Northern California Geological Society

Northern Sierra Nevada Region
Geological Field Trip Guidebook
June 14 & 15, 1997

Giant Gap, North Fork of the American River

Field Trip Leaders:
David Lawler
Gregg Wilkerson

Guidebook Editors:
Melville Erskine
David Lawler
NORTHERN CALIFORNIA GEOLOGICAL SOCIETY

NORTHERN SIERRA NEVADA REGION
- CALIFORNIA -

GEOLOGICAL FIELD TRIP GUIDEBOOK
JUNE 14-15, 1997

FIELD TRIP LEADERS:
David Lawler - FWGF
Gregg Wilkerson - BLM

GUIDEBOOK EDITORS:
Melville Erskine - NCGS/FWGF
David Lawler - FWGF

FIELD TRIP COMMITTEE:
Tim Ault
Tridib Guha
ACKNOWLEDGEMENTS

We wish to thank the many persons and organizations who helped make this field trip possible, including, as follows:

MINING COMPANIES
California-Engels Mining Company
Norman Lamb - CEO

Emperor Gold Corporation
Ross Guenther - Mine Manager
Mark Paine - Geologist

Siskon Gold Corporation
Tim Callaway - President/CEO
Robert Pease - Geologist

Sixteen to One Corporation
Mike Miller - President/CEO
Jason Burke - Mining Engineer

ORGANIZATIONS
California Division Mines and Geology
David Wagner - Senior Geologist
George Saucedo - Staff Geologist

Geological Society of America
Farwest Geoscience Foundation
United States Geological Survey

INDIVIDUALS - (Authors and/or Trip Co-Leaders)
Pat Antuzzi - Sierra College
Elwood Brooks - CSU-Hayward
Jason Burke - 16/L Corp
Scott Creely - CSU-San Jose
Howard Day - UC Davis
Eric Gohre - FWGF
Ross Guenther - Emperor Gold
Jim Haggart - Canadian Geol Survey
David Harwood - USGS (retired)
Richard Hilton - Sierra College
Rudy Kopf - USGS (retired)
Norman Lamb - Calif-Engle Co.
Doug Long - CAS
Howard Oliver - USGS
Eldridge Moores - UC Davis
Mark Paine - Emperor Gold
Robert Pease - Siskon Gold
LouElla Saul - UCLA
Lester Storey - Placer Dome
A. Tuminas
Russell Towle
Near Dutch Flat, in the Sierra Nevada northeast of Sacramento, the American River Canyon narrows into a gorge nearly 2,500 feet deep, named "Giant Gap" during the Gold Rush. This rendering was done using the free ray-tracing software POV-Ray, and is derived from the U.S.G.S. 7.5 minute series Digital Elevation Model data set. There is no vertical exaggeration. The view is towards the southwest, looking down the canyon.—Russell Towle, Box 141, Dutch Flat, CA 95714. Email: rustybel@foothill.net
TABLE OF CONTENTS

TECHNICAL PAPERS AND ROADLOG

I) ECONOMIC GEOLOGY

NORTHERN SIERRA - LODE GOLD DEPOSITS

1) Idaho Maryland Lode Gold Mine .................................. Mark Paine and Ross Guenther
2) Sixteen to One Lode Gold Mine ..................................... Jason Burke

NORTHERN SIERRA - PLACER GOLD DEPOSITS

1) Ancestral Yuba River (Early Tertiary age)-Auriferous Fluvial Deposits  . David Lawler
2) Geology and Mineralization of the San Juan Mine-Tertiary Gravel Deposit-Robert Pease
3) Cherokee Hydraulic Mine, Butte County, California ..................... Scott Creely

NORTHERN SIERRA - BASE METAL DEPOSITS

1) Early Years of the Plumas Copper Belt, 1861-1905 .......................... Norman Lamb
2) Geology and Mineralization of the Lights Creek Stock, Plumas County, California ......... Lester Storey

NORTHERN SIERRA - DIAMOND DEPOSITS

1) Diamonds in the Northern Sierra Nevada, California .................... Rudy Kopf
II) TECTONICS/STRUCTURE

1) Sierra Buttes - Structural Geology ................. Ellwood Brooks

2) Tectonics and Structural Setting of the Northern Sierra ........ Howard Day

3) Mesozoic Geology of Mt. Jura, Northern Sierra Nevada, California . . David Harwood

4) Stratigraphy and Tectonics of Paleozoic arc-related rocks of the Northernmost Sierra Nevada, California; The Eastern Klamatin and Northern Sierra Terrranes . Angela Jayko

III) STRATIGRAPHY AND PALEONTOLOGY

1) The Chico Formation at Granite Bay, Placer County, California. .................. Richard Hilton and Patrick Antuzzi

2) A New and Diverse Fossil Elasmobranch Assemblage From the Chico Formation, Butte County, California .................. Doug Long, David Lawler, and Eric Gohre

3) The Chico Formation - Geology and Paleontology - Pentz Valley - Butte County, California - Field Trip Stop. .................................................. Jim Haggard, LouElla Saul, Rodney Watkins, and Eric Gohre

IV FIELD TRIP - ROAD LOG

1) Auburn (Placer Co.) to Indian Valley (Plumas Co.) ..................... David Lawler and Gregg Wilkerson

2) Feather River Region-Northern Sierra . . Tim Fagan, Jason Mayfield, and Howard Day
PART I

ECONOMIC GEOLOGY

NORTHERN SIERRA NEVADA

LODE GOLD DEPOSITS
IDAHO-MARYLAND MINE
NEVADA COUNTY, CALIFORNIA

By Mark Payne and Ross Guenther
June 3, 1997

SUMMARY

Emperor Gold Corporation is principally engaged in the business of exploring and financing the Idaho-Maryland Mine property located near the city of Grass Valley in Nevada County, California, U.S.A. Emperor has started construction at its New Brunswick Shaft site to install a head frame, hoist, and pumping facilities to rehabilitate and dewater the shaft down to the 3280 foot level. Preliminary studies have been completed for pump designs, electrical hoist, head frame, and other requirements to dewater and explore the mine. The vertical shaft is open to at least the lowest developed level at 3,280 feet depth.

Emperor Gold Corporation, through its wholly owned subsidiary, Emperor Gold (U.S.) Corp., holds the Idaho-Maryland Mine located near Grass Valley, California. The property consists of about 130 acres of surface rights and 2,750 acres of mineral rights. Approximately 10% of the underground mineral rights area has been explored.

Emperor Gold has received a Use Permit from Nevada County to dewater the Idaho-Maryland Mine to the 3280 foot level and to drill promising areas, primarily from the 2000 foot level and below. An Environmental Impact Report has been approved for the project. The mine has produced about 2.4 million ounces of gold from 1863 to 1956 when rising costs and a gold price fixed by the government at $35 per ounce forced the mine to shut down. A review of the substantial mine records by a leading independent engineering firm indicates existing resources of as much as 9.1 million tons grading 0.326 ounces per ton, containing 3.0 million ounces of gold.

Known resources at the Idaho-Maryland Mine are primarily between the 2000 foot level and 3280 foot level, and are likely to continue below this level. The Idaho-Maryland Mine is second only to the adjacent Empire Mine in gold produced from underground mining in California. The
Empire has produced 6 million ounces of gold to a vertical depth of 5,100 feet.

Recent information received from old files leads our geologists to believe that the mine may also have bulk tonnage resources and, with a new shaft, could be operated at significantly higher production rates. This sets the Idaho-Maryland apart from other mines of the Grass Valley District. At least 33 separate bulk tonnage targets have been identified in five differing structural environments. The resource for these oreshoots has been largely ignored in the calculated resources for the project. This is due to insufficient development work needed to accurately estimate tonnage and grade for most of these zones. During the present exploration program Emperor will likely have the opportunity to delineate several of these bulk tonnage zones.

The gold resources at the Idaho-Maryland include 160 partially developed veins and another 55 veins which have been partially delineated by drilling completed prior to 1956. Resources are contained within veins and composite vein lodes ranging from 3 to a maximum of 122 feet true width. The weighted average width of the veins is more than 20 feet.

The Idaho-Maryland Mine is famous for its high grade continuous oreshoots, and has few rivals. For example, the Idaho No. 1 stope produced over 1 million ounces of gold at a grade exceeding 1 ounce per ton from a single oreshoot. It was continuously mined to a vertical depth of 1,600 feet and for 5,600 feet along its rake.

Infrastructure at the New Brunswick shaft site is excellent. There are paved roads to the site and electrical lines nearby for timely power connections. There is room for possible mill facilities on the site. An existing office building and 65,000 square feet of industrial buildings are available for use.

Emperor Gold is proceeding with the rehabilitation of the New Brunswick Shaft in order to confirm, by underground core drilling, a portion of the 3 million ounces gold resources in the Idaho-Maryland Mine indicated by a vast collection of old maps and records. There will likely be a ventilation benefit in 1997 through underground workings from the New Brunswick Shaft to the Round Hole Shaft.

During 1996, Emperor purchased a 13 acre parcel containing the surface rights around the historic "Round Hole Shaft" of the Idaho-Maryland Mine. This 5 foot diameter bored shaft was sunk 1,125 feet in 1935. Recent testing of the water level indicates that there is likely a good hydrological connection to the New Brunswick Shaft as well as probable openings available for ventilation upon completion of our present dewatering program. The Round Hole Shaft is strategically located over the Maryland portion of the Idaho-Maryland Mine in an area that has produced about 500,000 ounces of gold in ore grading about 0.5 ounces per ton. It may prove possible to do some confirmation drilling of our gold resources via this shaft. Historical maps and core drilling indicate resources of at least 500,000 ounces of gold, with a potential that is much greater. Several mine levels connect underground workings to this shaft.
After initial dewatering of the mine shaft and further exploration, Emperor Gold believes it may prove feasible to operate at 1,500 tons per day, (148,000 oz. per year) with the existing shaft. Increased production rates and more detailed cost studies are indicating substantially lower operating and cash costs.

The possible cash flow and profitability is sensitive to many factors. For instance, a 13% increase in the price of gold from $375 to $425/ounce will give an increase in annual cash flow of 47% through the year 2006. Besides production costs, gold prices, and production rates, there are many other possibilities to increase cash flow and profitability. The project will have sufficiently high grade to produce strong cashflow, even in times of depressed gold prices.

Frank A. Lang, Chairman of the Board of Directors, has been associated with a string of gold discoveries over the past two decades, including Hemlo's Golden Giant Mine and Aurizon's Sleeping Giant Mine.

James E. Askew, President of Emperor, is a mining engineer with extensive experience in mine finance, reopening old mine operations and mine contracting. Mr. Askew most recently was the Founder and Managing Director of Golden Shamrock Mines Ltd., a Company with substantial gold and copper production from surface and underground operations, which merged with Ashanti Goldfields Corporation in late 1996.

Emperor Gold Corporation trades on the Vancouver Stock Exchange under ticker symbol EMR.

HISTORY

The Idaho-Maryland Mine is in the heart of the prolific Grass Valley-Nevada City Mining District, Nevada County, California. This district is the fourth largest gold producing mining district in the U.S. and encompasses a 7 by 6 mile area centered around the towns of the same name. From 1851 to 1956, the Grass Valley-Nevada City District has recorded a total lode output exceeding 13 million ounces of gold from approximately 25 million tons with a recovered grade of .52 oz per ton of gold. The mine is located 2.5 miles east of the city of Grass Valley.

The Idaho-Maryland Mine had been in nearly continuous production from 1862 through 1956. In California, historically the largest gold producer in the U.S., the Idaho-Maryland is second in production only to the Empire Mine group, which lies adjacent to the south. Total recorded output for the Idaho-Maryland Mine was 2,383,000 ounces gold from 5,546,000 tons grading 0.43 oz/ton. The Idaho-Maryland vein system includes the past producing Eureka, Idaho, Maryland, Union Hill, Gold Point, and Brunswick Mines. During the first 33 years of operation, from 1862 to 1894, the Idaho and Eureka Mines produced over 1 million ounces gold from less than 1 million tons of ore, all from a single spectacular or shoot in the Idaho No. 1 Vein. The Idaho
oreshoot was continuously stoped from the 100 to 1,600 foot levels for 5,600 feet down plunge over a 600 foot height. Among mesothermal gold-quartz veins, the Idaho oreshoot has few rivals. In later years, starting in the 1920's, the mainstay of production in the Idaho portion of the mine was the newly discovered Id 3 vein and its many associated branches. This portion of the mine produced approximately 1,000,000 tons of ore grading 0.5 oz per ton gold, from both gold-quartz veins and mineralized mafic dikes. Much medium grade material was left behind in this portion of the Mine. Prior to the 1930's, production from the Brunswick Mine portion of the Idaho-Maryland property was predominantly from the Brunswick No. 1 vein. Starting in 1932, operation of the Idaho-Maryland and Brunswick Mines were combined. In 1940, the workings of the two mines were connected at the Brunswick 2300 foot level. Production from the Brunswick portion of the property totaled 3,157,000 tons grading 0.25 oz/ton, recovering over 800,000 ounces of gold. The Idaho Maryland-Mine was closed by the government during World War II and recommenced operation in 1945. Pumping and maintenance costs devoured the company funds during closure. Lack of funds for adequate development ahead of stoping left behind many good ore targets identified from drill holes in virgin ground.

The Idaho and Brunswick operations each had their own mills with combined throughout of 1,000 tons per day. The Idaho mill was the older of the two and had a capacity of 250 tons per day with a recovery averaging 94%. The 750 ton per day Brunswick mill was commissioned in 1940 and boasted a 96% recovery rate. Gravity circuits recovered 70 to 80% of the gold. Sulfides in the ore averaged about 1% and were concentrated in flotation circuits. The small amount of pyrite with minor chalcopyrite & galena concentrates from both mills were collected and treated in a small cyanide circuit at the Idaho mill or, at times, shipped to smelters. Historically the ores were metallurgically simple thus milling costs are expected to be relatively low.

The Brunswick portion of the Idaho-Maryland Mine produced tungsten concentrates from certain gold-quartz veins between 1954 and 1956. Records indicate that the scheelite-bearing veins averaged 1% tungstate (WO3). Additional testing is needed, but tungsten could become a by-product from the mine.

Underground mining at the Idaho-Maryland ceased in 1956 due to increased labor and materials costs coupled with a gold price fixed at $35.00 per ounce since 1934. Past mining operations were predicated upon development of quartz-dominated veins, leaving many quartz stringer lodes and mineralized schist zones ignored and undeveloped. The mine shut down leaving a developed reserve inventory of 1,049,000 tons, grading 0.20 ounces of gold per ton, representing some 200,000 ounces, some of which might be amenable to future production.

Commencing in August 1993, Emperor Gold Corporation, through its wholly owned subsidiary, Emperor Gold (U.S.) Corp., began leasing (with option to purchase) the Idaho-Maryland Mine. The property consists of about 130 acres of surface rights and 2,750 acres of mineral rights.
GEOLOGY

The Grass Valley- Nevada City District is hosted within submarine volcanic and lesser interflow sedimentary units with intrusive diabase and gabbro dikes and sills of the Jurassic-aged Lake Combie Complex in the western portion of the Sierra Nevada Foothills Metamorphic Belt. The Lake Combie Complex is comprised of Jurassic basaltic to andesitic volcanics with minor interflow slate, argillite, chert, and volcanoclastic beds, sitting atop an ocean crustal assemblage. Volcanics, interflow sediments, and subvolcanic intrusives have been cut by coeval diabasic and gabbroic intrusive dikes and sills. Those Jurassic units were later cut by Jurassic alpine-type serpentinized ultramafic intrusions that contain tectonic blocks of diorite to trondjhemite, cumulate gabbro, metavolcanics, metasedimentary mudstones, argillites, cherts, and diabasic sheeted dike complex affinities that represent remnants of a dismembered oceanic crustal sequence. All Jurassic units were subsequently intruded by the Cretaceous Grass Valley and Yuba River granodioritic plutons in the central and northern portions of the district during emplacement of the Sierra Nevada Batholith. The Lake Combie Complex represents formation of oceanic crust and later volcanic build-up and sedimentation in a fault-bounded Jurassic-aged rift within the late Paleozoic metamorphic basement of the Sierra Nevada Foothills. After "failure" of the Lake Combie Rift, compressional tectonics of the late Mesozoic Nevadan Orogeny folded and deformed the assemblage into its present position, flanked on the east and west by late Paleozoic metamorphic basement rocks of the Calaveras Complex and Clipper Gap Formation, or serpentinite-matrix tectonic melange derived from the Lake Combie Complex. The Lake Combie rift basin assemblage is tentatively thought to be bounded on the east and west by the Weimar and Wolf Creek Faults, both of which are major regional right-lateral wrench faults.

The gold deposits of the Grass Valley-Nevada City District are spatially related, in a broad sense, to the regional NW trending Wolf Creek and Weimar Faults and the NNE trending Gillis Fault. Only minor gold mineralization is associated directly with the Wolf Creek, Weimar, and Gillis Faults. The relationship between gold mineralization and the granodiorite plutons is purely structural in nature, and clearly post-dates intrusive activity in the region. Gold mineralization is localized in dilatant zones occurring in pressure shadows within and adjacent to the massive plutons and in regionally-strained and folded Jurassic volcanics and sediments. The fracture systems hosting the gold-quartz veins were created in response to regional stresses acting on rocks with highly contrasting fracturing characteristics.

The majority of the district gold production was found in narrow high-grade gold quartz vein systems developed within and adjacent to the margins of both the Cretaceous Grass Valley and Yuba River Plutons of granodioritic composition. The majority of this production was obtained from very narrow, shallow to moderately-dipping high-grade gold quartz vein systems exhibiting tensional and brecciated textures. Gold mineralization occurred within the quartz veins, with only limited wall rock alteration occurring in tight envelopes around the veins. In contrast, the
Idaho-Maryland vein system is comprised of high grade, wider, ribboned veins and mineralized wall rock which produced gold both from the quartz and adjacent deformed and altered wall rocks.

Thus the Idaho-Maryland Vein System is geologically unique within the Grass Valley-Nevada City District. The alteration aureoles around many of the veins are quite extensive. In Waldemar Lindgren’s 1896 study of the gold deposits in the district he noted that the Idaho-Maryland property encompassed the most intense quartz veining, wall rock fracturing, and areally extensive alteration zone in the entire district. For these reasons, the Idaho-Maryland Mine is considered to be the locus of gold mineralization for the entire district.

The neighboring Empire Mine was extensively developed down to 5,100 feet vertical depth, producing 6 million ounces of gold, while the Idaho-Maryland Mine produced predominantly from 2000 feet vertical depth and above. Both the Idaho-Maryland and Empire mines yielded similar quantities of gold per vertical foot of depth, but the Idaho-Maryland Mine is relatively compact, totaling only 16 percent of the areal expanse of the Empire Mine. Drilling and development work in the Idaho-Maryland down to the bottom level at 3,280 feet vertical depth indicates gold occurs in similar quantities and the vein system is open to depth. The Empire Mine was developed by 365 miles of underground workings, whereas the Idaho-Maryland was developed by 71 miles of underground workings. Relating gold ounces recovered versus total development, the Idaho-Maryland Mine recovered 6.4 ounces of gold per foot of development work, versus 3.1 ounces per foot of development at the Empire Mine.

The main developed portion of the Idaho-Maryland vein system is 10,500 feet in length, a maximum of 4,500 feet wide, and has been only partially mined from surface to a vertical depth of 3,280 feet. Nearly 300 separate vein structures have been recognized in the mine to date. Only a small proportion of these veins were systematically drilled or developed.

The host rocks for the Idaho-Maryland vein system are a Jurassic alpine-type serpentinite intrusion containing chaotic tectonic blocks representing all of the components of a dismembered oceanic crustal sequence. Tectonic blocks in the melange zone were derived from the Jurassic Lake Combie Complex. Individual tectonic blocks in the melange range from several feet to miles in extent. The melange zone contains tectonic blocks of folded and deformed andesitic to basaltic submarine volcanics, interflow slate, argillite, chert, and volcaniclastic beds cut by coeval diabase to gabbro dikes and sills. Dismembered blocks of diorite, gabbro, ultramafic rocks, and mafic sheeted dike complex also occur within the tectonic melange unit. All blocks are surrounded by a highly sheared serpentinite matrix. Continued regional deformational events folded all Jurassic units prior to Cretaceous intrusion of the Sierra Nevada Batholith. At the Idaho-Maryland Mine the nearest contact with the Cretaceous granodioritic plutons is 4,000 feet to the southwest.
The Idaho-Maryland vein system is a complex ore deposit comprised of at least seven separate composite vein sets hosted in geologically unique strain domains found across a broad expanse of the mineral rights area. Each of the seven composite vein sets consists of a master vein set and its accompanying branches, tensional cross veins, and flat veins.

The principal type of gold mineralization mined at the Idaho-Maryland consists of quartz-dominated veins and stringers within well-developed schistose carbonate - sericite - pyrite alteration envelopes. Massive to ribboned white quartz form the principal component of the Idaho-Maryland veins. Vein gangue includes quartz, ankerite, albite, and chlorite. Ore minerals include minor sulfides (pyrite, galena, chalcopyrite), scheelite, rare tellurides, and free gold. In many locations the wallrock to the quartz veins carried very significant quantities of gold. Wallrock alteration minerals include ankerite, ferro-dolomite, sericite, pyrite, and minor chlorite. This suite of minerals is characteristic worldwide of shear-hosted mesothermal gold-quartz vein systems.

The Idaho-Maryland ore deposit is localized entirely within a broad WNW trending deformation corridor informally referred to as the Spring Hill Tectonic Melange Belt. The NW trending Weimar Wrench Fault cuts off and terminates the Spring Hill Tectonic Melange Zone on its eastern end. Mineralization is found in ellipsoidal random heterolithic tectonic blocks as well as in the highly deformed, ductile serpentinite matrix of the melange belt. In the Idaho portion of the mine a zone of strong, subparallel, steeply-dipping, WNW trending faults have developed along contacts of individual tectonic blocks at points of obvious competency contrast. Strong sets of second order faults then developed as linking diagonals connecting the master faults. In the Brunswick and southern portions of the Idaho, faults also developed internally within a huge tectonic block of Jurassic metavolcanics and interflow sediments. The regional Weimar Wrench Fault exerted a shattering effect on the east end of the tectonic block creating hundreds of mineralized quartz veins in the Brunswick area of the mine.

The Idaho-Maryland vein system is comprised of a combination of both single vein shears and composite vein lodes. Vein widths vary from 1 foot up to a maximum of 122 feet in an unmined area of the Brunswick no. 4 vein lode. The average stoping width was five to six feet, although there are at least four known locations in the mine where stoping widths exceeded 50 feet, with a maximum of 100 feet in the Brunswick No. 16 vein lode. On the average, the oreshoots within the veins represent twenty-one percent of the available vein structure as determined from study of existing development workings and past stoping operations. It is estimated that sixty five percent of the resources will be contained in vein structures dipping 50 to 80 degrees, with the remainder localized in veins dipping considerably less than 45 degrees.

Oreshoots that may be amenable to bulk mining methods are known to occur in at least five different structural environments in the Idaho-Maryland Mine. These oreshoots include those hosted in 1) structurally prepared zones within interflow black slate beds, 2) structurally prepared diabase masses within the melange zone, that are associated with diagonally linking
structures connecting main shear zones, 3) structurally prepared wedge-shaped fault junctions, 4) large composite stringer zones forming at the junctions of steep and flat veins, and 5) wide stringer zones hosted in structurally prepared areas associated with faults crossing steep veins. Many of these bulk-tonnage targets tend to be quite thick and wedge-like with strike lengths ranging from 50 to 300 feet. Many such mineralized bodies identified in development workings or drill holes had thicknesses of 20 to 40 feet true width up to a maximum of 122 feet.

RESOURCE STUDIES

There is a vast data base available at the Idaho-Maryland consisting of more than 3,000 old mine maps and a nearly complete set of mine and mill records. In May of 1994, external consultants reported a resource of as much as 9.1 million tons grading 0.326 ounces of gold per ton.

The present detailed resource study by the Emperor Gold staff in Grass Valley expects to delineate about 6 million tons of calculated resources, within 200 feet of known assayed drill holes or workings, along the strike and dip of each vein. A large inferred geologic resource that extends greater than 200 feet from the assay information will also be calculated. The resource calculations are approximately 80% complete, with 4.4 million tons presently calculated. These identified resources are primarily between 2,000 to 3,280 feet beneath the surface. It is important to note that 95% of the resource blocks are open to further expansion with future drilling and underground development. As of August 1996, the grade of the resource for 4.42 million tons has been calculated at 0.25 ounces of gold per ton (uncut), 0.22 ounces of gold per ton (cut) without the "mine call factor"; and, 0.35 ounces of gold per ton (uncut), 0.30 ounces of gold per ton (cut) with the "mine call factor". These resources have an average weighted true width in excess of 20 feet.

Thirty years of mine records document the use of a "mine call factor". Sampling of drill intercepts, development workings, and stope muck severely undervalued the ore when compared to the amount of gold actually produced from this same ore, thus a "mine call factor" was used to determine what the expected gold recovery would be in developed ore blocks. A grade cutting factor of 2.5 ounces per ton was historically used at the mine. For the purposes of calculating resources, Emperor staff used a 1 ounce per ton assay cutting factor for the sake of conservatism. Recent statistical studies from nearly 40,000 development sample assays indicate a cutting factor exceeding 2 ounces per ton should be used, for the 1 ounce per ton cutting factor will underestimate the ore actual grade.

Continuing research has identified important ore controls not previously recognized in the Idaho-Maryland Mine. There are nearly 100 veins and lodes now identified by development and drilling in the Idaho portion of the Idaho-Maryland Vein system. A large proportion of those veins are localized in and at the contacts of mafic dikes cutting the deformation zone, and at the
intersections of the dikes with numerous individual shears within the deformation zone. Past stoping operations demonstrate these were favorable locations for oreshoots. Hundreds of diabasic dikes traverse the deformation zone and few of these have been systematically drill tested in areas projected to intersect the individual shears and lodes.

At least 33 separate targets have been identified that may be amenable to bulk tonnage mining methods. Bulk minable targets are defined as any oreshoot that is easily capable of producing several hundred tons per day from a single work place. These types of targets were described in the geological section of this summary. Only 13 of the 33 targets have been included in the resource calculations, due to lack of necessary information to accurately determine a grade and dimensions. One oreshoot localized in a faulted wedge at the junction of the Idaho No. 2 and No. 3 veins has seen very limited development from the Idaho 1000 level down to the Brunswick 3280 Level. The minimal development in this single body indicates average dimensions of 200 feet long by 30 feet wide by 4,500 feet measured along the rake of the zone which could contain well over 2 million tons grading approximately 0.20 oz per ton gold.

Recognition of a distinct type of orebody hosted in black slates warranted research to identify their controls. The intersection of steep WNW-trending Brunswick-style veins with a NNW-trending set of faults, both coincident with interflow black slate sequences, created favorable conditions for high grade bulk mineable oreshoots, particularly in the southeastern portion of the mine. The “Black Slate Orebodies” are characterized by flat quartz stringers extending outward from the hanging wall of steep veins. Coarse free gold occurs in both the quartz stringers and alone in carbonaceous slate partings. The “Black Slate Orebody” in the 1300 level Brunswick 16 Vein has a maximum width of 100 feet, the 900 level Brunswick 44 vein orebody has a width exceeding 75 feet, and the 1000 level Brunswick 19 vein orebody has a maximum width of 25 feet. These “black slate stopes” were only partially developed and mined. It is likely more such occurrences will be identified.

Highlights of the past drilling prior to mine closure in 1986 include the following:

- Six core holes drilled into the undeveloped ground in the footwall of the Idaho 2 vein have identified the Idaho 53 vein for a minimum 800 foot strike length and 450 foot dip length. The six drill intercepts through the Idaho 53 vein indicate 351,400 tons averaging 7.3 feet true width grading 0.41 oz/ton uncut or 0.29 oz/ton cut to 1 ounce. This resource lies a short distance from development workings on the 2700 and 3000 levels and remains open in all directions. Three additional vein splays from the Idaho 53 vein are estimated to contain more than 195,000 tons of ore grade resources in mineable widths. The Idaho 53 Vein will receive further attention in the proposed first phase of underground drilling.

- Four core holes drilled into the undeveloped hanging wall of the Idaho 2 Vein have
identified the Idaho 59 and 97 Veins between the 3000 and 3100 levels. Four drill intercepts through the Idaho 59 Vein average 16.7 feet true width grading 0.20 oz per ton, open in three directions. A short drift in the 59 lode on 3100 level yielded a minimum true width of 5.8 feet grading 0.76 oz/ton uncut or 0.54 oz/ton cut to 1 oz, with neither wall showing in the drift. Ore grades were showing in the face at the end of the drift. Two drill intercepts through the Idaho 97 lode average 13.8 feet true width grading 0.37 oz/ton uncut and .28 oz/ton cut to 1 oz. The Idaho 59 and 97 lodes are subparallel quartz stringer zones located 70 feet apart. The original drill data from the 1950's is continuing to be assessed and additional ore grade resources will be announced in the future.

A computer generated three dimensional mine model is presently being constructed. Maptek Vulcan software is being used to build this model. Development workings, calculated ore blocks, geology, and 960 existing core holes with assays are being incorporated into the model. This model will serve to inventory known ore blocks, identify additional drill targets, and help plan, direct, and continually evaluate the ongoing underground exploration program. The mine model will also assist in the engineering, mine optimization and feasibility studies.

During the present phase, the geological staff of Emperor Gold is well on its way to developing ore resources from the original mine maps and data to confirm and upgrade a preliminary reserve estimate made in 1992 by a leading independent consulting firm. The current exploration phase will delineate a portion of the 1992 resource estimates of as much as 9.1 million tons grading 0.326 ounces of gold per ton. Emperor Gold staff has a high level of confidence that this mine can soon produce at a rate of up to 1,500 tons per day, and that there are excellent possibilities of discovering lower grade bulk tonnage resources that might allow production at a rate of up to 5,000 tons per day.

DEWATERING AND EXPLORATION PROGRAM

The 3460 foot vertical New Brunswick shaft, which will be dewatered for future operations at the mine, had a production capacity of over 1,000 tons of ore per day. Probes and television cameras indicate that the shaft is open at least to the 3280 level. Careful sampling indicates that the water in the shaft is benign and conditioning constituting aeration to introduce oxygen to the water will allow precipitation of small amounts of iron and manganese, resulting in water discharge which exceeds the quality standard for drinking water set by government.

The New Brunswick Shaft is a rectangular, three compartment, vertical, timbered shaft extending 3,460 feet to depth. A fourth compartment was added for the lower 300' to facilitate future deepening of the shaft. Inside dimensions are approximately 5' by 15' with two identical 5' by
4' compartments being allocated to hoisting rock and personnel, and the third compartment for personnel, materials and emergency escape.

The mine was closed in 1956 with the New Brunswick Shaft being well serviced and in good shape. The timbers were always maintained in a wet condition. Proposed work includes dewatering the mine using two 450hp and one 420hp submersible pumps at a rate of 6 cubic feet per second, replacing all utilities and inferior shaft sets, if any, installing a permanent pump system, and preparing the 3280 level for suitable access to conduct exploratory core drilling.

