covering areas at the higher elevations of the ancestral Sierra Nevada, interspersed with periods of quiescence. So much ash fell during the Miocene epoch, particularly at lower elevations, that the drainage system that began to develop after the initial vulcanism formed gravel and placer deposits that were leaner in gold than those of Eocene time and were characterized by an abundance of rhyolite pebbles.

By late Miocene or early Pliocene time, about 10 million years ago, volcanic activity reached its peak with the emission of fluid flows of andesite as well as large volumes of fragmental andesite, the latter frequently giving rise to extensive mud flows. These volcanic products buried the Eocene channels and Miocene intervolcanic channels to depths of several hundred feet. The channels which developed after the andesitic vulcanism were still leaner in gold than the interrhyolitic channels.

Further burial of the Eocene channels by later basalt and latite flows served to protect the gold placers in some measure from obliteration by erosion.

As volcanic activity diminished, re-elevation of the Sierra began in late Pliocene time and continued into the

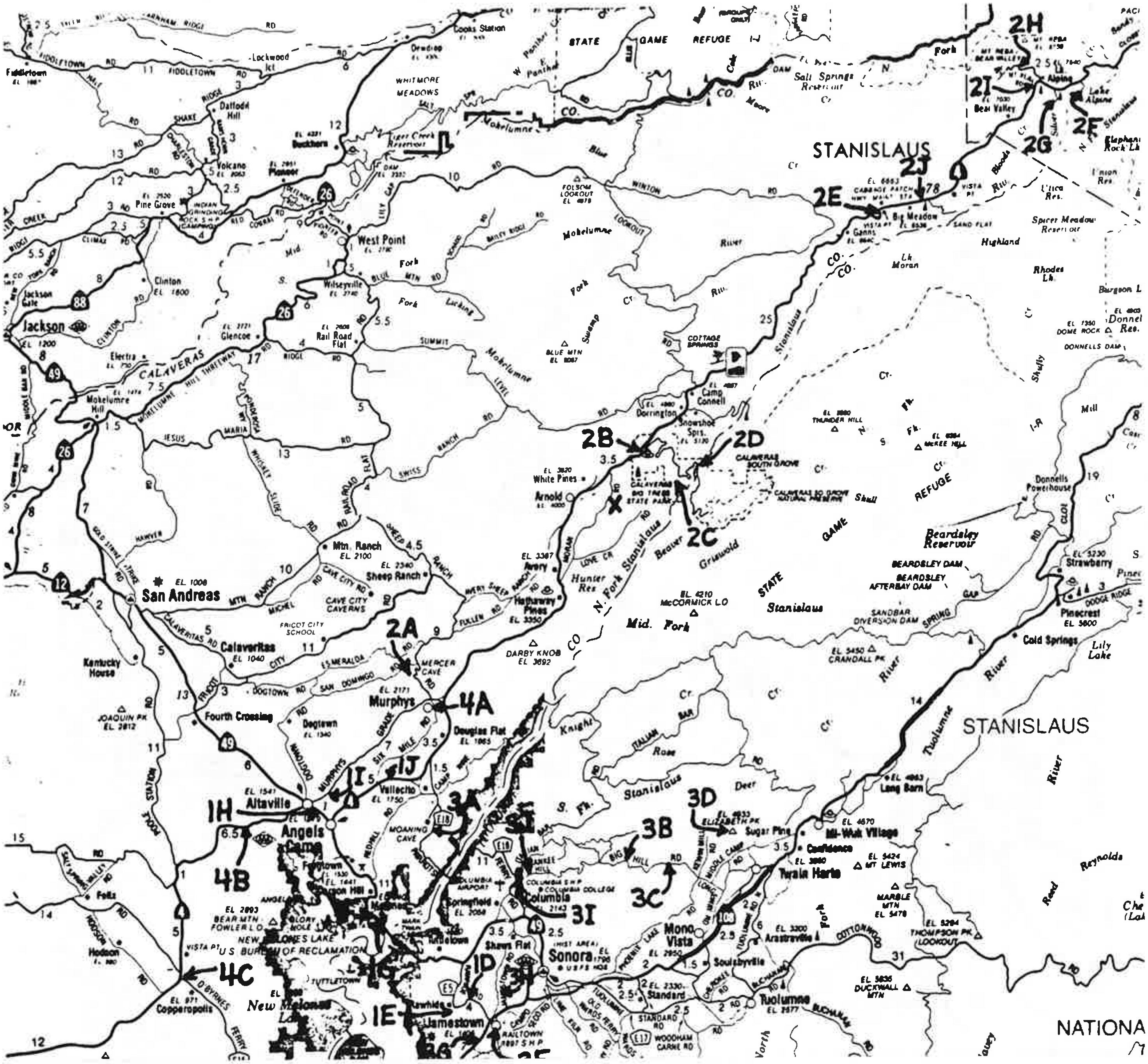
Summary of economic geology of Calaveras County

Geologic age			Rock units	Rock types	Mineral commodities
Era	Period	Epoch			
Cenozoic	Quaternary	Recent	Alluvium	Sand, gravel, silt	Placer gold, silver, platinum, sand and gravel, black sand
		Pleistocene	Latite of Table Mountain	Latite	Stone
	Tertiary	Pliocene			
		Mio-Pliocene	Mehrten formation	Andesitic detritus	Stone
		Miocene	Valley Springs formation	Rhyolite tuff	Stone, ornamental stone
		Eocene	Ione formation	Clay, sand, gravel	Placer gold, silver, platinum, fire clay, quartz sand, coal, black sand, quartz crystal, iron
Mesozoic	Cretaceous			Vein quartz and mineralized wall rock formed in other rock types	Gold, silver, copper, zinc, lead, pyrite, quartz, stone, quartz crystal, tellurium, cobalt, ornamental stone
				Contact metamorphic rocks related to granitic intrusions	Tungsten, copper, gold, silver, molybdenum, semi-precious stones
			Granitic rock	Granite, granodiorite, diorite, gabbro	Stone
	Middle-Upper Jurassic		Serpentine	Serpentine	Chromite, asbestos, soapstone, nickel, terrazzo chips
			Mariposa formation	Slate	Slate, stone
			Amador group {Logtown Ridge formation, Cosumnes formation	Metavolcanic rock, metasedimentary rock	Stone
Paleozoic	Permian Carboniferous		Calaveras formation	Metasedimentary rock	Limestone and dolomite, marble, graphite, stone, iron, terrazzo chips

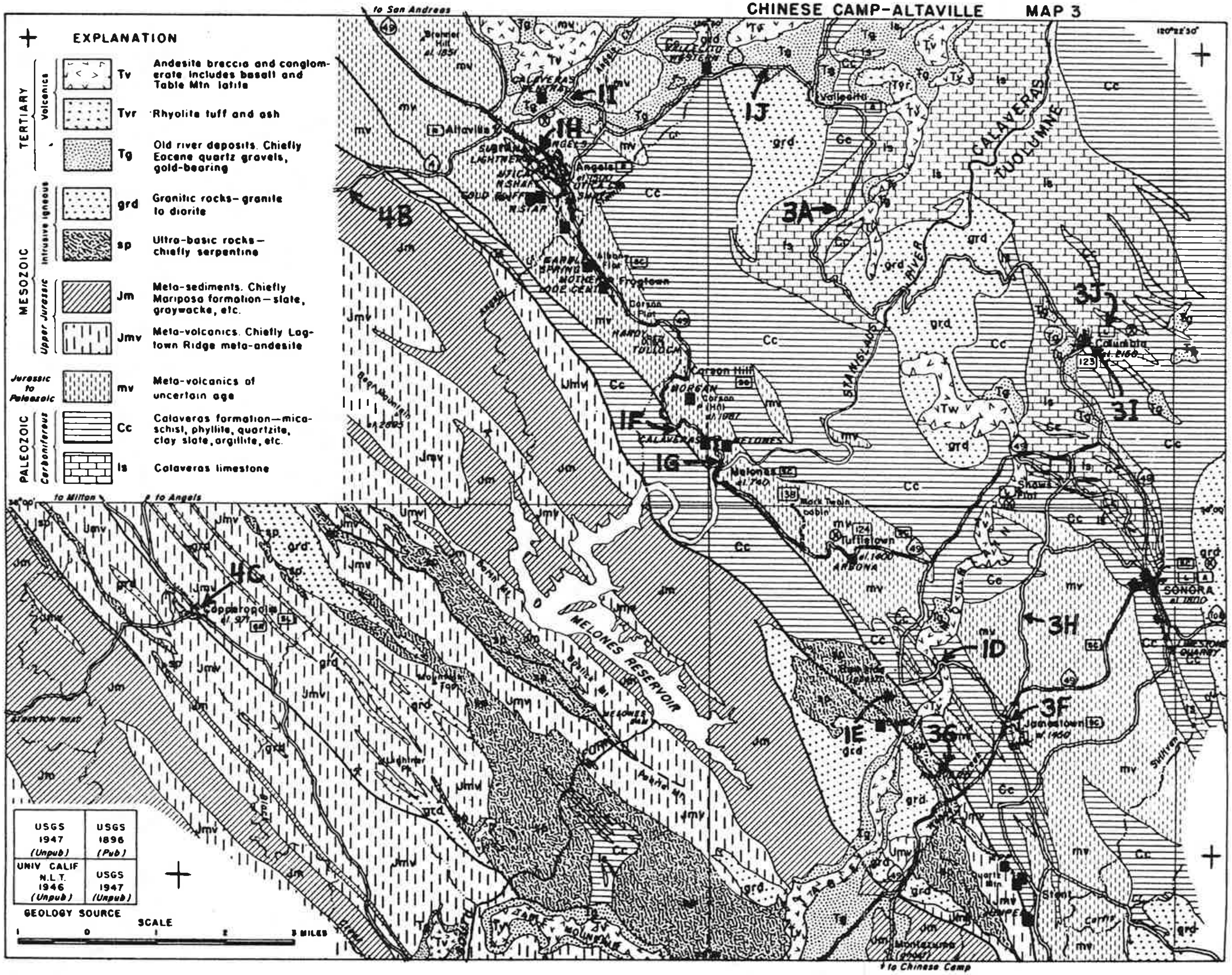
late Quaternary. This was accomplished by major faulting along the eastern flank which tilted the Sierra Nevada to the west. Westward-flowing rivers cut new deep canyons and removed much of the volcanic cover. With increased elevations the temperature was lowered, snow and ice packs formed and began migrating down the slopes as glaciers, elaborately carving the highland topography and further exposing the granitic core of the range. In Calaveras County, the Pleistocene glaciers occupied the eastern portion of the county in the vicinity of Big Meadow and Camp Tamarack.

The rejuvenation of the Sierra Nevada renewed the erosional cycle and permitted continued stripping of gold lodes in Pleistocene and Recent time, thereby enriching the present stream channels with gold. The glaciers retreated from Calaveras County and most of the Sierra about 25 thousand years ago in the early Recent epoch, after which the present climate and topography developed.

ROUTE MAP


2H
2I
2F
2G
STANISLAUS
2J
2E
Big Meadow
Salt Springs Reservoir
Bear Valley
Lake Alpine
Spicer Meadow Reservoir
Utica Res.
Union Res.
Highland
Rhodes Lk.
Donnell Res.
Jackson
Fiddletown
Volcano
Pioneer
Buckhorn
Pine Grove
West Point
Wilseyville
Glencoe
Rail Road Flat
Clinton
Electra
Mokelumne Hill
San Andreas
Mtn. Ranch
Sheep Ranch
Cave City Caverns
Calaveritas
Kentucky House
Fourth Crossing
Dogtown
Murphys
4A
2A
Mercer Cave
Avery
Hathaway Pines
White Pines
Arnold
2B
2C
2D
Dorrington
Camp Connell
Snowshoe Spgs.
Calaveras Big Trees State Park
Calaveras South Grove
Cottage Springs
Beardsley Reservoir
Beardsley Dam
Strawberry
Pinecrest
Cold Springs
Lily Lake
Donnells Powerhouse
Long Barn
Mi-Wuk Village
Sugar Pine
Confidence
Twain Harte
STANISLAUS
Tuolumne River
Douglas Flat
Vallecito
1I
1J
1H
Altaville
Angels Camp
4B
3A
3B
3C
3D
Columbia
3I
Springfield
Sonora
1D
1E
Jamestown
Shaws Flat
Mono Vista
Soulsbyville
Standard
Tuolumne
Arastraville
4C
Copperopolis
Felix
Hodson
New Melones Lake
U.S. Bureau of Reclamation
NATIONA

CHINESE CAMP-ALTAVILLE MAP 3



Route map for central portion of field trip. From California Division of Mines Bull. 141.