Two single drum hoists are required for Phase I dewatering and exploration. One of these may be moved for service at the Round Hole shaft after a larger hoist system is installed for the production phase. Both single drum hoists will be 6 feet in diameter with a 3 foot wide face and will be driven by an AC motor of approximately 150 hp. One winch with 50,000 lb line pull will also be installed temporarily for submersible pump installations. For future production, a 10' diameter double drum hoist with 72 inch face is currently being considered. A 1000 horsepower direct current drive system with 6 ton skips would give the New Brunswick Shaft a production rate of 1,500 tons per day from two 8 hour shifts/day. This hoisting system would be able to serve the shaft to a depth of 4,800'.

For the dewatering and exploration phase a 65 foot high steel headframe will be installed. In the future this structure will be increased in size to a 126 foot high structure to accommodate the 10' diameter sheave wheels, dump pockets, and service access for the later production phase.

A 200,000 foot exploratory core drilling program will be initiated from drill stations between the 2300 level and 3280 level. Approximately 200 NQ core holes, up to 800 feet in length will initially be drilled from 28 stations by contractors using portable underground electric rigs. The first 40 ore targets were identified from results of 960 existing core holes totaling 230,000 feet. These 40 ore targets will be delineated by closely spaced drilling in the first phase of exploration. An appropriate amount of development work will be completed on these reserve blocks. Additional wide spaced drilling will be completed in the second phase of exploration which should significantly add to the reserve base.

During its peak production years in the late 1930's, the Idaho-Maryland mine employed more than 900 men. A similar operation today would be more mechanized, employing some 200 people. Considering the high unemployment rate in the Grass Valley area, this mine will favorably impact the local economy. It is believed that each job at this mine would create, indirectly, another two jobs such as with contractors, suppliers, and merchandisers. Many of the residents of Nevada County have worked in the mines, and these miners and their descendants are especially vocal in expressing a desire for the return of the Idaho-Maryland Mine and the positive economic impact it will bring the community.
Geology and Current Mining
at the
Original Sixteen to One Mine
Alleghany, California

by
Jason Burke, Mine Engineer
Sixteen to One Mine
May, 1997
INTRODUCTION

Located mid-way up the west slope of the Sierra Nevada, the Original Sixteen to One Mine sits at the northern end of one of the most studied gold belts in the world. The richness of the various deposits found in this region and the hundred-odd years they have been mined have allowed generations of miners, geologists, and scholars to evaluate not just regional trends, but also specific ore controls in individual mines. In a sense, their methods reflect the nature of the mining at the Sixteen to One, as every pocket of gold has a slightly different character and provides new information as to the possible genesis of the ore. On one hand, there has been exhaustive work done and many reports written about the geological setting of the mine, but there remain questions as to the exact processes that took place and how best to evaluate their effects on gold deposition.

The Alleghany district lies in the region known as the Northern Mines, differentiated from the Mother Lode by higher grade but more pocket gold deposits. These deposits, located within quartz veins, were discovered after the gold rush placer mining in the mid- to late-1800’s. It was the oldtimers’ drive to trace the gold found in river gravels to an “El Dorado” mountain of gold that pinpointed these veins as the real source. Located in 1896 and mined nearly continuously ever since, the Sixteen to One still holds many mysteries, even as new discoveries prove that the gold remains as rich as the history.

This paper is a compilation of many of the reports that have been generated over 80 years, but it includes recent work that comes from exposing virgin ground 2500 feet below the surface. Every blast set off reveals another piece to the geological puzzle that has eluded so many before us: why does the gold rest where it does, and how can we best predict how far we are from the next million ounces of the yellow metal? With advances in geophysical tools, the mine is also able to amplify its search capability and look into the rock with new eyes. Current mining will prove or disprove the existence of any remaining pockets, but geological evaluations reveal no reasons why they would not.
GEOLoGIC SETTING OF THE SIXTEEN TO ONE

The quartz vein system of the Alleghany mining district fills a north trending series of east dipping thrust faults that are part of the Melones fault system. The veins cut through the Calaveras Formation, a layering of Carboniferous to Permian metamorphic rocks divided into six units, of which two are present in the Sixteen to One: the Tightner and Kanaka Members. The former is predominantly amphibolite and chlorite schist and is present in about 90% of the mine, while the latter consists of conglomerate, chert, and slate. The entire Calaveras was overturned and the contacts now dip steeply east. Subsequent ultramafic intrusives formed olivine-pyroxene dikes throughout the region and became serpentinized by their own high temperatures that drove off lighter elements. Reverse faulting, following weaknesses caused by the Calaveras' internal contacts and those with serpentinite bodies, then provided the primary channels for quartz and gold deposition.

As magmatic fluids coursed through the Melones fault zone, they encountered the relatively weak Calaveras and began significant alteration of both schist and serpentinite by sulfidization and carbonatization. There is evidence that most of the silica and possibly some gold may have been leached from the walls themselves. One of the more visible alteration minerals is the blue-green mariposite, a carbonate product of serpentinite. Also quickly recognizable is the pyrite present near the hanging wall and foot wall of the vein in various locations. Not only are these alterations a sign of hydrothermal activity, they also are usually indicators of later gold deposition.

Vein formation itself, from initial hydrothermal alteration to gold deposition, took place between 110 and 125 million years ago in a series of events. A significant amount of hydrothermal fluid, high in carbon dioxide, infiltrated the Melones fault system and began leaching silica and other minerals from the surrounding schist through intense alteration. At this stage, the crystallization of the quartz took place at the boundary between the vein and the wall rock. In other words, the vein formed from the center out, assimilating the wall rock and, in many places, causing a ribbon structure to form with tabular inclusions of altered schist. Also, where silica was leached from deeper in the crust and traveled upward in solution, the vein formed by filling voids
Figure 1: Taken from Ferguson & Gannett, 1932. Representative cross section (looking south) of the middle portion of the Sixteen to One. Note the steeply west-dipping cross faults that displace the vein. The drain tunnel is equivalent to the 800 level.
in the fault as it experienced decreases in pressure and temperature. To complicate matters further, the fault zone is just that: a zone of several hundred faults that interweave and have differing displacements. We see the resultant vein system follow the pattern to branch off unexpectedly in all three dimensions.

The sequence of events given above does not, however, tell the complete story. The vein structure is complicated by further Melones movement and cross-faulting that occurred during and after the vein was in place. As the vein formed, reverse faulting with westerly dip displaced the east-dipping faults. In some cases, these cross faults were then filled with vein solutions, but in others, they were themselves displaced by further movement on the initial faults. This series of vein deposition and faulting continued throughout the vein formation.

Not only did the vein solutions follow faults, they were also controlled by the serpentine dikes present throughout. Wherever the vein contacted a serpentine body, it was deflected into or around it. As it entered the serpentine, it soon frayed out into fine quartz "stringers" that are now surrounded by mariposite and last for only a few feet. Near smaller dikes, the vein continues through, but even in these areas, there is significant alteration and the vein is only present because of continued faulting that kept the contact fresh. In those places where the contact is frozen, the vein eventually pinches out and intense carbonate alteration, including mariposite, takes its place. It would appear, then, that it was the surrounding schist and its silica content that allowed the vein as we see it to exist. Where this silica was lacking, the "vein" manifests itself as hydrothermal alteration of the country rock with which it is in contact, but no quartz is present. A separate example, the Oriental Mine, is located on a quartz vein that cuts through a granitic pluton. Even here, laboratory analyses show that the silica forming the vein has been leached from the granite.

As this initial stage of quartz mineralization began to decline and the rock system cooled, the vein sealed itself and remained barren quartz until further fault movement occurred and hydrothermal fluids, this time carrying arsenic as well as carbon dioxide, infiltrated once again. On that occasion, the faulting tended to reopen voids along the serpentine contacts, probably because of the platy cleavage found there. Consequently, even more carbonate alteration took place with mariposite as the result. In addition, the arsenic present reacted with previous sulfur mineralization to produce arsenopyrite. This arsenopyrite was localized in microfractures within
the quartz vein, and therefore is found most commonly in regions of higher stress: vein splits and junctions or changes in strike, dip, or thickness.

Following the arsenopyrite deposition was a period in which gold, from unknown sources, was brought up with the vein fluids. The gold then precipitated from the solution in much the same manner as the preceding arsenopyrite with the added advantage that the arsenopyrite acts chemically to aid the process. At no time is the gold (or any other mineral) observed to replace the quartz. All mineralization succeeding the vein formation took place in microfractures caused by fault movement or as replacement of previous carbonate alteration. In some cases, the gold found its way to the hanging wall or foot wall contact and was later smeared into a "paint" as the faults persisted.

The process of gold precipitation in quartz veins has become virtually a science in itself. The oldtimers recognized many of the features that we associate with gold, but did not always have a definite scientific basis for their theories. Recent work, including absolute dating of the quartz veins and isotopic analysis of fluid inclusions, has shed further light on the characteristics of the mixture, the temperature and pressure of vein formation, and the chemical interactions that transpired with each influx of fluid. In addition, there are the issues of the purity and crystalline nature of the gold pockets that, along with making the ore even more valuable, make its origins less clear.

First recognized as controls on gold deposition were the structural characteristics of the vein. Just as arsenopyrite was localized in microfractures, so was the gold. Regions of high stress, as noted above, were therefore some of the positive indicators that an ore shoot may be nearby. In addition, these areas were likely controlled by the surrounding geology as the vein was formed. For example, as faults branched off from one another or serpentinite was encountered, the vein split or was deflected. Then, as it cooled and solidified, these became discontinuities that concentrated the stress applied by continued fault activity.

One aspect of gold localization that is poorly understood is its tendency to form "ore shoots," or pockets of gold that extend up and down dip. They are the basis for the term "pocket mine" and they continue to confound efforts to characterize their formation. As noted above, the gold solutions were guided into microfractures in the quartz. The issue then becomes, what controls concentrations of microfractures that follow the vein dip? There has been little presented in the
literature to correlate the direction and size of a given ore shoot with the surrounding geology. H.R. Cooke presented extensive quantitative associations between gold and vein structure, going so far as to assign association indices to various features. In terms of overriding ore controls, however, it seems more appropriate to describe the conditions for fracture formation within the vein.

The preceding illustration of Sixteen to One geology is meant to be a synopsis of the body of knowledge available regarding gold-quartz veins. Much of the field work was done in this mine or in others of the Alleghany, Pike, Forest, and other related districts. The geological interpretations found in the literature are upheld by the results we have achieved and the lack of any evidence otherwise. However, in practice, we must be able to apply the theories to the rock faces visible to the eye. In addition, in lean times when the gold is in short supply, there is a careful balance between exploration and active mining. We need to discover new pockets, but the technology is not far enough advanced to warrant a suspension of mining. Currently, the mine is curtailing a long term development phase and we are encountering a favorable block of ground for gold recovery. The following section describes in detail our recent accomplishments.

**CURRENT MINING PRACTICE**

Over the years, mining at the Sixteen to One has had two major objectives: expand the overall area available for gold recovery and follow a gold discovery to its limits. Each of these goals has different methods by which they are achieved: it is more efficient to drift horizontally along the vein strike (perpendicular to the “grain” of the ore shoots) until a pocket is reached, and then mine it by raising or stoping until the gold runs out. Additionally, there are development requirements such as ventilation and ore movement that govern the mining technique, but overall, these two goals are paramount.

With the foregoing details in mind, it is appropriate to relate them to the actual mining that takes place within the rock. All the illustration of geology is meaningless if it cannot be applied to the extraction of the gold from its cradle of quartz. Indeed, with recent breakthroughs and creative applications that have allowed small-scale geophysical exploration of the vein, we have moved into a new realm that may depress the value of geological interpretations in favor of technology. On the other hand, geophysical exploration for many deposits on any regional scale,
gold-quartz veins included, is inefficient without a geological evaluation to localize favorable targets.

With the introduction of metal detectors to the mine in the past decade, an incalculable benefit has been realized. The focus of mining became exploration of old workings of the mine, since the oldtimers could have been inches away from a pocket they could only hope to discover. We could then look through those inches of rock without explosives to examine a working face for invisible gold. It was also possible to scan old muck piles in known paying stopes to recover gold that was left behind years ago in favor of higher grade material. Even at active faces, they are used to help evaluate whether a pile of muck will be treated as ore or waste. Conventional metal detectors are not the only tool, however, and ever-expanding research is providing methods such as ground penetrating radar that may serve to increase our searches from a few to as many as 50 feet into the quartz, depending on the size of the unseen pocket. Until we can survey an extensive area, however, our applications of high technology will be governed by active mining and a preliminary evaluation of geology to fix a favorable target.

The development phase mentioned above was an expansion of the mine down to the 2600 level off the '83 winze. Even though the mine was deepened to the 3000 level off the Tightner shaft in the late 1920's, these areas were left behind with no evidence of significant gold. To the south, however, the vein splits into hanging wall and foot wall sections that diverge up dip and to the south. It is in this area that most mining over the past few years has taken place, and the 2600 level has led to some promising, money-making, but troublesome rock.

Our current mining is concentrated on and near the 2400 level south of the '83 winze. Between the 2400 and 2600 is a horizontal vein split, possibly the result of a large serpentinite body, that is a major feature in the Sixteen to One. The hanging wall vein is known as the "16" and the foot wall vein is called the "K." These two veins are seen on various upper levels, with mixed results regarding gold deposition. One hopeful area is the 2233-K underhand (on the 2200 level) where 600 ounces were found in the past and left in place in anticipation of an ore shoot below. We are now actively searching on the 2400 level for that pocket that might lead up dip to the 2233 with gold all the way.

Above the 2400, and extending below it for at least 30 feet, is a small pocket that generated about 300 ounces on April 1. Each day, we are able to get a picture of the boundaries of a
Sixteen to One Mine Southern Workings

Detail of Lower Levels

16 Vein Drifts and Raisens
K Vein Drifts and Raisens
Simplified Vein Cross Section, Looking North
potentially large deposit. We feel that there is a connection between this gold, or some near it, and the 600 ounces in the 2233-K. Soon, we will be selecting a location for a raise from the 2400 to this location. Our decision, like the oldtimers', will be based on where we see the gold and what that vein looks like compared to the underhand.

Conclusion

Intended as a short geological introduction to the Sixteen to One and its mining operation, this report by no means takes the place of the resources available in the historical essays and the more recent work done to reveal additional mechanisms of the gold deposition. Virtually all of the literature supports the models presented as far back as 1913 by Ferguson that specific ore controls may be found by examining the physical structure of the vein. Those who disagree do so not by disproving his theories, but by expanding on them with new knowledge. With every new discovery, further information is gained to help predict where the next deposit will be. Advances in geophysical technology will also help raise the mysterious curtain on the secrets of gold deposition within these veins and those similar that are found throughout the world. The Sixteen to One is one of the last operating hard rock gold mines in the country, and its history and valuable service as a geological laboratory in the earth's interior will hopefully ensure its continued existence as a producing mine.
REFERENCES


NCGS - NORTHERN SIERRA NEVADA REGION
GEOLOGICAL FIELD TRIP GUIDEBOOK

PART I

ECONOMIC GEOLOGY

NORTHERN SIERRA NEVADA

PLACER GOLD DEPOSITS
ANCESTRAL YUBA RIVER (EARLY TERTIARY AGE)

AURIFEROUS FLUVIAL DEPOSITS

BY

DAVID LAWLER - DIRECTOR -
SISKON GOLD CORPORATION

SISKON GOLD CORPORATION
350 CROWN POINT CIRCLE #100
GRASS VALLEY, CA 95945

SUBMITTED FOR:

NORTHERN CALIFORNIA GEOLOGICAL SOCIETY
NORTHERN SIERRA NEVADA REGION
1997 - GEOLOGICAL FIELD TRIP GUIDEBOOK

JUNE 1997
ANCESTRAL YUBA RIVER (EARLY TERTIARY AGE)
AURIFEROUS FLUVIAL DEPOSITS

BY

DAVID LAWLER - DIRECTOR
SISKON GOLD CORPORATION

INTRODUCTION

Vast quantities of unmined gold-bearing gravel in Northern California, on the divides between the North Fork of the American River and the South Fork of the Feather River. This gravel was deposited by an immense prehistoric river system called the ancestral Yuba. It existed approximately 60 to 40 million years ago, during the early Tertiary period, and extended over a large area of the present day northern and central Sierra Nevada Range. (Figure 1).

A major portion of the total placer gold from Tertiary deposits in California has been produced from the ancestral Yuba; estimated at nearly 12 million ounces and worth approximately $5 billion. Much of this was produced during the period of 1850 to 1884 when hydraulic mining was developed and extensively used in California. In 1884 a court injunction prohibited widespread use of hydraulic mining, leaving large volumes of virgin gold-bearing gravels unworked.

The area of the ancestral Yuba shown on this map contains the largest remaining deposits of Tertiary gold-bearing gravel in the Sierra Nevada. A significant gold resource exists here, with relatively good access and channel exposures. The small-scale miner has the opportunity to exploit these small, rich accumulations which large mining companies pass by, due to limited ore reserves. Much of this mining can be carried out at reasonably small expense, and encouraging results can be obtained rapidly.

GENERAL GEOLOGIC HISTORY

Formation of the Ancestral Yuba River Deposits

Voluminous quantities of gold-bearing gravel were deposited in the ancestral Yuba River drainage system, mainly during the Paleocene and Eocene times of the early Tertiary period. Geologic investigations indicate that this vast river system probably originated along highlands or the crest of the ancestral Sierra Nevada Range in western Nevada, and flowed westward into a marine basin located in the present day Sacramento Valley. The early history of the ancestral Yuba River during the Paleocene to early Eocene was characterized by rapid downcutting and high relief of surrounding areas. Much of the gold that was constantly being supplied to the drainage was concentrated in the 50 to 100 feet of gravel covering the floor of the river valleys.
During Paleocene to middle and late Eocene times, the river valleys became broader and extended their basins eastward. The formerly rugged landscape was transformed into a gentle one. Sediment thickness increased in the river valleys, and extensive flood plains and river meanders formed as the rivers continued to accumulate rather than downcut. Semitropical climatic conditions, high precipitation (estimates range from 200-600 inches per year), and lush closed canopy-type rainforest vegetative cover caused intense chemical weathering and breakdown of less resistant rocks in the river sediments. By the end of the early Tertiary, gold-bearing river deposits had accumulated that were up to 400-600 feet thick and well over a four miles wide in some places.

**Volcanic Episode**

Intermittent volcanism began at the end of the Eocene in the ancestral Sierra Nevada and surrounding areas and continued until Pliocene times. Mudflows and volcanic ash covered much of the Sierra, including the ancestral Yuba. Widespread mudflows of andesite and rhyolite composition (Valley Springs and Mehrten Formations) effectively protected the softer gold-bearing sediments from extensive erosion. During this period new river systems formed and established drainage patterns different from those of the ancestral Yuba system.

**Rise of the Sierra Nevada**

Recent geologic and tectonic investigations and reevaluation of the channel gradients of the Ancestral Yuba River System suggest that the northern Sierra Nevada Range may have existed as early as late Cretaceous times. This new tectonic model (cf. Dr. David Jones - unpublished data) contrasts drastically with classic Sierran uplift model characterized rapid uplift and westward tilting of the northern Sierra and marked subsidence of volcanic activity by the Late Pliocene (+3 m.y.) times.

Since Pliocene times, the volcanic cover has been largely eroded, exposing much of the ancestral Yuba gold-bearing deposits, with the essentially modern-day Sierra rivers systems, such as the Yuba and the American River drainage, quickly downcut into topographic lows during Pleistocene times (perhaps in response to increased precipitation), and establishment the deeply incised canyons, which are so spectacular and so rich in placer gold today.

**HISTORY OF MINING**

Placer gold was first discovered by the forty-niners in the streams and rivers of the Sierra Nevada. Later it was traced to the prehistoric river deposits on the divides between river canyons. Miners discovered that his gold-bearing gravel was partially covered by extensive volcanic cover but was exposed numerous places between the North Fork of the American and the Bear Rivers, and between the South and Middle Forks of the Yuba River.
Hydraulic Mining

Small scale mining methods, such as use of a gold pan, sluice, or rocker box were replaced by hydraulic mining, initially developed in 1852. This method used vast systems of canals and large diameter iron pipes connected with huge nozzles (monitors) to cheaply mine large volumes of gravel. Hydraulic mining was used extensively on the gold-bearing deposits of the ancestral Yuba from 1855-1884.

During the nearly 30 year period, an estimated 250 million cubic yards of material were mined from the ancestral Yuba deposits and washed into nearby river drainages. At the Malakoff hydraulic pit near North Bloomfield (now a scenic state park), nearly one cubic mile of material was removed. The accumulations of hydraulic mine debris rapidly lowered river gradients, choking and filling channels where they emptied into the Central Valley. Subsequent repeated sitting and flooding destroyed vast acreages of farmland and led to more than ten years of litigation between farmers and miners, culminating in the famous court case Woodruff vs. North Bloomfield Gravel Mining Co. In 1884 a court injunction was issued, effectively banning extensive hydraulic mining in California. Legislative attempts to revive hydraulic mining were unsuccessful, and the large hydraulic operations shut down. As a result, significant quantities of gold-bearing gravel were left unworked.

Drift Mining

Drift mining, which had been common 10 to 20 years earlier, was revived and extensively used following the shutdown of the hydraulic mines. The richest gold-bearing gravels at the base of the ancestral Yuba deposits were extracted by driving an underground tunnel into bedrock close to and along the gravel-bedrock contact. It has been estimated that nearly 30 million cubic yards of gravel were mined using this method (Gilbert, 1917).

Dredge Mining

Floating bucket line and clamshell type dredges were developed at the turn of the century and rapidly became the leading producers of placer gold in California until World War II. The vast deposits of hydraulic tailings from earlier mining of the ancestral Yuba and Feather River deposits were mined using these methods.

SEDIMENTARY GEOLOGY AND GOLD DEPOSITS

Channel Location and Extent

Accuracy of channel locations varies with the state of knowledge about a particular area. Where a sizable channel segment has been eroded by major existing river drainages or is under thick volcanic cover, its approximate location is shown.
The ancestral Yuba River Map shows the probable maximum extent of the ancestral Yuba channel, as indicated by geologic field data. This does not imply that in-situ (in place) gravel is present throughout the channel area. Erosion may have removed a part or nearly all of gravel deposits in certain locations prior to historic mining.

**Lower Gravels and Channel Base**

An idealized section across the ancestral Yuba River channel is shown in Figure 3. The gold bearing gravel deposits can be divided into a lower and upper unit (Yeend, 1974).

The deeper portion of the channel is occupied by the lower gravel, which tends to be a coarse, poorly sorted mixture of cobbles, pebbles, sand, and clay. Large boulders up to 6-10 feet in diameter are also common. The lower gravel can be divided into an upper red gravel and a lower blue gravel, the color being simply a function of whether the gravels are in a chemically oxidized or reduced state. Thus, the term "Blue Lead" refers to bluish gravels which occur below the water table, as noted by Lindgren (1911). The lower gravel contains relatively high gold concentrations and was the unit most actively sought by the early miners. It ranges from 70-140 feet in thickness.

Depending upon local bedrock geology, a deep gut or groove may exist in the center of the channel, shown on the map by a double line. These basal areas have yielded high gold concentrations.

**Upper Gravels**

The upper gravels or bench gravels overlie the lower gravels and are considerably finer and better sorted. They tend to be compositionally more mature and thus named the "white gravels" for the proportionally greater amount of quartz clasts. The upper gravel also contains many beds of sand- and clay-sized material. Thickness of this unit may vary up to 400 feet.

**Gold Size**

Figure 4 shows the occurrence, weight, and discovery date of famous gold nuggets found in the lower gravels of the ancestral Yuba. The source of these large gold masses was likely nearby high grade lode pockets which were scoured out by the channel. Larger flakes and nuggets of gold are found associated with the coarse, bouldery portions of the lower gravel more commonly than in the upper gravels. Gold particles as small as 400 mesh (Tyler mesh size) have been recovered from the upper gravels.
Gold Values

Gold values in the upper and lower gravels vary widely along the ancestral Yuba and it is difficult to provide accurate information since many mine areas had been exploited and exhausted before production figures were recorded. However, areas such as Liberty Hill, French Corral, and Smartsville had relatively high values due to the exclusive presence of lower gravels (Yeend, 1974) while unknown factors created extremely rich gold deposits in the lower gravels at Indiana Hill, Dutch Flat and Debec drift mines.

Intervolcanic Channels

Intervolcanic channels, not shown on this map, represent river systems formed during periods of volcanism in the later Tertiary. They are geologically younger than the ancestral Yuba and reflect a general change in drainage pattern. These channel deposits have an overall lower placer gold content than deposits of the ancestral Yuba. However, some sections of these intervolcanic channels have “robbed” or eroded gold from the ancestral Yuba where they crossed. The rich gold deposits in the intervolcanic channel developed by the ruby drift mine in Sierra County are an excellent example of this situation.

OTHER HEAVY MINERALS

Detrital heavy minerals commonly found in the ancestral Yuba deposits are ilmenite, zircon, sphene, amphibole, epidote, chlorite, siderite, and pyrite. Ilmenite and zircon are the most common heavy minerals in the upper gravels (Yeend, 1974).

Secondary sulphides such as pyrite are common in the lower bluish (reduced) gravels. Gold-bearing sulphides termed “sulpherets” were reportedly recovered from several hydraulic and drift mines along the southern tributary of the ancestral Yuba and assayed as high as 15 ounces of gold per ton. Lindgren (1911) has reported a similar occurrence from a gravel mine in Butte County, California.

Detrital platinum has been recovered from several hydraulic mines along the ancestral Yuba in Sierra and Plumas Counties. Alluvial diamonds have also been reported from heavy mineral concentrates derived from the gravels. Most notable was the occurrence of a number of diamonds up to 7.25 carats, recovered from the French Corral gravel mines (Whitney, 1880).

MAP LEGEND - DESCRIPTIVE NOTES

Map Symbols
The map symbols designate important features such as distribution, location, and extent of the ancestral Yuba river deposits, as well as locations of major hydraulic pits and drift mines, historic townsites, land ownership, etc. Points of interest can be located relative to present day roads, towns, streams, and the Yuba River drainage system.
Map Index

The map index lists locations of important hydraulic and drift mines, historic townsites and historic nugget discoveries.

Topographic Data

The topographic base provides information on the elevation of different parts of the ancestral Yuba deposits, steepness of slopes in river canyons and surrounding areas. Note that the ancestral Yuba deposits are commonly located 500 to 1,000 feet above the present major drainages.

Historic Townsites

Townsites occupied during the 19th Century and now abandoned are shown in gold on the map and listed in the index. The existence of most of these townsites or settlements was related directly or indirectly to mining activities along the ancestral Yuba.

Topographic Index Map

Topographic index map shows the location of the ancestral Yuba within the particular 7.5 and 15 minute USGS quadrangle maps. This is particularly useful for persons interested in a detailed area requiring larger scale maps.

Land Ownership

The land ownership base is useful in quickly determining whether a given area is public or private. Within public lands, those managed by the U. S. Forest Service are designated. For more detailed information on public land status, check with the appropriate USFS, BLM (Bureau of Land Management), County, or State Lands offices. Private land ownership can be checked in more detail at the respective county offices. Always obtain permission from private landowners prior to entering their property.
Figure 1(right). Tertiary channels and dredge fields, Sierra Nevada. After Lindgren(1911) and Clark(1970). (Courtesy of California Div. of Mines and Geology)
Ancestral Yuba River
Gold Map
Sierra Nevada Region, Northern California
Figure 3. Idealized section across the ancestral Yuba River channel. *After Petersen (1968).*

<table>
<thead>
<tr>
<th>Location</th>
<th>Date Found</th>
<th>Weight (troy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polar Star claim, Dutch Flat district</td>
<td>1876</td>
<td>288 oz.</td>
</tr>
<tr>
<td>Minnesota, Alleghany district</td>
<td>1850's?</td>
<td>266 oz.</td>
</tr>
<tr>
<td>Remington Hill, Nevada County</td>
<td>1855</td>
<td>186 oz.</td>
</tr>
<tr>
<td>Live Yankee claim, Alleghany dist</td>
<td>1854-62</td>
<td>12 nuggets 30-176 oz.</td>
</tr>
<tr>
<td>Remington Hill, Nevada County</td>
<td>1869?</td>
<td>107 oz.</td>
</tr>
<tr>
<td>Lowell Hill, Nevada County</td>
<td>1865</td>
<td>58 oz.</td>
</tr>
<tr>
<td>Ruby mine, Alleghany district</td>
<td>1930's-40's</td>
<td>Nuggets up to 57 oz.</td>
</tr>
<tr>
<td>Steelman-Hayes Claim, Downieville district</td>
<td>1886</td>
<td>39 lbs</td>
</tr>
</tbody>
</table>

Figure 4. Large nuggets and gold masses from ancestral Yuba channel. *After Clark (1970).*
BIBLIOGRAPHY


GEOLOGY AND MINERALIZATION
OF THE
SAN JUAN RIDGE MINE
TERTIARY GRAVEL DEPOSIT

BY
ROBERT C. PEASE
PROJECT GEOLOGIST
SISKON GOLD CORPORATION
MAY 8, 1997

SISKON GOLD CORPORATION
350 CROWN POINT CIRCLE #100
GRASS VALLEY, CA  95945

SUBMITTED FOR:
NORTHERN CALIFORNIA GEOLOGICAL SOCIETY
NORTHERN SIERRA NEVADA REGION
GEOLOGICAL FIELD TRIP GUIDEBOOK
GOLD DEPOSITS OF THE SIERRA NEVADA
JUNE 14-15, 1997
GEOLGY AND MINERALIZATION OF THE
SAN JUAN RIDGE MINE TERTIARY GRAVEL DEPOSIT

INTRODUCTION

The San Juan Ridge Mine is owned by Siskon Gold Corporation. It is located on San Juan Ridge in northern Nevada County, California, about 80 miles north of Sacramento and about five miles east of the town of North San Juan (Fig 1). It is situated in the western foothills of the Sierra Nevada along the Mother Lode gold belt, at an elevation of 2700 feet. The property consists of 2,000 acres of patented land.

For years the property has been explored as a possible open pit mining target, but Siskon determined that underground mining would be the most efficient method to use. Construction of the underground mine began in July 1993 shortly after receiving operating permits, and gold processing began at the end of 1994. The mine entered the production phase in 1996.

This paper discusses the geology and mineralization of the deposit, emphasizing exploration and development.

HISTORY

Placer gold was mined on San Juan Ridge from 1850 to 1884 using hydraulic methods. After hydraulic mining ceased, underground drift mining began and continued until 1940.

The San Juan property was originally consolidated into single ownership in the 1920’s by the San Juan Gold Company. Several small underground drifts and shafts were excavated on the east end of the property near North Columbia (in the 1930’s) and on the northwest side near Badger Hill. Exploration drilling programs were conducted in 1917 and 1939 by Selection Trust, from 1979-1984 by Placer Service Corporation, a subsidiary of St. Joe Minerals, from 1984-1988 by Coastal Mining Company, a subsidiary of M. A. Hanna Company, and from 1988-1992 by San Juan Joint Venture, a joint venture between Battle Mountain Gold Company and Centurion Gold Incorporated. Siskon Gold purchased the property in 1992. Siskon’s predecessor company, Centurion Gold, originally became involved as a partner in the San Juan project in 1987.

From 1968 to 1972, the U. S. Bureau of Mines conducted a detailed underground mining and testing program at Badger Hill as part of their heavy metals program. This extensive project evaluated various mining parameters, including blasting methods, ground support techniques and backfilling methods.
PREVIOUS GEOLOGIC WORK

The Sierra Nevada region was investigated in great detail by W. Lindgren and H. W. Turner in which they developed numerous geologic maps and texts. Lindgren (1911) described in detail the Tertiary river deposits in the Sierra Nevada foothills that were being mined for gold. He also inferred the original extent of the Tertiary river system, and many of his interpretations are still considered valid today. Yeend (1974) conducted a detailed study of the Tertiary fluvial sediments on the San Juan Ridge property near North Columbia, which included a discussion of gold occurrence. Placer Service Corporation (a subsidiary of St. Joe Minerals) carried out internal geologic investigations of the fluvial deposits on the property (Pease, 1981). The State of California Division of Mines and Geology conducted a Mineral Resource Classification study of Nevada County (Lloyd and Clinkenbeard, 1990). An internal update of the site geology was done by Battle Mountain California Inc. (Pease, 1992) following a large exploration drilling program. Lawler (1995) has studied the Tertiary river channels and updated Lindgren's interpretations.

GENERAL GEOLOGY OF THE SAN JUAN RIDGE MINE

The placer deposit is an ancient river channel of early Tertiary (Eocene to early Oligocene) age carved into bedrock, containing three distinct units of fluvial sediments and a volcanic tuff. In a descriptive sense, the river sediments indicate a fining upward sequence (Fig 2).

BEDROCK

The oldest bedrock units exposed in the vicinity of the mine are metamorphosed sediments and volcanics of the Triassic Clipper Gap formation. These rocks comprise the bedrock floor of the river channel throughout the western half of the mine property.

Intermediate intrusives are the oldest igneous rocks in the area and comprise the bedrock floor under the eastern half of the property. The rocks are predominantly diorite and gabbro, and were termed gabbrodiorite by Lindgren and Turner. They are considered to be of Jurassic age (Lloyd and Clinkenbeard, 1990).

TERTIARY UNITS

The oldest fluvial deposit directly overlies diorite and slate bedrock and is at the base of the stratigraphic section. It was called blue gravel by early miners (Yeend, 1974) due to a blue-gray color. This color was caused by a reducing environment plus the color of the calcite cementing agents and gravel clasts. The conglomerate is 80 feet thick and up to 500 feet wide.

The unit has been termed lower gravels in internal reports due to stratigraphic position, and it roughly correlates with Yeend's (1974) lower gravel unit. It is a sandy gravel conglomerate
averaging 26 percent cobbles, 30 percent pebbles, 34 percent sand and 10 percent clay by volume. It ranges from weakly indurated to strongly cemented (as hard as concrete), with the strongest cementing agent being calcite and the weaker cements being silica and pyrite. This unit contains economically important concentrations of gold, and is the target of gold exploration. It has been sampled by all four types of drilling.

Unconformably overlying lower gravels is a layer of relatively non-indurated gravelly sand that contains six percent cobbles, 35 percent pebbles, 47 percent sand and 12 percent clay. This deposit was called red gravel due to a reddish color caused by oxidation. Yeend (1974) included this unit with his lower gravel. Termed middle gravels, this unit is non-indurated and lacks cement. It is generally finer-grained than lower gravels, transmits much more groundwater and is the aquifer on the property. The layer is 100 feet thick.

The youngest unit is a layer of gravelly clayey sand, made up of one percent cobbles, 19 percent pebbles, 51 percent sand and 29 percent clay. It unconformably overlies middle gravels. Termed upper gravels, this unit was also described as white gravel and was part of the upper gravel of Yeend (1974). It is up to 300 feet thick.

The oldest volcanic deposit associated with the Tertiary sediments is a decomposed intermediate volcanic tuff that is present near the base of the channel. It has been altered to clay and contains sub-angular metamorphic rock fragments. The overall stratigraphic relationship of the tuff and lower gravels is currently not clear, for it overlies a thin deposit of older lower gravel in one area, but may have been scoured through by the lower gravel elsewhere. Based on absolute age dating, the tuff is 45 million years old (Lawler, 1996).

PREVIOUS DRILLING PROGRAMS

The San Juan property was first explored with churn drills in 1917 and then again in 1939. Years later, between 1979 and 1984, a large diameter caisson drill, the German BADE drill, was operated on the property. Diamond core drilling was successfully conducted from 1985 through 1987, and was described by Stone et al, 1988. Reverse circulation drilling was first begun in 1988 and a large program was conducted from 1989 to 1990. Since 1992 Siskon has utilized reverse circulation for annual definition drilling to guide underground mine planning.

CHURN DRILLING

The drills used at San Juan required driving a six-inch diameter casing. When the ground became cemented, the drillers had to drill ahead of the casing, and then if possible, under-ream the hole and drive the casing down afterward. At times this was impossible in
which case they would continue to drill ahead as an open hole. Calculations of grades involved using a core rise factor (Stone et al, 1988). Further studies have indicated that this factor was slightly more conservative than using gold weights and bucket volumes without correction factors, and therefore was safe to use.

CAISSON DRILLING
The BADE caisson drill was hydraulically powered and drilled a 36 inch diameter hole. Because of its power, the machine could continue to drive casing through cemented gravel, although there were times when drilling ahead of the casing was required and then the casing was driven down afterwards. Tenor calculations included a swell factor to account for the excess material recovered from the hole.

CORE DRILLING
Diamond drilling utilized four inch core with conventional wireline machinery. In upper and middle gravels an outer casing was set first to maintain the open hole. In unconsolidated ground core recovery was poor, but in consolidated and cemented ground recovery was excellent. Core recovery throughout the lower gravels was 95 percent, and for the overall program it was 84 percent. Tenor calculations were straightforward, simply the weighed gold per volume of core.

REVERSE CIRCULATION DRILLING
The method of reverse circulation drilling chosen was a triple-tube rotary method. A triple tube rig capable of drilling a six inch outer casing into the ground was found to be best suited for the ground conditions of the deposit. The six-inch outer casing was drilled to depths of 300 feet. Dual tube sampling was then conducted inside and below the outer casing through lower gravels to bedrock to depths of up to 500 feet. Tools included four-inch rods and a 5 1/4-inch tricone bit. This equipment was available from Lang Exploratory Drilling of Salt Lake City.

Samples were blown out of the hole through the cyclone as a slurry and into a four compartment skid-mounted sample bin. Each compartment was capable of containing enough sample for a ten foot interval. Samples were removed from the bin into buckets and transported by pickup to a test plant. The volumes were then measured, and the samples processed. Processing consisted of concentrating the sample through a portable trommel and bowl test plant, followed by final recovery of gold at a commercial assay laboratory.

Tenors were calculated as recovered gold divided by recovered volume for each sample interval. If the recovered sample volume was less than the theoretical volume for an interval, then the theoretical volume was used instead of recovered volume, which produced a lower tenor. Low recovered volumes result from mechanical problems such as worn bits, and from drilling soft
clayey ground where the sample gets pushed away from the drill bit rather than being sucked it into it. Through the years drilling results from each of the above types of drilling on the San Juan project have been compared statistically to each other, and it has been concluded that all methods of drilling, sampling and analysis provided suitable and accurate results. This has since been confirmed through actual mining.

MINABLE ORE RESERVES

All four drilling methods have been successfully used in delineating the ore reserve that is currently being mined. Using the test drilling and sampling results, ore reserves for underground mining were developed on cross sections using a cutoff grade of .05 ounce per cubic yard. Reserves, after being audited by Pincock, Allen and Holt, are 2 million cubic yards of ore containing 257,000 ounces of gold. The average grade of the ore is 0.143 oz/cu yd, and the minable channel is 12,000 feet long, 300 feet wide and 16 feet thick.

Two orebodies, termed east and west, exist and are separated by a barren zone 1000 feet in length. The east orebody starts near the eastern edge of the property near North Columbia and extends west for a distance of 6200 feet, and the west orebody extends for 6000 feet in a westward direction.

MINE GEOLOGY

Mining occurs near the base of the lower gravels within 40 feet of bedrock. The geologic units include bedrock and three facies of lower gravel sediments.

BEDROCK

Bedrock varies from decomposed (clayey) diorite to hard diorite and gabbro. In shear zones diorite becomes altered and sometimes contains quartz stringers. Below the bottom of the river channel the diorite is weathered to depths of 30 feet. To the west of the current mine workings slate will be encountered. Because the bottom of the orebody is on bedrock, the floor and some of the ribs in the mine are also on bedrock.

BOULDER GRAVEL

In the lower gravels, three facies are being mined. The oldest facies is a layer of boulder gravel layer that is a light gray conglomerate that was deposited on bedrock and occurs as a discontinuous remnant, having been found in two areas within the mine. It is unconformably overlain by "normal" (younger) boulder gravel and shows deep scours of eight feet where normal boulder gravel has eroded into it. Gravel clasts appear to be of the same lithologies as in the normal boulder gravel. Gold grades are similar to the normal boulder unit. Because it underlies normal boulder gravel, it may be the same layer that exists beneath the
volcanic tuff.

The facies of lower gravels situated between cobble gravel and bedrock is a medium gray boulder gravel conglomerate termed "normal" boulder gravel in this report. This facies is the principal ore zone within the mine and consists of boulders one to three feet in diameter in a hard to soft sandy matrix cemented with calcite or silica. It has about 50 percent gravel and 50 percent sand and silt with 0-5 percent clay. This layer is a channel-fill deposit and may become a channel-lag deposit near the base of the unit. Ore grades range from 1000-70,000 milligrams per cubic yard with the average being 4900, or 0.157 oz per cu yd.

High grade gold lenses situated within this boulder gravel contain concentrations of gold rich enough for underground mining. These lenses are 30 feet wide, several hundred feet in length, and are within ten feet of bedrock. In some areas two or three lenses occur side by side, and usually there is a distance of about 100 feet on strike from the end of one lens to the start of the next. Detailed channel sampling of one lens indicated tenors averaging 15,000 milligrams per cubic yard (0.5 ounce per cubic yard) with zones up to 72,000 milligrams (or 2.3 ounces) per cubic yard.

This normal boulder gravel is dark gray, has a wet appearance, and exists throughout the mine, having been deposited directly on bedrock. It has been scoured by cobble gravel and is unconformably overlain by cobble gravel.

CLAYEY BOULDER GRAVEL
Where the boulder gravel is situated relatively close to the altered volcanic tuff, the clay content and matrix characteristics change substantially such that the sandy boulder conglomerate becomes a clayey boulder gravel, with little cementation. This gravel layer is found on the northeast and southeast edges of the east orebody. The clay content increases up to 50 percent, but generally is between 20-30 percent. The detailed stratigraphic relationships of boulder and clayey gravel are not clear, and it may be a separate, possibly older facies rather than being a clayey sub-unit. While contacts were not seen in the mine, the stratigraphic position is adjacent to boulder gravel and at the same elevation, and suggests that the clayey gravel is an older unit that was eroded through by the boulder gravel orebody. Clayey gravel is ore.

COBBLE GRAVEL
The upper facies is a layer of dark greenish gray well- indurated cobble gravel conglomerate consisting of 50 percent 2-4 inch gravel clasts and 50 percent sand and silt with 0-5 percent clay. It is cemented with calcite and is generally very hard and provides good ground conditions. The cobble conglomerate is a channel-fill deposit that unconformably overlies the boulder gravel ore unit. It is relatively low-grade and mineralization is discontinuous.
Tenors range from 0-15,000 milligrams per cubic yard. One to three feet of this gravel is mined (even when it is not ore) to provide a hard back in the tunnel. The source of gold mineralization in this deposit appears to be reworked boulder gravel. Evidence for this includes the unconformable deposition, and that the gold is present in the base of the cobble gravel near the contact with boulder gravel.

ORE GRADE CONTROL
Ore grade control is accomplished by surface definition drilling with a reverse circulation drill as described above and underground channel sampling. Vertical channel samples are taken along ribs and at the faces in 5 foot intervals using a backhoe, small loader, or air spade, depending on the hardness of the ground. The backhoe is the preferred method. These samples are processed through the test plant using the same procedure as is used when processing drill samples.

Several stopes have been test mined to compare drill-indicated grades and channel sample results to actual production. In addition, the tests provided additional information on orebody dilution and gold recovery. The results indicated that the grade of the ore was 100 percent of the drill-estimated tenors.

ROCK MECHANICS
The cobble and boulder gravel vary from being very hard conglomerates cemented with calcite and silica to less competent, weakly indurated gravel. Ground conditions in hard gravel are good and only needs back support and, in main tunnels, shotcrete. The weaker matrix is caused by an absence of calcite and silica. When soft gravel contains more than 30 percent clay, mining conditions become difficult. Thick sand lenses, sometimes up to 8 feet thick, can cause considerable difficulties and have to be avoided or removed.

Decomposed clayey bedrock conditions also exist and produce a weak foundation for pillars and roads in the mine. In clayey bedrock routine road construction and maintenance become more difficult and the potential for unusual problems such as floor heave must be considered.

MINING METHODS
The San Juan Ridge Mine is being mined underground by conventional room and pillar methods. The mine uses rubber-tired diesel and electric equipment. Access to the mine is through a decline tunnel that is 1800 feet in length, 16 feet high and 16 feet wide. In the orebody two main haulage tunnels are advanced on strike, and crosscut stope drifts are mined to the edge of the ore zone. Retreat mining is followed by backfilling with waste rock.
MINING
Drilling (for blasting) is done with a two-boom electric/hydraulic jumbo that drills holes 12 feet deep. Emulsion explosives are then loaded into the holes and detonated. A two cubic yard track loader loads 11 ton trucks, and eight yard rubber-tired loaders haul ore directly to the underground processing plant. Roof support, required in all drifts, is accomplished by scaling the back and ribs of the drift with a backhoe to remove loose rock, and then bolting wire mesh (cyclone fencing) with 6 to 8 foot rock bolts. Shotcrete is also applied in main haulage tunnels to prevent air-sack.

The mine ventilation system has fresh air being supplied down the decline with two 150 horsepower fans exhausting air up two ventilation shafts. Auxiliary fans are utilized in the stopes as needed.

MINERAL PROCESSING
One of the unique features of the mine is the mineral processing circuit. Gold is contained in the fraction of sediment that is smaller than one-quarter inch size. Ore is hauled to an underground plant that separates gravel from gold-bearing sand using an eight-inch grizzly, a scrubber, and single deck screen (Fig 3). Water is the only agent needed to remove the gold from the sand. The quarter-inch minus ore slurry is then pumped 300 feet to the ground surface and directly into a jig plant where it undergoes three stages of jigging. The concentrates are then transported to the refinery for final processing. The jig tailings are dewatered with a sand screw and the sand tailings are placed in piles on the ground surface, contoured and reclaimed (Fig 4). Slimes are pumped to a settling pond and after clarification this process water is recycled back to the processing circuit in a closed loop system. At the refinery the ore concentrates are tabled twice and final cleanup is done with a rotary spiral wheel. At this point the product is about 95 percent gold, and then it is melted in a furnace and poured into gold bars. The gold is 920 fine.

ACKNOWLEDGEMENTS
The author thanks Tim Callaway, President and CEO, Siskon Gold Corporation, and Dave Lawler, Consulting Geologist, for their comments on this report.

REFERENCES

Lawler, D. A., and Brimhall, G., 1995 (Sept.), Personal communication.
Lindgren, W., 1911, The Tertiary gravels of the Sierra Nevada of California: USGS Prof. Paper 73.


Pease, R. C., and Watters, W. S., 1996, San Juan Ridge gold mine begins production: Mining Engineering, SME Vol. 48 #12


Yeend, W. E., 1974, Gold-bearing gravel of the ancestral Yuba River, Sierra Nevada, California: USGS Prof. Paper 772.
FIGURE 2

TOPOGRAPHIC SURFACE

- 2700'

UPPER GRAVELS

- 2600'

MIDDLE GRAVELS

- 2500'

LOWER GRAVELS

PEBBLE-COBBLE GRAVEL

COBBLE GRAVEL (HARD)

EDGE OF ORE

BOULDER GRAVEL

EDGE OF ORE

GRAVELLY SAND

GENERALIZED N-S CROSS SECTION
IN YEAR 1 MINING AREA
ORE ZONE IN BOULDER GRAVEL

DIORITE BEDROCK
FIGURE 3
UNDERGROUND PLANT
FIGURE 4
SURFACE JIG PLANT

ROUGHER JIGS

SECONDARY JIGS

TERTIARY JIG

CON BIN

9" PIPE

SLURRY FROM UNDERGROUND SCRUBBER PLANT

DISCHARGE CONVEYOR

SAND SCREW

MINUS .25" WASTE

SLIMES PUMPED TO TAILINGS POND

JIG CONCENTRATES TO REFINERY
Geophysical investigations of gold-bearing Tertiary channel gravel in northern Nevada County, California

by H. W. Oliver

Summary

Modern geophysical methods were tested to determine their feasibility for locating high gold values within gold-bearing Tertiary gravel and for tracing Tertiary channels under 200 to 600 ft (30 to 210 m) of volcanic-rock cover. Most tests were made on the ancestral Yuba River drainage in the northern Sierra Nevada because this drainage area contains the largest amount of unmined Tertiary gravel in California. It had previously been estimated that the exposed parts of this drainage system contain gold valued at $2.7 billion (at $500/troy oz.) distributed in 977.5 million yd$^3$ of gravel. The tests were greatly facilitated by extensive drilling and gold sampling done in 1939 by a private company in the North Columbia diggings; this sampling showed that the highest gold values occur in the lowermost 50 ft of gravel near the center or "gut" of the Tertiary channel. This bottom gravel is commonly blue, and because of its higher gold values, it was desirable to find a rapid method of determining its location and depth. In the present investigation, geophysical tests were conducted at the North Columbia, Malakoff, Badger Hill, and French Corral diggings, as well as on the late Tertiary volcanic rocks of San Juan Ridge.

In general, low-grade metasedimentary and metavolcanic rocks form the basement in the northern Sierra Nevada. Plutonic rocks, ranging in composition from granite to gabbro, intrude the older metamorphic rocks throughout the region. Sporadically occurring gold-bearing gravel overlies
the basement rocks and marks the position of early Tertiary river systems; the clasts in these deposits range in size from boulders at the base to granules and sand and clay at the top. A sequence of volcanic sedimentary rocks of varying texture overlies the gold-bearing gravel in places and forms ridgetops between the major drainages.

Seismic-refraction tests to locate channel centers were made at the North Columbia and Malakoff diggings. At the North Columbia diggings, where the channel gravel is 300 to 450 ft (90 to 135 m) thick and drill holes were available for subsurface control, depths to bedrock were computed by seismic-refraction methods at 50- to 100-ft intervals along two lines of drill holes. The seismically computed depths to bedrock along one line of nine drill holes agree, on the average, to within 3.7 percent with the depths determined by drilling; the maximum discrepancy was 5.7 percent. Along a second line of six drill holes, the average discrepancy was 5.0 percent, although one hole (121) had a discrepancy of about 70 percent (190 ft by drilling versus a seismically determined depth of 325 ft). Redrilling in 1968 (hole c) yielded a revised depth of 310 ft that roughly confirmed the seismic interpretation. These results indicate that channel centers can be approximately located by seismic-refraction methods in areas where the gravel is exposed.

The seismic-refraction technique was also tested to locate and trace the centers and breadths of presumed gravel-filled Tertiary channels where they are covered (500 ft) by volcanic rocks. Although the depths to basement could be determined to within an accuracy of 20 percent, it was difficult to recognize channel centers accurately from the seismic data because of the masking effect of lateral variations in the velocities of both the gravel and the volcanic rocks, as determined by sonic logs.
Gravity measurements and reductions, using new miniaturized digitization methods developed for this study, show that Bouguer gravity anomalies in the Nevada City-Alleghany, Calif., area generally decrease toward N.60°E, at about 2.5 mGal/mi (1.6 mGal/km). After removal of this regional gradient, residual gravity highs of 1 to 12 mGal occur over bedrock units known to have higher than average densities, such as amphibolite and diorite. Similarly, residual-gravity lows of 2 to 6 mGal occur over serpentinite, slate, and quartzite.

Smaller gravity lows of 0.8 and 1.4 mGal occur over the 200- and 450-ft-thick deposits of Tertiary gravel at Badger Hill and North Columbia, respectively. Comparisons of drilled depths to bedrock with models interpreted from the gravity data indicate that the gravity method may be used to determine the general form of bedrock configurations beneath the exposed gravel in these areas from a density contrast of -0.27 g/cm³ between the gravel and bedrock. However, a semiregional gravity survey over the bedrock surrounding the Tertiary gravel is required to isolate these gravel-associated anomalies from those caused by intrabedrock density contrasts. Where the Tertiary gravel-filled channels are buried by 200 to 600 ft of late Tertiary volcanic rocks, gravity anomalies of -0.5 to -2 mGal are associated with the Tertiary channels, although these anomalies are difficult to distinguish from those caused by other sources, without some other means of control.

Ground magnetic methods were tested for determining those parts of the Tertiary gravel that contain the most gold by locating detrital magnetite, which is associated with gold in some places. Traverses at the North Columbia upper pit and the Badger Hill and Malakoff diggings showed no significant anomalies; however, traverses in the North Columbia lower pit and near French Corral revealed anomalies of 60 to 100Y over the deepest, richest gravel. Analyses of the black-sand concentrate were not made at French Corral, but at
North Columbia the concentrate was found to consist largely of the relatively nonmagnetic minerals ilmenite and chromite, and a few samples contained abundant magnetite. Thus, these methods offer some promise and deserve further attention.

An aeromagnetic survey of the Nevada City and Alleghany quadrangles, in combination with limited magnetic-property measurements on basement samples, indicates that the argillite and slate of the Calaveras Formation are nonmagnetic ($k \leq 10^{-4}$ emu/cm$^3$) and provide a magnetically quiet basement background at North Columbia. The Mesozoic intrusive rocks are mildly magnetic ($k = 5-10 \times 10^{-4}$ emu/cm$^3$) and thus cause interpretative problems where they underlie the gravel. The aeromagnetic method is highly successful for tracing pre-Cretaceous serpentinite beneath Tertiary gravel and volcanic rocks.

Tests of the electrical-resistivity (ER) method indicated that it is most useful for defining layers and their structure within the gravel. At North Columbia, four distinct layers were found to have resistivities, in descending order, of 6,100, 3,500, 1,000, and 25 $\Omega$ m. The low resistivity of the bottom gravel at North Columbia was confirmed by measurements on exposed basal (blue) gravel at French Corral (30 $\Omega$ m), and later by resistivity logs at North Columbia (10-40 $\Omega$ m). Tests of the ER method were hampered on San Juan Ridge by rough topography. Nevertheless, this method has some advantages over the seismic-refraction method in its ability to detect the effects of the conductive gravel, which is invisible to refracted seismic rays because of velocity inversion. The resistivity contrasts are enormous: they range from about 20 $\Omega$ m for the gravel, through about 150 $\Omega$ m for the volcanic rocks, to more than 500 $\Omega$ m for basement.
The Slingram electromagnetic (EM) method, which is normally used in exploration for highly conductive mineral deposits, was tested in several localities. EM anomalies were detected along the margins of the channel in the lower pit at North Columbia; these anomalies are probably caused by conductive lenses of mud- or clay-rich material commonly deposited near the channel margins. Blue gravel was readily detected where it occurred within range of the Slingram method; in the Badger Hill pit, the approximate depth to the top of the blue gravel is indicated by the EM results. In several localities, EM results showed that the "basement" metamorphic rocks are conductive; one such locality is near the edge of the Malakoff diggings, where the fact that the basement is not an insulator is important in interpreting the ER sounding data.

As regards tests of the induced-polarization (IP) method, clay minerals are known to be present within the Tertiary gravel, in addition to secondary sulfide mineralization in the blue gravel. The presence of these polarizable minerals suggested that the IP method might be useful in locating the gravel, particularly the lower, gold-rich blue gravel. Moderate polarization anomalies were identified with the gravel at each of the diggings surveyed; the largest response was associated with the exposed blue gravel at French Corral. The response of the gravel, however, varies considerably, in view of the additive responses contributed by both clay and sulfide mineralization. Sulfide mineralization of the blue gravel is not high enough to give the gravel a unique signature.

The IP and ground magnetic work at Badger Hill identified coincident positive anomalies on the east edge of the pit that are attributed to bedrock mineralization.
Six churn- and four rotary-bore holes were drilled at North Columbia and on San Juan Ridge, respectively. The purpose of the drilling in both areas was to obtain samples of complete, unmained gravel sections to study their gold-bearing characteristics and vertical distribution, and to check the validity of the geophysical interpretations. In addition, the drilling at North Columbia provided a check on the gold values obtained from earlier (1939) drilling in the same area.

Drill holes A, B, and C at North Columbia penetrated 308 to 455 ft of gold-bearing gravel, and the depths to bedrock confirmed the seismic interpretation. Hole D was drilled at the center of a gravity high; the measured depth to bedrock (27 ft) confirmed the shallow depth estimated from the gravity data. Holes E and F, which were drilled on a 40 percent EM anomaly obtained at 1,800 Hz, revealed a shallow deposit of bentonite with a resistivity of 2 Ohm.

The four rotary-drill holes on San Juan Ridge were located on seismic and gravity anomalies and penetrated 140 to 330 ft of upper-bench-type gravel beneath 500 to 650 ft of andesite breccia. Depths to bedrock ranged from 574 to 880 ft, and bedrock cores were obtained whose measured physical properties facilitated interpretation of the geophysical data. The gold values in the gravel sections were disappointingly low; apparently the four holes were drilled along the margin of the flood plain of the Tertiary channel.

Borehole geophysical logging measurements were made in the four holes drilled on San Juan Ridge and in three of the holes drilled in the North Columbia pit. These measurements, made primarily to obtain control data for some of the surface geophysical methods tested in those areas, also contributed significantly toward understanding the lithologic and mineralogic textural and physical properties in sections of the Tertiary channel gravel.
and related rocks, because only a few core samples were obtained from these holes.

ER, IP, magnetic-susceptibility, and gamma-ray-intensity logs helped to define contacts between the three major geologic units in San Juan Ridge. Responses from some of these logs defined three distinctive ash(? beds within the local breccia penetrated by the four holes. From this information, an average dip of 1°41'W. (15° feet/mile) for these beds was determined. The percentage of the accumulated thickness of clay and (or) silt in the gravel unit penetrated in three of the holes on San Juan Ridge was estimated from the gamma-ray logs. These data suggested that drill hole SJR1 is nearer the channel margin, whereas drill hole SJR2 is closer to the channel center. Crossplots of density and sonic-transit times showed a distinctive grouping for the three major lithologic units that is not evident when their rock properties are compared individually.

The magnetic-susceptibility logs indicated no detectable amounts of detrital magnetite in most of the gravel, a result consistent with observation of an absence of ferromagnetic minerals in the bedrock (possible source rock) in these areas.

The gamma-ray intensity logs indicated that phyllitic slate of the now-abandoned Cape Horn Slate (or similar bedrock type) is a possible source for the radioactive minerals detected in the clay sections of the gravel.

The degree and vertical extent of water saturation in the volcanic breccia and gravel in two localities were determined from the drill logs. In many sections above the main water table, the degree of water saturation is 0.3 to 0.5, and, in some sections, as low as 0.2. The high degree of unsaturation of these rocks strongly influences their electrical, sonic, and bulk-density values. These lateral and vertical variations in saturation,
therefore, contribute to the uncertainty in interpreting the corresponding surface ER, seismic, and, to some extent, gravity data.

The main conclusions of the geophysical tests are that: (1) the seismic-refraction method is best for determining the configuration of the upper bedrock contact beneath exposed gravel, although the gravity and ER methods also are useful; (2) the ER method is best for defining layers within the gravel, whereas the EM method was able most rapidly to locate high-conductivity zones caused by blue gravel where it occurs within about 50 ft (45 m) of the surface, as well as within local deposits of altered tuff (bentonite) preserved near the edges of the channel; (3) the IP method is best for locating mineralization in the bedrock; and (4) ground magnetic methods may help to locate higher gold values within exposed gravel where magnetite is associated with the gold.

Locating and tracing Tertiary gravel beneath volcanic rocks is difficult at best, and the difficulty increases with the thickness of volcanic-rock cover. Although seismic-refraction methods cannot "see" the gravel as such beneath the higher velocity volcanic rocks, the Tertiary channels incised within the bedrock can be detected from rapid horizontal changes in apparent bedrock velocities. Once a measured gravity low has been determined to be associated with a known channel, the gravity method is probably the most economical way to trace the channel.
CHEROKEE HYDRAULIC MINE
BUTTE COUNTY, CALIFORNIA
GEOLOGY AND MINING
By
Scott Creely, Professor of Geology - Emeritus
San Jose State University

INTRODUCTION

The Cherokee hydraulic mine (Figure 1) stands as a striking monument to the determination and energy of California's early-day miners. But the rewards are not only the gold (and occasional diamonds) that have been won. Cherokee's main west face, over 300 feet high and a mile long, reveals details and relationships of the strata here which would have remained largely hidden without the "clean sweep" of the monitors.

Much of the text and most of the photographs are adapted from California Division of Mines and Geology Bulletin 184 (Creely, 1965).

ACKNOWLEDGEMENTS

Ollie Bowen and Mort Turner were good field companions in 1953 and '54, and came through again this time with critical materials and recollections. Bill Beatty shared some interesting ideas about the course of the Cherokee paleochannel under Table Mountain. Finally, Dave Wagner of the California Division of Mines and Geology and Dave Lawler of the Far West Geoscience Foundation helped in several ways.