FIELD TRIP ROUTE LOG

DAY 1

Leave CSUN and follow Interstate Highways 405 and 5 and US Highway 99 to Merced. Take the "V" Street (State Highway 59) offramp from the Highway 99 freeway, turn right, and follow Highway 59 north to Snelling (after crossing the railroad track, there is a left turn and shortly thereafter a right turn before leaving town; watch for the signs). Be sure that your **gas tank is full before leaving Merced**. For cheap Arco gas, turn left off the offramp, go under the freeway, and turn right to the station (return under the freeway to get back onto Highway 59). For state cars, turn right off the offramp, cross the railroad track, and turn right to an Exxon station (go north from the station to return to Highway 59). Continue north on Highway 59 to Snelling. The remainder of the route is shown on the route maps on the previous two pages. — Proceed on the main road through Snelling and shortly after passing through town turn left onto La Grange Road (County Route J59). A short distance down the road pull to a stop on the right near some piles of cobbles.

Stop 1A — Discussion of gold dredge operations.

Follow La Grange Road north. Shortly after crossing State Highway 132 (boulevard stop), stop at a wide pullout on the left near a roadcut of cross-bedded sandstone and conglomerate.

Stop 1B — Discussion of Tertiary rocks in the Sierra Nevada.

Continue north on La Grange Road to a point 4.7 mi north of the intersection with Bonds Flat Road. Park on the right at a small farm-road intersection.

Stop 1C — Discussion of Jurassic meta-volcanic rocks and "tombstone" outcrops.

Continue north to end of La Grange Road. Turn right on State Highway 108 and stay on 108 around the north edge of Jamestown to Rawhide Road. Turn left on Rawhide Road (County Route E5) and proceed to a turnout on the right just before the pass through Table Mountain.

Stop 1D — Discussion of Table Mountain Latite.

Continue north across Table Mountain and into the Rawhide area. Turn left at the first paved intersection and go a short distance to a wide spot on the right where the old road used to be. Park on the old road.

Stop 1E — Discussion of ultramafic rocks.

Return to Rawhide Road and continue to the intersection with State Highway 49. Turn left and, after a few miles, cross the bridge over New Melones Reservoir. Continue on Highway 49 up the hill to the intersection with old Highway 49, that now leads to a boat ramp. Park on the right.

Stop 1F — Discussion of the Calaveras Complex.

Go down old Highway 49 to a parking lot west of and above the boat ramp.

Stop 1G — Discussion of the Mother Lode quartz veins.

Return up old Highway 49 to the new Highway 49 and turn right. Continue through Angels Camp to a city park on the left side of the road where there is a sign that describes the Lightner Mine.

Stop 1H — Examination of Lightner Mine artifacts.

Continue north on Highway 49 to Altaville. Just past Bret Harte High School, turn right on Murphys Grade Road. Go about a mile to Rolleri Bypass and turn right. Park on the left side of the road near the entrance to Rolleri Ranch.

Stop 1I — Discussion of the Valley Springs Formation.

Continue south on Rolleri Bypass to its intersection with State Highway 4. Turn left and, after a couple of miles, park on the right near conglomerate-bearing roadcuts.

Stop 1J — Discussion of Eocene gold-bearing gravel deposits.

Continue east on Highway 4 to about a mile past Arnold. Turn right on Moran Road. Follow Moran Road until you come to a golf course on the left. At the end of the golf course turn left on Rainy Drive. Cross the meadow and turn right on Meadow Drive. Home base accommodations are at 2315 Meadow Drive.

DAY 2

Go west on Meadow Drive, cross Moran Creek, and turn left on Moran Road. Follow Moran Road to its intersection with Highway 4 (part of this road is very narrow; watch for oncoming traffic on the corners and drive carefully). Turn left on Highway 4 and proceed to the town of Murphys. Watch for the turnoff from Highway 4 just before the town. About halfway through Murphys, watch for Mercer Caverns signs and turn right on Sheep Ranch Road. Follow the signs to the parking lot at Mercer Caverns. We have an 8:45 a.m. appointment.

Stop 2A — Tour of Mercer Caverns and examination of the "limestone" of the Calaveras Complex.

Return to Murphys and proceed northeast, back up Highway 4, to Calaveras Big Trees State Park. Fees for all the vehicles will be paid by the trip leader. Park in the main parking lot.

Stop 2B — Visit the Visitor Center and walk through the *Sequoiadendron gigantea* grove. Eat lunch whenever you wish and be ready to leave at 12:30 p.m.

Leave the parking lot, make two right turns onto the main park road, and drive to the Lava Bluffs trailhead parking lot.

Stop 2C — Hike to see the Mehrten Formation and discussion of Miocene Sierran history.

Turn right out of the parking lot and proceed down to the Stanislaus River. Park in the parking lot on the right just before crossing the river.

Stop 2D — Swim in the Stanislaus River.

Return to the Big Trees Park entrance and continue right up Highway 4. Pull off the road and park at the vista point just beyond Ganns.

Stop 2E — Discussion of Sierran granitoid intrusive rocks.

Continue east on Highway 4 to Lake Alpine. Turn right on the Lake Alpine west shore road (dirt), follow it to its end, and park.

Stop 2F — Discussion of glacial features.

Return to Highway 4 and turn left, back toward Arnold. After a short distance, turn left into Silvertip Campground and drive to the south end of the camp and park.

Stop 2G — The Mehrten Formation and glacial moraines.

Return to Highway 4, turn left, and after a short distance turn right onto the road to the Mount Reba ski area. Go up the road to a parking lot and overlook at the top of the hill.

Stop 2H — Summary of eastern Sierran geology.

Return to Highway 4, turn right, drive about 100 yd, and park on the right.

Stop 2I — Discussion of recognition of the various Sierran gravel deposits.

Continue west on Highway 4, past a vista point, to just before Big Meadow. Park off the road on the right near a boulder conglomerate roadcut.

Stop 2J — Examination of a glacial moraine.

Continue west back to home base via Highway 4, Moran Road, Rainy Drive, and Meadow Drive. Prepare yourself for a beef stew dinner.

DAY 3

Go from home base to Highway 4 and travel west to just beyond Douglas Flat. Turn left on Parrots Ferry Road (County Route E18) toward Columbia. Drive south past Moaning Cavern and across Coyote Creek. A mile or so past Coyote Creek, park on the right next to a green gate that bears a sign that reads "pack it in, pack it out".

Stop 3A — Short hike to a natural bridge.

Continue on Parrots Ferry Road toward Columbia. On the outskirts of town turn left onto Jackson Street (also called Yankee Hill Road). Continue on this road for 1.5 mi and turn right on Big Hill Road. Go 0.1 mi and turn left, staying on Big Hill Road. Travel 1.2 mi and park near high roadcuts.

Stop 3B — Discussion of the "argillite" of the Calaveras Complex.

Continue west on Big Hill Road for 3.8 mi. Park on the right near a fresh granitoid roadcut. Parking is tight here. Get off the road as far as is comfortable and watch for traffic when in the street.

Stop 3C — Discussion of the Standard Pluton.

Continue west on Big Hill Road. At the junction with Phoenix Lake Road, stay left on Longeway Road, which eventually turns into Middle Camp Road. At the junction with Joaquin Gully Road, take a sharp left onto a dirt road that goes to Elizabeth Peak. Park by the gate near the top of Elizabeth Peak.

Stop 3D — Discussion of the quartzite of the Calaveras Complex.

Return to Joaquin Gully Road and follow it to the right into Twain Harte. Turn right onto Twain Harte Drive and follow it to its junction with State Highway 108. Turn right onto Highway 108 and follow it west, past Sonora to James- town. On the outskirts of Jamestown, make a left turn onto Fifth Avenue. Then in fairly rapid succession make the following turns: right onto Ninth Street, left onto Third Avenue, left onto Seco Street, right onto Campo Seco Road, left onto Algerine Road, right onto Stent Cutoff Road, and finally left onto Stent-Jacksonville Road. Travel 1.3 mi to the new bridge across Sullivan Creek. Park on the right at 0.1 mi beyond the bridge, where the old road from the old bridge rejoins the new road.

Stop 3E — Discussion of the volcanic rocks of the Calaveras Complex.

Return via Stent-Jacksonville Road, Stent Cutoff Road, and Algerine Road to the center of Jamestown. The road deadends on the main street directly across from the town park. Park wherever possible.

Stop 3F — Eat lunch in the park and be ready to leave at 12:40 p.m.

Leave Jamestown going west on Highway 108. Shortly after leaving town, turn right through a gate into the James- town Gold Mine. Park in the Administration Building parking lot. We have a 1:00 p.m. appointment.

Stop 3G — Tour of the Jamestown Gold Mine.

Return to Jamestown via Highway 108 and turn left off of 108 onto Jamestown Road, the next street past Rawhide Road. Proceed 1.3 mi on Jamestown-Shaws Flat Road. Pull over and park carefully on the left (another very tight parking place; be careful).

Stop 3H — More volcanic rocks of the Calaveras Complex.

Continue on Jamestown-Shaws Flat Road past Shaws Flat and straight across Highway 49 on Shaws Flat Road. Turn left on Parrots Ferry Road. Follow the signs to the parking lot of Columbia State Historic Park.

Stop 3I — Visit the historic gold-mining town of Columbia.

Leave the parking lot and turn right on Parrots Ferry Road, then right again on Jackson Street. Drive about 0.5 mi, turn right into the Marble Quarr and park to the east of the office.

Stop 3J — Short walk to the Co marble quarry.

Return to home base via Jackson Street, Parrots Fe Road, Highway 4, Moran Road, Rainy Drive, an Meadow Drive.

DAY 4

Go from home base to Highway 4 and travel west to Murphys. Park along the main street at the east end of town.

Stop 4A — Short visit of the historic town of Murphys.

Continue west on the main street, which becomes Murphys Grade, and proceed to Altaville. Turn right onto Highway 49 and soon thereafter left onto Highway 4. Travel about 2 mi and park, if possible, near roadcuts in metasedimentary rocks.

Stop 4B — Examination of Mariposa Formation.

Continue west on Highway 4 for several miles. About a mile past a vista point, turn left on O'Byrnes Ferry Road (County Route E15). Park near the historic marker in Copperopolis.

Stop 4C — Collecting on the old mine dumps.

Continue south on O'Byrnes Ferry Road, cross the bridge over Tulloch Reservoir, and park where possible near roadcuts on the south side of the bridge.

Stop 4D — Folds in the Mesozoic rocks.

Continue southeast on O'Byrnes Ferry Road to its intersection with Highway 108. Turn right and follow Highway 108 to about a mile west of the Stanislaus County line. Turn right on Sonora Road, cross the Stanislaus River, and park in Knights Ferry.

Stop 4E — Summary of the Tertiary history of the Sierra Nevada.

Return to Highway 108 and turn right. Follow Highway 108 west to Oakdale. Turn left on Albers Road (County Route J14) and proceed south through Turlock to the Highway 99 freeway. Return home via Highway 99 south and Interstate Highways 5 and 405. Hope you had a good time and have a safe trip home.

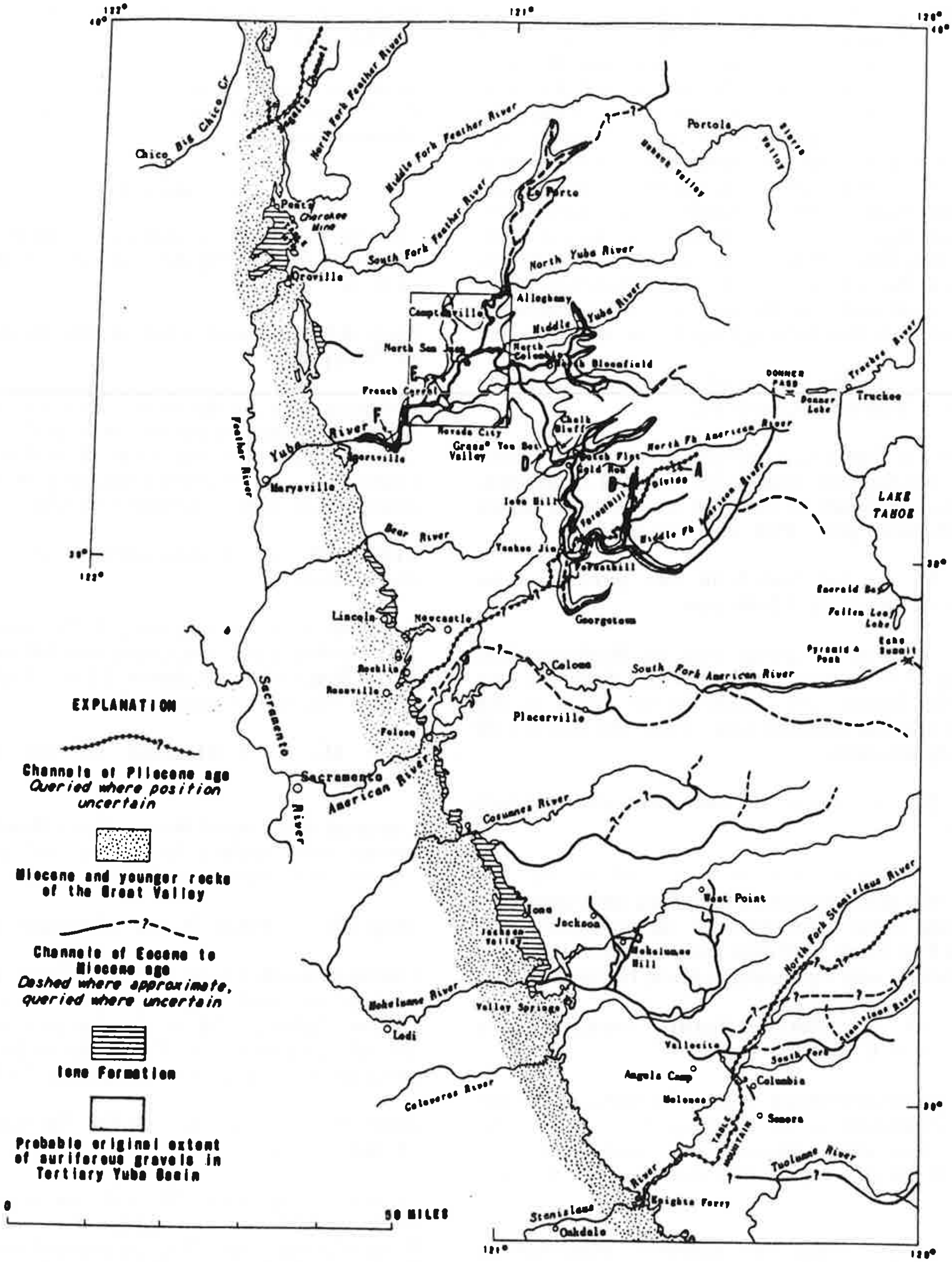


Figure 5. Map showing localities in northern Sierra Nevada mentioned in text, and prevolcanic and intervolcanic channels, Ione Formation, and inferred original distribution of auriferous gravels in the basin of the Tertiary Yuba River. Channels from: Gold Belt Folios; Lindgren, 1911, plate 1; Browne, 1890; Storms, 1894; Clark and others, 1963; Goldman, 1964. Ione Formation from Chico sheet, Sacramento sheet (prelim. comp.), and San Jose sheet (prelim. comp.) of Geologic Map of California, Olaf P. Jenkins edition.

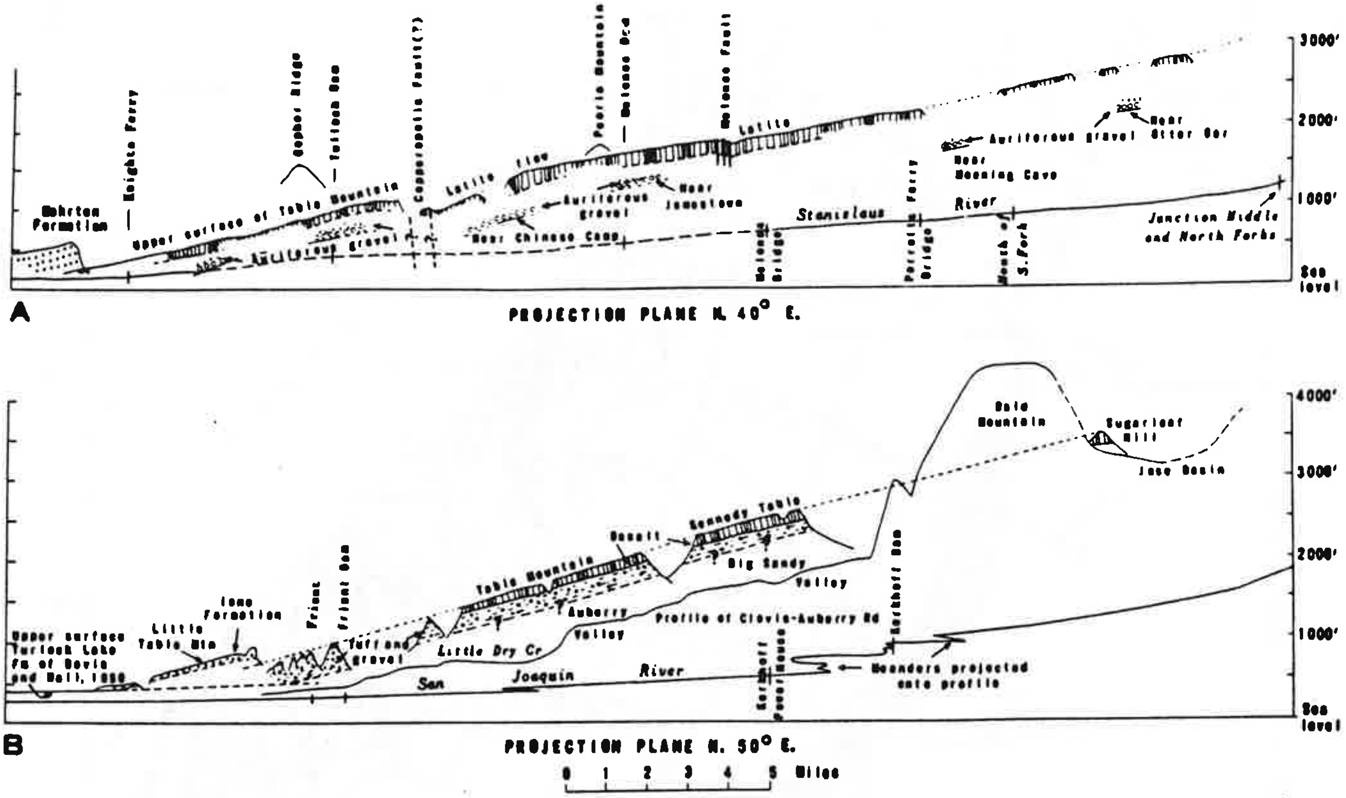


Figure 13. Projections of two volcanic table mountains of the western Sierra Nevada. A. Projection of Tuolumne Table Mountain onto a vertical plane striking N. 40° E. Geology modified from Taliaferro and Solari, 1949; Eric and others, 1955; and Big Trees Folio. B. Projection of Little Table Mountain and the basalt of Table Mountain on the San Joaquin River onto a vertical plane striking N. 50° E. Geology modified from Macdonald, 1941, and original surveys. For location of projection planes see figure 10. Vertical exaggeration about 10 ×.

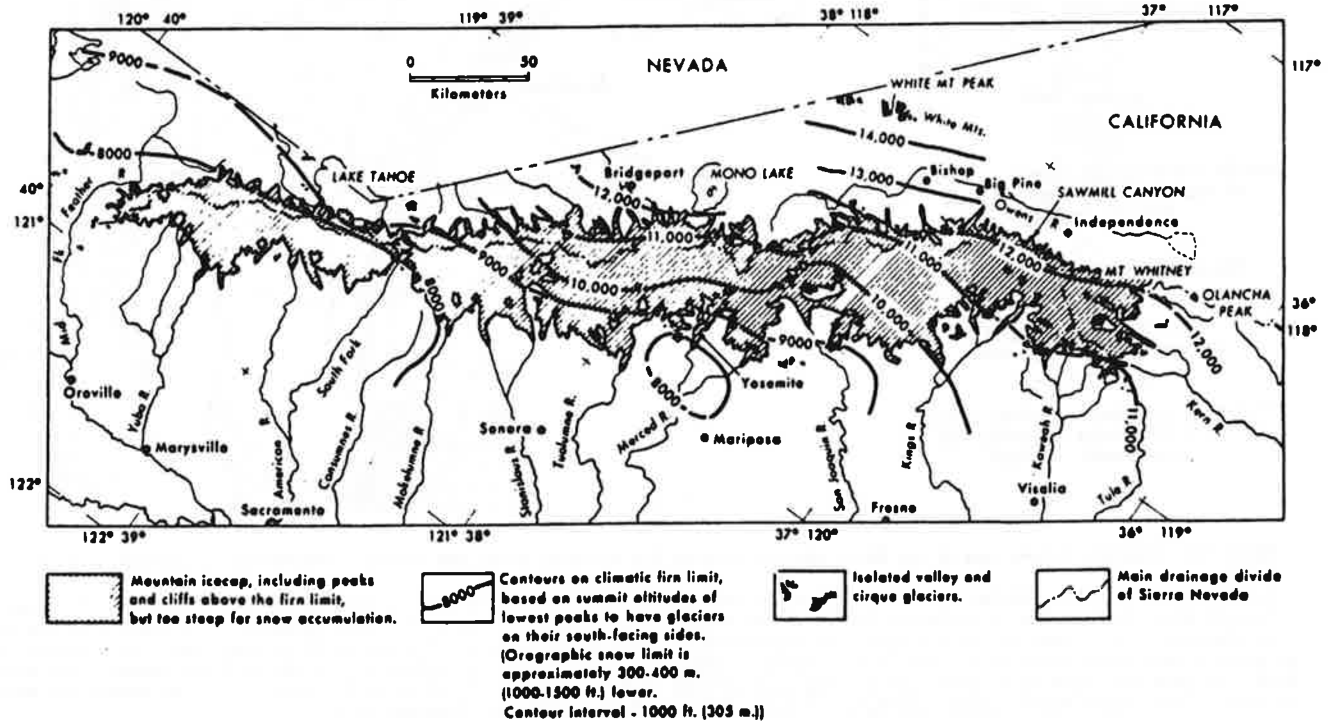


Figure 17. Wisconsin(?) glaciation and climatic firn limit in the Sierra Nevada and White Mountains. From Wahrhaftig and Birman, 1965, figure 2, which should be consulted for sources of information.