GEOLOGY

As has been traditional in other parts of the Sierra, the rocks at Cherokee can be divided conveniently into the "Bedrock series" and the "Superjacent series". These are separated by a marked angular unconformity. The "Bedrock series" is a complex of steeply dipping metamorphosed sedimentary and volcanic rocks which have been invaded, in places, by a wide variety of igneous intrusions. In marked contrast, the later "Superjacent series" is a nearly flat lying sequence of undeformed sedimentary and volcanic rocks which have been deposited upon the upturned, deeply eroded edges of the bedrock strata or upon unroofed intrusive bodies (Figures 2,3).
Figure 1. Aerial view of Cherokee hydraulic mine (Sawmill Ravine.) Cherokee in foreground. Paleochannel marked by broad line of tailings at lower left. In background is North Table Mountain capped by Loveroy Formation ("older basalt"). Note large columns of basalt beginning to topple, another on side, and recent rockslide covering old landslide. Camera bears S 25 W. Photo by T.C. Slater, 1964.
GEOLeGIC MAP OF CROVILLE TABLE MOUNTAIN AND VICINITY

BUTTE COUNTY, CALIFORNIA

EXPLANATION

Q - alluvium, landslides, etc. - Quat.
Tt - Tuscan Formation - Pliocene
Ti - Lovejoy Fm. (older basalt) - Mioc.
Tm - Mohrton (?) Formation - Miocene
Tg - "auriferous gravel" - Eocene
Te - Ione Formation - Eocene
Tc - "Dry Creek" Formation - Eocene
99 - "greenstone gravel" - K or E
Kc - Chico Formation - U. Cret.
br - bedrock complex - Pz. / Mz

Figure 2. (modified from Creely, 1965)
### Columnar Section, Oroville Quadrangle, California

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Column</th>
<th>Thickness (Feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holocene</td>
<td>Alluvium, Etc.</td>
<td></td>
<td>?</td>
<td>Sand, gravel, clay, silt, landslides, etc.; mine and dredge tailings.</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Fanglomerate</td>
<td>0–65</td>
<td></td>
<td>Coarse debris from &quot;older basalts&quot; and from Tuscan Formation.</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Red Bluff Formation</td>
<td>0–200+</td>
<td></td>
<td>Reddish-brown conglomerate, sandstone, siltstone.</td>
</tr>
<tr>
<td>Upper Pliocene</td>
<td>Tuscan Formation</td>
<td></td>
<td></td>
<td>Basaltic and andesitic mudflow, tuff, volcanic sandstone, volcanic conglomerate, tuffaceous siltstone and claystone.</td>
</tr>
<tr>
<td></td>
<td>Undifferentiated</td>
<td>0–680</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nomlaki Tuff</td>
<td>0–20</td>
<td></td>
<td>Rhyolite-pumice lapilli tuff.</td>
</tr>
<tr>
<td>Upper Pliocene</td>
<td>Unnamed Rhyolitic Pumice Tuff</td>
<td>0–25</td>
<td></td>
<td>Rhyolite la rhyolite pumice lapilli tuff; exact stratigraphic position uncertain.</td>
</tr>
<tr>
<td>Upper Pliocene</td>
<td>New Era Formation</td>
<td>0–100</td>
<td></td>
<td>Reddish-brown conglomerate, sandstone, siltstone.</td>
</tr>
<tr>
<td>Middle Miocene</td>
<td>Lovejoy Formation</td>
<td></td>
<td>80–250</td>
<td>Basalt: flow.</td>
</tr>
<tr>
<td></td>
<td>(&quot;Older Basalt&quot;)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Miocene</td>
<td>Mehrten (?) Formation</td>
<td>0–200</td>
<td></td>
<td>Andesitic mudflow, volcanic sandstone, conglomerate, tuff.</td>
</tr>
<tr>
<td>Middle Eocene</td>
<td>Ione Formation</td>
<td></td>
<td>0–600</td>
<td>Tuff Formation: white to red quartz sandstone, claystone, siltstone; minor conglomerate, shale, and lignite.</td>
</tr>
<tr>
<td></td>
<td>&quot;Auriferous Gravels&quot;</td>
<td></td>
<td>0–352</td>
<td>&quot;Auriferous gravels&quot;: quartz-chert-pebble conglomerate, quartz sandstone, claystone and siltstone; minor shale, plant fossils locally.</td>
</tr>
<tr>
<td>Lower Eocene</td>
<td>Dry Creek Formation</td>
<td>0–75</td>
<td></td>
<td>Gray, thin-bedded, fossiliferous shale and biotite sandstone.</td>
</tr>
<tr>
<td>Cretaceous or Eocene</td>
<td>&quot;Greenstone Gravel&quot;</td>
<td>0–40+</td>
<td></td>
<td>&quot;Greenstone&quot;: cobble-boulder conglomerate, breccia; minor interbedded fossiliferous sandstone; exact stratigraphic position uncertain.</td>
</tr>
<tr>
<td>Upper Cretaceous</td>
<td>Chico Formation</td>
<td>0–175</td>
<td></td>
<td>Yellowish-buff, massive to thin-bedded, fossiliferous, biotite sandstone; minor pebble conglomerate, shale.</td>
</tr>
<tr>
<td>Jurassic and Older</td>
<td>Various</td>
<td></td>
<td></td>
<td>Low-grade metasedimentary and metavolcanic rocks</td>
</tr>
</tbody>
</table>

(modified from Creely, 1965)
"Bedrock Series"

The bedrock at Cherokee is the “greenstone” of the Oregon City Formation (Creely, 1965). This unit is Upper (?) Jurassic low-grade metamorphosed mafic volcanioclastic rocks. Some pillow lavas also are present.

The Oregon City has been strongly folded. Foliation and sparse bedding stand at high angles to the approximately horizontal erosion surface upon which the “Superjacent series” was laid down.

The basement rocks are quite fresh in many parts of the area, but there is considerable variability. Locally, the meta-volcanics have been altered via intense tropical or subtropical weathering, producing thick lateritic paleosols (lithomarge).

"Superjacent Series"

"Greenstone Gravel"

At the north end of the Cherokee mine, a short segment of an ancient stream channel has been partially exhumed by mining operations and by natural erosion (Figure 4). Over much of this channel, the bedrock is overlain by coarse conglomerate and sedimentary breccia composed largely of cobbles and boulders of “greenstone” identical to that characterizing the underlying Oregon City Formation. These beds, because of their very limited distribution, have not been assigned a formal name. Instead the colloquial but aptly descriptive term “greenstone gravel” is employed. Comparable terms used for similar beds elsewhere in the Sierra are “blue gravel” or “deep gravels”.

The “greenstone gravel”, because it is usually more or less consolidated, better fits the definition of conglomerate or breccia than that of gravel. It is extremely ill-sorted with respect to size (Figure 5). Boulders up to 3 or 4 feet across are very often interspersed with more abundant cobbles and pebbles. Boulders of 6 or 7 feet in maximum dimension are common (Figure 6), and several measuring 15 feet across have been observed. The boulders and cobbles are largely sub-angular, and many of them show incipient rounding. They consist mostly of grayish-green bedded tuff or volcanic sandstone, lapilli tuff, and tuff-breccia, identical in all respects to the underlying bedrock (Oregon City Formation). Cobbles and boulders of vein-quartz are locally abundant. Pebbles and cobbles of quartz and chert and a few of diorite and feldspar-porphry accompany the predominant “greenstone”. At most localities the matrix is quartz-chert-“greenstone”-pebble conglomerate, cemented by calcite or by iron oxide; at others the matrix consists of ill-sorted, olive-green argillaceous, biotitic, lithic sandstone and grit. Bedding in the conglomerate and breccia is usually obscure or lacking altogether (Figure 7), but at a few localities it is well-defined by interbeds of sandstone. At one point in Sawmill Ravine, several beds of dirty olive-green argillaceous, biotitic, lithic sandstone and calcite-cemented lithic grit are intercalated with the “gravel".
Figure 4A
PRELIMINARY GEOLOGIC MAP OF
THE CHEROKEE MINE
BUTTE COUNTY, CALIFORNIA

(mapping by O.E. Bowen, Mort D. Turner, and Scott Creely, 1954)

EXPLANATION

tg - tailings
Qa1 - alluvium
ta - talus
Q13 - landslide
Tb - "older basalt"
wg - white gravels
yel - yellow pebbly clay
Tdc - "dry creek" (?) Fm.
wgg - weathered gg
gg - "greenstone gravel"
ir = irc - "ironstone" crust
img - lithomarge
wbr - weathered bedrock
br - a fresh bedrock

(points "X" & "Y" common to both Figs. 4A & 4B.)
Figure 5. "Greenstone gravel", Cherokee mine.

Figure 6. "Greenstone gravel" resting on irregular bedrock surface. Above pick is 6-foot block of "Greenstone". North end of Cherokee channel.

Figure 7. Early-day miners realizing the futility of seeking paleocurrent indicators, decide to try for gold instead (c.1850's source unknown; only label is: "The first carload, old Cherokee mine, Butte Co....D...G.P.W.").
The "greenstone" cobbles and boulders are usually quite fresh. At some localities, however, especially in the upper part of the channel, they are strongly weathered and have been altered to yellowish-brown or reddish-brown clayey material. The cobble sizes seem to be most severely affected, but even the boulders are encased in "rotten" shells. Lindgren (1911) noted that a "few feet of rotten boulders" lay above the fresh "greenstone gravel", and that they represent "simply decomposed gravels" from the material below. Allen (1929) discussing Lindgren's "few feet of rotten boulders", stated that they are "composed of boulders so decayed and soft that they could not have been transported without disintegrating." The bedrock in the upper end of the channel, unlike that found to the southwest, has been converted to red and yellow, soft, clayey lithomarge which, in places, exhibits relict bedding and cleavage inherited from the original rock. The decomposition of the "greenstone gravel" and of the underlying bedrock are attributed to the deep chemical decay which, as Allen (1929) pointed out, preceded the deposition of the Ione Formation. It follows that the "greenstone gravel" itself must have been deposited prior to the pre-Ione period of chemical weathering.

The "greenstone gravel", because it covered an irregular, hummocky bedrock surface, varies rapidly in thickness from place to place. The maximum exposed thickness, about 40 feet, occurs at the collar of the main drainage shaft in Sawmill Ravine, but since the base is not exposed there, the total thickness may be much greater. At most places, however, the thickness does not exceed 15 feet.

The "greenstone gravel" is overlain by quartz-kaolinite* sandstone and conglomerate of the middle Eocene "auriferous gravels". The contact between the two units was observed on the northwest side of the ancient stream channel described above. There, about a foot of gray, argillaceous sandstone lies above "rotten greenstone gravel", and is gradational with the matrix of the "gravel". The upper few inches of the sandstone are stained orange and are capped by a thin, undulating crust of iron-oxide. The crust is in turn overlain by sandstone and conglomerate typical of the lower part of the "auriferous gravels". The contact is interpreted as a slight erosional disconformity.

That the "greenstone gravel" was deposited in a stream channel is beyond question. It is restricted to a long, southwest-trending, trough-like depression cut into the underlying bedrock. The width of the depression varies between 800 and 1400 feet. It slopes approximately 200 feet per mile southwestward. The upper end has been eroded away so that a projection of the channel toward the northeast passes off into space. The lower end is covered by later sediments. The bottom of the depression has an overall flatness, but in detail is very hummocky, and exhibits such features as fluting and potholes in abundance.

*I use the term Kaolinite as an abbreviation for any member of the Kaolinite-anauxite series. Much of the material so designated in this paper has been called "anauxite" in prior works.
The "greenstone" boulders and cobbles show little, if any, rounding and are composed of material derived from the same bedrock volcanic formation which at present directly underlies the "gravel". This, combined with the unusually large size of the clasts, indicates that the material composing the "gravel" was subjected to very little stream-transportation. Instead, it seems likely that the cobbles and boulders were emplaced in their present positions largely as talus and rockslide material derived from steep hillsides which once rose from the edges of the channel. Bedrock slopes as high as 30 degrees exist today at the edges of the channel, and these may have been even greater when the stream was active. On the other hand, the finer-grained material which now fills the spaces between the clasts—largely quartz sand and pebble-gravel—is no doubt the product of stream transportation and rounding. It may well have been carried considerable distances from highlands lying in the drainage area of the stream and washed into the spaces between the larger clasts. At any rate, it seems doubtful that the two types of sediment were ever transported together for any great distance.

So far as I am aware, no fossils have been found in the "greenstone gravel" at Cherokee. Allen (1929) suggested the possibility that the "greenstone gravel" is correlative with the Upper Cretaceous Chico strata which lie to the west near Pentz. The stratigraphic position of the "greenstone gravel" and the abundance of biotite in the finer-grained sediments interbedded with the "gravel" support this view. On the other hand, the abundance of quartz and chert pebbles in the matrix of the "gravel" could indicate an Eocene age, since quartz and chert are also the dominant materials in the conglomerate of the Eocene "auriferous gravels" and in the few pebbly beds found in the Eocene "Dry Creek" Formation.

"Dry Creek" (?) Formation

At several points in the southern part of the Cherokee mine (Sawmill Ravine) a few feet of alternating thin-bedded argillaceous sandstone and gray shale occur at the base of the Tertiary section. These sediments are biotitic and bear a superficial resemblance to the "Dry Creek" beds on the opposite side of Table Mountain. However, microscopic examination of the sandstone shows that it is much less feldspathic than the typical "Dry Creek" sandstone and that it contains, in addition to biotite, abundant kaolinite. Some of the kaolinite is interlaminated with biotite, suggesting that the kaolinite has formed at the expense of the biotite. In other cases, the kaolinite may be a product of the alteration of feldspar. Kaolinite is found rarely in the "Dry Creek" on the west side of Table Mountain, but is a characteristic mineral of the overlying lone Formation (Allen, 1929). Thus if the beds at the Cherokee mine are actually correlative with the type "Dry Creek" Formation, it may be that the present differences represent a sort of "alteration facies".

"Auriferous Gravels"

The term "auriferous gravels" is used here in a restricted sense to mean the white quartz-rich gravels (and conglomerates) found occupying various paleochannels and other fluvial situations in the western Sierra. Further qualifications are that they are "pre-volcanic", early Tertiary, and are correlative with the lone Formation (in some cases these gravels have been called "proximal lone"; see, e.g., Wood, et al, 1995).
The "auriferous gravels" crop out extensively around the north end of North Table Mountain. They are especially well and continuously exposed in the hydraulic faces of the Cherokee mine. (Figures 8, 9, 10).

The most characteristic lithologic types which make up the "auriferous gravels" are light-colored, loosely consolidated, quartzose sandstone and conglomerate, and varicolored, massive siltstone and claystone. The sandstone and conglomerate are intimately interbedded and frequently grade into one another. These coarser-grained sediments are most often white, light gray or light buff, upon which may be superimposed streaks of orange or yellow iron oxide. Individual strata may be thick-bedded or thin-bedded. Often where thin bedding occurs, cross-bedding is excellently developed. Channeled breaks between two units are common. Most of the sandstone contains scattered pebbles and often grades through increasingly pebbly portions into conglomerate. The conglomerate itself invariably contains a prominent matrix of sand like that with which it is intercalated.

Both the sandstone and the conglomerate are typically quite friable. Yet these loosely consolidated sediments may support steep, nearly vertical faces for a considerable length of time. The weak consolidation may be attributed mainly to the abundance of finer-grained matrix material rather than to the presence of any introduced cementing agent. Locally, certain thin beds are hard and well-cemented by dark red or reddish-brown iron oxide. Under the microscope, irregular patches of siderite are seen to accompany the oxide and appear to have been replaced by the latter.

Grain-size in the sandstone varies from fine to coarse; medium- or coarse-grained types are most common. Individual sandstone beds usually exhibit fair size-sorting if grains alone are considered, but because the sandstone almost always contains significant amounts of silt or clay, or both, as matrix material, the overall aspect is one of poor size-sorting. Also noteworthy is the predominance of angular grains.

By far the most abundant framework mineral present in the sandstone is quartz, which occurs as angular, often "splintery" grains, accompanied by subordinate amounts of detrital chert and feldspar. Pearly white or cream-colored plates of kaolinite ("anauxite") are characteristically present in small amounts (to 5%) in the lower part of the "auriferous gravels", while biotite is the only micaceous mineral of any importance in the upper part of the section. Feldspar is rare or absent in the lower part of the formation but is characteristically present in small quantity in the upper part. Among the heavy minerals, which make up from 1 to 4 percent of the sediment, the dominant opaque minerals are epidote, zircon, and clinozoisite. In one sample from about 150 feet above the base of the formation at Cherokee, a single euhedral diamond was found. The lowest sandstones at Cherokee carry little else besides opaque minerals and euhedral zircon in the heavy mineral fraction. Overall, there is close similarity between the sandstones of the "auriferous gravels" and those of the Ione Formation, which is close at hand to the west.

The conglomerate is made up largely of subrounded to well-rounded pebbles and cobbles of hard siliceous materials—principally white quartz and both light- and dark-colored chert. The clasts range in maximum dimension from a few millimeters to 5 or 6 inches, but the average size in any single stratum of conglomerate rarely exceeds one inch. Almost without exception, the clasts are loosely packed and are set in a matrix of light-colored
Figure 8. Aerial view of Cherokee hydraulic mine, showing "older basalt" and landslides. View S. 85 W. Photo by T.C. Slater, 1954.

Figure 9. West face of Cherokee mine as seen from paleochannel. Tailings piles of greenstone rubble in foreground. On left skyline is cap of "older basalt" (Lovejoy Formation) overlying 350-foot-thick section of "auriferous gravels". Several varieties of mass-movement can be seen. View is Southwest.
Laxey Formation ("Older basalt"); anguair basaltic rubble. **Slight Angular Unconformity**

Unnamed Escanet (?)-beds:
- Sandstone, light buff with orange streaks, thin-bedded and cross-bedded, extremely friable, fine- to medium-grained, angular-grained, quartzose, with clasts of limestone in "black sand" (hornblende, magnetite); thin layers of dark grey, sandy, firm, micaceous biotite, fossil leaf-bearing (see locality no. 13, appendix 6) clay-shale, and lenses, up to 2 feet thick, of light grey, massive, sandy, clayey, compact and firm, biotite siltstone; siltstone at base contains abundant pebbles of chert and quartzite identical to that of underlying unit. Present only locally. 0-11

**Disconformity**
- Claystone, dark grey (weathering to light grey), massive, compact, soft, silty; present only locally. 0-22
- Sandstone, greenish-brown to dark olive, massive, friable, very poorly sorted, fine- to medium-grained, angular-grained, argillaceous, biotite, quartzose (many flakes of biotite are 3 or 4 mm across). 6
- Claystone, blue or mottled blue-grey and red. 6
- Claystone, mottled yellow and grey, grading up into light-grey, soft, shaly, clayey, micaeous siltstone, grading up into grey, soft, slightly silty and micaceous (biotite), plant-bearing clay-shale; may be gradational with overlying unit. 33
- Claystone, mottled orange-brown and light grey, massive, soft, slightly silty, grading up into yellow claystone, grading up into dark grey, plastic claystone interbedded with greyish-brown to dark grey, silty, micaceous, locally sandy, plant-bearing (carbonized) clay-shale; may be gradational with overlying unit. 33
- Siltstone, orange-yellow to reddish-brown, thin-bedded, sandy and clayey, firm; grades into overlying unit. 15-23

**Diastem**
- Sandstone alternating with minor siltstone; light grey to buff, thin-bedded and cross-bedded, friable, medium-grained, angular-grained, very silty, biotite quartz sandstone; pebbles of claystone locally abundant; minor beds of Light grey, thin-bedded, biotite siltstone and thin beds of quartz-feldspar-claystone-pebble conglomerate near base; tends to form vertical baffle (upper clast baffle). 14-22

**Diastem**
- Claystone, mottled brick-red or pale yellowish with greyish white or bluish-grey to solid brick-red, massive, firm, plastic, slightly sandy; unit thickness to north. 42

**Diastem**
- Siltstone, light yellow-siltstone with reddish-brown streaks, thin-bedded, clayey, hard and firm, micaceous (kaolinite). 3-5

**Diastem**
- Sandstone, white to pale buff, thin-bedded and cross-bedded, fine- to medium-grained, angular-grained, poorly sorted (size), friable, firm, argillaceous, biotitic (with minor kaolinite), quartzose; some pebbly beds; green clay-partings near base; tends to form vertical baffle (lower clast baffle). 0-8
- Sandstone and conglomerate, interbedded, approximate ratio of 2:1: cut-and-fill, cross-bedding common; few thin beds of siltstone; white to light grey (locally orange or pale lavender stained), thin- to medium-bedded, moderately well-sorted (size), fine- to very coarse-grained, angular-grained, extremely friable to firm, argillaceous in part, kaolinitic (biotite at top) quartz sandstone; white, crudely bedded, friable, fairly well-sorted (size) pebble conglomerate (pebbles well-rounded to sub-rounded and consist of white quartz (30-90%), chert (10-50%), and white chertstone (0-30%); matrix is prominent to predominant and is identical to sandstone described above; grades into overlying unit. 159

**Conformity**
- "Dry Creek" (?)-Formation: sandstone, shale, claystone, minor lignite; thin-bedded alternating succession: light-grey to white, thin-bedded, fine-grained, angular-grained, fairly well-sorted, friable, argillaceous micaceous (biotite, kaolinite) quartz sandstone with thin clay-shale partings and scattered fossil plant fragments (grasses); dark grey to dark grey, firm micaceous (abundant kaolinite) clay-shale to light grey, massive, locally shaly, firm, compact, even-textured, slightly micaceous claystone. Very local distribution because of disconformable position on bedrock. 0-6

**Profound Angular Unconformity**
- Bedrock: Oregon City Formation ("greenstone"); slightly metamorphosed tuff, tuff-breccia, volcanic sandstone and conglomerate of Mississippian age; deeply weathered locally

Figure 10. MEASURED STRATIGRAPHIC SECTION OF "AURIFEROUS GRAVELS" AND RELATED UNITS AT CHEROKEE MINE

(section measured at west face of mine at point approximately 2500 feet southwest from Sugarloaf by O.F. Bowen and Mont D. Turner, then with California Division of Mines and Geology, and Scott Creely, 1954)
quartz sand like that described above. White quartz usually constitutes at least 50 percent of the pebbles and cobbles, and in many instances reaches 80 or 90 percent. Chert may make up 10 to 50 percent of the clasts. Pebbles of firm white or yellow claystone commonly accompany these more resistant types, and locally may constitute 20 percent of the pebbles.

Variegated claystone and siltstone are abundant in the "auriferous gravels". Much of the upper part of the section consists of pelitic types, and thin, lenticular strata of claystone or siltstone are commonly intercalated with the coarser grained sediments in the lower half of the "gravels". The colors most often observed in the pelitic sediments are white, light gray, and yellow. Mottled color-combinations, such as brick-red and blue-gray, brown and gray, or red and cream-white, also occur frequently. Most of the claystone is massive and quite compact and, when dry, breaks into blocky fragments.

Much of the claystone is markedly similar in appearance to the residual claystone or lithomarge upon which the "gravels" frequently rest. Undoubtedly some, and perhaps most, of it represents material reworked directly from the residual clays. Where detrital claystone lies at the base of the section it is easily mistaken for residual clay, and may be distinguished only by its content of scattered angular sand grains. An interesting type of detrital claystone occurs at several localities on the northwest edge of the Cherokee channel. It is pebbly and has a crude, subparallel fissility. Close examination shows that the fissility is due to the presence of slabs of bedrock which have been converted to clay and in which an original slaty cleavage is still recognizable.

At many localities, the "auriferous gravels" rest directly upon, and have preserved, a deeply decayed bedrock surface. Without doubt, the alteration of the bedrock can be attributed to the pre-lone period of deep chemical weathering or partial laterization which Allen (1929) postulated to account for similar features seen in other parts of the Sierra. The general effect of the pre-lone weathering in this area has been the production of a variegated clay or clay-like rock which presumably represents that part of the lateritic profile known as lithomarge. At a few places, true laterite may be present. One such occurrence is in the head of Sawmill Ravine, near Campbell Flat, where a small clearing is underlain by dark red pisolithic clay. On the other hand, transitional stages between lithomarge and fresh bedrock are frequently found. The lithomarge varies widely in color, but is usually white or some shade of yellow or red. Mottled combinations of various colors are common.

The surface of the lithomarge at Cherokee is often capped by a hard, flaggy reddish-brown crust of iron-oxide (Figure 11). The crust may have a thickness of several inches. It usually contains scattered angular grains of quartz and in some places cements the lowest part of an overlying conglomerate or sandstone. The "iron crust" (sometimes called "ferricrete") may be related to the process of laterization, or may have been formed by precipitation of the necessary materials after the lithomarge had developed and been buried by later sediments. Similar crusts are found on various strata of the "auriferous gravels", and it is possible that not all of the "iron crusts" are of an identical origin.
An interesting example of the crust occurs in the southern part of Sawmill Ravine. There, a series of small terraces or benches, cut in both residual and reworked lithomarge, has been exposed by hydraulicking and natural erosion. The fronts of the terraces trend slightly east of north and slope toward the west as much as 60 degrees. They have presumably been cut by stream- or wave-action. The terraced surface is coated with "iron crust" which in turn is partly buried by sediments of the "auriferous gravels" (Figures 12, 13). Similar crusts are "perched" in the overlying sediments.

The maximum exposed thickness of the "auriferous gravels" in this area is approximately 350 feet. The formation is in onlap contact with a west-sloping bedrock surface so that its thickness rapidly diminishes toward the northeast. A small part of the marked thinning is due to the slight angular discordance which exists between the "auriferous gravels" and the overlying "older basalt", but most of it can be attributed to the slope of the bedrock surface.

At least three well-defined stratigraphic breaks occur within the "auriferous gravels" section at the Cherokee mine. All of these breaks are marked by laterally consistent undulating sheets of "iron crust", similar to those described above. They are not restricted to individual beds but transect true bedding and appear to lie on irregular, channeled surfaces. The "iron crusts" occur at breaks between sediments of different porosity and permeability, such as an interface between sandstone and claystone. In almost all cases, the less permeable material lies below the crust. Presumably the "iron crusts" consist in large part of iron oxide that has been carried in waters which percolated through a permeable medium and was precipitated at or near the interface with a material of lower permeability.

At one point in the Cherokee hydraulic mine, the uppermost claystone of the "auriferous gravels" is overlain by about 15 feet of pale buff thin-bedded, cross-bedded quartz sandstone. Unlike the sandstone of the underlying section, this sandstone is quite well sorted and free of argillaceous matrix material. It may represent the accumulation of grains reworked and washed free of clay from some of the underlying auriferous gravels. Because of the very limited extent of this unit, it was not mapped separately or assigned a formational name. Thin partings of dark gray clay-shale near the base of the sandstone contain abundant fossil leaves of probably Eocene age.

Many workers have stated their belief that the Sierran "auriferous gravels" or a part thereof are equivalent to the lone Formation. Reference to the "auriferous gravels" as "proximal lone" has already been noted. Allen (1929) showed conclusively that the "mineral composition of the white quartz gravels [of the "auriferous gravels"] is similar to the lone, and the gravels were deposited by the same streams which laid down the delta deposits of the lone". In the vicinity of Oroville Table Mountain, the "auriferous gravels" and the lone occupy an identical stratigraphic position, are laterally continuous, and contain, in part, mutually identical lithologic types. The contact between the two units as shown on the geologic map (Creely, 1965) is vague and arbitrary and represents at best the mean position of a very gradual change from the generally coarser-grained sediments of the "auriferous gravels" into the dominantly finer-grained sediments of the lone.
Figure 11. Terraced lithomarge surface overlain by "iron crust". South end of Cherokee hydraulic mine. Two terrace levels are visible. View is to southwest.

Figure 12. Terraced lithomarge surface overlain by "iron crust". View northwest. South end of Cherokee hydraulic mine.

Figure 13. Terraced lithomarge surface overlain by hard, flaggy "iron crust". Two terrace levels are visible. South end of Cherokee hydraulic mine.
The youngest rocks lying beneath the "Auriferous gravels" belong to the "greenstone gravel" in the northern part of the Cherokee hydraulic mine and the "Dry Creek" (?) in the southern part of the mine. But because of the irregularity of the underlying bedrock surface, both of these units are rather limited in distribution and neither occurs over a wide area. The contact between "Dry Creek" (?) beds and "auriferous gravels" was directly observed at only one locality and appears to be sharp but conformable. The contact between the "greenstone gravel" and the "auriferous gravels", as mentioned above, is apparently a slight disconformity. At many places the "gravels" rest directly upon bedrock, and the contact is a profound angular unconformity. In detail the bedrock surface is quite irregular, but in broad aspect it slopes gradually westward, and in several places the beds of the "auriferous gravels" sharply onlap this surface (Figure 14).

The "auriferous gravels" are overlain with slight angular unconformity by the "older basalt", which forms the broad, flat-topped eminence of Table Mountain. The contact is essentially planar and dips a few degrees toward the west-southwest. The relation between the two formations is best seen at the Cherokee hydraulic mine. Several units at the top of the "gravels" section, present on the west side of the mine, are missing on the east side of the mine (e.g., below Sugarloaf), so that the "gravels" appear to be gradually overlapped toward the east.

The earliest sediments of the "auriferous gravels" represent fluviatile deposition in stream channels which may have existed for a considerable length of time. At Cherokee, the "auriferous gravels" initially accumulated in the same channel in which the "greenstone gravel" had been previously deposited. To the southwest, contemporaneous deltaic sediments accumulated at the mouth of the various streams, forming the deposits of the Lone Formation. As sedimentation progressed, successively younger sediments were spread out on a broadening flood plain, and the identity of the original channels was gradually lost.

Fossil leaves were collected by me at two localities in the Cherokee hydraulic mine (Creely, 1965). The older of the two assemblages is near the base of the "auriferous gravels" section, while the younger is in the unnamed beds at the top of the section. The leaves were identified by Professor Ralph W. Chaney of University of California, Berkeley. The older assemblage was classified as "no older than middle to upper Eocene", and represents a "warm temperate or subtropical climate". The upper horizon was also suggested to be "middle to upper Eocene."

**Lovejoy Formation ("Older Basalt")**

Oroville Table Mountain forms a conspicuous landmark in central Butte County. The mesa owes its topographic form to the presence of a nearly flat lying, highly resistant cap of black dense basaltic lava, referred to as the "older basalt". This unit now is generally correlated with the Lovejoy Formation (Durrell, 1959). I believe that this is likely a correct interpretation, but there are some discrepancies regarding ages that have not yet been resolved.
Outcrops of the Lovejoy cover approximately 12 square miles in the Oroville area. The lava is exposed on North and South Table Mountains as a relatively thin, undeformed plate dipping gently west-southwest (10°-20°). A small disconnected part of the basalt underlies Sugarloaf, near Cherokee.

The Lovejoy is typically a black, hard, microcrystalline to extremely fine-grained, more or less equigranular basalt. In most localities it is sparingly vesicular, but vesicles may be locally abundant (to 30%). In hand specimens, the basalt typically appears nonporphyritic; usually the only primary mineral distinguishable with the hand lens is feldspar, present in abundance as microlites. Phenocrysts laths of plagioclase, up to 3 or 4 mm in length, are rarely visible.

As seen in thin section, typical specimens of the Lovejoy are slightly porphyritic, with scattered phenocrysts of plagioclase (An43-An87), and sometimes of augite, set in a hypocrystalline groundmass of variable character. In some specimens, the groundmass carries abundant microlites of plagioclase and is feltly to trachytic, with intergranular augite, olivine, and magnetite and some intersertal black or green basaltic glass. Where phenocrysts of augite occur, a subophitic texture may be developed. In other specimens, a base of opaque black glass constitutes as much as 50 percent of the rock, and the texture is then intersertal to hyalophitic.

A chemical analysis of the "older basalt" from Oroville Table Mountain was published by Turner (1894, p. 491). It is presented with the normative composition in the table below.

### Chemical analysis and normative composition of "older basalt" from Oroville Table Mountain.
(Turner, 1894, p. 491; Washington, 1903, pp. 320-321)

<table>
<thead>
<tr>
<th>Element</th>
<th>Analysis</th>
<th>Normative composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>39.56</td>
<td>or</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>13.97</td>
<td>en</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>2.53</td>
<td>ol</td>
</tr>
<tr>
<td>CaO</td>
<td>10.20</td>
<td>ol</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.45</td>
<td>ol</td>
</tr>
<tr>
<td>MgO</td>
<td>4.22</td>
<td>ol</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.43</td>
<td>ol</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.77</td>
<td>ol</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.77</td>
<td>ol</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.39</td>
<td>ol</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.22</td>
<td>ol</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.01</td>
<td>ol</td>
</tr>
<tr>
<td>CaO</td>
<td>0.22</td>
<td>ol</td>
</tr>
<tr>
<td>MnO</td>
<td>0.02</td>
<td>ol</td>
</tr>
<tr>
<td>SrO</td>
<td>0.02</td>
<td>ol</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.02</td>
<td>ol</td>
</tr>
<tr>
<td>Total</td>
<td>99.11</td>
<td></td>
</tr>
</tbody>
</table>

*Analyst: W. F. Hildebrand.*

[Page 18]
The upper part of the Lovejoy is a massive columnar-jointed lava. The lower part is seldom directly observable due to the presence of a thick accumulation of talus from the upper part. In several places where it is not covered, however, such as at the Cherokee mine, the lower part of the lava is seen to consist of non-columnar basalt which has broken into angular blocks.