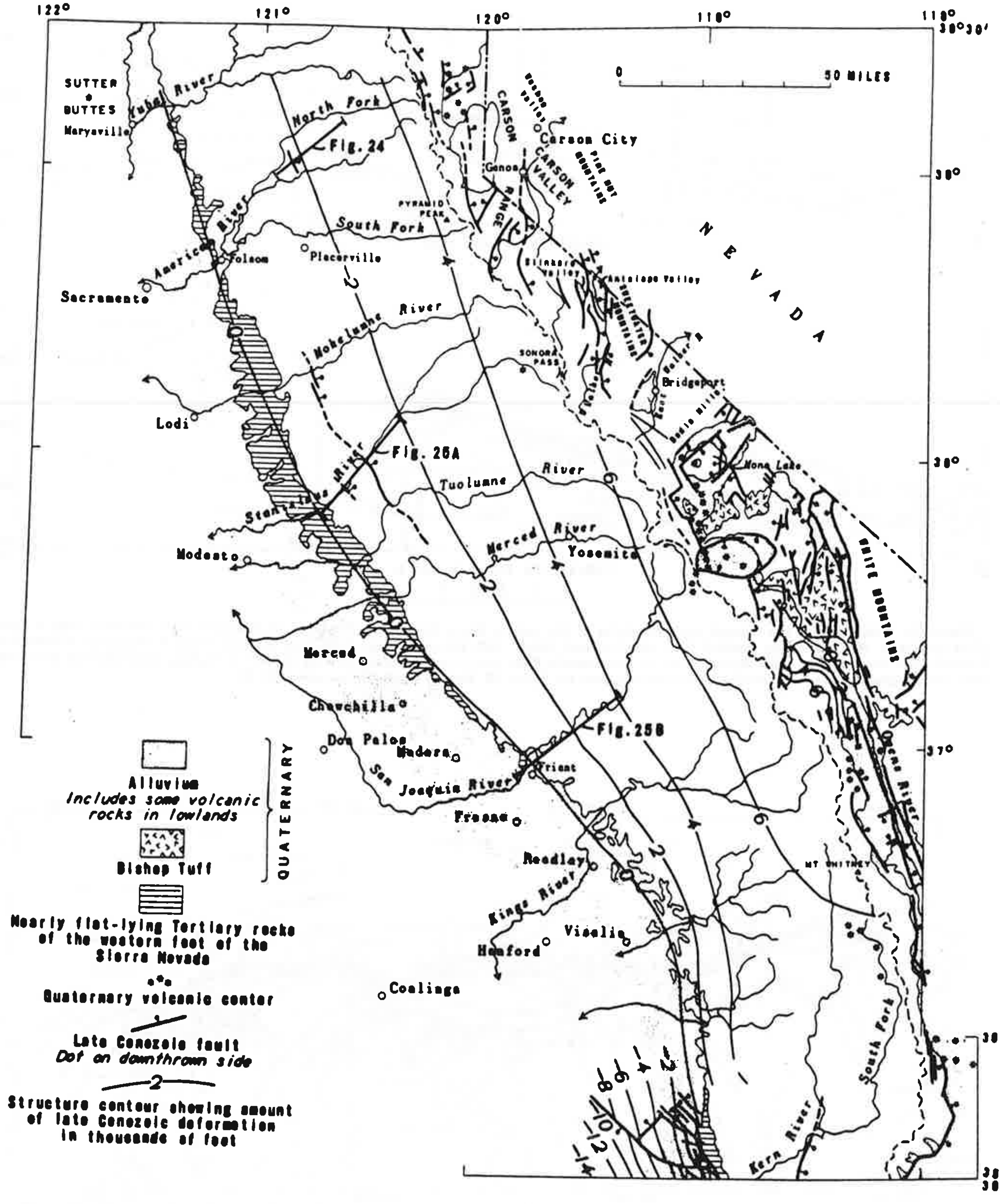
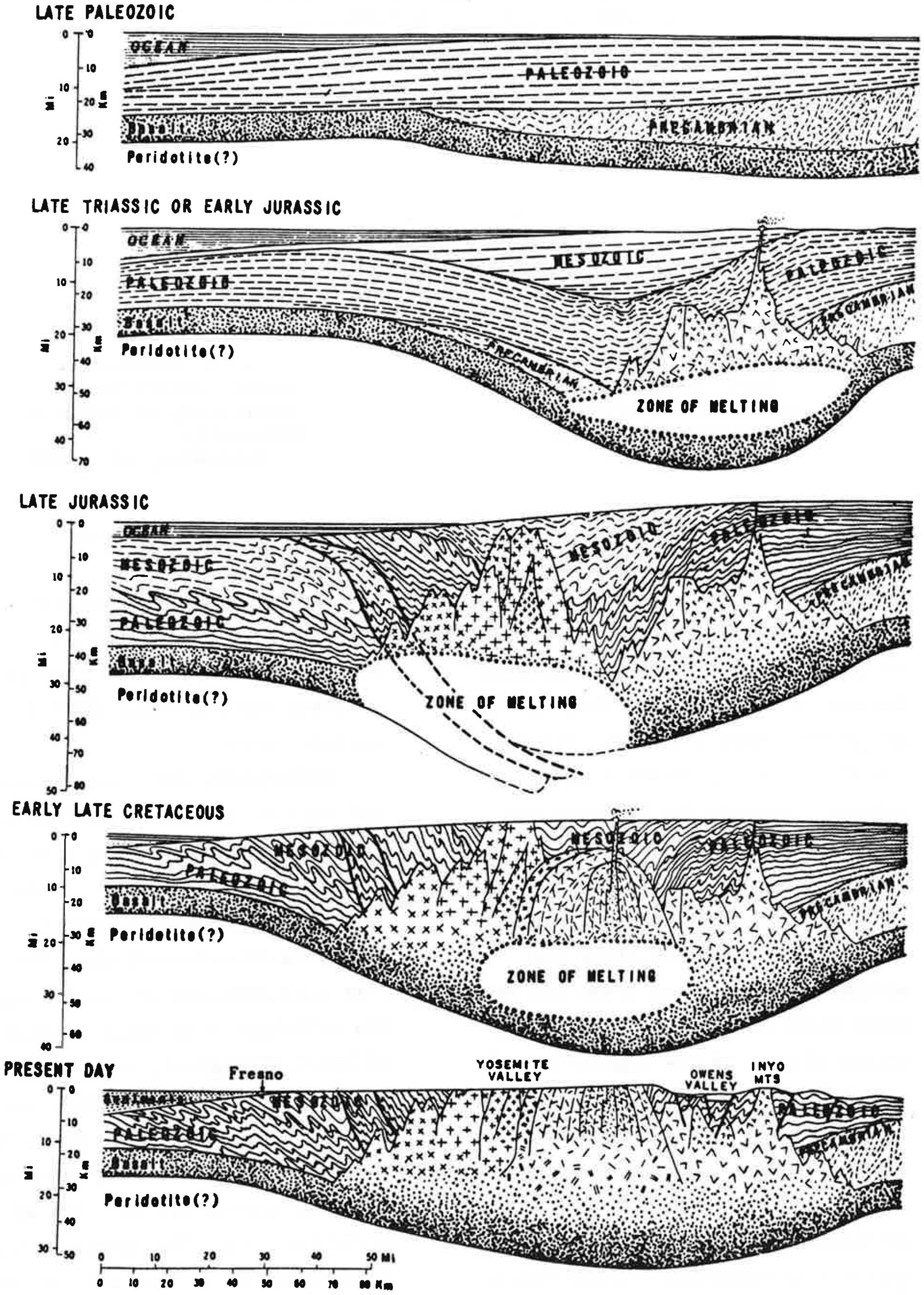


Figure 10. Cenozoic tectonic map of the Sierra Nevada, showing late Cenozoic faults, late Cenozoic deformation by contours, and Quaternary volcanic centers.

Contacts from Chico sheet, Walker Lake sheet, Sacramento sheet (prelim. comp.), San Jose sheet (prelim. comp.), Fresno sheet (prelim. comp.), and Bakersfield sheet, Geologic Map of California, Olaf P. Jenkins edition, and from Bateman and others, 1963; Bateman, 1965; and Pakiser and others, 1964. Contours on west slope of Sierra Nevada after Christensen, in press, 1966; contours and buried faults at south end of San Joaquin Valley on top of Vedder Sand (lowermost Miocene), from Richardson, 1965. Contours on Coyote Flat surface on east side of Sierra Nevada, from Bateman, 1965, and generalized from topography south of Bridgeport; altitudes of these contours reduced by 4,000 feet to agree with deformation datum of contours on west side of Sierra Nevada. Distribution of Bishop Tuff from Gilbert, 1938; and Bateman, 1965.


LATE PALEOZOIC
OCEAN
PALEOZOIC
PRECAMBRIAN
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LATE TRIASSIC OR EARLY JURASSIC
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0 10 20 30 40 50 60 70 80 Km

16

Prepared for the 73rd Annual Meeting of the
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TECTONICS AND STRATIGRAPHY OF THE CALAVERAS COMPLEX CENTRAL SIERRA NEVADA FOOTHILLS

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Summary

This two-day field trip is devoted to the sedimentologic and structural history of the Calaveras Complex in the central Sierra Nevada. The log for the first day covers important exposures between the Tuolumne and Stanislaus rivers which illustrate the major lithologic units we have defined (see fig. 1). On the second day, we will examine exposures along the middle fork Stanislaus river and Rose creek which demonstrate the chaotic nature of much of the complex and the superposed deformations which have affected these rocks.

Our studies indicate that metamorphic rocks of the Calaveras Complex originated mainly as chaotic rocks emplaced as submarine olistostromes. These chaotic deposits apparently accumulated on a volcanic substrate consisting of pillow lava, tuff-breccia, and tuff. The thick pillowed sections may represent layer 2 of oceanic crust.

Sedimentary units that overlie the volcanic unit consist of, from oldest to youngest, an argillite unit, a chert unit, and a quartzite unit. These units were probably on the order of thousands of metres thick. The argillite unit consists of chaotic argillite and siltstone with small olistoliths of chert throughout, and lenses of marble in its upper (eastern) part. The chert unit consists largely of chert-rich olistostromes, with locally coherent olistoliths of chert up to a kilometre long. The quartzite unit contains thick to thin well-bedded and sometimes graded quartz sandstone

and shale, and occasional interbedded olistostromes with quartzite olistoliths.

The volcanic, argillite, and chert units clearly have gradational contacts and are closely interrelated units. The quartzite unit may have been deposited on and may locally interfinger with the chert unit, but distinctive augen gneiss and mylonite occur near the contact north of the Standard pluton (fig. 1), raising the possibility that this contact may be tectonic.

Fossils in an olistolith near the top of the argillite unit indicate a maximum Permo-Carboniferous age for that unit (Schweickert and others, 1977); a fossil locality in the chert unit near the southern end of the Calaveras Complex near the Kaweah River suggests a Late Permian age (Schweickert and others, 1977). Late Triassic and Early Jurassic fossils have been reported from rocks identical to the quartzite unit 200 km south (Christensen, 1963; Jones and Moore, 1973; Schweickert and others, 1977).

The Calaveras Complex was affected by at least three phases of hard rock deformation. First, a pervasive flattening foliation (S-1) and extension lineation (L-1) developed in all lithologic units along with amphibolite facies metamorphism. Folds (F-1) are present where rare bedding existed in the chaotic rocks. Figure 1 shows that S-1 and lithologic layering (especially that of the quartzite unit) define a complex and very large east-plunging synform whose hinge zone is occupied by the Standard pluton. A widespread 110/90 foliation (S-2) defined by aligned metamorphic biotite flakes is axial planar to the synform and to minor associated F-2 folds. Hinge lines of these folds define an L-2 lineation that is often parallel with L-1. Later, post metamorphic structures include minor folds (F-3) with axial planar crenulation cleavage (S-3) that commonly strikes about 140-150/90. There appear to be several other sets of crenulations, some of which may be conjugate with the dominant northwest-trending set.

Structures related to the first two deformations predate the Standard pluton, which has a 162 m.y. K-Ar hornblende date (Evernden and Kistler, 1970). We feel they are related to a pre-Nevadan event; possibly the earliest structures developed during the Sonoma orogeny. The crenulation cleavages appear to be younger and may be related to the Melones fault zone.

The evidence we have at present indicates to us that the Calaveras Complex accumulated during late Paleozoic time in a tectonically unstable oceanic or marginal basin that separated a volcanic arc to the north from the continental margin to the southeast (Schweickert and Wright, 1975a,b; Schweickert and others, 1977). Within this oceanic basin, tectonically high regions were repeatedly denuded of their thin pelagic and hemipelagic cover, while other regions remained tectonically low and collected immense thicknesses of olistostromes that flowed off of the tectonically higher regions. Subsequent early phases of hard rock deformation and metamorphism are probably manifestations of the Permo-Triassic Sonoma orogeny, during which the correlative marginal basin rocks of the Havallah sequence in north-central Nevada were thrust many tens of kilometres over coeval shelf sequences (Silberling and Roberts, 1962; Silberling, 1973). Southwestern parts of the orogen apparently were tectonically removed after the Sonoma orogeny; the complex Melones fault zone now represents both the scar of the truncation (Schweickert, 1976) and the suture between the Calaveras Complex and a Late Jurassic island arc that collided with the Calaveras Complex during the Nevadan orogeny (Schweickert and Cowan, 1975). Late crenulations and folds apparently are related to the Melones fault zone and probably reflect its complex tectonic history.

The acknowledgements below go with the paper on the following page.

ACKNOWLEDGEMENTS

The author would like to thank Sonora Mining Corporation for allowing this paper to be published. A special thanks to Al Dahlstrand, Technical Services Superintendent, and Bob Allgood, Mill Superintendent, for proof reading and providing technical input to this paper. Finally, thanks to the Technical Services and Laboratory Departments whose hard work has given us the understanding of the Harvard deposit that we have today, and who contribute greatly to the continued operation of the Jamestown Mine.

Ms. Allgood is chief geologist at Sonora Mining Corporation's Jamestown Mine. She obtained a B.S. in geology from Auburn University in 1978 and a M.S. in geoscience from the University of Arizona in 1983. Ms. Allgood began working summers in the coal fields of Alabama in 1975. She worked as an exploration geologist for Duval Corporation while working on her thesis, and came to work at Sonora Mining Corporation in 1984. Ms. Allgood co-authored a paper for the Mineralogical Record in 1986 on gold occurrences in Tuolumne County.

GEOLOGY AND OPERATIONS at the JAMESTOWN MINE SONORA MINING CORPORATION, CALIFORNIA

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ABSTRACT

The Jamestown Mine comprises a chain of five low grade, disseminated gold deposits centered on the Mother Lode vein system. The deposits are along a major fault system in a terrain of metavolcanic, metasedimentary and, meta-ultramafic rocks. Alteration types include albitization, sericitization, carbonatization, and silicification.. Fine gold is associated with pyrite.

The Harvard pit has been mined since mid-1986 using standard open pit mining techniques. Beneficiation is by conventional flotation. The concentrate is treated by cyanide leaching. Gold is recovered by electrowinning. To date, the Harvard open pit mine has produced approximately 200,000 ounces of gold.

INTRODUCTION

The Jamestown Mine is the third largest gold producer in California, currently yielding approximately 110,000 ounces of gold per year at a milling rate of 6,300 tons per day. Gold is recovered by standard flotation techniques and agitated cyanide leach of the flotation concentrate.