The Lovejoy in most of the area rests, with slight angular unconformity, on several of the older Tertiary formations. On the east side of North Table Mountain the lava overlies bedrock with marked angular unconformity. The youngest rocks directly underlying the basalt are the fragmental andesite and volcanic sediments of the Mehrten (?) Formation. The basalt overlaps the andesitic rocks to the east and north, and over most of North Table Mountain it rests on Eocene strata. The thickness of the “older basalt”, where it has not been affected by later erosion, is fairly uniform. It is thickest on South Table Mountain, where about 250 feet of lava are exposed. The average thickness in other places is 175 or 200 feet. This overall uniformity of thickness shown by the basalt indicates that the flow was poured out upon a rather even plain.

Determination of the age of the Lovejoy Formation, or “older basalt”, has been problematic. I regarded it as being lower Pliocene (Creely 1955, 1965), based on stratigraphic considerations. However, Durrell (1959, 1959 a) believed the Lovejoy to be upper Eocene or lower Oligocene.

Dalrymple (1964) obtained a K-Ar date of 23.8 m.y. (24.4 per 1977 constants) (lower Miocene) on a dacite within the Mehrten (?) section at South Table Mountain which underlies the Lovejoy. Dalrymple also published a date of 22.2 m.y. from strata above the Lovejoy near Blairsden, in Plumas County. Dalrymple concluded that the Lovejoy Formation is lower Miocene (Arikareean).

Wagner and Saucedo (1990) published data that support Dalrymple’s early Miocene date on the dacite tuff at South Table Mountain. In addition, they cited a date of 14.38 ± 0.29 m.y. on an andesite clast in Mehrten (?) deposits stratigraphically below the Lovejoy (but above the dacite tuff). They concluded that the Lovejoy Formation (“older basalt”) at Oroville Table Mountain is mid Miocene, which seems reasonable to me.

MINING AT CHEROKEE

Gold may have been discovered at Cherokee as early as 1849, but steady mining dates definitely to 1854. The town of Cherokee did not appear on maps as late as 1857. Yet it was there, as a large settlement, by 1862 (Gudde, 1975). By 1870, around 7,000 souls called Cherokee home. The U.S.G.S. Chico sheet (1: 125,000) of 1895 schematically showed Cherokee as being even larger than Oroville. In its heyday, Cherokee boasted a post office, a hotel, and an assay office. The number of saloons and other places of diversion is not recorded.

Until 1858, the surface was worked by individual locators on 100-foot-square claims, successively by rockers, long toms, and finally sluices. After that time, the work was exclusively hydraulicking (Irelan, 1887) (Figure 15). Two companies had large holdings in the area (Figures 16, 17). The north part of North Table Mountain, including the upper
Figure 14. "Auriferous gravels" in onlap contact with bedrock (lithomarge). Cherokee mine.

Figure 15. Hydraulic mining at Cherokee in the late 1880's (photo from Hammond, 1889).
slopes of the west side of Sawmill Ravine, belonged to the Cherokee Flat Blue Gravel Company. The lower slopes of the west side and all of the east side, plus the Cherokee paleochannel, were in the hands of the Spring Valley Hydraulic Mining Company (Preston, 1893).

The operations of 1858 and onward were necessarily limited because they drew on a very small watershed, something around 10 square miles. In 1870, a bold plan to relieve this situation was instituted. A complex system of canals and pipes was emplaced to import water from the Concow Valley, some 6 1/2 miles distant. The centerpiece was an inverted siphon of iron pipe, 30 inches in diameter and 2 1/2 miles long, and with a deflection of over 900 feet below grade, which moved the water across the gorge of the West Branch of the Feather River.

Resistance to hydraulic mining in California, led especially by Central Valley farm interests, steadily increased through this period. Key judicial decisions were forthcoming in 1883, and by 1890 most of the Sierran hydraulic mines had shut down. Cherokee was one of the few, if not only, exceptions, since the operators there had purchased considerable acreage downstream on which to dispose of debris. Thus, hydraulic mining there continued until 1915. Since that time, mining has been almost exclusively underground (Figure 18).

Records provided by the U.S. Bureau of Mines, Sacramento, indicate total production from 1888 to 1966, inclusive, to have been 51,364 fine ounces of gold and 719 fine ounces of silver.

Part of the lure of the Cherokee mine is the fact that more diamonds have been found here than in any other place in California. The first diamonds were found in 1852 or 1853 (Hill, 1972). Between 400 and 500 stones have been recovered, the largest being one found in 1868 that tipped the scales at six carats (Clark, 1970; Hill, 1972).

![Figure 16. Oroville Table Mountain and vicinity, early 1890's (map after Preston, 1893).](image-url)
Figure 17(A). Detailed map of Cherokee mine area in early 1890's. Note that north is toward bottom of map. Note that Cherokee paleochannel is labeled "old workings". Large unlabeled parcel on top of Table Mountain was held by the Cherokee Flat Blue Gravel Company (map from Preston, 1893).

Figure 17(B). Modern topographic contour map of same area and same scale for comparison (U.S.G.S. Cherokee 7 1/2 -minute quadrangle, 1972, advanced edition).


Ireland, W., 1887, Spring Valley hydraulic mine: Calif. State Mining Bureau, Sixth Rept. State Mineral., pp. 24-25.


NCGS - NORTHERN SIERRA NEVADA REGION
GEOLOGICAL FIELD TRIP GUIDEBOOK

PART I

ECONOMIC GEOLOGY

NORTHERN SIERRA NEVADA

BASE METAL DEPOSITS
GEOLOGY AND MINERALIZATION OF THE LIGHTS CREEK STOCK,
PLUMAS COUNTY, CALIFORNIA

by

Lester O. Storey

Abstract

The Lights Creek stock is located in northern California about 100 miles northwest of Reno, Nevada. It is within the Sierra Nevada physiographic province near its juncture with the Cascade and Basin and Range provinces. Structurally it is closely associated with Basin and Range-type features. The area is thought to lie within the influence of the Walker Lane structural lineament and may also be affected by the eastward projection of the Mendocino fracture zone.

The Lights Creek stock is of Late Jurassic to early Eocene age and was emplaced as a differentiated satellite of the Sierra Nevada batholith. The stock hosts at least three large porphyry-type copper-bearing zones. These zones are at the site of the old Superior mine and at the newly discovered Sulfide Ridge and Moonlight Valley areas. Geologic reserves at a 0.2% copper cutoff for the Moonlight Valley are estimated at 250 million tons of 0.35% copper. For the Superior mine, the reserves are approximately 100 million tons of 0.33% copper. An undetermined large tonnage of low-grade material in the Sulfide Ridge area is estimated to grade approximately 0.25% copper.

Petrographic studies indicate that the stock is of heterogeneous composition with a granodioritic center grading outwardly to a granitic periphery. The peripheral areas of the stock are also shown to be more fractured, exhibit the most copper mineralization, and have a higher content of potassium feldspar.

There is a most striking association of copper sulfides occurring with tourmaline as intergrowths in veinlets and disseminations. The abundant tourmaline suggests a late pneumatolytic vehicle for at least some of the ore.

There is a lack of characteristic alteration zonal patterns in the Lights Creek deposits. Alteration assemblages of minerals are present locally and occur overlapping in the ore areas: however, strong and discrete zonation is not apparent. The low sulfur content in the ore zones, as well as the possible contribution of late pneumatolytic copper to the ore zones rather than abundant hydrothermal ore, may account for the unusual mineral assemblages at Lights Creek.

It is suggested that the Lights Creek-type of copper occurrences are not easily recognized because of their unique mineral assemblages and that these low-grade types with relatively fresh appearing outcrops could become the orebodies of the future.

Introduction

The Lights Creek stock is located at the northern limit of the Plumas County copper belt in the Diamond Mountains (Fig. 1). The copper belt is about 16 miles long and has a northwesterly trend. It is defined by the Walker mine at the south and the Engels and Superior mines at the north. Numerous other smaller mines and copper showings occur scattered within the zone. The Walker mine, largest of the producers, recorded more than 80 million pounds of copper during about half of its active life between 1922 to 1930 (Smith, 1970). The Engels and Superior mines were jointly operated by the Calaveras Engels Mining Company during the years 1916 to 1930. Production from both of these mines was about 161.5 million pounds of copper recovered from 4.5 million tons of ore (Smith, 1970). This indicates an

1 Placer Amex Inc., San Francisco, California 94111
Fig. 1. Location map of the Lights Creek copper deposit
Fig. 2. Geologic map of California—from U.S.G.S. Map 1-512
average recovery grade of 1.79% copper. The Superior mine is within the southern boundary of the Lights Creek stock, and the Engels mine is in a gabbroic complex just east of the stock.

Some notable figures in American geology, including Turner, Diller, Tolman, Rogers, Graton, D. H. McLaughlin, C. A. Anderson, and A. Knopf are associated with early investigations of the Engels and Superior mines. Knopf and Anderson (1930) published one of the latest and most definitive accounts of the geology. Additional work by Anderson (1931) and Knopf (1933) was further contributions to the geologic knowledge. The areal mapping of the area by Anderson and the ore deposit geology by Knopf and Anderson provided the foundation for the Placer Amex geologic work. More recently, Smith (1970) and Putman (1972, 1975) have made significant contributions to the knowledge of the distribution of base metals within the stock.

American Exploration & Mining Co., now operating as Placer Amex Inc., began a regional study of the Plumas County copper belt in 1962. Underground workings at the Superior mine were visited and intravene wall rocks were noted to be mineralized. Subsequent sampling of crosscuts indicated large zones of >5% copper. Subsequent geochemical and geologic work delimited the strongly anomalous copper-bearing monzonite stock.

Description of the Lights Creek Quartz Monzonite Stock

The Lights Creek stock has a surface area of about seven square miles (Fig. 3). It is thought to have been formed as one of a complex series of multiple intrusive satellites of the Sierra Nevada batholith. It intrudes low-grade metamorphosed Jurassic-Eocene formation and sedimentary rocks. The main Sierra Nevada batholith, east of the stock in the vicinity of Honey Lake, has been dated by the potassium-argon method as in the range of 97.4 to 101 m.y. (Everden and Kistler, 1970). Nonmarine, gently dipping Eocene sedimentary rocks cover some northwestern portions of the stock, and they correlate with Diller's (1908) auriferous gravels of the same age. Therefore, the age of emplacement and subsequent mineralization of the stock is considered to be within the interval of Early Cretaceous to Paleocene. Most likely the age of mineralization would be closer to the intrusive age and would approximate 100 m.y., thus having the same general age as the copper deposit at Yerington, Nevada.

Early work by Anderson (1931) has defined five distinct Sierra Nevada batholith differentiates in the Lights Creek area. These are, in order of their emplacement from oldest to youngest:

1. Engels mine gabbro (main host to high-temperature Engels mine copper deposit).
2. Quartz diorite (also host to Engels mine ore).
3. Granodiorite (main batholith, nonmineralized).
4. Quartz monzonite (host to porphyry-type copper occurrences of intermediate temperature).
5. Coarse-grained granite (non-copper bearing with rare molybdenum occurrences).
The quartz monzonite is the most heterogeneous in overall make-up of any of the segregated intrusive bodies. The overall aspect of the quartz monzonite is one of angular blocky outcrops (Fig. 4). These outcrops form conspicuous cliffs in the area (Fig. 5).

A study of the Lights Creek stock by Juillard (1976) deals with the complex chemistry of the stock. He examined thin sections and polished sections, including samples taken from underground workings and drill core. By plotting the potassium feldspar to plagioclase feldspar ratio at various sample points and contouring the values he described several compositional zones within the stock. These zones range according to their modal analysis from granite through quartz monzonite to granodiorite (Fig. 3). He further points out a strong relationship between the potassium-rich areas of the stock and the better copper mineralization.

The chief minerals of the stock are plagioclase, K-feldspar, hornblende and soda amphibole, quartz, tourmaline, epidote, magnetite, and limonite with minute amounts of chalcopyrite, bornite, and pyrite. The rock is equigranular, fine to medium crystalline with few coarse crystalline zones. Aplitic and porphyritic textures are also recognized locally, especially in the Moonlight Valley area. Overall, the rock is weakly magnetic but in localized areas magnetite can be abundant, especially in the mineralized zones. Table 1 shows the...
Fig. 4. Quartz monzonite showing angular blocky outcrops


Table 1. Lights Creek Stock—After Juilland (1970)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-feldspar</td>
<td>56.2</td>
<td>20.4</td>
<td>32.9</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>42.0</td>
<td>23.0</td>
<td>31.4</td>
</tr>
<tr>
<td>Quartz</td>
<td>43.2</td>
<td>18.1</td>
<td>21.4</td>
</tr>
<tr>
<td>Totals</td>
<td>94.7</td>
<td>80.5</td>
<td>85.7</td>
</tr>
<tr>
<td>Mafics</td>
<td>27.7</td>
<td>0.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Metallics</td>
<td>12.2</td>
<td>0.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Mapping in the stock area has shown three dominant structural trends, which are northwest, northeast, and north-south (Fig. 3). Mineralization is most commonly associated with the northeast and north-south structural directions. Northwest structures commonly enhance the mineralization and/or cut it off.

Copper Mineralization in the Stock

The Lights Creek stock appears to be unique in the area in that it hosts porphyry copper-type mineralization. Putman (1975) shows by statistical analysis that copper mineralization has been introduced on a large scale and that it is not merely a small-scale segregation of magmatic-stage constituents. He further suggests a largely magmatic source for the metals in the stock.

At least three zones of copper mineralization have been delimited, two of which contain economically significant grades of copper. Over 200,000 feet of diamond drilling and 3,550 feet of rotary drilling have helped to define these zones. The site of the old Superior mine is the southernmost of the areas, having an estimated geologic reserve of 100 million tons of 0.33% copper at a 0.2% copper cutoff. The Moonlight Valley deposit, 1.9 miles northwest of the Superior deposit, is estimated to have a geologic reserve of 250 million tons grading 0.35% copper at a 0.2% copper cutoff. The Sulphide Ridge area, 1.7 miles northeast of the Superior mine, indicates an undetermined large tonnage of material, which could average 0.25% copper.

These three major mineralized zones occur entirely within the quartz monzonite stock near its contact with the older intruded rocks. Each of these areas show a greater degree of fracturing than elsewhere within the stock. Mineralization is found as disseminations and fracture fillings. Juilland (1970) has postulated at least two generations of copper mineralization. The first is of magmatic stage origin no later than pneumatolytic, while the second is of hydrothermal origin and has taken place after crystalization of the stock when fractures were formed and sustained.

Alteration of the Quartz Monzonite

Typical porphyry copper-type alteration zoning as illustrated by Lowell and Guilbert (1970) is nonexistent. Recognizable hydrothermal alteration of the Lights Creek deposits is unimpressive compared with that accompanying most porphyry copper deposits in the southwestern United States.
Of the three mineralized zones, the Moonlight Valley deposit resembles other porphyry systems. However, sericitic and argillitic alteration occur most typically only in the fracture zones and not pervasively throughout the rock. Chlorite is apparent at each of the mineralized areas and has formed at the expense of some of the ferromagnesian minerals. Although the stock is more potassium-rich in the Moonlight area, Juillard (1970) considers only the K-feldspar that occurs in veinlets to be positively hydrothermal and that which occurs as disseminations to have formed during crystallization of the magma (Fig. 6). If this is correct, potassic alteration would also be considered as minimal. However, the nearly complete absence of primary biotite in the stock has led Juillard to further conjecture that it may have been completely destroyed by late deuteric alteration from K-feldspathization and he cites the work of Hemley (1959) and Rutherford (1969) to support this hypothesis.

Tourmaline is the most remarkable mineral associated with the copper deposit. It is found principally as the iron-rich dark variety, schorlomite, in both fracture vein fillings and as sunburst blebs throughout the rock. Interesting intergrowths with bornite and chalcopryite are often associated with both forms of tourmaline (Fig. 7). Quartz commonly occurs with tourmaline in the mineralized veinlets. Epidote occurs throughout the stock in patches and veins and is particularly abundant within the zones of sulfide mineralization. It appears to increase in density closer to the contacts with the intruded rock or where xenoliths are abundant in the quartz monzonite.

Pyrite is relatively scarce in the Lights Creek stock. The predominant sulfides of the system are chalcopryite and bornite. Magnetite and hematite are present as disseminations and in veins. However, hematite, generally occurring as specularite, is much more prominent in the Moonlight Valley area than magnetite. Specular hematite appears to be more pervasive on the southwest end of the Moonlight Valley deposit where it plunges under the older volcanic cover. This occurrence may represent a flooding front of iron out from the copper mineralized center into the overlying volcanic rock. The absence of pyrite and abundance of hematite at Moonlight Valley is evidence of a low sulfur environment and probably would account for the lack of supergene clay alteration.

Copper Occurrences

Moonlight Valley Deposit

The main ore minerals occurring in the Moonlight Valley deposit are bornite and chalcopyrite with lesser amounts of covellite and chalcocite. Important gangue metallic minerals found with the ore are magnetite, hematite, and lesser amounts of pyrite. Nonmetallic vein minerals accompanying the copper mineralization are quartz, tourmaline, siderite, dolomite, calcite, epidote, chlorite, and rarely actinolite. Typically, there are centers with best copper mineralization which show abundant bornite and minor amounts of chalcocite. As the grade decreases, chalcopryite increases and bornite decreases. Farther away from the...
high-grade centers, the appearance of increased pyrite indicates even lower grades. Chalcopyrite occupies an intermediate position and perhaps makes up the greatest bulk of the ore. The chalcopyrite, with few exceptions, is believed to be hypogene. Under the microscope it appears to form exsolution textures with bornite and to replace bornite (Bryner, 1972). Bornite and chalcopyrite also commonly exhibit exsolution features (Bryner, 1972).

Other minerals occurring in very minor amounts are pyrrhotite, molybdenite, sphalerite, galena, tetrahedrite-tennantite, and luxonite. None of these minerals contributes economically recoverable metals with the exception of possibly the tetrahedrite-tennantite, as silver values for the deposit average 0.1 oz per ton.

Very little supergene enrichment has occurred at the Moonlight Valley deposit. Surface exposures and the tops of some holes show meager oxidation and leaching with limited limonite, manganese oxides, malachite, azurite, chrysocolla, and native copper. Sparse scotty chalcopyrite is found in some holes but certainly does not express a significant enrichment to the orebody.

Although it is difficult to map structure in the Moonlight Valley area because of lack of surface outcrops, it is quite evident from drillhole information that the better copper mineralization is closely associated with a higher degree of shattering and fracture fillings. Strong structural control for the ore is very apparent. The deposit is broadly arch shaped, conforming to a domelike feature with a long dimension northeast-southwest (Fig. 8). From a limited few deep drill holes it is indicated that the orebody has several roots, with the largest and most persistent under the volcanic cover to the southwest. Geologic surface mapping has suggested a dome in the older volcanics conformable to both the Superior mine and the Moonlight Valley ore zones. Bryner (1972) postulated the occupancy of these domal structures by local apophyses into the roof by the stock. This would mean that these deposits are positioned in the uppermost portions of the stock.

Strong northeast, northwest, and northsouth sets of shears in the Moonlight Valley area appear to be important for the overall structural plumbing system for the ore; however, the local brecciation and cracking which is apparent in the best ore zones may be closely related to the plutonic emplacement, perhaps as late resurgence into a semiconsolidated rim. This is substantiated by the fact that there is much less fracturing developed toward the center of the stock than near its margin.

**Superior Mine**

The Superior Mine mineralization is thought to be of a higher temperature of formation than Moonlight Valley. Anderson (1931) has given good descriptions of the Superior orebody. He has considered the ore-forming minerals to have been introduced under hydrothermal conditions into previously formed higher temperature pneumatolytic gangue minerals.
the zonal alteration assemblages usually found with such a system. A combination of low sulfur and pyrite with some pneumotytic rather than hydrothermal introduction of at least a portion of the copper sulfides may have helped to obscure more pervasive alteration. Also, very little supergene activity together with minimal surficial clay alteration has given outcrops a relatively fresh appearance. Some of these and other unique features at Lights Creek may indicate more subtle mineral assemblages that perhaps will lead to copper deposits in the future. The successful exploration results at Lights Creek should encourage the pursuit of nonconventional copper systems. Perhaps this will result in additional new districts being found.

Acknowledgments

I would like to thank Placer Amex Inc. for allowing me to present this paper. Particularly, I would like to acknowledge H. J. Matheson, Vice President of Exploration, and J. B. Bush, Manager of Exploration, for their help and encouragement in the preparation of this paper. Recognition should also be given to C. B. Gillette for critical review and suggestions for this manuscript.

References


Putman, G. W., 1975, Base metal distribution in granitic rocks. II. Three-dimensional variation in the Lights Creek Stock, California: Econ. Geol., v. 70, p. 1225-1241.


The Superior deposit occupies a stockwork around seven parallel, northerly striking, easterly dipping (8 to 10 feet thick) vein zones with accompanying sheathing and brecciation (Fig. 9). Strong N, 30° E, shear zones dipping 55° E, limit the high-grade veining in an east-west direction. Mineralization is enhanced and/or cut off by northwest-striking, southwesterly-dipping shear zones superimposed on the vein system. The typical mineralized vein zone contains chiefly chalcopyrite with smaller amounts of bornite, magnetite, and pyrite in a dark gangue of black schorlomite, green mica, actinolite, quartz, epidote, chlorite, sericite, apatite, titanite, and siderite. Intervein wall rock is also mineralized with disseminations and fracture fillings.

Magnetite is much more prevalent in the Superior area than at Moonlight Valley; however, specularite, which is very strong at Moonlight Valley, is nearly nonexistent at the Superior mine.

**Sulfide Ridge Deposit**

The Sulfide Ridge copper occurrence is more like the Superior mine than the Moonlight Valley deposit. However, the only subsurface information available for the area is from diamond drill cores. Cutcrops show the strong influence of structural control of the mineralization (Fig. 10).

**Summary and Conclusions**

In summary, it can be stated that the Lights Creek quartz monzonite stock contains large concentrations of copper. These copper-bearing zones are of sufficient cohesion to qualify them as porphyry copper systems. However, some of the features commonly associated with the copper porphyry deposits of the southwestern United States are missing at Lights Creek. Most conspicuously absent are

*Fig. 10. View looking east of Sulfide Ridge*
EARLY YEARS OF THE PLUMAS COPPER BELT, 1861-1905
By Norman Lamb

The Plumas Copper Belt extends 18 miles from the Engels and Superior mines on the north to the Walker Mine on the South. (See Index Map.) It is California's most significant zone of copper-iron sulfide mineralized rock that is either wholly within or closely associated with granitic intrusions. The important copper minerals at the major producing mines were chalcopyrite and bornite. Historically, the total dollar amount of copper production has been worth twice as much as the total dollar amount of gold produced in Plumas County.

Outcrops of oxidized (weathered) copper were probably first noticed by placer gold prospectors and miners in Plumas County during the Gold Rush. However it was not until the American Civil War (1861-1865) which brought high copper prices that a speculative boom occurred in California. Beginning in 1861 at Copperopolis, Calaveras County, hundreds of copper mining companies were organized as partnerships or corporations to develop known and new copper discoveries. Plumas County was no exception. Many claims were staked in Genesee Valley and Indian Valley. Most of the copper occurrences along the Plumas Copper Belt were discovered during this period with the notable exceptions being the Lucky S found in 1882 and the Walker Mine located in 1905. The Cosmopolitan Quartz Ledge in Genesee Valley was located on December 18, 1862, by a large number of prospectors. In 1863 James Ford, an early settler (1853) in the North Arm of Indian Valley, leased three copper prospects, the Plumas Ledge, the Sovereign Ledge and the Stellar Ledge in the Union Mining District (today known as the Lights Creek Mining District) owned by his partnerships, Summit Copper Company and Copper Hill Company, to San Francisco capitalists for development. At the same time, high-grade copper ore, assaying 48% copper, two oz. gold and 40 oz. silver per ton, was transported in wagons from the Cooper Mountain Mine in Genesee Valley to Marysville, then by boat to San Francisco and then reloaded and shipped to Swansea, Wales where the world’s largest

---

1 Smith, A.R., 1970, Trace Elements in the Plumas Copper Belt, Plumas County, California: California Division of Mines & Geology Special Report 103, pp. 7-8.


3 Aubury, L.E., The Copper Resources of California: California State Mining Bureau, Bulletin 50, pp. 33-34, 1908.

4 Deed Book of Plumas County No. 1, p. 455.

5 Book of Sales of Plumas County, pp. 233-234, 1863.
smelters were located. John C. Chapman, an 1852 arrival in Plumas County, had experience in smelting copper near Iron Mountain, Missouri. He states in a letter to his parents dated March 24, 1864, that with the backing of two prominent Indian Valley mining men, James Blood and William Bollinger, he was planning to build a furnace on Little Grizzly Creek in Genesee Valley. Later that year he did build a small, open-hearth smelter at a cost of $30,000 (1860’s dollars). Thus began the Plumas Copper Smelting Company (aka Plumas Copper Works). It should be noted that this smelter was only capable of handling oxidized ores and not the sulphide ores that were soon to appear after mining began. The town that grew up around the smelter was known as Coppertown or Chapmantown. Ore for the smelter came by ox team from the above mentioned Cosmopolitan Quartz Ledge (Reward Mine today), the Queen of Genesee Ledge (Austrian Syndicate today), the Plumas Ledge (Engels Mine today) and a number of other oxidized copper deposits in the two valleys.

Some of the companies incorporated during the 1860’s copper boom in Plumas County include the Green Ledge Company by Jobe T. Taylor and Judge William T. Ward in 1863, Knickerbocker Quartz Mining Company by James Ford and William J. Young in 1863, Mountain Meadow Copper Mining Company by Jobe T. Taylor in 1863, the Scott Copper Mining Company by James Ford in 1864, the Metropolitan Copper Mining Company by James Blood and William Shinn in 1864 and the Cosmopolitan Central Copper Mining Company by its original locators in 1865. These men and many others were early settlers and prominent businessmen of the time. James Ford was the County Supervisor from Indian Valley from 1864 to 1867. They had contacts with mining men in San Francisco and Virginia City, Nevada who undoubtedly provided some of the capital for exploration and development of the copper deposits.

---

6 Aubury, op. cit., p. 34.
8 John C. Chapman Letter No. 2, March 24, 1864.
9 Aubury, op. cit., p. 179.
11 Articles of Incorporation file, Plumas County Museum.
12 "Plumas County Board of Supervisors - 1855 to 1907," Plumas Memories, Nos. 4 and 14, pp. 21-22, 1980.
The Cosmopolitan Central Copper Mining Company which was organized to raise more money to develop its mine failed the same year it was incorporated\(^4\). The creditors then formed the Cosmopolitan Mining Company on September 6, 1866\(^5\). However, the collapse of copper prices in 1866 after the end of the Civil War, the increased cost of mining and transportation and the failure of most mines to pay dividends must have been a heavy blow to Cosmopolitan and the other mining companies and the smelter. The new Cosmopolitan Company was forced into liquidation and sold at auction on the steps of the Plumas County Courthouse on November 9, 1868. The buyer was A.M. Killey, a major creditor, noted prospector of the day and an original locator of the Cosmopolitan Quartz Ledge in 1862\(^6\). Thus ended the first copper boom in Plumas County.

The year 1867 was not a good one for John Chapman. On August 29th his partner, William Bollinger, sold his one-third share in Plumas Copper Smelting Company back to Mr. Chapman\(^7\). During its short heyday, the Plumas Copper Works had produced 10 tons of copper matte valued at $100,000 (1860's dollars). The matte had been shipped to smelters at Swansea, Wales for further refining\(^8\). Operations at the Genesee smelter proceeded sporadically into 1868. However the mining companies were unable to provide enough oxidized ore to keep the smelter running, and, as previously noted, the smelter could not recover copper from the sulphide ore\(^9\). The mining and smelter ventures during the Civil War had been a financial failure but they put the Plumas Copper Belt on the map.

During the next 40 years a number of booms and were motivated by higher prices for copper caused by periodic wars in Europe. In 1873, General John Bidwell of Chico mined and shipped high-grade sulphide ore worth $30,000 from the the Glory Hole at the Superior Mine in the Union Mining District to Swansea, Wales. The ore was hauled by wagon to Oroville where it was loaded on the railroad to San Francisco. From there it was transferred to a ship which sailed around the Horn of South America to the smelter\(^10\). The cost of transportation and smelter charges probably rendered this operation uneconomic as it did not resume the next year. Nevertheless, the prospectors along the copper belt were not idle. James Ford and his brother, Jack, discovered the oxidized outcrop

\(^{14}\) Deed Book of Plumas County No. 2, pp. 555-557.
\(^{15}\) Deed Book of Plumas County No. 3, pp. 182-184, pp. 295-298, pp. 359-360.
\(^{16}\) Deed Book of Plumas County No. 4, p. 19.
\(^{17}\) Quitclaim Deed, August 29, 1867.
\(^{19}\) John C. Chapman Letter No. 11, June 28, 1868.
\(^{20}\) "Engels Mine Worked Many Years Ago," Plumas Independent, May 1, 1918.
of the Bullion prospect in the Union District above Hulsman Ravine in 1882\textsuperscript{21}. Later that year Jack was elected Secretary of the newly organized Emerald Mining District formed around Blough & Harvey's Lucky S Mine\textsuperscript{22}. Another flurry of activity occurred in 1899 when W.P. Detert of the Argonaut Mining Company, a very successful Mother Lode gold mine at Jackson, California, sent crews into Genesee Valley to examine all of the old copper mines\textsuperscript{23}. Nothing material came of any of these ventures. The isolation of the county, the high cost of transportation and the fact that most copper came from the easily accessible Lake Superior region of Michigan probably discouraged capital from investing in any of the mines or proposed smelter projects.

One event, which was later to prove important, was the visit of Henry A. Engels and his sons, Charles, Henry and William, to the Plumas Copper Belt in the late 1870's. Henry Engels, Sr. was the manager of the Pacific Brass and Lock Foundry in San Francisco. His copper came from the Lake Superior region and cost him 35 cents to 60 cents a pound. He first came to the county because of his interest in the metal from a manufacturer's standpoint\textsuperscript{24}. None other than James Ford showed them around the Union Mining District\textsuperscript{25}. Apparently they liked what they saw. By 1880 they began to establish themselves on Lights Creek in Plumas County on the county road from the North Arm of Indian Valley to Susanville, below the Superior Mine. Their settlement became known as "Engels" or Lower Camp. They restaked James Ford's Superior Mine claims and his Plumas Ledge claims which became the Engels Mine at Upper Camp. In 1882 Henry, Sr. was 72, Charles was 38, Henry was 28 and William was 25 years of age\textsuperscript{26}. The family also included Mrs. Henry, Sr. and daughters, Emily and Elizabeth.