The Jamestown Mine is a joint venture operation controlled 70 percent by Sonora Mining Corporation and 30 percent by Pathfinder Gold Corporation. Sonora Mining Corporation is owned by ABM of Vancouver, B.C. and Northgate Exploration of Toronto, Ontario. The property consists of five deposits located along the historic Mother Lode district in central California (Fig.1). Projected open pit reserves as of January 1, 1990 total 20.8 million tons of ore with an average gold grade of 0.063 ounces per ton (opt).

The historic lode mines centered in each of the five Jamestown ore deposits are, from north to south, the Rawhide, the Crystalline, the Harvard, the Dutch-App-Nyman, and the Jumper (Fig. 1). The Harvard deposit is currently being mined. This paper will discuss the deposit and operations there.

LOCATION

The Jamestown mine is located in the foothills of the Sierra Nevada province of central California (Fig. 1). The site is 100 miles east of San Francisco, and is four miles from Sonora, county seat of Tuolumne County. State Highway 108 passes through the property. The project consists of one active open pit, a rock storage facility, concentrator, a tailings disposal facility, and support facilities. A concentrate leach-recovery plant is located in Yerington, Nevada.

HISTORY

Gold was first discovered in Tuolumne County in 1848 by the Wood's party along the creek that flows south of the Harvard mine. The first claim was located on Harvard Hill in 1850 by a placer miner who prospected the near-surface soils when the nearby placer gravels became depleted. His success prompted others to follow, and the area became a patchwork of small claims (DeFerrari, 1981). Attempts to consolidate the properties and commence serious development were unsuccessful until 1899. In that year, a group of Boston capitalists purchased the property, built a 60-stamp mill and began full scale development and production. The property was operated almost continuously until the end of 1916. It produced almost 100,000 ounces of gold from ores with an average grade of only 0.13 opt gold. The mine reached a depth of 1,850 feet on the incline (Julihn and Horton, 1940).

Before the mine was abandoned, Oscar Hershey, a prominent mining engineer of the time, examined the Harvard mine in detail (Hershey, 1916). His projections of ore targets revived interest in the Harvard in the 1930's when the price of gold was raised to $35.00 per ounce. Fifteen diamond core holes were drilled from the surface to test Hershey's indicated ore zones, and the mine workings were dewatered to the 500-foot level. The operators of the Alaska Juneau gold mine reviewed the old Harvard mine data and the new information provided by the drilling. In late 1938, the Alaska Juneau Gold Mining Company obtained an option on the Harvard property and commenced an extensive exploration program. Almost 32,000 feet of core were collected from holes drilled on lines spaced 100 feet

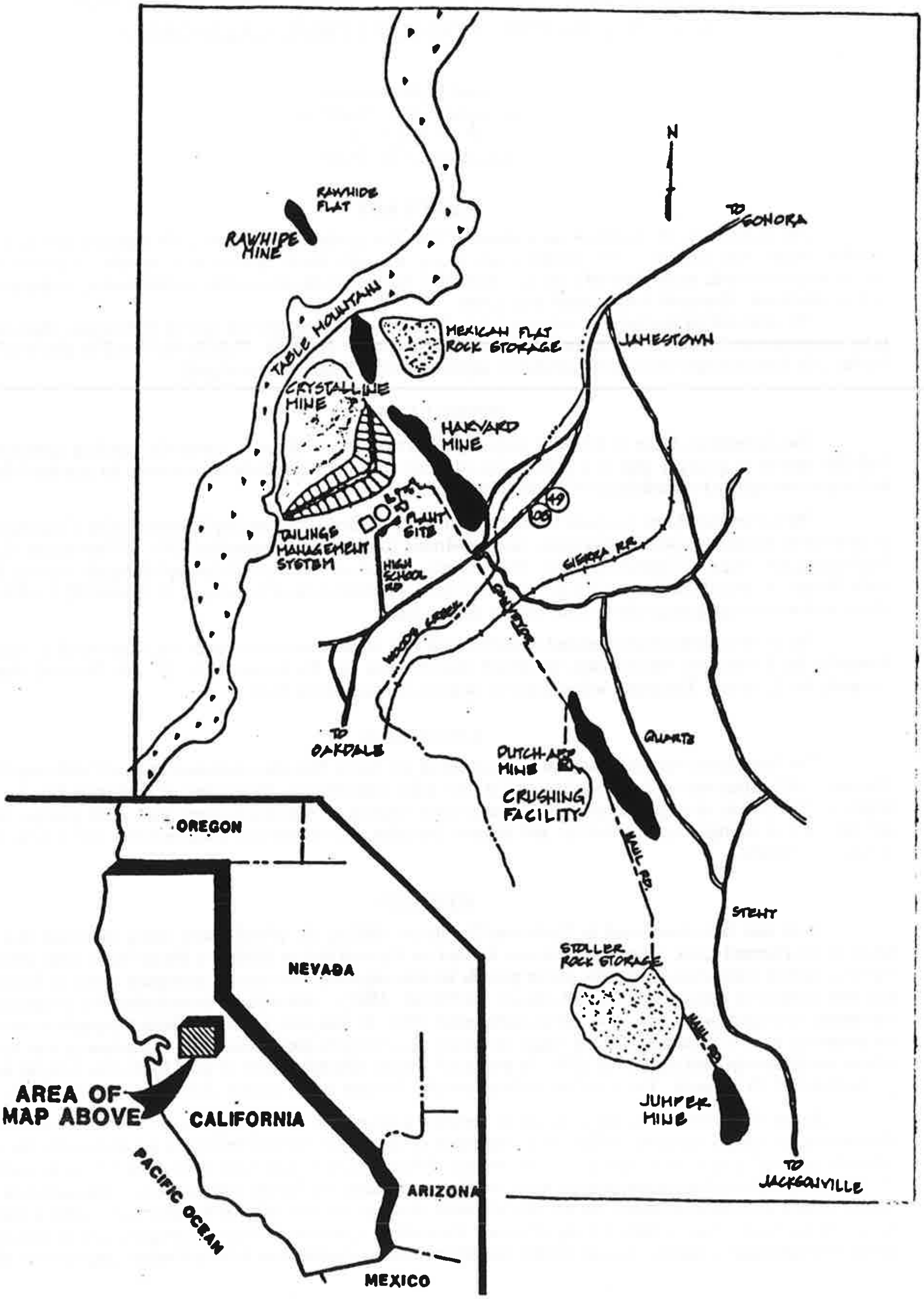

Figure 1. Location map of the Jamestown Mine area.

apart along a strike length of 1,300 feet. In addition to surface coring, holes were drilled from the 200-, 350- and 500-foot levels. In all, Alaska Juneau defined 4.6 million tons of ore with an average grade of 0.079 opt gold. Development work was begun in mid-1940, and continued until pressures from World War II caused the closure of the mine in 1942 (Bradley, 1981).

The property sat idle for forty years until the high gold prices in the late 1970's spurred exploration for the precious metal. The New Jersey Zinc Company conducted a literature survey for likely low-grade gold targets. This brought them to the southern Mother Lode, and the Harvard mine again came under review. Initial surface soil geochemical surveys revealed a bull's-eye anomaly of gold over what later proved to be the Harvard open pit deposit (Fig. 2).

The Harvard deposit was drilled on a staggered grid. To test oxide mineralization, shallow holes were drilled fifty feet apart on lines spaced one hundred feet apart along strike. To test sulfide mineralization, deeper holes were drilled on lines offset fifty feet along strike between the shallow holes. The New Jersey Zinc Company drilling program, together with the deep drilling from the 1940's, outlined 9.4 million tons of ore containing 0.074 opt gold. A change in the company's priorities in 1983, lead to the sale of the Harvard property and the four other Jamestown deposits.

Sonora Mining Corp. purchased the properties from New Jersey Zinc in September of 1983. Work continued on environmental studies and permitting at both the state and county levels. In September of 1985, a joint venture partnership was established between Pathfinder Gold Corporation and ABM of Vancouver, B.C. Facility construction commenced in February of 1986. Stripping of the Harvard deposit started in August of 1986, and mill processing began in January of 1987. As of September 1, 1989, Sonora Mining Corporation has produced over 200,000 ounces of gold.

GEOLOGY

The Jamestown Mine is in the Mother Lode vein system, which in the Jamestown area is coincident with the Melones fault zone. Deformation in this region has been interpreted to be the result of subduction and compression along the continental margin. A succession of sedimentary and volcanic rock has been tightly folded and metamorphosed to greenschist facies. Shearing, alteration, and mineralization followed peak metamorphism (Schweickert and Cowan, 1975).

Hanging Wall Rocks

The hanging wall rocks consist of metasedimentary and metavolcanic slate, phyllite, and schist (Fig. 3). Major rock types include graphitic slate, chlorite schist, and fine-grained green to grey greenstone. Many of the sedimentary rocks contain volcanic components such as tuffaceous layers and pebbles of volcanic lithic fragments. All of the rocks have been subjected to greenschist rank metamorphism that has eliminated most of the primary ferromagnesian minerals.

The hanging wall rocks have been isoclinally folded. The more competent rocks are well jointed. Narrow shear zones roughly parallel the Mother Lode vein and cut the hanging wall rocks at a low angle to the foliation. These shear zones controlled hydrothermal metasomatism in the wall rock. In places they contain quartz veins and dike rock. These altered zones are commonly mineralized, but most are too narrow to be profitably mined by open pit.

Pyrite is the dominant sulfide mineral. It is present from trace quantities up to five percent, depending on the rock type. Pyrite is present as framboidal clusters or as fine-grained cubic crystals in foliation. It also occurs as medium- to coarse-grained crystals growing across foliation. Quartz, plagioclase and/or, carbonate are found in pressure shadows of some pyrite crystals. Euhedral pyrite is also present in quartz and quartz-carbonate veinlets. Some altered hanging wall rocks contain traces of chalcopyrite, galena, sphalerite, and pyrrhotite.

Rocks of the Ore Zone

General character

The rocks in the main ore zone have been extensively metamorphosed, sheared, and altered. The ore zone includes lenses of footwall and hanging wall metamorphic rocks torn from their normal sequence and juxtaposed (Fig. 3). Shear zones are characterized by lenses of folded and disrupted serpentinite, albitite, and metasedimentarty rock; mylonite zones are marked by high talc content and by the presence of mariposite in the hanging wall rocks.

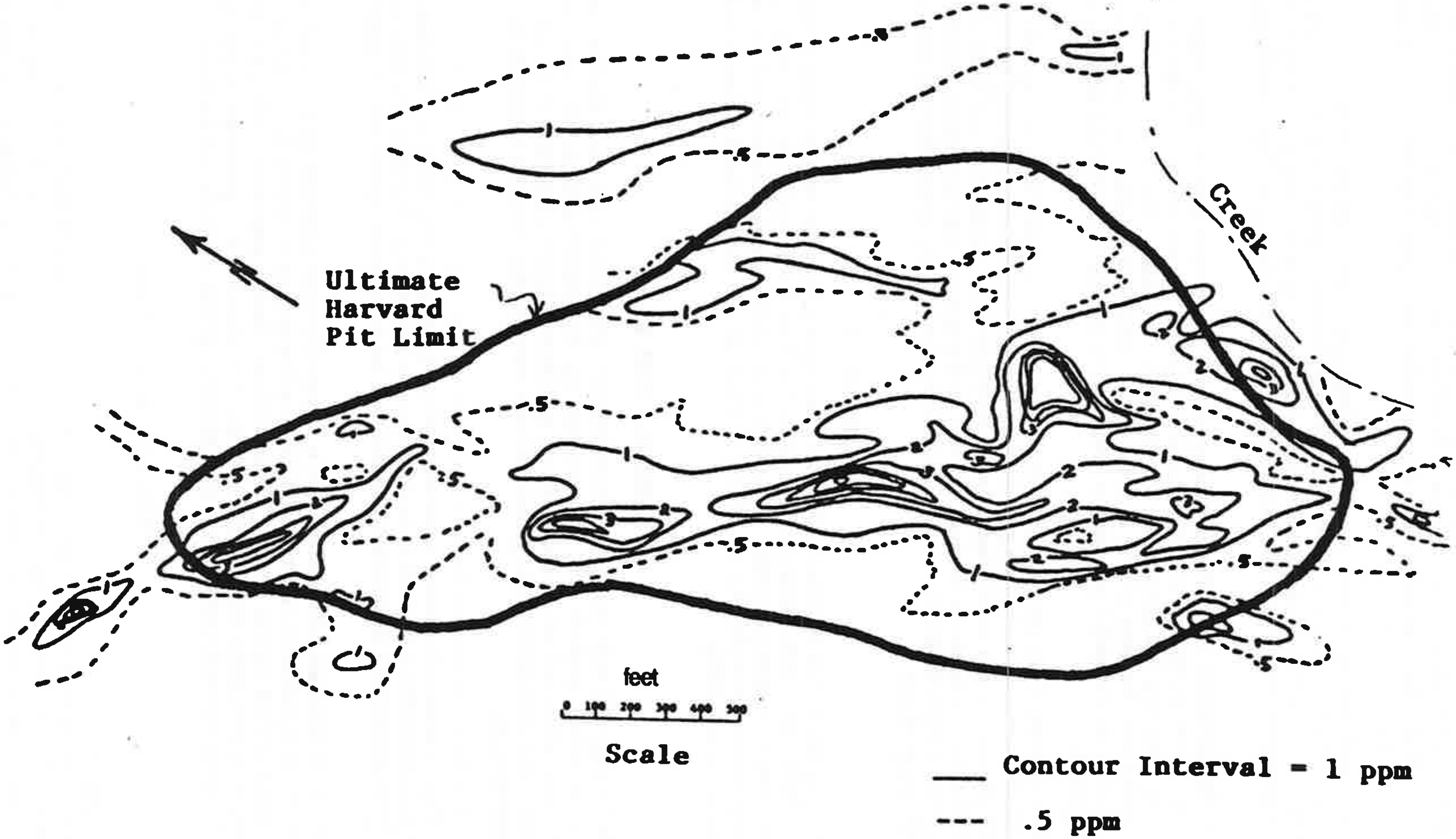

Figure 2. Map of gold concentrations in soils.

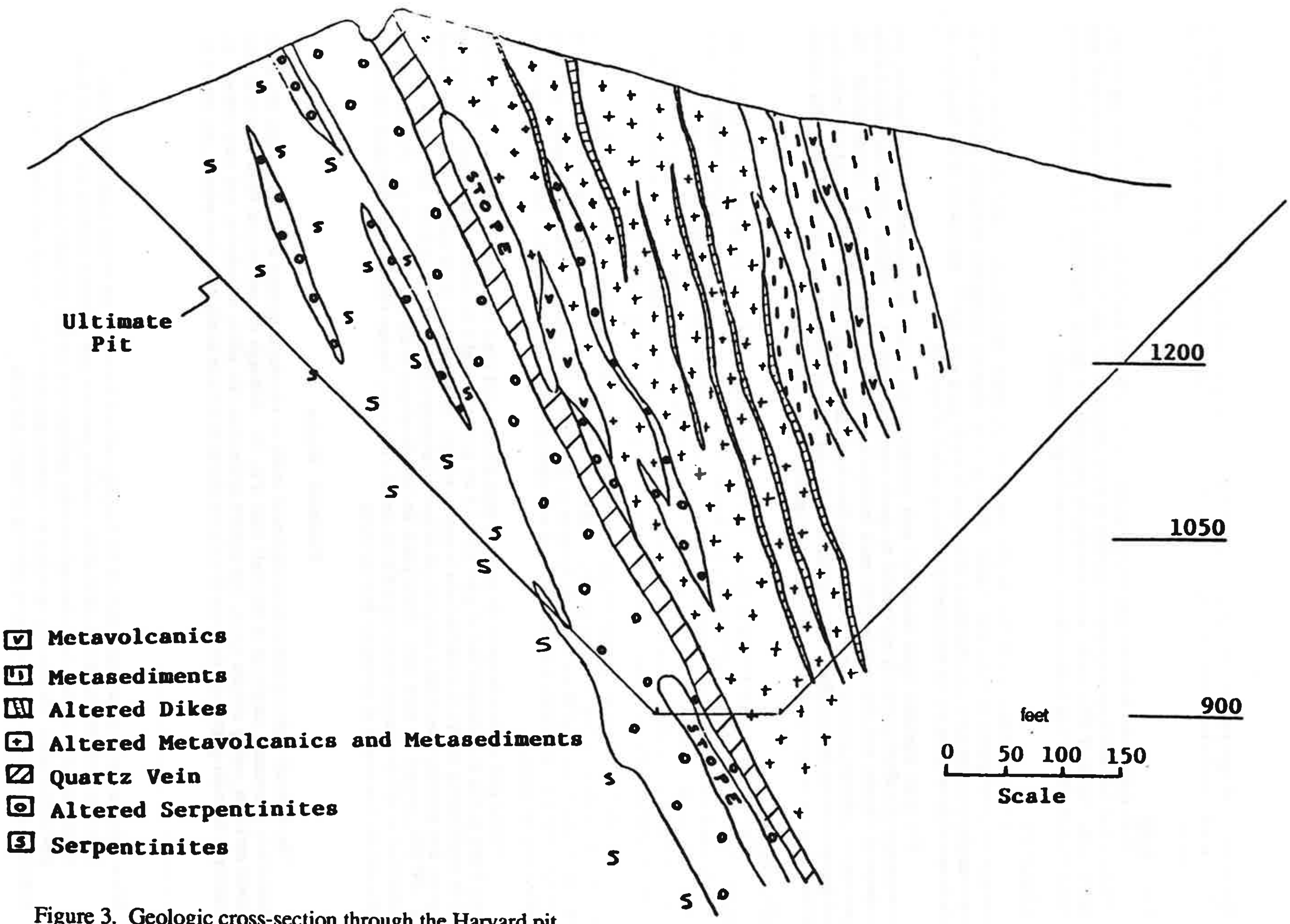

Figure 3. Geologic cross-section through the Harvard pit.

Quartz veins and igneous dikes occupy some of the shear zones. Repeated fault movement during hydrothermal activity is indicated by local brecciation of wall rock, quartz veins in dikes, dikes intruding quartz veins, and banded quartz veins.

Rock types

Rock types found in the ore zone include ankerite schist, ankeritic banded slate, metavolcanic greenstone, chlorite schist, talc schist, quartz-ankerite-mariposite rock, sericite schist, altered dike rock, altered metatuff, and quartz vein. Some of these rocks were completely recrystallized during albitization and later hydrothermal metasomatism. Other rocks retain remnant foliation and original minerals.

Alteration

The main alteration events include albitization, sericitization, carbonitization, and silicification mainly through the development of veins and veinlets. Prior to mineralization and related alteration, greenschist rank metamorphism caused pervasive albitization of feldspar in the hanging wall rocks[1]. Albitization of the hanging wall rocks east of the ore zone has not been confirmed owing to lack of exposure.

The main alteration types associated with mineralization include sericitization, carbonitization, and concomitant silicification (mainly represented by quartz veins and veinlets). Typically, sericite developed at the expense of chlorite, and chrome-rich white mica (mariposite) developed at the expense of chrome-spinel. The products of carbonate alteration are ferroan dolomite (previously described as ankerite[2]), calcite, and magnesite; they are pervasive or veinlet-controlled. The carbonate-altered rocks are typically grey to grey-green. These rocks weather reddish or orangish-brown owing to the presence of iron-bearing carbonate minerals.

Ore minerals

The dominant sulfide mineral is pyrite. It is generally more abundant in the ore zone than in enclosing rocks. Pyrite forms anhedral aggregates along foliation, but more typically is fine- to coarse-grained euhedral crystals which are usually cubic. Some pyritohedrons are present. Chalcopyrite and pyrrhotite are common trace minerals associated with pyrite. Traces of sphalerite, galena, gersdorffite, and tetrahedrite are found associated with pyrite in altered rocks and in quartz-carbonate veinlets. Bornite, covellite, cubanite, linneite, cobaltite, millerite, calaverite, melonite, hessite, petzite, and bravoite have also been identified at the Harvard Mine.

Most of the gold is associated with pyrite as surface coatings, fracture fillings, and micro-inclusions. Gold particles are commonly 30μ -100μ in size, but grains locked within pyrite average 5μ - 10μ in size. A limited number of inclusions of gold are found in fractures in quartz or along cleavage planes in carbonate and mica minerals. There is a secondary association of gold with chalcopyrite, usually found filling fractures or coating the surface of pyrite grains.

Visible gold is not common in the Harvard open pit mine, but a few pieces have been found. The largest piece found to date is a crumpled leaf of gold 1.0 x 1.5 cm growing out of a terminated quartz crystal. All of the visible gold found at the Harvard site has been in quartz veinlets. Although none of the specimens have been found in place, they probably come from a dominant set of quartz/carbonate-filled joints that strike N. 20° - 50° W. and dip 15 - 45° SW., toward the main vein. These joints are best developed in the main Harvard pit. Free gold (gold uncombined in sulfide minerals) is interpreted to be part of a late stage, fracture filling event. Free gold contributes approximately five percent of production from the mine.

Footwall Rocks

The footwall rocks comprise metamorphosed mafic to ultramafic igneous rocks and exotic blocks of metavolcanic greenstone caught up in the fault zone (Fig. 3). Although the miners call them serpentine, the footwall rocks are mainly chlorite schist, fine-grained greenstone, talc schist, metadiorite, and meta-gabbro. In proximity to the main quartz vein, the footwall rocks are altered to talc and locally pervasive ankerite, and are cut by

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[1] Primary plagioclase of metavolcanic rocks in the hanging wall and footwall of the Mother Lode and Melones fault zone have been mostly altered to albite ± sericite, prehnite, and carbonate minerals owing to sodium metasomatism of sea floor hydrothermal alteration (spilitization) and later dynamic metamorphism of greenschist facies. The detrital plagioclase in metasedimentary rocks is also typically albite. [Ed.]

[2] Ankerite is and has been in common usage referring to ferroan dolomite.

quartz-carbonate veinlets. Joints and fractures in the blocky greenstone are commonly filled with calcite. Pyrite is generally absent except in altered zones or in proximity to quartz-carbonate veinlets. In some places altered footwall material contains low grade (0.02-0.04 opt) gold values.

Faults that roughly parallel the main Mother Lode quartz vein are fairly regularly spaced across the footwall. Mylonite is from a few inches to several feet wide. In places, quartz-ankerite-mariposite alteration and quartz veins developed along the trace of the faults. In other places, mafic dikes intrude the sheared zones and are altered. All these environments contain low grade gold.

Pyrite is present only in altered rocks. Locally, chalcopyrite forms lenses up to two inches thick. The bright golden color of these lenses creates great excitement among the miners. The high concentrations of copper sulfide minerals probably are related to exotic blocks of metavolcanic greenstone faulted into the footwall. About 10 miles to the west, metavolcanic rocks contain massive sulfide deposits that were mined for copper during World War II.

Ore Controls

Observations during the three years of mining in the Harvard Pit have formed the basis of some ideas about ore controls. The extent of day-to-day duties prevents the type of detailed studies necessary to prove these ideas, yet these observations provide some insights into the nature of the Mother Lode ores.

The trace of the principal vein traverses the property at a N. 30° W. and dips approximately 60° NE. However, in the heart of the ore deposit, the strike of the vein deflects due north. At the extremities of the property, the quartz vein forms prominent, bold, fifteen to twenty feet-thick outcrops along the ridge. Yet, in the heart of the ore deposit, the quartz vein is only one or two feet wide, and in places it disappears completely. A dike swarm and an extremely sheared and altered mylonite occupy the place where the vein should be. The deflection of the vein to a north strike may be the result of cross-fracturing that allowed for oblique slippage and faulting. The result is a pervasively altered zone that extends 150 to 200 feet into the hanging wall. In this zone, the cross-fracturing seems to have created access for mineralizing and altering fluids. Although grades vary, most of the zone is ore.

Similar fracturing, alteration, and mineralization characterize ore in the footwall. Mineralization in the footwall is in competent, blocky greenstone that is highly fractured and veined. The fault structures that roughly parallel the N. 30° W. veins were likely avenues for mineralizing fluids. The well-foliated chlorite and serpentine schist of the footwall are barren of ore.

North and south of the fractured heart of the ore zone, the gold-bearing material is restricted to highly altered rocks in sheared zones. The extent of the mineralization and alteration is determined by (1) the parallel shear structures which gave the fluids access to the rocks, and by (2) the susceptibility of certain rock types to reaction with the fluids. Farther from the main ore zone, ore in these narrow shears is lower grade and discontinuous. The north end of the Harvard pit was developed on a swarm of these shear zones which have been disrupted by northwest-striking cross-faults. Gold values in this area are sporadic and generally low grade. Some very high grade intercepts were drilled in this area, but adjacent low grade assays indicate localized pockets of coarse gold rather than a disseminated body of ore.

MINING

Open pit mining operations are conducted at the Jamestown Mine with strong emphasis on minimizing environmental impact. The mine facility operates under strict environmental standards for air and water quality, and seismic and noise impact. An extensive network of sensors monitors compliance with all standards. Noise restrictions limit mining to 15 hours per day, six days per week. Twelve 100-ton Lectrahaul trucks haul an average of 40,000 tons per day at an average stripping ratio of 3.48:1.[3] Materials are loaded by one 13-yard and two 11-yard hydraulic shovels manufactured by Hitachi. Noneconomic material is removed to a rock storage site or to the rock-fill tailings dam. Ore is segregated by degree of oxidation, talc, and graphite content and by gold content. These ore types are blended by a Caterpillar 992C loader while feeding the primary crusher.