Newspaper articles from 1883 report the Engels Brothers prospecting the large oxidized outcrop at the Engels Mine\textsuperscript{27}. They probably began work there first rather than at the Superior Mine because of the softer rock. In February, 1885, the Greenville Bulletin states that arrangements were nearly complete to erect a 30-ton Water Jacket Smelter on the Engels copper claim the coming summer\textsuperscript{28}.

\textsuperscript{22} "New Mining District," Greenville Bulletin, September 13, 1882.
\textsuperscript{24} A.B. Parsons, "Operations of the Engels Copper Mining Company," Mining and Scientific Press, July 30, 1921, p. 151.
\textsuperscript{26} Great Register of Plumas County, 1882.
\textsuperscript{27} "Copper," Greenville Bulletin, June 6, 1883.
\textsuperscript{28} "Copper Mine," Greenville Bulletin, February 25, 1885.
Nothing further is reported about this project. It is likely that Henry Engels, Sr. was unable to raise the capital, possibly because the price of copper that year fell to 11 cents a pound, its lowest price in 25 years. Copper prices remained depressed for another 14 years but with the rapid growth of the electrical industry, prices began to improve by 1899. These years must have been a difficult time for the Engels family. To financially survive they began the manufacture of butter firkins for the farmers in Honey Lake and Indian valleys. The parents both died within three days of each other on April 27 and May 1, 1894 and were buried in the Taylorsville cemetery. Henry, Sr., who had been born in Prussia, was 84 years old and Mrs. Engels (first name unknown) was 76 years old.

By this time Henry, the son, and Elizabeth had returned to San Francisco leaving Charles, William and Emily to carry on. With copper prices finally improving at the turn of the century, the Engels Brothers incorporated Engels Copper Mining Company on June 19, 1901, in San Francisco. The purpose was to raise capital for the erection of a 100-ton blast-furnace plant to smelt medium-grade carbonate ores. I will end this short history of the early years of the Plumas Copper Belt here. Many obstacles lay ahead before the great productive period for the Engels, Superior and Walker mines was achieved.

Norman Lamb, President of California-Engels Mining Company, Greenville, has for a number of years been researching for a book on Engels Copper Mining Company, the Lights Creek Mining District and the Plumas Copper Belt.

---

29 Aubury, op. cit., p. 29.

30 "Will Bring Copper Zone to the Front, Plumas Independent, March 13, 1907.


32 Plumas Independent, May 12, 1894.

33 Articles of Incorporation file, Plumas County Museum.

34 Parsons, op. cit., P. 152.
Figure 1. Index map of the Plumas Copper Belt.
PART I

ECONOMIC GEOLOGY

NORTHERN SIERRA NEVADA

DIAMOND DEPOSITS
Diamonds in the northern Sierra Nevada, California

Rudolph W. Kopf

ABSTRACT

A review of the literature reveals that over 400 diamonds have been recovered from early Tertiary gold-bearing sand and gravel deposits in the northern Sierra Nevada. Some of these finds were made in fluvial deposits of the ancestral Yuba River. However, most appear to have been associated with essentially contemporaneous auriferous gravels that were deposited in a west-southwest flowing river valley immediately north of the ancestral Yuba. The name "ancestral Feather River" is herein applied to this postulated river system. When plotted on maps showing the distribution of the ancestral Yuba and Feather Rivers, the distribution of these finds seems to indicate several possible source areas.

INTRODUCTION

In 1848, the Reverend Chester S. Lyman, one of the first gold prospectors to have entered the newly discovered gold fields in the foothills of the Sierra Nevada, was shown a translucent straw-yellow stone about the size of a small pea. It had been recovered from a gold pan. He recognized it as a diamond crystal having twelve crystal faces. He mentioned this incident in one of many letters to his friend, Benjamin Silliman, Jr. Fortunately Silliman, the junior editor of the American Journal of Science, published this event as a brief note in that Journal, thereby assuring that this incident, the first report of a diamond found west of the Mississippi River, was recorded in the literature (American Journal of Science and Arts, 1849; Kopf, 1989).

THE PROBLEM

During the following 150 years, over 400 diamonds have been recovered in California as byproducts of gold placer mining operations. During that same period, new diamond fields have been discovered in Africa, Siberia, Australia, and Canada. Since then, the first diamond-bearing breccia pipes in the world were discovered in South Africa. Yet we seem to have learned very little concerning the origin of California's diamonds. In fact, the marked decline since the 1870's in the number of newspaper articles on California's diamonds may explain why the general public seems to have largely forgotten that California has been a diamond-producing state. Furthermore, most published information on past diamond finds in California is scattered throughout numerous federal and state publications, professional and trade journals, and magazine and newspaper articles. In addition, some authors have incorrectly referenced many sources of information thereby increasing the difficulty of relocating the desired article.
SOLUTION

In order to undertake an independent investigation of the source of California's diamonds, I decided on a five-pronged attack. About 30 years ago I began to review the literature of published articles that discuss or even mention all known diamond occurrences in California. As this was begun before the widespread use of the personal computer, each reference was noted on a 3- by 5-inch punch card in which the state and county mentioned in the article is identified by holes punched along the border of the card. This compilation, currently containing 423 published references to diamonds in California, is probably the most complete compendium of information on this subject in existence.

The second phase consisted of an evaluation of each reported diamond find. This included a field examination of the reported locality in order to determine if existing geologic features at the site are compatible with the reported occurrence. This examination revealed that some of the reports are of questionable validity. These include: 1), areas in which a report of a single and anomalously large diamond find exists; 2), reported finds in which no one familiar with the mineralogy of diamonds has verified the identity of the mineral; and 3), the find is a diamond but the location was contaminated when milling equipment, from which the diamond was recovered, had been transported to the site from an unknown location. Such reports, although included in the table, are omitted from the maps (Figures 1 and 2).

During the third phase of this investigation I used these data to compile a list of diamond finds recorded from Yuba, Nevada, Sierra, Butte, and Plumas Counties in the northern Sierra Nevada (table 1). This work is an extension of my earlier investigation of diamond finds on the South Fork of the Yuba River and its tributaries in Yuba and Nevada Counties.

The literature clearly reveals that all diamond finds in the Sierra Nevada have been associated with gold-bearing gravels deposited by early Tertiary rivers or by later streams and rivers cutting the earlier deposits. Most of California's diamonds were found in the Spring Valley hydraulic mine at Cherokee, Butte County. Their size ranged from microscopic to 6 carats (Mansfield 1918, p. 369) although most appeared to weigh less than 2 carats (table 1). Many were of gem quality. Stones normally containing incipient fractures or inclusions, when undergoing stream transport, commonly are fractured along planes of such weakness thereby reducing their size. Thus alluvial diamonds that survived stream transport are typically of higher quality than those obtained by hard rock mining (Ball, 1922, p. 594, 601). The velocity of water used in sluices was selected to separate gold from its lighter matrix, not for recovering diamonds. Nevertheless, microscopic diamonds were numerous in black
sand discarded from sluices at the Cherokee mining operation (Raymond, 1877, p. 98). Clearly, then, most of Cherokee’s diamonds have been flushed with the tailings.

The fourth phase of the investigation consisted of plotting apparently valid diamond finds listed in the tables onto a geologic map showing the courses of these Tertiary rivers (figures 1 and 2).

The fifth phase consisted of using these maps and other geologic data to reveal possible sources of the stones.

The fourth phase was most difficult to complete. The courses of the early Tertiary rivers are currently preserved as erosional remnants or outliers commonly miles apart. Following the deposition of the auriferous gravels, the area had been tilted to the west hastening erosion on the uplifted portion. Elsewhere, high-angle faults have displaced these gravels. Subsequent erosion commonly has destroyed the gravels on uplifted blocks and has buried the gravels on downthrown blocks. Thus, a reconstruction of these ancient river systems is obviously a matter of interpretation. Lindgren’s (1911, pl. 1) monumental work in reconstructing the course of Tertiary rivers that deposited the auriferous gravels in the Sierra Nevada has remained the bible for students in this field of study. He considered the northern limit of the ancestral Yuba River to have extended into what is now Yuba, Nevada, and Sierra Counties.

Although most of Lindgren’s work has withstood the test of time, several of his interpretations have been challenged. The following statements affect this study. Lindgren (1911, p. 33-37, 40) believed that a north-trending mountain range that he termed the “Tertiary range” essentially coincided with the limits of the present Sierra Nevada. He recognized six major Tertiary rivers – the Tertiary Tuolumne, Calaveras, Mokelumne, American, and Yuba Rivers, and the Magalia channel – that drained the west slope of this range. He also believed that similar rivers had drained the east slope, that their headwaters originated at or near the present crest of the Sierra Nevada, and that erosion had destroyed most of the evidence of the existence of these rivers.

In addition, Lindgren (1911, p. 33, 40) recognized a Tertiary river, named the “Jura River,” that he believed may have originated east of the drainage divide and actually had flowed from near Meadow Lake, eastern Nevada County, north-northwest across Sierra County to the vicinity of Susanville in Plumas County, a distance of almost 75 miles (120 km).

Durrell (1959a, p. 166, 181-182), in studying rocks of Plumas County, recognized a large proportion of well-rounded pebbles and cobbles of white and black, weakly metamorphosed chert in the auriferous gravels at La Porte that must have
had their source in the Paleozoic rocks of central or northern Nevada. He also recognized Tertiary clasts in the Miocene Delleker and Bonta Formations that also appeared to him to have been transported westward or southwestward from what is now western Nevada (op. cit., 1987, p. 152, 173-174, 179, 193, 205, 209, 227). These and other lines of evidence led Durrell to conclude that there never had been a north-flowing Jura River, and that no mountain range had existed during the early Tertiary; rather, Tertiary streams as late as Miocene had flowed westward uninterrupted from Nevada into the Sacramento Valley before the Sierra Nevada began its rise (op. cit., 1987, p. 153, 175).

Durrell (1987, p. 148, 159) further surmised that some of the gold in these auriferous gravels may have been derived from what is now Nevada.

Normal faulting and differential erosion have surely complicated a reconstruction of the original course of these Tertiary rivers. However, the preserved portions are sufficiently numerous to outline the approximate limits of the drainage basin for a river north of the ancestral Yuba River. Just as the ancestral Yuba River developed a delta west of Smartville, the gravel at Cherokee is interpreted as a deltaic deposit of a river north of the ancestral Yuba. I call this river the "ancestral Feather River" because it occupies the drainage basin of the modern Feather River (fig. 2). Its deposits are generally lower in the percentage of quartz pebbles, and of placer gold, than in the ancestral Yuba. The drainage divide between these two rivers appears to have essentially coincided with Mooreville Ridge.

Where both are present, the auriferous gravels in Butte and Plumas Counties are locally unconformably overlain by the early Miocene Lavejoy Basalt. Durrell (1959b, maps 1 and 2) traced this basalt from Stony Ridge, just west of Honey Lake, to Oroville Table Mountain, then discontinuously in the subsurface of the Sacramento Valley as far south as Putnam Peak, near Vacaville. Such a wide distribution implies that these basalt flows must have been highly fluid. Had the ancestral Yuba extended northward into Plumas and Butte Counties, some of these basalt flows should have flowed down some of Yuba's river valleys and into the Sacramento Valley through the Smartville watergap. Instead, they entered the Sacramento Valley through a topographic depression now preserved as Oroville Table Mountain. Here these basalts cap the auriferous gravels, its Eocene marine equivalent, the Lone Formation, and underlying Cretaceous gravel, evidence that this Cretaceous and Eocene watergap into the Sacramento Valley continued to exist into Miocene times.

DISCUSSION

Examination of figure 1 reveals that diamonds found in
Sierra County appear to have been transported southward via the LaPorte and Fort Wine channels of the ancestral Yuba River through the areas of North San Juan, French Corral, Smartville, Sicard Flat, and Hamilton. Some of the diamonds in these channels appear to have been reworked into modern gravels deposited by the South Fork of the Yuba River. Conversely, if accounts of diamond finds at Chalk Bluff and Edwards Crossing are valid, they may have been washed northward through the You Bet area.

Diamonds found at Cherokee, here considered part of the ancestral Feather River (figure 2), were associated with considerable quantities of platinum-group metals and chromite (Silliman, 1873; Raymond, 1877, p. 98). Diamonds found in the upper part of Spanish Creek, Badger Hill, Gopher Hill, Mumford's Hill, and La Porte were also associated with high concentrations of platinum-group metals and chromite (Edman, 1894). In fact, the name Silver Creek, a tributary of Spanish Creek, was selected in the mistaken belief that a grain of platinum in the creek was silver (Edman, 1898). Platinum-group metals are generally uncommon in deposits of the ancestral Yuba River.

Michael Cooney, a mining engineer, sunk two prospect shafts, one near Cherokee, the other near Oroville, in the belief that he had discovered kimberlite pipes. Sterrett (1907, p. 1218) identified the rock as serpentinitized peridotite breccia, apparently part of a northwest trending belt of amphibolite schist running through the country. Cooney assumed that the presence of numerous diamond finds in these areas indicated a nearby source of the stones. He apparently greatly underestimated the distance that diamonds could undergo stream transport.

Lindgren (1911, p. 85) considered the gravels at Cherokee to have been deposited by a small stream, not a river. However, the high percentage of quartz pebbles in the gravel indicates a source area containing numerous quartz veins, a terrain not present near Cherokee. Also, the common occurrence of well-rounded pebbles at this locality, pebbles consisting of argillite cut by a conspicuous crisscrossing network of dark gray silicous veins, were identified by Durrell (written commun, 1975?) as resembling the Calaveras Formation as exposed in the Nelson Creek area of Plumas County. Such a distant source area implies transport by a long river.

POSSIBLE SOURCES

But where is the source(s) of these diamonds? This question has puzzled geologists and prospectors for more than a century. The answer not only may yield important clues as to how minerals of deep-seated origin have reached the earth's surface but also has interested several domestic and foreign mining companies with economic interests in mind.
1. Hydrogeologic factors

Minerals in a placer deposit are derived from the erosion of rock types that were exposed within its drainage basin somewhere upstream from the site of that deposit. The source of the modern Yuba River is the crest of the Sierra Nevada.

Comparison of the volume of the placer deposits of the ancestral Yuba River with that of the modern Yuba River indicates that the flow—and, therefore, the area of the drainage basin—of the ancestral Yuba River must have been considerably larger than the flow of the modern Yuba.

Practically nothing is known about the location of the sources of these ancient rivers. If some had originated in areas east of the present range, as suggested by Bateman and Wahrhaftig (1965, p. 139), Peterson and others (1968, p. 8), Yeend, 1974, p. 35), and Durrell (1967, p. 148, 159), it might indicate that the origin of Tertiary gold placers east of California’s Mother Lode may well have been derived from the erosion of gold lode deposits in Nevada. Dickinson (written commun., 1994) noted that none of the Paleogene clasts he and his coworkers had found in the Sierra Nevada showed any evidence of derivation from areas any farther east than westernmost Nevada. These limitations imply that the source of the Yuba River’s diamonds may have been exposed during the Eocene somewhere east of 121 and west of 117 degrees west longitude. Although reports of diamond finds in western Nevada exist (Hill, 1972, p. 54), none have ever been authenticated. Nevertheless, if the source of these sources were in eastern California or western Nevada, could it be that they have been buried by later Tertiary volcanic rocks or valley fill?

2. Breccia pipes or dikes

J. A. Edman, a mining engineer and geologist of Plumas County, discovered an unusual corundum-bearing rock about two miles due east of the summit of Spanish Peak, Plumas County. The rock, described and named "plumasite" by Lawson (1903), was interpreted to occur in a north-northwest trending clastic pipe or dike 125 feet long by 15 feet wide in Meadow Valley (see also locality 1044 of Hietanen, 1973, p. 29, pl. 2). The corundum-bearing rock may represent one or more tectonic clasts in a breccia pipe or dike injected hydrotectonically into a range-front fault (Kopf, 1979; 1982).

According to Golconda Resources Ltd., in 1995 this company located five pipe-like structures containing lamproitic tuff and breccia in the upper part of Spanish Creek, Plumas County (Mining Record, Dec. 4, 1996). Drill samples reportedly contained diamond indicator minerals. However, no diamonds were found.
In 1995 and 1996, Diadem Resources Ltd. and Silverstone Prospecting drilled a number of exploratory holes near Leek Springs, El Dorado County, and claimed to have recovered 234 diamond shards (shattered fragments) with a total weight of less than one carat from 200 pounds of material drilled from what they believed to be the crater facies of a diamondiferous breccia pipe having a surface area of about 125 acres (Mining Record, July 10, 1966, p. 3).

Records indicate that placer diamonds occur in several Tertiary fluvial deposits on the western slope of the Sierra Nevada extending from Plumas County southward to at least Stanislaus County, a distance of 160 miles (250 km). This suggests that the diamonds were eroded from some sort of diamondiferous rock that had been exposed in those west-flowing Eocene watersheds.

Could California's diamonds have been derived from the erosion of several clusters of diamond-bearing pipes or dikes that were exposed in some of these watersheds? Or could they have been recycled from a pre-Tertiary diamond-bearing sedimentary deposit having a northerly strike?

3. Serpentinized peridotite

A number of previous authors have suggested that the source of some of California's placer diamonds may have been a north-trending outcrop of serpentinitized peridotite along one of the major faults high in the Sierra Nevada, rocks such as are described by Janze (1994) from other areas of the world. It should be noted that Humford's Hill, whose black sands yielded microscopic diamonds identified by Edman (1994), is on the west edge of a north-trending serpentine belt which also passes near Spanish Creek, Gopher Hill, and Badger Hill. Black sands in these areas also yielded microscopic diamonds, chromite, and fine grains of platinum and iridium-osmum.

ACKNOWLEDGMENTS

I am indebted to Hal Morris and Mel Erskine for reviewing early versions of this manuscript and to instructors at Sierra College for formulating the tables on a computer. I am also deeply indebted for contributions to our knowledge of the auriferous gravels of the northern Sierra Nevada by previous investigators, in particular, John A. Edman, H. W. Turner, Waldemar Lindgren, Olaf P. Jenkins, Cordell Durrell, and David Lawler.

References

Ball, S. H., 1922, The geologic and geographic occurrence of


Mansfield, G. C., 1918, History of Butte County with Biographical Sketches: Historical Record Company, Los Angeles, Calif., 1331 p.


Raymond, R.W., 1877, Statistics of mines and mining in the states and territories west of the Rocky Mountains, 8th
Silliman, E. B., 1873, Mineralogical notes on Utah,
California and Nevada, with a description of priceite, a
new borate of lime: Engineering and Mining Journal, 4th
series, v. 16, no. 7, p. 82, 98-99.
Sterrett, D. B., Precious stones, p. 1213-1252, in D. T. Day
and E. W. Parker, 1907, Mineral resources of the United
States (for the) calendar year 1906: U.S. Geological
Survey, 1307 p.
Yeend, W. E., 1974, Gold-bearing gravel of the ancestral Yuba
River, Sierra Nevada, California: U.S. Geological Survey
Professional Paper 772, 44 p.
References to table I on diamond finds in the northern
Sierra Nevada, California