Rock is broken in the pit by drilling 6.5 inch diameter holes using one Ingersol Rand T-4 and four Driltech DK40 drills. Holes are drilled 35 feet deep in the main pit, but only 24 feet deep in the north part of the pit where a

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[3] On average, 3.48 tons of waste are mined for each ton of ore delivered to the mill.

20 foot bench height is employed. Dry holes are loaded with ANFO (ammonium nitrate blasting agent) and wet holes are loaded with Emulsion using an average powder factor of 0.5 pounds of blasting agent per ton of rock. Careful control of ground vibration and the slabby character of the rock combine to make secondary breakage necessary. This is accomplished by a drop-cross crane in the pit area and a hydraulic rock breaker on the crusher pad.

The gold grade of ore mined is controlled using samples recovered from the blast hole drilling. A collector mounted through the drill deck collects samples continuously. Because the ore dips, the driller collects samples at ten-foot intervals, rather than collecting a single sample per hole as is the practice in uniformly mineralized deposits. The ore samples are fire assayed, and the results are plotted on cross-sections showing the drill holes. The cross-sections are evaluated, and ore boundaries are established considering the attitude of the ore, the angle of repose for broken material, and the amount of rotational movement during blasting. Ore boundaries are plotted in plan, tonnages and grades are calculated, and the boundaries are staked by color code in the pit. Shovel operators segregate ore types by color code and by referring to the ore plan maps. They tell the haul truck drivers by radio where to deliver their loads. Estimated dilution of ore by waste rock in the heart of the ore zone is 5 percent, and in the narrower, more discontinuous zones is 30 - 40 percent, depending on the orientation of the ore. Overall dilution in the mine is 22 percent.

MILLING

The mill facility processes an average of 6,300 tons of ore per day[4] producing an average of 180 tons of concentrate containing 2.0 opt gold (Fig. 4). All milling facilities are enclosed in buildings to minimize noise and to allow 24-hour operation.

Blended ore is fed by a hydrostroke feeder to the primary crusher, a 42 x 48-in Birdsboro jaw crusher. Crushed ore is discharged onto a conveyor belt which is scanned by a metal detector to identify tramp metal so it can be prevented from lodging in the secondary crusher.. A 7-ft Nordberg standard cone crusher followed by a Nordberg short head cone crusher complete the crushing circuit. This circuit discharges 3/4-in ore which is stored in a pair of 5,000 ton fine-ore bins. Bins, rather than open stockpiles, are used in order to minimize fugitive dust.

Ore from fine ore storage is conveyed into a 13 x 19.5-ft Koppers rod mill where it is ground to minus-20 mesh. The discharge is segregated by size in hydrocyclones. The coarse underflow material from the hydrocyclone passes through a 42 x 42-in duplex jig to recover coarse gold. The remainder of the underflow material is ground in a 14 x 23.5-ft Koppers ball mill to 90 percent minus 100 mesh and is returned to the hydrocyclone circuit. The hydrocyclone overflow containing the fine material is directed to the flotation plant.

Rougher flotation is completed in two parallel banks of 500-cubic foot Agitair flotation cells. The final cell in each bank is a 1,350-cubic foot Dorr Oliver cell. The rougher flotation reagents have been Aerofloat 25+, pine oil, M.I.B.C., potassium amyl xanthate, and soda ash. The sulfide concentrate is pumped to a 11 x 18.5 ft Koppers regrind ball mill which produces a 10 percent plus 325 mesh concentrate. The concentrate is cleaned in three consecutive banks of cleaner flotation cells. Depramin C, a carboxymethyl cellulose product, is added during this stage to depress talc and carbonaceous material. The final concentrate is thickened and vacuum filtered to produce a cake containing about 18 percent moisture.

Recent plant-scale test work has been conducted on a new product from Cyanamid, S-5688, which is a selective gold collector. Use of this product has increased concentrate grade to 4-5 opt gold. The plant is in the final stages of converting to the use of this reagent as a replacement for the Aerofloat 25+.

The concentrate is shipped by truck to a conventional carbon-in-pulp leach plant near Yerington, Nevada. There, the concentrate is repulped and leached in a dilute NaCN solution in a series of agitation tanks (Fig. 5). Charcoal is added to the last 6 tanks in the series to recover the gold from solution. The gold-laden charcoal is separated from the slurry and leached by a high temperature, high strength cyanide and sodium hydroxide solution. This strips (dissolves) the gold from the charcoal and forms a high grade solution. The gold is electrowon onto a steel wool cathode. The gold-laden steel wool is periodically removed from the electrowinning cell and fire-refined into 50 pound gumdrop-shaped buttons. This final product, called doré, contains approximately 67 percent gold, 30 percent silver, and 3 percent copper, iron and other contaminates. The doré is shipped to a commercial refinery for final treatment and sale.

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[4] Ore and waste rock are mined 83 hours per week on average; the mill operates 168 hours per week.

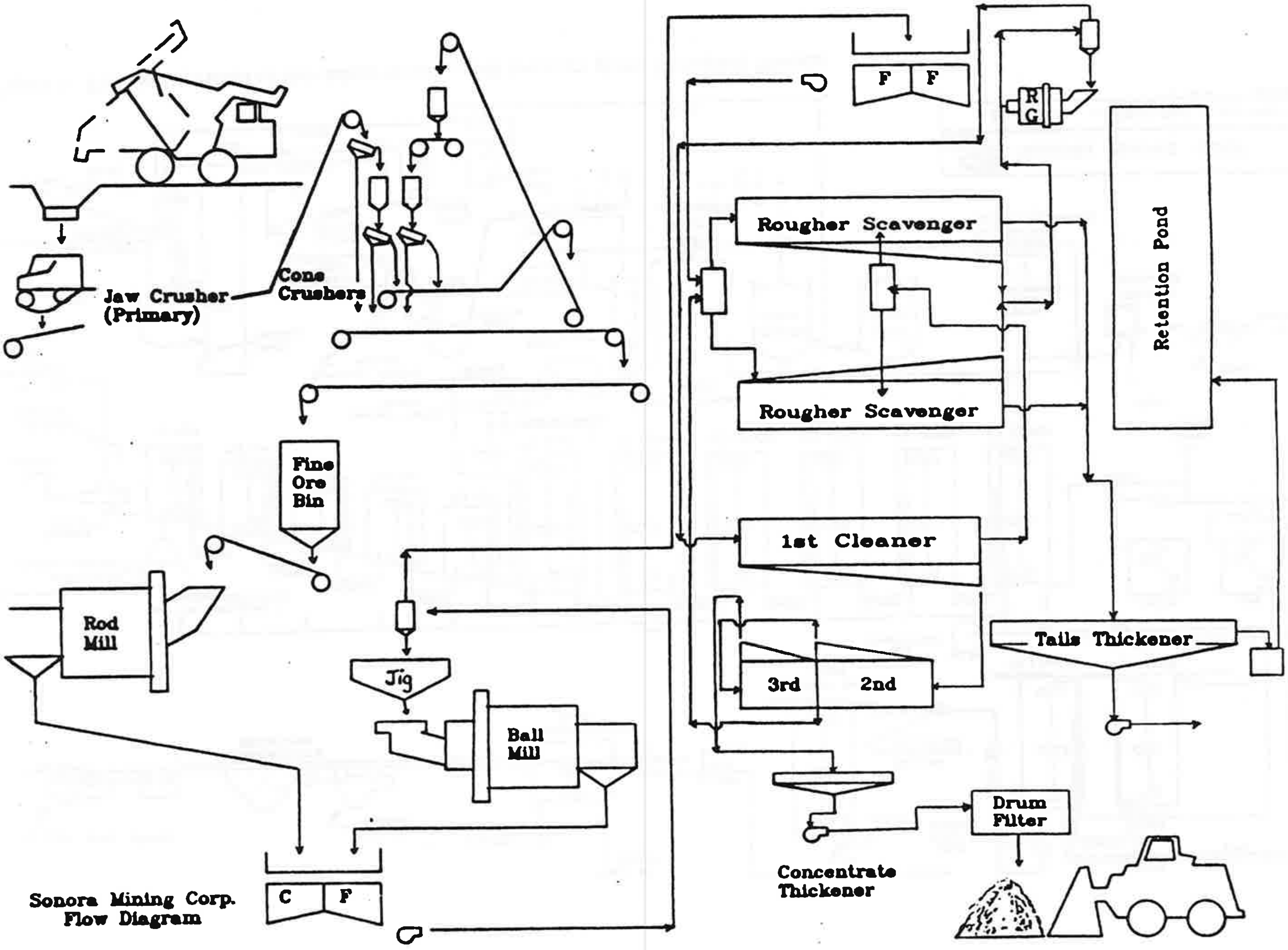

Figure 4. Flow diagram of the Sonora Mining mill.

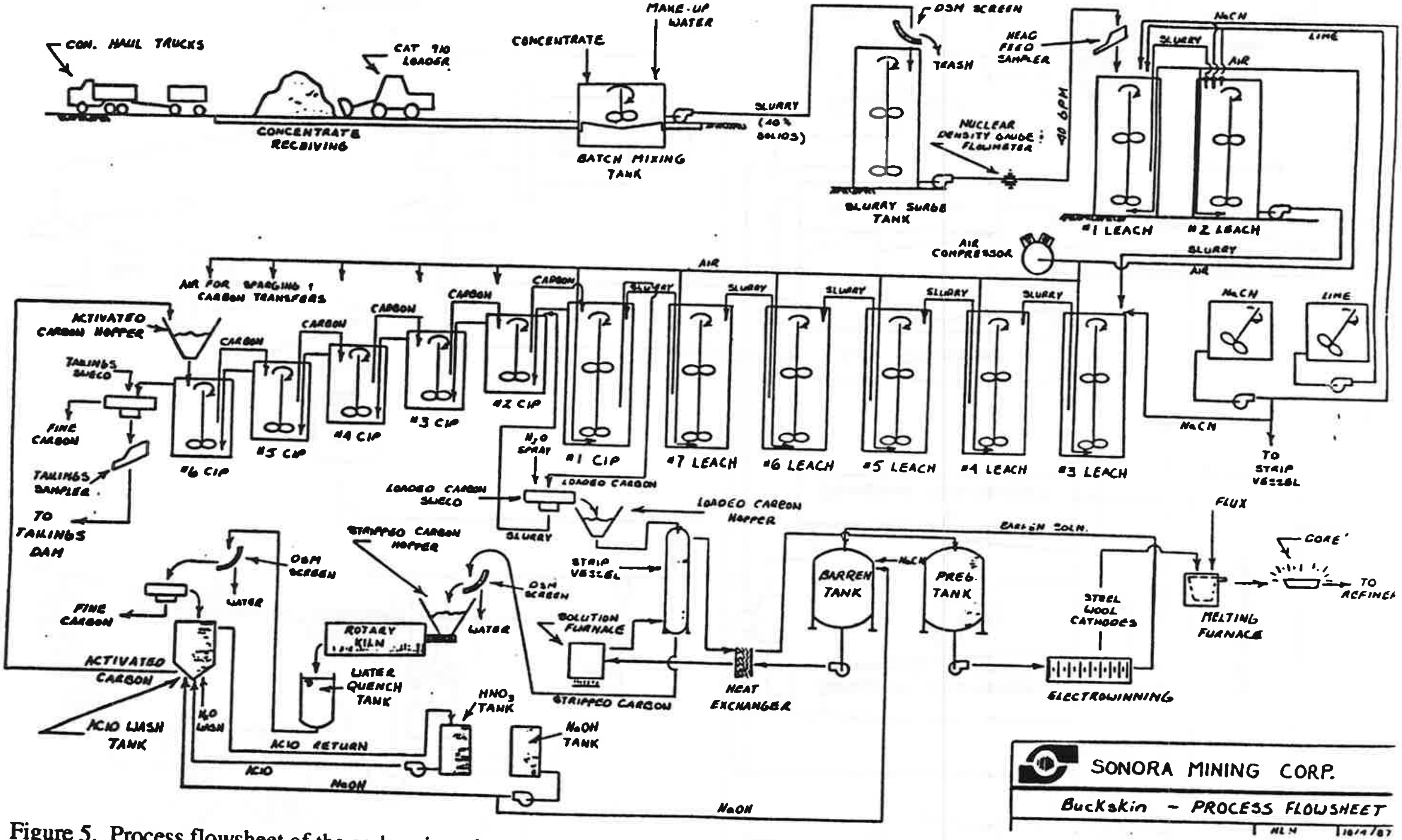

Figure 5. Process flowsheet of the carbon-in-pulp, gold recovery plant, Yerington, Nevada.