Rudolph W. Kopf

Anon., 1959, Diamonds in California: Pages of History,
Sausalito, Calif., 55 p.
Anon., 1992?, [consultant's report to the California
Division of Mines and Geology], table 5.
Appeal - Democrat, Marysville, July 14, 1934, p. 1, cols. 3
and 4.
-------------------, Marysville, Aug.
Blake, W. P., 1866, Annotated catalogue of the principal
mineral species hitherto recognized in California and the
adjoining states and territories: Report to the
California State Board of Agriculture, Sacramento, 31 p.
Reprinted on pages 200-215 in Browne, J. R., and
Taylor, J. W., 1867, Reports upon the mineral resources
Blank, E. W., 1934, Diamond finds in the United States, Part
III: Rocks and minerals, v. 9, no. 12, p. 179-182.
Bowen, O. E.,Creely, R. S., and Turner, M. T., 1959,
Geology and economic possibilities of the Eocene and
Cretaceous gravels at Cherokee, Butte County, California
(28 page unpub. ms.): California Mining Bureau.
Bradley, W. W., 1929, California's commercial non-metallic
minerals: Mining Congress Journal, v. 14, no. 9, p.
569-578, 718.
Butte Democrat, Chico, April 6, 1861, p. 2, col. 2.
Creely, R. S., 1965, Geology of the Crovville quadrangle,
California: California Division of Mines and Geology
Bulletin 184, 86 p.
Daily Alta California, San Francisco, Jan. 30, 1865, p. 2,
cols. 1 and 2.
Edman, J. A., 1894, Gold mining: Ore deposits and vein
mining in Plumas County (California). Plumas National -
-------------------------------, Apr. 11, 1908, p. 752.
1.
-------------------------------, March 14, 1914, p. 559, col.
1.
Enterprise Record, Chico, Nov. 1, 1961, p. 9A, col. 3.
George, Ward, and George, Vivienne, 1970, Diamonds of
Cherokee: Treasure World, May, P. O., Drawer L., Conroe,
Texas, p. 60-63.
Grass Valley Union, Dec. 21, 1873, p. 2, col. 2.
-------------------, Aug. 11, 1912, p. 3, col. 4
-------------------, Feb. 21, 1936, p. 4, col. 4.
Hanks, H. C., 1882, Diamonds in California, p. 241-254:
California Mining Bureau, Second report of the State
Mineralogist, 283 p.
------------, 1886, California minerals, p. 91-141: Sixth
annual report of the [California] State Mineralogist for
the year ending June 1, 1888, part I.
Hausel, W. D., 1995, Diamonds, kimberlites, lamproites and
related rocks in the United States: Exploration Mining
Geology, v. 4, no. 3, p. 243-270.
Hearst, A. L., 1961, Butte County holds record for diamonds:
Chico Enterprise, August 23, 1961, p. 4D, col. 5.
Hill, Mary, 1972, Hunting diamonds in California (revised
p.
Hoope, C. L., 1973, What makes a man: The Annie E. Kennedy
and John Bidwell letters 1866-1868: Valley Publishers,
102 p.
Joque, M. S., 1973, Prospecting for diamonds: Lapidary
Kopf, R. W., 1995, Diamond occurrences in the vicinity of
the South Fork of the Yuba River, Nevada and Yuba
Counties, California: unpublished 13 p. manuscript.
---------, R. W., Hurlbut, C. S., and Kolvula, J. I.,
1990, Recent discoveries of large diamonds in Trinity
County, California: Gems & Gemology, v. 26, no. 3, p.
212-219.
Kunz, G. F., 1890, Gems and precious stones of North
America: The Scientific Publishing Company, New York, 336
p.
-----------, Precious stones, p. 680-702, in D. T. Day,
1894, Mineral resources of the United States [for the]
-----------, Precious stones, p. 895-926 in D. T. Day,
1895, Mineral resources of the United States [for 1894],
Part III, nonmetallic products except coal, p. 543-1058,
17th annual report of the U.S. Geological Survey to the
-----------, Precious stones, p. 419-462, in D. T. Day,
1901, Part VI, Mineral resources of the United States
[for 1899]: 21st annual report of the U.S. Geological
Survey, 634 p.
-----------, 1905, Gems, jewelers' materials, and
ornamental stones of California: California Mining Bureau
Lenhoff, James, 1958, Oroville's mystery diamonds: The
Feather River Territorial, Summer, 1958, pp. 4-9.
Logan, C. A., 1930 [1931], Butte County, p. 360-412 in 26th
report of the State Mineralogist, v. 26, no. 4, p.
359-535.
Lyman, Frank, 1928, Five roaming diamonds * * An 'Examiner'
Motorologue: San Francisco Examiner, Jan. 1, 1921, p. A1,
A2, col. 1.
Mansfield, G. C., 1918, History of Butte County with
biographical sketches: Historic Record Company, Los
Angeles, pp. ?
McAtee, S. J., 1907, Is California producing diamonds?: San
Francisco Call, Mar. 10, 1907, p. 4, cols. 1-7.
Mercury-Register, Oroville, March 16, 1920.
Mining and Scientific Press, v. 26, no. 13, Mar. 26, 1870,
p. 194, cols. 1 and 2.
Morning Union, Grass Valley, July 27, 1934, p. 4, col. 4.
-------------, Grass Valley, Feb. 21, 1936, p. 4, col. 4.
---------, Quincy, Sept. 28, 1872, p. 3, col. 2.
---------, 1875, Statistics of mines and mining in the states and territories west of the Rocky Mountains, Seventh annual report [for 1874]: 43rd Congress, 2nd session, House Executive Document 177, 540 p.
Sacramento Daily Record - Union, Jan. 25, 1887, p. 3, col. 4.
Sacramento Union, June 27, 1864, p. 5, col. 2.
---------, July 1, 1873, p. 3, col. 4.
---------, Oct. 28, 1873, p. 3, col. 5.
San Francisco Call, March 11, 1894, p. 11, cols. 1 - 3.
San Francisco Post, Sept. 28, 1872, p. 1, col. 2.
Scott, Winfield, 1926, A diamond quest in California:
Scientific American, v. 134, no. 1, pp. 312-313.
Silliman, B., 1873, Mineralogical notes on Utah, California and Nevada, with descriptions of priceite, a new borate of lime: American Journal of Science, 3rd series, v. 6, p. 133.
Weekly Butte Record, Oroville, Mar. 31, 1866, p. 3, col. 2.
Weekly Butte Record, Oroville, May 5, 1866, p. 3, col. 1.
Figure 1(right). Tertiary channels and dredge fields, Sierra Nevada. After Lindgren(1911) and Clark(1970). (Courtesy of California Div. of Mines and Geology)
<table>
<thead>
<tr>
<th>No</th>
<th>Year</th>
<th>Location</th>
<th>Description</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1853</td>
<td>Cherokee</td>
<td>About 2 1/4 ct. (=8 grains-Hanks) stone recovered from sluice by John More</td>
<td></td>
<td>Silliman, 1873b, p. 133; Hanks, 1882, p. 252</td>
</tr>
<tr>
<td>2</td>
<td>Pre-1860</td>
<td>Cherokee Flat</td>
<td>Several well-formed highly modified crystals from 1/8th to 3/16th inch in diameter. Generally pale yellow</td>
<td></td>
<td>Blake, 1866, p. 12; 1867, p. 203</td>
</tr>
<tr>
<td>3</td>
<td>1861 or earlier</td>
<td>Cherokee</td>
<td>2 stones found by S. Glass at Cherokee Ravine. Sent to New York City where they were identified as diamonds</td>
<td></td>
<td>Butte Record, Apr. 6, 1861, p. 2, col. 2; Sacramento Union, Dec. 21, 1872, p. 3, col. 6</td>
</tr>
<tr>
<td>4</td>
<td>1861</td>
<td>1 1/2 mi. NW of Yankee Hill</td>
<td>1 1/2 cts. (=6 grains) perfectly clear stone recovered from sluice box at placer mine. Estimated value $125. Sold to M.H. Wells who presented it to John Bidwell, of Chico, who had it cut in Boston in 1867. Weighed 1 1/2 cts. after cutting</td>
<td>Bidwell gave it to his fiancée, Annie E. Kennedy, who wore it on her finger</td>
<td>Hanks, 1882, p. 253; Kunz, 1905, p. 42; Hoopes, 1973, p. 59</td>
</tr>
<tr>
<td>5</td>
<td>1861 or earlier</td>
<td>Cherokee</td>
<td>Found by John S. Bassett while puddling clay for washing. Identified by Mr. Young, Jeweler</td>
<td></td>
<td>Butte Record, Apr. 6, 1861, p. 2, col. 2</td>
</tr>
<tr>
<td>6</td>
<td>1862</td>
<td>Cherokee?</td>
<td>One yellow stone found by A. McDermott, druggist, Oroville. Size of small pea. Nearly globular, obscurely crystallized</td>
<td></td>
<td>Hanks, 1882, p. 150; Rosenhouse, 1975, p. 53</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>--------</td>
<td>----------</td>
<td>----------------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>1864 or earlier</td>
<td>Cherokee</td>
<td>A stone, with estimated value of $250, was cut in Boston in 1864</td>
<td></td>
<td>Raymond, 1875, p. 150</td>
</tr>
<tr>
<td>8</td>
<td>1864</td>
<td>Cherokee pit</td>
<td>Three stones, weighing 12 grains and valued at $1 to $2 per grain were found on top of black sand. Sent to Crosby and Morse, Boston, only house in U.S. where diamonds are cut. Cost of cutting is between $12 and $24. Set in rings</td>
<td>Being exhibited at Flory's [Jewelry], J Street, Sacramento</td>
<td>Sacramento Union, June 27, 1864, p. 5, col. 2; Weekly Union, Crovile, July 16, 1864, p. 5, col. 1 and July 30, 1864, p. 3, col. 1; Sacramento Union, Jan. 17, 1866, p. 2, col. 1; Stillman, 1867, p. 355; George and George, 1970, p. 63</td>
</tr>
<tr>
<td>9</td>
<td>1864</td>
<td>Cherokee</td>
<td>Mrs. W. C. Hendricks, of Morris Ravine, had a stone cut and set in a ring</td>
<td></td>
<td>Hanks, 1882, p. 253; Anon., 1992?, table 5</td>
</tr>
<tr>
<td>10</td>
<td>1865</td>
<td>Cherokee Flat</td>
<td>About three diamonds were recovered from sluices. Sent to R.B. Gray and Co., Jewelers, San Francisco. Estimated value was $75 each. Set in rings as rough stones</td>
<td></td>
<td>Daily Alta California, Jan. 30, 1865, p. 2, cols. 1 &amp; 2</td>
</tr>
<tr>
<td>11</td>
<td>1866</td>
<td>Near Table Mountain west of Messilla Valley</td>
<td>Rumored find of diamonds at this locality. Specimens supposedly verified as diamonds by experts in San Francisco</td>
<td>Did author mean east rather than west of Messilla Valley?</td>
<td>Weekly Butte Record, Mar. 31, 1866, p. 3, col. 2</td>
</tr>
<tr>
<td>12</td>
<td>1866</td>
<td>Cherokee</td>
<td>Blue diamond found by Mike Maher at mouth of &quot;Cherokee hydraulic wash,&quot; while cleaning his sluice. Owned by Mrs. Walbeyar, San Francisco</td>
<td></td>
<td>Mansfield, 1918, p. 369; Lenhoff, 1958, p. 5; George and George, 1970, p. 62</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>13</td>
<td>1866</td>
<td>Cherokee Fl</td>
<td>Straw yellow stone found by Mr. Durett.</td>
<td>Largest stone yet found [weight not given]. Found in mine tailings</td>
<td>Weekly Butte Record, May 5, 1866, p. 3, col. 1</td>
</tr>
<tr>
<td>14</td>
<td>1867</td>
<td>Cherokee</td>
<td>Fine white stone (Kunz) found by Wm. Brandeth. Kunz gives weight of cut stone as 1 3/16 ct. but Mansfield gives weight as 1 1/3 ct.</td>
<td></td>
<td>San Francisco Call, Mar. 11, 1894, p. 11, col. 1; Kunz, 1905, p. 42; Mansfield, 1918, p. 369</td>
</tr>
<tr>
<td>16</td>
<td>1868</td>
<td>Cherokee</td>
<td>6 ct. good-quality stone found by John Moore who refused to sell it for $200 in 1885</td>
<td>Could finder be same person identified by Hanks (1882, p. 252) as John Moore?</td>
<td>Mansfield, 1918, p. 369</td>
</tr>
<tr>
<td>17</td>
<td>1868</td>
<td>Cherokee</td>
<td>About 20 stones “accidentally” recovered by Mr. Slissman (Mansfield)</td>
<td></td>
<td>Mansfield, 1918, p. 369; Scott, 1926, p. 313</td>
</tr>
<tr>
<td>18</td>
<td>1868</td>
<td>Cherokee Fl</td>
<td>Mr. N.A. Harris found a rough diamond which was set in a ring. Later donated to Calif. Div. Mines and Geology's museum, Ferry Building, San Francisco. Weight of uncut stone in display case given as 18.251 [grains?] (Kopf)</td>
<td></td>
<td>Hanks, 1882, p. 253; Anon., 1992?, table 5; Kopf, written commun., May 18, 1971</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td></td>
</tr>
<tr>
<td>-----</td>
<td>-----------</td>
<td>--------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1868 or</td>
<td>Cherokee</td>
<td>Jack Powers found several diamonds here</td>
<td>Mansfield, 1918, p. 369</td>
<td></td>
</tr>
<tr>
<td></td>
<td>later</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1868 or</td>
<td>Cherokee</td>
<td>Halls brothers found several stones, weight of largest being 3 1/2 cts.</td>
<td>Mansfield, 1918, p. 369</td>
<td></td>
</tr>
<tr>
<td></td>
<td>later</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>1870</td>
<td>Cherokee Flat</td>
<td>Several recovered from sluice boxes after washing large quantities of auriferous gravel</td>
<td>Mining and Scientific Press, v. 20, no. 13, Mar. 26, 1870, p. 194, col. 1</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1873?</td>
<td>Cherokee</td>
<td>Faint yellow crystal with curved faces. Weighed about 2 1/4 ct. (Silliman)</td>
<td>Silliman, 1873b, p. 133; Raymond, 1975, p. 150</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1873 or</td>
<td>Cherokee</td>
<td>About 20 diamonds picked out of sluices at mine. Well-formed crystals. Some were of a pure water and have been cut and set as gems</td>
<td>Silliman, 1873b, p. 133; Sacramento Union, Oct. 26, 1873, p. 3, col. 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>earlier</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>1873</td>
<td>Cherokee?</td>
<td>Robert Atherton found a yellow stone having a green tint. Believed by some to be an opal instead of diamond</td>
<td>Grass Valley Union, Dec. 21, 1873, p. 2, col. 2</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------</td>
<td>-------------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>25</td>
<td>1873</td>
<td>Cherokee</td>
<td>Three small diamonds recovered during clean-up of Spring Valley and Cherokee mine. One was described as large and straw-colored while others were smaller but very pure (Kunz)</td>
<td></td>
<td>Sacramento Union, July 1, 1873, p. 3, col. 4; Kunz, 1905, p. 42</td>
</tr>
<tr>
<td>26</td>
<td>1873</td>
<td>Morris Ravine</td>
<td>Occasional diamonds found here</td>
<td></td>
<td>Grass Valley Union, Dec. 21, 1873, p. 2, col. 2; Bradley, 1928, p. 673</td>
</tr>
<tr>
<td>27</td>
<td>1873</td>
<td>Thompson's Flat</td>
<td>Occasional diamonds are found here</td>
<td></td>
<td>Grass Valley Union, Dec. 21, 1873, p. 2, col. 2; Silliman, 1873b, p. 133</td>
</tr>
<tr>
<td>28</td>
<td>Pre-1875</td>
<td>Cherokee</td>
<td>About 50 diamonds were found during earlier days when primitive mining methods were practiced. Perfectly formed microscopic diamonds are in black sand in sluices. Many larger stones were cut and set in rings</td>
<td></td>
<td>Raymond, 1877, p. 98</td>
</tr>
<tr>
<td>29</td>
<td>1879</td>
<td>Cherokee</td>
<td>Identified by Mr. Howard. Purchased by Frank Morse, Grass Valley, for $40. Stone sent to a San Francisco firm to be cut and mounted. Firm offered to purchase it for $60</td>
<td></td>
<td>Weekly Mercury, Oroville, Aug. 8, 1879, p. 3, col. 1</td>
</tr>
<tr>
<td>30</td>
<td>1886 (Bowen)</td>
<td>Cherokee Flat</td>
<td>A fine blue-white rough diamond from Spring Valley mine was presented by G.F. Williams, Supt. of mine, to State Museum as No. 4033 and placed on exhibit</td>
<td></td>
<td>Whitney, 1880, p. 364, 483; Hanks, 1882, p. 253; Kunz, 1905, p. 41, ill. 8; Bowen, et al, 1959, table, p. 12</td>
</tr>
<tr>
<td>No.</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>31</td>
<td>1881</td>
<td>Cherokee</td>
<td>Linda Voight found two stones</td>
<td>Identified by Kunz who showed them to N.Y. Academy of Sciences, Jan. 2, 1886</td>
<td>Kunz, 1890, p. 28; Kunz, 1905, p. 42</td>
</tr>
<tr>
<td>32</td>
<td>About 1882</td>
<td>Cherokee</td>
<td>Campbell De Bock, a Belgian, mined with a group of Belgians in early 1880's and found 80 stones</td>
<td>Appears to be same person mentioned by Mansfield, 1918, p. 369-370</td>
<td>Scott, 1926, p. 313</td>
</tr>
<tr>
<td>33</td>
<td>Pre-1886</td>
<td>W. branch Feather River</td>
<td>About 4 mm in diameter. Subsequently lost</td>
<td></td>
<td>Hanks, 1886, p. 106</td>
</tr>
<tr>
<td>34</td>
<td>Pre-1886</td>
<td>Yankee Hill</td>
<td>A number of diamonds have been found here but exact number is unknown (Bradley)</td>
<td></td>
<td>Hanks, 1886, p. 106; Bradley, 1928, p. 673</td>
</tr>
<tr>
<td>35</td>
<td>1886?</td>
<td>Cherokee</td>
<td>Louis A. Glass, Superintendent, Cherokee mine, has a rough stone weighing 1 1/2 cts. Largest stone found at Cherokee to date. Identified by Levinsons Jewelers, S.F. Cut by Morse of San Francisco. After cutting, weighed 9/16 cts. Very brilliant</td>
<td></td>
<td>Sacramento Daily Record - Union, Jan. 25, 1887, p. 3, col. 4; Engineering and Mining Journal, Oct. 1906, p. 703</td>
</tr>
<tr>
<td>36</td>
<td>1892</td>
<td>Cherokee</td>
<td>Find of one small diamond reported by H.S. Durden, Calif. State Mining Bureau</td>
<td></td>
<td>Kunz, 1894, p. 683</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>37</td>
<td>1893</td>
<td>Cherokee</td>
<td>Find of one small diamond reported by H.S. Durden, Calif. State Mining Bureau. Largest found in 1892 and 1893 weighed 2 cts.</td>
<td></td>
<td>Kunz, 1894, p. 683</td>
</tr>
<tr>
<td>38</td>
<td>1895</td>
<td>Feather River near Oroville</td>
<td>Dwight Whiting found five small diamonds</td>
<td></td>
<td>Kunz, 1896, p. 896</td>
</tr>
<tr>
<td>39</td>
<td>1895</td>
<td>&quot;about 4 miles from head of the creek&quot;</td>
<td>About 5 diamonds found by Dwight Whiting Name of creek not identified by Kunz</td>
<td></td>
<td>Kunz, 1896, p. 896</td>
</tr>
<tr>
<td>40</td>
<td>1907</td>
<td>Thompson Flat</td>
<td>About 12 diamonds supposedly recovered from M.J. Cooney's mine and displayed by him. Weighed from 1 to 1 1/2 cts. after cutting</td>
<td></td>
<td>McAtee, 1907, p. 4, col. 7</td>
</tr>
<tr>
<td>41</td>
<td>1908</td>
<td>Cherokee</td>
<td>A few small diamonds have been reportedly found here by M.J. Cooney</td>
<td></td>
<td>Engineering and Mining Journal, v. 85, Apr. 11, 1908, p. 782</td>
</tr>
<tr>
<td>42</td>
<td>1908</td>
<td>Oroville</td>
<td>Two ct. stone found in Christmas turkey by Oroville housewife</td>
<td></td>
<td>Rosenhouse, 1964, p. 33, cols. 1 &amp; 2</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>44</td>
<td>1910</td>
<td>Thompsons Flat?</td>
<td>Benjamin Utz found a good quality stone on property owned by U.S. Diamond Mining Co. Sold to jeweler in Oroville</td>
<td></td>
<td>Engineering and Mining Journal, Feb. 11, 1911, p. 340, col. 1</td>
</tr>
<tr>
<td>45</td>
<td>1910</td>
<td>Cherokee</td>
<td>George Stone recovered a brilliant, perfectly clear, flawless, slightly yellow diamond weighing 1 3/4 to 2 cts. from a rocker on old hydraulic ground owned by T.L. Vinton. Identified by D.B. Sterrett. Crystal a trisoctahedron or hexoctahedron</td>
<td></td>
<td>Sterrett, 1911, p. 759-760</td>
</tr>
<tr>
<td>46</td>
<td>1910</td>
<td>Cherokee</td>
<td>Second stone recovered by George Stone in March from his rocker on land owned by T.L. Vinton. Weighed about 1/2 ct. Sold to an Oroville resident</td>
<td></td>
<td>Sterrett, 1911, p. 759-760</td>
</tr>
<tr>
<td>47</td>
<td>1911</td>
<td>Cherokee</td>
<td>1 1/2 ct. diamond found by Benjamin Utz</td>
<td></td>
<td>Engineering and Mining Journal, Feb. 11, 1911, p. 340</td>
</tr>
<tr>
<td>48</td>
<td>1912</td>
<td>Cherokee</td>
<td>John Hufford found a stone during placer mining for gold. Weighed 1 1/16 cts. before cutting and yielded a fine white flawless gem weighing 17/32 ct. Subsequently owned by R.S. Powers of Oroville</td>
<td></td>
<td>Sterrett, 1913, p. 1040</td>
</tr>
<tr>
<td>49</td>
<td>1912</td>
<td>Cherokee</td>
<td>Two stones were found here in 1912</td>
<td></td>
<td>Sterrett, 1913, p. 1040</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>Reference</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>51</td>
<td>1913</td>
<td>Cherokee</td>
<td>1/14 ct. first quality white diamond found by John McGregor in old placer grounds of U.S. Diamond Mining Co. Estimated value of rough stone; $75.</td>
<td></td>
<td>Sterrett, 1914, p. 665</td>
</tr>
<tr>
<td>52</td>
<td>1913</td>
<td>Cherokee</td>
<td>Several smaller stones of inferior quality found in same area in 1913</td>
<td></td>
<td>Sterrett, 1914, p. 665</td>
</tr>
<tr>
<td>53</td>
<td>1914</td>
<td>Cherokee</td>
<td>One diamond of &quot;first water&quot; found by unidentified prospector. Stone sold to an Oroville jeweler for over $100.</td>
<td></td>
<td>San Francisco Chronicle, Feb. 14, p. 1, col. 4</td>
</tr>
<tr>
<td>54</td>
<td>1914</td>
<td>Cherokee</td>
<td>One diamond was found by Thomas Riley. Value estimated by Oroville jeweler at $100.</td>
<td>Supposedly second diamond found in 1914 at Cherokee. Could this be same stone mentioned above? If so, what are details concerning first find of year?</td>
<td>Engineering and Mining Journal, Mar. 14, 1914, p. 588, col. 1</td>
</tr>
<tr>
<td>55</td>
<td>About 1915</td>
<td>Thompsons Flat?</td>
<td>A Mexican found one stone at &quot;Oroville diamond ground&quot; [Thompson's Flat?]. Sold to an Oroville citizen for $1. First quality stone. Cut by J.R. Woods and Sons, New York City</td>
<td></td>
<td>Mansfield, 1918, p. 370; George and George, 1970, p. 63</td>
</tr>
<tr>
<td>56</td>
<td>1915</td>
<td>Thompson Flat (Anon.)</td>
<td>At least two stones found in placer diggings 2 miles north of Oroville (Waring). Harry Jacoby, Oroville jeweler, has cut many diamonds from north of Oroville (Mansfield)</td>
<td></td>
<td>Mansfield, 1918, p. 370; Waring, 1919, p. 187; Anon., 1992, table 5</td>
</tr>
</tbody>
</table>

Table 1 - Diamond finds in Butte County, California
<table>
<thead>
<tr>
<th>No</th>
<th>Year</th>
<th>Location</th>
<th>Description</th>
<th>Remarks</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>57</td>
<td>1915</td>
<td>Cherokee</td>
<td>Three white first quality stones were recovered from old placer diggings of U.S. Diamond Mining Co.</td>
<td>Schaller, 1917, p. 848</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>1915</td>
<td>Cherokee</td>
<td>Six stones found. Two, according to William Fiedner, weighed 11/16 and 1/4 cts.</td>
<td>Schaller, 1917, p. 848; Scott, 1926, p. 312-313</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>1916</td>
<td>Cherokee</td>
<td>Stone found by John Hufford was valued at $125 after cutting</td>
<td></td>
<td>Waring, 1919, p. 187</td>
</tr>
<tr>
<td>60</td>
<td>1916</td>
<td>Cherokee</td>
<td>Stone found by Ben Jutz was valued at $52. Apparently same person identified in 1911 as Ben Utz</td>
<td></td>
<td>Waring, 1919, p. 187</td>
</tr>
<tr>
<td>61</td>
<td>1916</td>
<td>Cherokee Flat</td>
<td>Three stones found in 1916 weighed 1.2, 0.73, and 0.54 cts respectively</td>
<td>Two of these probably referred to by Waring, 1919, p. 187</td>
<td>Schaller, 1919, p. 892</td>
</tr>
<tr>
<td>62</td>
<td>Pre-1918</td>
<td>Cherokee</td>
<td>A Belgian is said to own 8 to 10 diamonds found in &quot;clean ups&quot; at Cherokee mine</td>
<td></td>
<td>Mansfield, 1918, p. 370</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>---------</td>
<td>-------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>63</td>
<td>Pre-1918</td>
<td>Cherokee</td>
<td>8 or 9 stones found by Mr. Sturmer and son</td>
<td></td>
<td>Mansfield, 1918, p. 369</td>
</tr>
<tr>
<td>64</td>
<td>Pre-1918</td>
<td>Cherokee</td>
<td>Campbell de Bock, a Belgian, sold a stone to Joseph De Clare who returned to Belgium</td>
<td>Is this one of 80 stones found in early 1880's mentioned by Scott, 1926, p. 313?</td>
<td>Mansfield, 1918, p. 369-370</td>
</tr>
<tr>
<td>65</td>
<td>Pre-1918</td>
<td>Moms Ravine</td>
<td>Occasional finds reported from here</td>
<td></td>
<td>Mansfield, 1918, p. 370</td>
</tr>
<tr>
<td>66</td>
<td>Pre-1918</td>
<td>Cherokee</td>
<td>A Belgian miner said to own 8 or 10 diamonds found during clean up of sluices at Cherokee mine</td>
<td></td>
<td>Mansfield, 1918, p. 370</td>
</tr>
<tr>
<td>67</td>
<td>Pre-1918</td>
<td>Cherokee</td>
<td>Harry Jacoby, Oroville jeweler, owns a 1 7/8 ct hexoctahedral diamond, one of 6 found by Ben Yutz</td>
<td>Is it Yutz, Jutz, or Utz?</td>
<td>Mansfield, 1918, p. 370</td>
</tr>
<tr>
<td>68</td>
<td>Pre-1918</td>
<td>Morris Ravine</td>
<td>Occasional finds reported from here</td>
<td></td>
<td>Mansfield, 1918, p. 370</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------</td>
<td>-------------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>69</td>
<td>1918</td>
<td>Cherokee Flat</td>
<td>A 3/4 ct. stone was found here</td>
<td></td>
<td>Schaller, 1921, p. 9</td>
</tr>
<tr>
<td>70</td>
<td>Pre-1920</td>
<td>Cherokee</td>
<td>Lee Koford, of Pentz, recovered diamond from a flume. Oroville jeweler pronounced it a &quot;good stone&quot; and polished and mounted it in a ring. Given by Koford to Lois Hansen, of Durham and Pentz, as an engagement ring</td>
<td></td>
<td>Enterprise Record, Nov. 1, 1961, p. 9A, col. 3</td>
</tr>
<tr>
<td>71</td>
<td>Pre-1928</td>
<td>Cherokee</td>
<td>A collection of more than 5 small uncut stones was shown to Lyman by Mr. Lou Vinton, storekeeper and owner of former hydraulic mine</td>
<td></td>
<td>Lyman, 1928, p. 2A; Oroville, Calif., Press, Jan. 31, 1936</td>
</tr>
<tr>
<td>72</td>
<td>1928</td>
<td></td>
<td>Estimated combined value of diamonds and sapphires produced in Butte Co. during 1928 given as $400</td>
<td></td>
<td>Symons, 1929, p. 105</td>
</tr>
<tr>
<td>73</td>
<td>1929</td>
<td>Cherokee</td>
<td>William Wilhelm found a 3/4 ct. stone. Discovery reported by D.L. Vinton of Cherokee. Finest stone found in many months. Wilhelm plans to take stone to San Francisco for evaluation and cutting</td>
<td></td>
<td>Mercury-Register, Oroville, Mar. 16, 1929, p. 1, col. 7</td>
</tr>
<tr>
<td>74</td>
<td>1930</td>
<td>Cherokee</td>
<td>J.R. Presley found a 2 ct. stone here</td>
<td></td>
<td>Logan, 1930 [1931], p. 368</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------</td>
<td>-------------</td>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>75</td>
<td>1930</td>
<td>Cherokee</td>
<td>F. Zotter found 0.6 ct. stone here</td>
<td>Photo shows C.E. Grant's use of sluice box to recover diamonds in old mine pit</td>
<td>Logan, 1930 [1931], p. 368</td>
</tr>
<tr>
<td>76</td>
<td>1930</td>
<td>Cherokee?</td>
<td>S. B. Clingham found a few gems</td>
<td></td>
<td>Rosenhouse, 1964, p. 33</td>
</tr>
<tr>
<td>77</td>
<td>Early 1930's</td>
<td>Cherokee</td>
<td>Local prospector found stone subsequently owned by C.F. Huntington. Cut and set in ring with two cut diamonds from Kimberley, South Africa</td>
<td></td>
<td>Lenhoff, 1958, p. 8</td>
</tr>
<tr>
<td>78</td>
<td>1931</td>
<td>Cherokee</td>
<td>0.5 ct. stone found by Pete Felthausen</td>
<td></td>
<td>Blank, 1934, p. 179</td>
</tr>
<tr>
<td>79</td>
<td>1931</td>
<td>Cherokee</td>
<td>2.27 ct. stone found by Mary Jackson. Sold to Mr. Duncan, Crowville</td>
<td>Designated &quot;Mary diamond&quot; by Hausel, 1995, p. 243, table 1</td>
<td>Symons, 1932, p. 100; Blank, 1934, p. 179; Hausel, 1995, p. 243, table 1, and p. 264, col. 2</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------</td>
<td>------------------------------------------------------------------------------</td>
<td>------------------------------</td>
<td>-------------------------------------</td>
</tr>
<tr>
<td>81</td>
<td>Pre-1933</td>
<td>Cherokee</td>
<td>&quot;Several hundred thousand dollars in [diamonds], one gem alone weighing over five karats in the rough, have been taken from a single hill. Three hundred diamonds have been found there:...&quot;</td>
<td></td>
<td>Rensch and Hoover, 1933, p. 35</td>
</tr>
<tr>
<td>82</td>
<td>1934</td>
<td>Clipper Mills</td>
<td>G.W. Wooley reported finding what he believed to be a broken portion of a diamond in an old stream bed. Six feet under surface in bedrock</td>
<td></td>
<td>Morning Union, July 27, 1934, p. 4, col. 4</td>
</tr>
<tr>
<td>83</td>
<td>Pre-1936</td>
<td>Cherokee</td>
<td>Alex E. Wilson owns three diamonds that were found here</td>
<td></td>
<td>Oroville Press, Jan. 31, 1936, p. col.</td>
</tr>
<tr>
<td>84</td>
<td>Pre-1936</td>
<td>Cherokee</td>
<td>Mrs. Mary Thomas owns one diamond found here</td>
<td></td>
<td>Oroville Press, Jan. 31, 1936, p. col.</td>
</tr>
<tr>
<td>85</td>
<td>Pre-1936</td>
<td></td>
<td>Mrs. Susie Miller, Chico, owns one diamond</td>
<td></td>
<td>Oroville Press, Jan. 31, 1936</td>
</tr>
<tr>
<td>86</td>
<td>Pre-1936</td>
<td>Cherokee</td>
<td>Former Senator W. E. Duncan owns one diamond found here. Approximate weight 3 cts.</td>
<td></td>
<td>Oroville Press, Jan. 31, 1936</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>---------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>87</td>
<td>1936</td>
<td>Cherokee</td>
<td>71/100 ct. diamond found by Fred M. Johansen at then-called Nigger Gully, one of several outlets of Cherokee diggings. Louis Vinton, pioneer Cherokee merchant, estimated value at $60. 428 stones found at diggings to date. Largest weighed 4 3/4 cts.</td>
<td>Apparently Louis Vinton kept record of number of diamonds found at Cherokee</td>
<td>Oroville Press, Jan. 31, 1936; Morning Union, Feb. 21, 1936, p. 4, col. 4</td>
</tr>
<tr>
<td>89</td>
<td>1952-1957</td>
<td>Cherokee</td>
<td>O.E. Bowen found two microscopic stones. One euhedral stone found about 150 feet above base of gravel (Creeley)</td>
<td>Anon., 1958, p. 4; Bowen, 1959, p. 11; Creeley, 1965, p. 5</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>Pre-1961</td>
<td>Cherokee</td>
<td>Mrs. Wendell Miller found one stone in flume. Had it polished and set in ring which she wore</td>
<td></td>
<td>Enterprise Record, Nov. 1, 1961, p. 9A, col. 3</td>
</tr>
<tr>
<td>91</td>
<td>Pre-1961</td>
<td>Bangor</td>
<td>Diamond production reported at several localities between Bangor and Cherokee</td>
<td></td>
<td>Hearst, 1961</td>
</tr>
<tr>
<td>92</td>
<td>1973</td>
<td>W. fork Feather River near Magalia</td>
<td>M.S. Joque reported finding 6 or 7 tiny diamonds here near serpentine</td>
<td></td>
<td>Joque, 1973, p. 1502-1503</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>93</td>
<td>1978</td>
<td>Feather River</td>
<td>Unidentified suction dredger reported finding several small diamonds and red</td>
<td>Kopf, verbal commun.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>garnets in riffles at present site of Oroville Dam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>1989</td>
<td></td>
<td>Three diamonds displayed at California State Mining and Mineral Museum,</td>
<td>Kopf, personal visit, July, 1989</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mariposa, Calif. Accompanying label stated they came from &quot;near Cherokee.&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>1992</td>
<td>Cherokee</td>
<td>Five Cherokee diamonds seen on display at museum, Mariposa, Calif. One was</td>
<td>Wm. Rohert, tel. commun., Nov. 11, 1992</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>cut. Remaining four appeared to be trisoctahedrons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>1992</td>
<td>Cherokee</td>
<td>Saw necklace containing about 100 tiny diamonds found in Cherokee</td>
<td>Wm. Rohert, tel. commun., Nov. 11, 1992</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>this locality in their collection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>stones in lady's platinum ring. Donated to Plumas County Museum, Quincy, by</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>the late Helen M. Powers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
<td>-----------------------------------------</td>
</tr>
<tr>
<td>99</td>
<td>1993</td>
<td>Feather River</td>
<td>Mel Wilcoxen recovered two stones while operating suction dredge. Largest was</td>
<td>Mel Wilcoxen, verb. commun., Sept. 3, 1994</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>near Cherokee</td>
<td>approximately 3/8 inches long. Identity verified by jeweler in Gridley.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Year or earlier</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------</td>
<td>------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>101</td>
<td>1865 or earlier</td>
<td>North San Juan</td>
<td>Several found in gravel. Estimated value: $75 to $100 each</td>
<td>Nevada Daily Transcript, Feb. 2, 1865, p. 2, col. 2; Daily Alta California, Jan. 30, 1865, p. 2, cols. 1 and 2</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>1867 or earlier</td>
<td>French Corral</td>
<td>Egbert Judson found a slightly yellow flawless symmetrical stone weighing 1 1/3 cts. Recovered from sluices on puddling boxes</td>
<td>Stillman, 1867, p. 354-355</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>1867 or earlier</td>
<td>French Corral</td>
<td>Largest California diamond found to date. Weighed 7 1/4 grains (Whitney, in Stillman)</td>
<td>Stillman, 1867, p. 354, 355; Whitney, 1880, p.364; Kopf et al, 1990, p. 213</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>1882</td>
<td>Chalk Bluffs</td>
<td>Grains of sand in heavy mineral concentrates had luster and brillance, appearance common to rough diamonds</td>
<td>Hanke, 1882, p. 97</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>1912</td>
<td>Jones Bar</td>
<td>W.J. Barrett panned stone weighing less than 3/4 ct. Identified by Grass Valley jeweler Mr. Zapf</td>
<td>Grass Valley Union, Aug. 11, 1912, p. 8, col. 4</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>111</td>
<td>1990</td>
<td>French Corral</td>
<td>One slightly yellow diamond was almost 1/4 inch in diameter</td>
<td></td>
<td>Walter Keller, oral commun., Sept. 19, 1990</td>
</tr>
<tr>
<td>112</td>
<td>Pre-1933</td>
<td>Chalk Bluff</td>
<td>Calif. State Mining and Mineral Museum, Mariposa, contains a diamond from this locality. No further information was available</td>
<td></td>
<td>S. Mitchell, written commun., Mar. 18, 1993</td>
</tr>
<tr>
<td>113</td>
<td>1995?</td>
<td>North Bloomfield</td>
<td>One microscopic diamond recovered from heavy mineral concentrates in trommel at Crystal placer mine, sec. 1, T. 17 N., R. 9 E., MDB&amp;M</td>
<td>Trommel believed to have been brought in for storage from another site. Entry ignored</td>
<td>Wm. Rohtert, personal commun., Mar. 25, 1997</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
<td>----------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>114</td>
<td>1884</td>
<td>Upper Spanish Creek</td>
<td>Microscopic diamond reported from here</td>
<td></td>
<td>Edman, 1884, p. 356; Edman, 1894, p. 4, col. 8; Turner, 1899, p. 184</td>
</tr>
<tr>
<td>115</td>
<td>1884</td>
<td>Gopher Hill</td>
<td>Microscopic diamond reported from here</td>
<td></td>
<td>Edman, 1894, p. 4, col. 8; Turner, 1899, p. 184</td>
</tr>
<tr>
<td>116</td>
<td>1884</td>
<td>Badger Hill</td>
<td>Microscopic diamond reported from here</td>
<td></td>
<td>Edman, 1894, p. 4, col. 8</td>
</tr>
<tr>
<td>117</td>
<td>1884</td>
<td>Mumford's Hill</td>
<td>Microscopic diamond reported from here</td>
<td></td>
<td>Edman, 1894, p. 4, col. 8</td>
</tr>
<tr>
<td>118</td>
<td>1899</td>
<td>Nelson Point</td>
<td>F. Mandeville found irregular-shaped stone at end of sluice. Greatest diameter about 1/4 inch. Contains flaw reducing value to less than $75</td>
<td>Identified by Mr. Lord, jeweler, Quincy.</td>
<td>Mining and Scientific Press, 1899, p. 638, col. 3; Kunz, 1901, p. 423</td>
</tr>
<tr>
<td>119</td>
<td>1913</td>
<td>Sawpit Flat</td>
<td>Ed Bryan found nearly round stone weighing about 10 cts. Resembled diamond found nearby in same hydraulic mine</td>
<td></td>
<td>Sacramento Union, Aug. 18, 1913, p. 7, col. 5; Hill, 1959, p. 35; Hill, 1972, p. 50</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>----</td>
<td>-------</td>
<td>------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>120</td>
<td>Pre-1913</td>
<td>Sawpit Flat</td>
<td>August Fiss found 1+ ct. stone. Cut and polished by Tiffany &amp; Co., New York. Pronounced by them to be of &quot;first water.&quot; Owned by wife of Attorney General U.S. Webb</td>
<td></td>
<td>Sacramento Union, Aug. 18, 1913, p. 7, col. 5; Hill, 1959, p. 35; Hill, 1972, p. 50</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>121</td>
<td>1872</td>
<td>Slate Creek</td>
<td>One ct. diamond owned by gentleman in La Porte (Whitney)</td>
<td>Was owner C.W. Handel?</td>
<td>San Francisco Post, Sept. 28, 1872, p. 1, col. 2; Plumas National, Sept. 28, 1872, p. 3, col. 3; Whitney, 1880, p. 456</td>
</tr>
<tr>
<td>122</td>
<td>1872</td>
<td>Gardiners Point</td>
<td>Gem quality. First and larger of two stones found here. Lost by foreman</td>
<td></td>
<td>Plumas National, Aug. 10, 1872, p. 3, col. 1; Mountain Messenger, Aug. 31, 1872, p. 3, col. 1; Raymond, 1873, p. 83; Whitney, 1880, p. 456</td>
</tr>
<tr>
<td>124</td>
<td>1884</td>
<td>La Porte</td>
<td>Microscopic stone reported from here</td>
<td></td>
<td>Edman, 1884, p. 356; Edman, 1894, p. 4, col. 8</td>
</tr>
<tr>
<td>No</td>
<td>Year</td>
<td>Location</td>
<td>Description</td>
<td>Remarks</td>
<td>References</td>
</tr>
<tr>
<td>-----</td>
<td>------</td>
<td>----------------</td>
<td>----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>127</td>
<td>1934</td>
<td>Parks Bar</td>
<td>Approximately 0.48 ct. clear diamond found by Albin Larsen</td>
<td>Identified by Marysville jeweler</td>
<td>Appeal - Democrat, July 14, 1934, p. 1, cols. 3 and 4; Kopf, unpub. ms., 1996, p. 2, 3</td>
</tr>
<tr>
<td>129</td>
<td>1934</td>
<td>Rose Bar</td>
<td>Wm. F. Hallstrom found a clear diamond weighing 30 to 35 points. Estimated value $100 after cutting</td>
<td></td>
<td>Appeal - Democrat, Oct. 4, 1934, p. 1, col. 1; Kopf, unpub. ms., 1996, p. 2, 5</td>
</tr>
<tr>
<td>130</td>
<td>1945</td>
<td>Near Parks Bar</td>
<td>Louis Drake found a 16 point diamond. Contains a few facets (=faces). On display at Moorey jewelry store, Marysville</td>
<td></td>
<td>Appeal - Democrat, Aug. 16, 1945, p. 3, cols. 7 and 8; Kopf, unpub. ms., 1996, p. 2, 5</td>
</tr>
<tr>
<td>131</td>
<td>1974</td>
<td>Hammond</td>
<td>Frank Andres recovered about 4 clear diamonds, each less than 0.4 cts., from idle bucket dredge</td>
<td></td>
<td>Kopf, unpub. ms., 1996, p. 2, 6</td>
</tr>
<tr>
<td>132</td>
<td>Pre-1992</td>
<td>Sicard Flat</td>
<td>Several diamonds recovered from nearby placer operations years ago</td>
<td></td>
<td>Kopf, unpub. ms., 1996, p. 2, 6</td>
</tr>
</tbody>
</table>
PART II

TECTONICS AND STRUCTURE

NORTHERN SIERRA NEVADA
GEOLOGY OF THE EASTERN BELT OF THE NORTHERN SIERRA NEVADA

ELWOOD R. BROOKS
Department of Geosciences
Hayward State University
Hayward, CA 94542-3088

The Eastern Belt of the northern Sierra Nevada (Day and others, 1985)—also known as the Northern Sierra terrane (Coney and others, 1980)—lies east of the Feather River Peridotite Belt (Melones fault zone). It consists largely of the early Paleozoic Shoo Fly Complex, to the west, and unconformably overlying late Paleozoic and Jurassic volcanic-arc sequences (Fig. 1).