From Axelrod, D. I., 1957, Late Tertiary floras and the Sierra Nevadan uplift: Geological Society of America Bulletin, v. 68, p. 19-46.

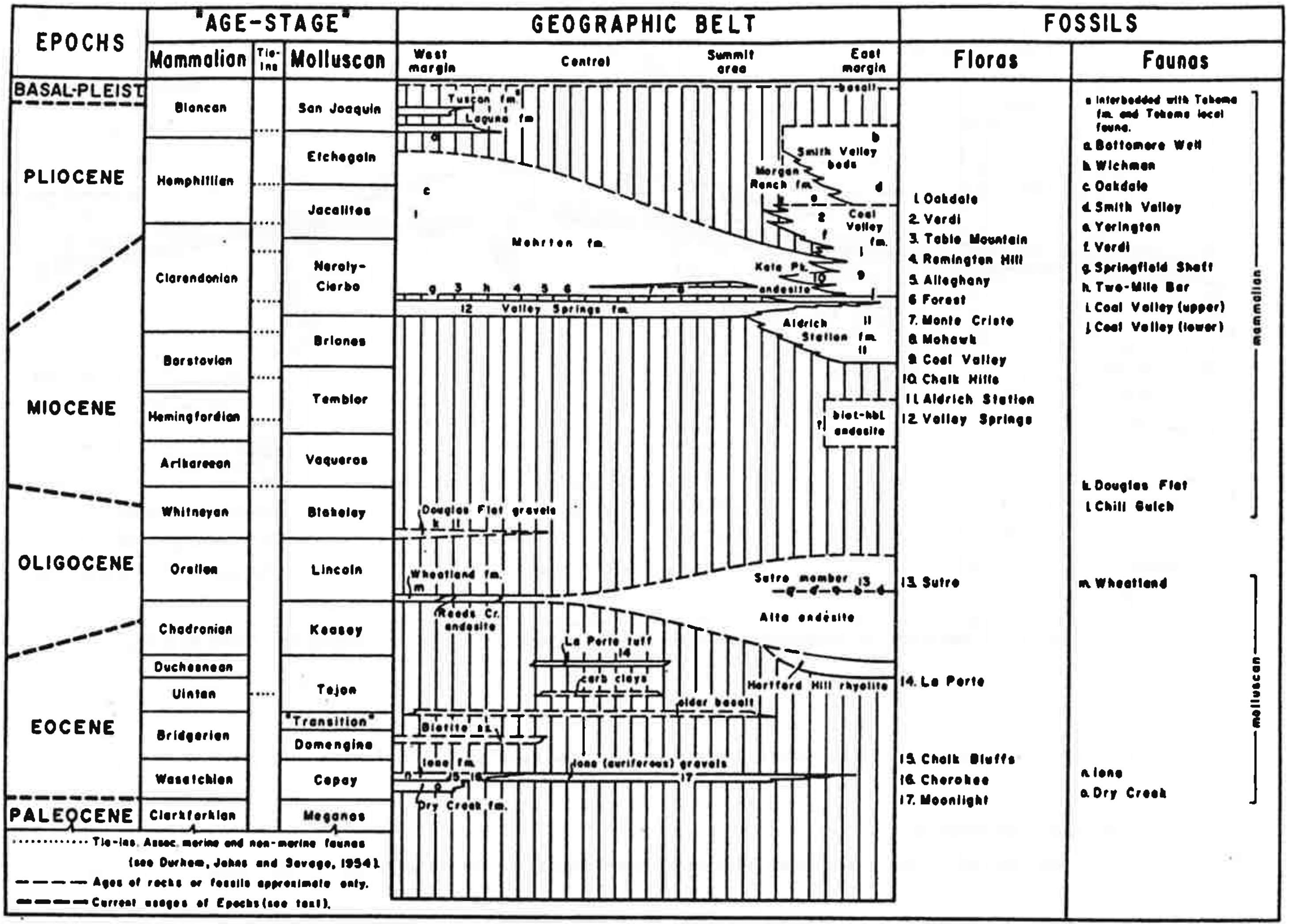

FIGURE 3.—TERTIARY STRATIGRAPHY OF THE CENTRAL AND NORTHERN SIERRA NEVADA

TABLE 1.—MIO-PLIOCENE FLORAS FROM THE SIERRA NEVADA, THEIR PROBABLE ALTITUDE, AND THEIR YEARLY RAINFALL, AS INFERRED FROM RELATED LIVING VEGETATION*

Fossil floras	Present position	Probable Mio-Pliocene altitude	Estimated rainfall (inches)
Carson Pass	on crest	near 2500 feet	35–40
Mohawk; Monte Cristo	middle-upper slopes	2000 feet	40–45
Remington Hill; Forest	lower-middle slopes	1000 1500 feet	30–35
Table Mountain	foothills	500 feet	25–30
Valley Springs	low foothills to piedmont	200–300 feet	25–30

* Some of the data presented here for age, altitude, and rainfall differ moderately from those given in an earlier study of these floras (Chaney, Condit, and Axelrod, 1944).

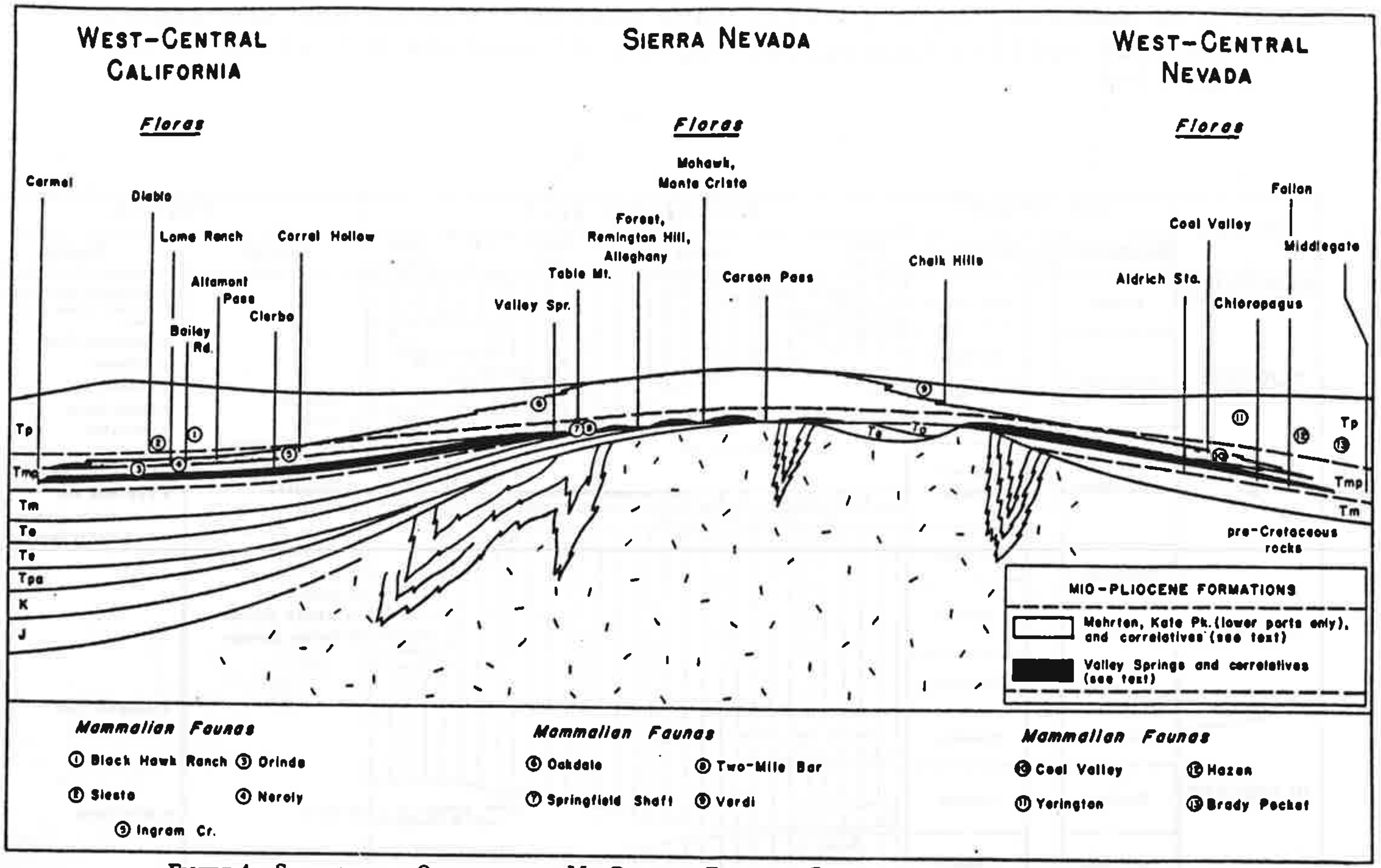

FIGURE 4.—STRATIGRAPHIC OCCURRENCE OF MIO-PLIOCENE FLORAS IN CENTRAL CALIFORNIA AND WESTERN NEVADA

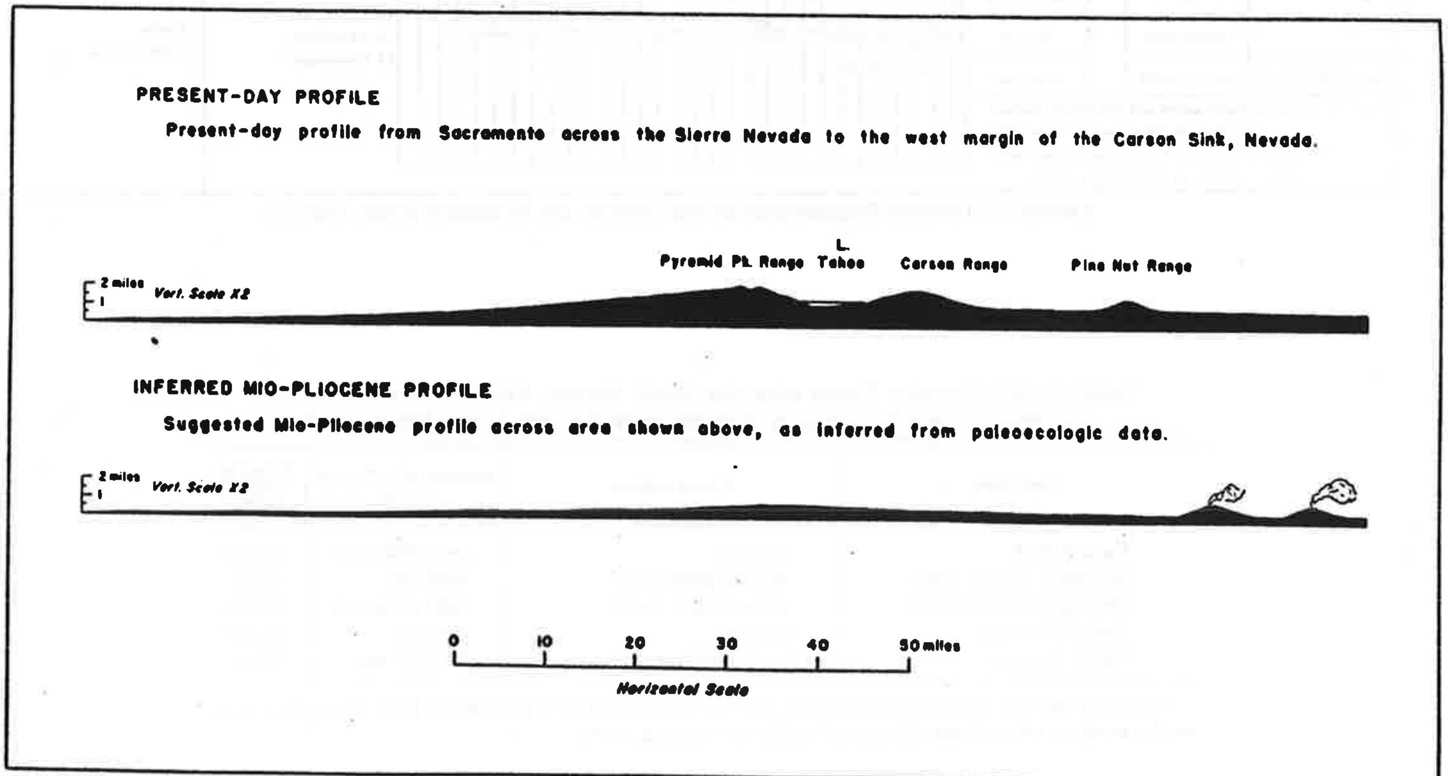

FIGURE 6—TOPOGRAPHIC PROFILE ACROSS THE CENTRAL SIERRA NEVADA TODAY COMPARED WITH INFERRED PROFILE JUST BEFORE MIO-PLIOCENE VULCANISM