**Shoo Fly Complex**

The angular unconformity at the base of the Upper Devonian Grizzly and Sierra Buttes Formations (the former not shown separately in Fig. 1) is a profound one, truncating faults that subdivide the Shoo Fly Complex into four imbricate thrust blocks. In ascending structural order, these thrust-bounded units are the Lang sequence ("Lang-Halsted unit" in Fig. 3), the Duncan Peak chert, the Calvert Lake allochthon, and the Sierra City mélangé (Gentry and others, 1990).

The 375 ± 10 Ma Bowman Lake batholith (Hanson and others, 1988) attains the three structurally lowest units of the Shoo Fly Complex (Fig. 1, where "Bowman Lake tonalite" = the Bowman Lake batholith). The 378 ± 5 Ma Wolf Creek granitic stock actually intrudes the unconformity between the Shoo Fly Complex and the Sierra Buttes Fm. near Greenweir, north of Figures 1 (Sawyer and others, 1987). These plutons are considered sources of Upper Devonian volcanic rocks in the Sierra Buttes Fm.

The time of deposition of the Shoo Fly Complex is difficult to determine, because nearly all radiometric ages and fossil as come from blocks (or suspected blocks) in mélangé. U/Pb mazatzal ages range from 423 ± 4 Ma (Shuler, Salamay and others, 1987) to approximately 600 Ma (latest Proterozoic, probably SFC basement; Saleby and others, 1989), and trilobites and conodonts are Middle to Late Ordovician (Potter and others, 1990; Harwood and Murray, 1990). Rudistian cherts in the Calvert Lake allochthon probably are post-Cambrian (Gentry and others, 1990).

**FIGURE 1.** Generalized geologic map of the Sierra Buttes-Bowman Lake region (Fig. 2 in Brooks and Schweickert, 1982). Locations of field trip stops 1-17 are shown by the filled triangles. Mapping by R. A. Schweickert, R.E. Hanson, G.H. Girty, and G.C. Bond, 1973-82; area south of 38° from Harwood (1983). Reactions are urged to consult Plate 1 in Harwood (1992) for a more detailed and up-to-date geologic map of the region.
Edelman and others (1989, p. 8) remind us that "the abundance of micaceous and coarsely polytextural framework quartz grains...suggests a continental provenance, generally assumed to be North America." Also, current works evidently still agree generally with R.A. Schweickert and R.E. Hanson (Brooks and Schweickert, 1982, p. 3) that the Shoo Fly Complex along the North Yuba River "...can be interpreted as part of a...subduction complex (Sierra City melange) which has incorporated large slabs of sediment from continental-derived deep-sea fans (Callerton Lake allochthon) and which ultimately scraped up and incorporated part of a continental slope and rise assemblage as the subduction complex approached a continental margin..." We will look at the Shoo Fly Complex only once on this field trip, in the Lang segment (STOP 1).

**Taylorville Sequence**

The submarine volcanic and volcanioclastic rocks, radiolarian cherts, and locally prominent epiclastic deposits which unconformably overlie the Shoo Fly Complex—referred to as the Taylorville sequence by Harwood (1988) —range in age from Late Devonian (Frasnian) to Late Early Permian (Wordian) (Harwood, 1988). The Taylorville sequence ("Paleozoic pyroclastic sequence" in Fig. 1) consists of two distinct volcanic assemblages separated by radiolarian chert (chert member of the Pelean Fm.) that signals a period of volcanic quiescence and pelagic deposition (from Middle Mississippian to at least Middle Pennsylvanian). Furthermore, the Taylorville sequence is subdivided by a major erosional unconformity that spans the Late Pennsylvanian and Early Permian (Fig. 2); the unconformity is thought to reflect uplift associated with crustal heating and extension prior to late Early Permian basaltic volcanism (Goodnough Fm.; Harwood, 1988).

The Taylorville sequence was succeeded, in the Early and Middle Jurassic, by a third volcanic assemblage and, during the Late Jurassic Mississippian and middle, all rocks were folded into the Nevedan synclinorium. Rocks of the Taylorville sequence along the North Yuba River occupy the horst and basin, so that all of them face easily, (and most dip easily).

Estimates of relative abundance of volcanic rocks made by Harwood (1988) indicate that volcanics began with voluminous eruption of lavas of the Sierra Buttes Fm. in the latest Devonian (mid-Frasnian; Hanson and Schweickert, 1986), continued at a high rate during accumulation of the Taylor Fm., but waned dramatically in the Early Mississippian, with eruption of the lower, volcanic member of the Pelean Fm. Permian volcanism produced only about half the amount of material recorded in either the Sierra Buttes or Taylor Fms. (Harwood, 1988).

We will concern ourselves on this field trip only with the first-formed, Upper Devonian-Lower Mississippian volcanic assemblage, and will view rock units belonging to three of its formations, the dacitic to andesitic Sierra Buttes Fm., the andesitic Elwell Fm., and the andesitic basaltic to basaltic Taylor Fm. (we will not see the Grizzly or Pelean Fms.). The Elwell Fm. is sandwiched between the other two formations north of the North Yuba River, but is considered the uppermost member of the Sierra Buttes Fm. in that area by Hanson and Schweickert (1986). I follow Durrell and D'Allura (1977) in mapping it separately.

Concentrations of immobile trace elements in the basaltic rocks show that they originated in an island arc and belong to the tholeiitic rock association (Brooks and Coles, 1980). Also of interest is that the Upper Devonian-Lower Mississippian island arc is compositionally inverted, volcanism commencing with andesites (Sierra Buttes Fm.) and progressing to basaltic andesites and basalts (Taylor Fm.). The earliest silica fluxes in the Sierra Buttes Fm. have epsilon Nd from -15 to -20, suggesting derivation wholly or in part from Early Precambrian or Archean continental crust, consistent with the notion that the island-arc rocks and their basement of Shoo Fly Complex originated along the western margin of North America.
Amettea (Silva and others, 1991). Harwood and Murchey (1990) review stratigraphic and tectonic evidence suggesting that the Upper Devonian-Lower Mississippian arc formed along the active North America margin.

Sierra Buttes Formation

R.E. Hanson has written extensively about the Sierra Buttes Fm. (Hanson and Schweickert, 1986, Hanson, 1991). Figure 3 shows the distribution and internal stratigraphy of the Sierra Buttes Fm. for a strike length of about 30 km (Hanson and Schweickert, 1986); the Sierra Buttes Fm. is about 1.75 km thick at the type section in the Sierra Buttes. According to Hanson (1991, p. 807), the Sierra Buttes Fm. “...consists of submarine and subaerial pyroclastic and volcaniclastic deposits penetrated by numerous related hypabyssal intrusions”. In the Sierra Buttes Lookout area, “massively bedded lapilli tuffs and tuff-breccias are randomly intercalated with finer grained tuff turbidites, horizontally laminated ash-fall tuffs, and numerous horizons of radiolarian chert”, and “penecontemporaneous hypabyssal intrusions range from basaltic andesite to rhyolite in composition...” (Hanson, 1991, p. 807).

Ewell Formation

I studied the problematic Ewell Fm. – established by Durrell and D'Alturo (1977) – along strike between Mt. Ewell and Dugan Pond, and found it to be characterized by 11 km interval of black, phosphatic chert interbedded with turbidites and debris-flow deposits rich in siliceous detritus, penecontemporaneous andesitic sills and minor peperite, and, locally, andesitic pillow lava (Brooks and others, 1982). South of Dugan Pond, Hans and Schweickert (1986, p. 993) found that the Ewell Fm. (Member C of their Sierra Buttes Fm.) consists of “...massive, massive, andesite breccias, and andesitic andesite breccias...”. North of Dugan Pond, I find that the Ewell Fm. consists of pillow lava of basalt and basaltic andesite intercalated with andesitic andesite andesite rocks, as if a vent were being more closely approached in this direction. Correspondingly, the Taylor Fm., 200 m thick, only 2.3 km thick east of Dugan Pond and about 3.1 km thick north of Gold Lake. The reader will note a difference of opinion regarding the composition of rocks in the Taylor Fm. Although most authors refer to andesite, my chemical analyses indicate that these clinopyroxene- and plagioclase-phryic rocks are basalt and basaltic andesite (17 of 19 analyzed samples have SiO2 between 50.5 and 56.2 wt. %).

Figure 3. Longitudinal section of Grizzly, Sierra Buttes, and Taylor Fms. between Dugan Pond (circled locality 1) and Grouse Ridge; base of chert member of Peale Fm. used as datum (Fig. 2 in Hansen and Schweickert, 1986). In area of Sierra Buttes Lookout, Member C of Sierra Buttes Fm. = Ewell Fm. and, according to Harwood and others (1991), Member D of Sierra Buttes Fm. = Taylor Fm. south of Middle Yuba River.
FIELD TRIP LOG

The balance of this chapter consists of descriptions of 17 field trip stops in the Eastern Belt. Figure 1 shows that the 17 stops are divided among three areas separated by considerable distances. STOP 1 is located beside California Highway 49 just east of Downieville, while STOPS 2-6 and 7-17 are reached from trailheads west of the Gold Lake Road, which connects California Highways 49 and 89 across the crest of the Sierra Nevada. The locations of STOPs 2-6 and 7-17 are indicated on topographic map bases in Figures 4 and 11, respectively. Most field trip stops include detailed petrographic descriptions that are identified by finer typeface.

Directions to STOP 1

Take California Highway 49 north from Nevada City to Downieville. At the T-intersection in the middle of Downieville, turn right (south), following Highway 49 across the Yuba River. For several hundred feet, we drive approximately along the fault—the Downieville fault of Edelman and others (1989)—that marks the eastern edge of the Melones fault zone (Fig. 1). STOP 1 is 1.4 miles from the T-intersection in Downieville, along a south-trending stretch of the highway. Limited parking is present on the left side of the highway. Ahead is a blind curve, so LISTEN and WATCH for traffic before crossing the highway and descending the path to the North Yuba River.

STOP 1 (FIGURE 1) - North side of North Yuba River east of Downieville (Downieville 7 1/2’ quadrangle)

Long sequence, Shoo Fly Complex

This stop is a good place to view mesoscopic structures in the westernmost, structurally lowest part of the Shoo Fly Complex, the Lang sequence of Harwood (1988). The Lang sequence is the most extensive of the four thrust-bounded units making up the Shoo Fly Complex and the only one that we will look at on this trip (“Lang-Halsted” unit in Fig. 1). According to R.A. Schweickert and R.E. Hanson, the Lang sequence consists of “…phyllite and quartzose sandstone with chert and rare marble”, in which “...locally preserved sedimentary features and the overall tectonic succession suggest the original depositional environment may have been continental rise and/or slope” (Brooks and Schrader, 1982, p. 2).

The stream-polished outcrops adjoining the North Yuba River reveal tight, approximately similar (Class 2), mesoscopic folds that deform thinly interlayered black phylitic phyllite and gray metachert(?). Some folds are nearly isoclinal, and some have kink-like hinges. The cleavage in the phylite, which is axial planar to the folds, has the attitude N5°W, 85°E. One can see it relaxed across metachert(?) layers in places. Lineation parallel to the fold hinges plunges 65° NSW. Small folds in the east limb of a relatively large fold exhibit e-symmetry. According to R.A. Schweickert, “...the phylitic layers is a result of deformation by strata-parallel shortening within the Sardine Lake Formation.” Early folds would be interpreted as late Jurassic and related to the Nevadan orogeny.

You may notice the coarsely phylitic boulders in flood deposits adjacent to the Shoo Fly outcrops. The plicato-phylitic boulders were derived from the Raeve Fm (Pennsian) far upstream, while the quartz-phylitic boulders are from the nearer Bowman Lake batholith (Devonian).

Thin-section petrology

The black phylite consists almost entirely of quartz, pyrite, and carbonaceous material. Some of the carbonaceous material occurs roundish specites about 0.006 mm in diameter; the rest is present as fine "dust" strings out along the cleavage. Pyrite euhedra occur prominently as "pupils" centered in lenses of granular quartz flattened in the cleavage; pyrite crystals often are tabular parallel to the cleavage.

The gray metachert (?) exhibits several interesting features in thin section. Rhombic single crystals of calcite averaging about 0.3 mm in length form tiny porphyroblasts (revealed on the weathered surfaces by pinhole-size solution pits). Rock cleavage bends around the porphyroblasts, and films of carbonaceous material coat certain parts of the calcite crystal faces. Pyrite schists and elliptical bodies of relatively strongly recrystallized quartz are nearly as large as the calcite porphyroblasts. The elliptical bodies of gneissose quartz suggest completely recrystallized radiolarians; the quartz occupies polygonal crystals with straight boundaries that frequently intersect to form triangle points. The matrix of the metachert (?) is much finer-grained and consists largely of quartz, calcite, carbonaceous material, iron oxides, and aligned flakes of white mica.

A thin section of the kinked hinge of one of the approximately similar folds discloses sub-millimeter-scale lithologic layering and strong axial-plane cleavage; carbonaceous material is both concentrated in some of the thin layers and present as films along the cleavage. The well-developed cleavage is largely attributable to the presence of extremely fine-grained, but voluminous white mica. The elliptical bodies of relatively poorly recrystallized quartz are very numerous and generally much smaller than those described above (a large one is 0.2 mm long). They are strongly flattened into biconvex lenses that lie in the cleavage, and resemble poorly preserved radiolarians in cleaved carbonaceous chert in the Devonian Elwell Fm. (Brooks and others, 1982). The protolith probably was radiolarian "siliceous argillite".

Directions to STOPs 2-6

Continue eastward on California Highway 49 to Sierra City. About 5 miles beyond Sierra City, the Gold Lake Road joins Highway 49 at the way station of Bassett. Turn left (north) on the Gold Lake Road and drive 1.3 miles to its junction with the Sardine Lake-Packer Lake Road.

Turn left (west) on the Sardine Lake-Packer Lake Road, go 0.3 miles, and turn right on the Packer Lake Road. Drive 2.4 miles and park at the Packer Lake Campground on your left. The Deer Lake trailhead is 200' to the northeast, back down the Packer Lake Road. We will hike for about 25 minutes (a lot over a mile) north-westward along the Deer Lake Trail to STOP 2, in "Prelata Valley" about 450' above the trailhead.
Initially, the trail is on ground moraine associated with the latest glacial advance in this region, termed “later post-Sangamon” by Mathiasson (1981). The conspicuous quartz-pyritic boulders of clastite were excavated from the Sierra Buttes Fm., not far southwest of us by the “Packe Lake Canyon Glacier” (Mathiasson, 1981). Beyond the second stream crossing, the trail climbs in a single switchback to the crest of the northern lateral moraine associated with this later post-Sangamon glacial advance.

STOPS 2-6 are linked by a counterclockwise circuit about midway between Deer and Packe Lakes, in the Gold Lake 7 1/2” quadrangle (Fig. 4). STOPs 2 and 6 are in the Sierra Buttes Fm., STOPs 3-5 in the Ewell Fm. (Fig. 4).

Almost every sample you pick up this afternoon will have prehnite, pumpellyite, or both prehnite and pumpellyite in it; some will contain prehnite ± actinolite. PLEASE COLLECT SAMPLES FROM THE ABUNDANT TALUS, NOT FROM THE OUTCROPS.

STOP 2 (Figures 1 and 2) - View stop, with orientation to the stratigraphy.

The Sierra Buttes south-southeast of us (Fig. 5) were mapped by R.E. Hanson, but their name was given to the Sierra Buttes Fm. much earlier by V.E. Mathiasson (1966). According to Hanson (1991), the high peaks consist mostly of andesitic and felsic hypabyssal intrusions and pyroclastics breccias formed during emplacement of magma into wet sediments beneath the sea floor. The Taylor Fm. underlies the small peak S30°W of us, the true line approximately marks its contact with the underlying Ewell Fm. (Fig. 5).

We are standing on a heavily iron oxide-stained lapilli tuff called the “cannonball tuff” because of its spheroidal weathering. This bright red, exceptionally pumiceous unit extends N40°W to the hill on the skyline south of Deer Lake (Fig. 4). It is rich in micrometric pumice and is thought to be a subaqueous pyroclastic-flow deposit, like the Tamarack tuff occurring beneath it to the southwest. To the west-southwest, joint-controlled surfaces inclined toward us approximately parallel rare bedding in the Tamarack tuff (Legier and others, 1991). (All beds in this area dip and face eastward.) The upper contact of the Tamarack tuff is near the west edge of the alluvial plain below us, and its lower contact mostly runs just behind the high ridge forming the western skyline. The Tamarack tuff rests depositions upon deities (an unroofed hypabyssal intrusion?) that are seen as boulders in the later post-Sangamon ground moraine.

The ridge just northeast of us is held up by a relatively thick, coarse-grained sill of andesitic andesite (Brooks and others, 1962). Note the rough columnar jointing, better seen to the north-northwest. The top of the next lower sill is in contact with black phosphatic chert just across the old trail from us, at STOP 3. The andesitic sills and black phosphatic chert belong to the Ewell Fm. The contact between Ewell and Sierra Buttes Fms. is placed in the valley along the old trail, the subaqueous pyroclastic-flow deposits being assigned to the Sierra Buttes Fm.

STOP 3 (Figures 4-8) - Oolitic and andesite in the Ewell Fm.

Here is a knife-sharp, largely concordant contact between black phosphatic chert and the top of one of the numerous andesitic sills that cut the Ewell Fm. Some sills encountered still-
moist, incompletely lithified chert during emplacement, resulting in generation of peperite (Brooks and others, 1982), but this undisrupted contact is the kind most frequently found. Distinctive, closely spaced (near 1-2 cm) sheets of tiny vesicles adjoin both margins of the sills, the vesicles probably formed along slip planes separating rapidly congealing andesite laminae. Note that the contact, the vesicle sheets, and white to gray phosphatic lenses and laminae, which mark bedding in the chert, are all parallel.

Examine the loose blocks of black phosphatic chert to discover the curious primary geometry of the phosphatic masses, thought to be the result of direct inorganic precipitation of fluoropatite from pore water (Brooks and others, 1982). The white-weathering phosphatic nodules, lenses, and laminae consist largely of quartz and collophane, the black chert largely of quartz and carbonaceous material, probably graphite (Brooks and others, 1982). The chert is rich in radiolarians, and such black phosphatic radiolarian cherts, widespread in Paleozoic rocks of the western U.S., are thought to have accumulated in a few thousand meters, or less, of water, adjacent to the North American continent (Coles and Varga, 1988).

Thin-section petrography

The undeformed, relatively weakly recrystallized samples of black phosphatic chert available at this locality exhibit poorly-to reasonably well-preserved radiolarians belonging to the family Enzactinidae. Paleozoic spumellarians with single or multiple, spherical or ellipsoidal lattice shells (Brooks and others, 1982). Poorly preserved radiolarians are represented simply by granoblastic aggregates of quartz free of the carbonaceous material that encloses and draws attention to them; these are commonly circular or elliptical and a little over 0.1 mm long. Even more poorly preserved radiolarians appear as ill-defined, lens-shaped quartz aggregates lying in the bedding. Lenticular masses of carbonaceous material also paralleled the bedding, but most of the voluminous carbonaceous material occurs as finely divided "dust". Not all of the carbonaceous material was exuded from radiolarians in other samples, and lattice shells (Fig. 69) and spines, occasionally still attached to shells, are preserved.

In the phosphatic lenses and laminae, microgranular quartz is charged with tiny lamellar masses of brown isotropic collophane; in places, collophane occupies 0.02-mm spheres with uncertain internal structure. The most recrystallized chert elsewhere contains colloid form fluorapatite masses whose edges bristle with stout prisms 0.005 to 0.015 mm long.

A sample of aphanitic andesite collected 10 cm from the contact with black phosphatic chert shows that the vesicle sheets are only one vesicle thick, and that the vesicles, widely spaced and still largely open, lie flattened in the plane of the vesicle sheets. The original andesite was charged with tiny prismatic plagioclase microlites; quenched hoppers microlites appear near the vesicle sheets. The microlites now consist of simply twinned albite. Small (e.g., 0.35-mm), irregularly shaped quartz poikiloblasts have replaced much of the original, presumably glassy matrix between the plagioclase microlites and thereby incorporated them. Quartz poikiloblasts occupy most of the rock along the vesicle sheets, and some individual poikiloblasts grew into the vesicles, where they formed euhedral, inclusion-free crystals. Abundant chlorite also replaced original glassy matrix. The andesite also is rich in finely granular sphele, and apatite needles may be found in the quartz poikiloblasts.
STOP 4 (FIGURE 4) - Chert veins in andesite sill in the Ewalt Fm.

We are standing on the uppermost exposed part of the next higher, relatively thick andesite sill (about 12 m are exposed). Crude columnar jointing is apparent near the base of the sill. The andesite here is finely granular because it is more coarsely recrystallized than that at STOP 3; the larger, 0.5-mm prisms prove to be quartz porphyroblasts. If you look closely, you will find scattered, gray, bipyramidal quartz megacrysts in the andesite. These are quite large— up to nearly 1 cm across—and though often embayed, straight sides are common.

The sill is traversed by persistent, long (a few meters), roughly planar veins of black chert. These dip steeply and strike N20°E, and are up to 4 cm thick and widely spaced (up to about 2 m). One of these clearly follows columnar joints in the andesite (Fig. 7), and others abruptly branch and pass into small patches of peperite. Evidently, fluid chert injected these shrinkage joints as they opened.

The average major-element oxide analysis of five samples of andesite collected from sills between this locality and Mt. Ewalt appears in Table 1 below (Brooks and others, 1982, Table 1: H20, P205, and CO2 were not determined).

Except for substantially higher FeO* and lower CaO, the average analysis is similar to that of classical Fijian tholeiitic andesites. More convincing evidence of the tectonic setting of volcanism are the rare-earth abundance patterns of the five sills (samples 5, 15, 20, 35, and 43A in Fig. 6; Brooks and others, 1982, Fig. 13). Except for relative enrichment of LREE in sample 15, the samples possess parallel, nearly flat patterns with slight relative depletion of LREE. Such patterns characterize the tholeiitic rock association in island arcs.

### TABLE 1: Composition of andesite sills in Ewalt Fm.

<table>
<thead>
<tr>
<th></th>
<th>recastculated to 100 wt. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>56.80</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.99</td>
</tr>
<tr>
<td>Al2O3</td>
<td>13.81</td>
</tr>
<tr>
<td>FeO*</td>
<td>10.97</td>
</tr>
<tr>
<td>MgO</td>
<td>3.34</td>
</tr>
<tr>
<td>CaO</td>
<td>4.54</td>
</tr>
<tr>
<td>Na2O</td>
<td>3.37</td>
</tr>
<tr>
<td>K2O</td>
<td>0.11</td>
</tr>
<tr>
<td>MnO</td>
<td>0.17</td>
</tr>
<tr>
<td>Sum</td>
<td>94.14</td>
</tr>
</tbody>
</table>

*all Fe calculated as FeO
sea-floor alteration. Inclusion-free edges of the quartz porphyroblasts are in contact either with large interstitial patches of chlorite that also enclose recti pleocomal microlites or with spherule-like, radiating clusters of prehnite fibers. Rhombic to square sphenoid grains replace recti euhedral magnetite microlites. Epikrite is intergrown with the prehnite, and acicular apatite again appears in the quartz.

STOP 5 (FIGURE 4) – Pepetite in the Swell Fm.

A relatively well-exposed section about 17 m thick discloses at least four andesite sills intercalated with black phosphatic chert and pepetite. A sill about 0.3 m thick was almost completely transformed to pepetite in situ; vesicle sheets at its base remain undisturbed in place. Closely spaced (2-5 mm) vesicle sheets occur prominently at the top or bottom of each of the sills.

The most dramatic examples of pepetite are found at the base of the uppermost, thick sill (about 9 m are exposed), at the southeast end of the outcrop near the double pine tree. Here, the vertical outcrop surfaces, and blocks in the talus littering the slope below, exhibit hairline, black chert-filled, recti shrinkage fractures, some of which narrow upward, away from the bottom of the sill. Andesite fragments are bounded by straight or sharply curved shrinkage fractures whose intersection frequently resulted in sharply pointed, fragile corners (Fig. 9). Curved bounding fractures are both convex- and concave-outward, and, indeed, individual fractures may change rapidly from one configuration to the other when traced laterally. Three- or four-combed, equant to platy fragments are common (Fig. 9). The base of the thick sill, here fragmented and converted to pepetite, is intact to the northwest, where it exhibits vesicle sheets parallel to a knife-sharp, concordant contact with underlying black phosphatic chert; pepetite occurs only sparingly along the edges of the sills, evidently only where the chert was sufficiently fluid to inject shrinkage fractures opening in the freezing sill margins. The pepetite at this locality is “poorly sorted” (ash to coarse block-size andesite fragments), and many fragments (“puzzle fragments”) can be imagined easily fitted back together by removing the thin films of chert separating them; this sort of pepetite, reflecting non-explosive, cooling-concentration granulation of quenched glassy lava, may be referred to as “poorly dispersed”.

Thin-section petrography

Black phosphatic chert at this locality contains relatively coarse (e.g., 0.4 mm long) prehnite. Crystals are tabular parallel to (001), display distinct (001) cleavage, and have a large 2V (ow, weak) birefringence is about 0.027. Also, relatively large, highly irregular prehnite grains occur in the black chert matrix of some pepetite samples. Harper (1991) reports prehnite in chert in the Jeffersonian cyhalite where the chert adjoins broken pillow...
formation of this phreatite is attributed to hot-spring activity at a spreading center.

Narrow (e.g., 0.05 and 0.5 mm) black chert veins variously terminate abruptly, gradually pinch out, contain ash-size andesite fragments, and have carbonaceous material variably concentrated in strips parallel to vein walls, doubting the result of laminar flow of chert injecting shrinkage fractures.

Originally glassy andesite fragments in the pumice contains numerous plagioclase microlites, but no vesicles. Glass in the interior of each fragment having a high proportion of glass to microlites (hyalopilitic texture) was completely replaced by chlorite. The relic plagioclase microlites have prominent brown jackets of extremely fine-grained sphene; most microlites are lath-shaped, averaging perhaps 0.09 mm in length. Tiny square sections of microlites indicate that many were square prisms, but occasional large rhombic sections show that some were rhombic tablets. Microlites were replaced by twinned albite, the composition plane(s) of which parallel their long axes. Calcite joins chlorite in the edge of this andesite fragment, where it replaced both glass and plagioclase microlites, and the sphere here occupies 0.01-mm spheres that nucleated both on plagioclase microlites and within glass. Other, more richly microlitic andesite fragments in the same sample are replaced by finely granular mixtures of chlorite, calcite, sphene, quartz, etc. In another sample, glass in the edge of a fragment was replaced by chlorite whereas that in the central part of the fragment now is represented almost entirely by calcite. In general, the nature of glass replacement is complex. Sphene may be concentrated in bands just inside and parallel to fragment boundaries, perhaps another relic of seafloor alteration.

The smallest andesite fragments (0.1 and 0.5-mm-sized) tend to be bounded by two long fractures, resulting in sharply pointed silvery fragments as small as 0.075 mm long are recognizable. Relict plagioclase microlites may project beyond fractured fragment margins into adjacent chert, and microlites freed from broken fragments are enclosed in chert.

FIGURE 8. Tamarack tuff in the Sierra Buttes Fm.

The Tamarack tuff (Brooks and Legler, 1989; Legler and others, 1991) crops out discontinuously for at least 11 km along strike; a conservative estimate of the preserved thickness in the Packer Lake-Deer Lake area is 145 m. It consists almost entirely of juvenile tephra (about 1/6 pumice blocks and vesicles in 100-g sample), about 5/6 generally less richly vesicular, fine lapilli and ash; lithic clasts of quartz-phyllic dacite and, rarely, trondhjemite and black phosphatic chert constitute a tiny fraction of the Tamarack tuff. The Tamarack tuff was emplaced abruptly in a mass flow that locally underwent lamellar flow, as indicated by dimensional preferred orientation of spindly-shaped blocks, and by alternately block-free and block-rich layers (this locality). Pumice blocks are large, the very largest exceeding 2 m in length. The average maximum dimension of the five largest blocks at 20 locations varied from 15 to 49.5 cm. The coarsest blocks (>30 cm) were found among the southernmost outcrops, near Young America and Tamarack Lakes, which are thought to be most proximal by June Legler (Legler and others, 1991). Though many pumice blocks are equant (this locality), many others were drawn out into distinctive spindles linearly parallel to their long axis (Fig. 10; aspect ratio ranges up to 16:1). Spindles were broken off at either end, and ends often are rounded, presumably by abrasion during transport in the mass flow (Fig. 10). Spindles commonly are distorted, even telescoped; such ductile behavior most likely occurred during toothpaste-like exudation of vesicular pumice blocks (Fig. 10). Hanson (1991) terms that the pumice blocks are pillows in isolated-pillow breccia.

Pumice blocks have been selectively silicified and phosphatized. Vesicles largely are filled with quartz and blocks weather white. Twelve of 27 pumice blocks analyzed contain over 1 wt. % FeO (1.18-6.17; PO4)-rich sea water evidently entered vesicles at the time of deposition of the mass flow. Assuming constant Al, the average pumice block (N=27) gained P, Si, Na, and Ca, and lost K, Ti, Fe, Mn, and Mg, with respect to the average matrix sample (N=19). The composition of the average matrix sample—recollected in Table 2 below, thought to approximate, except for high FeO and low CaO, that of the low-K, high-SiO2 andesite erupted originally. The composition of the average matrix sample—recollected in Table 2 below—is compared in Table 2 to the average composition of nine samples of andesite silt and pillow breccia in the Elwood Fm. (Brooks and others, 1982, Table 1). I believe that
the Tamarack tuff represents the explosively erupted, volatile-rich upper portion of an andesitic magma body that somewhat later was the source of the Eloow sills and lava flows.

### Table 2: Composition of andesitic matrix of Tamarack tuff (Sierra Buttes Fm.) compared to that of andesite sills and pillow lavas in the Eloow Fm.

<table>
<thead>
<tr>
<th></th>
<th>average of 19 Tamarack tuff matrix samples</th>
<th>average of 9 Eloow Fm. samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>60.5</td>
<td>61.2</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.72</td>
<td>1.06</td>
</tr>
<tr>
<td>Al2O3</td>
<td>16.59</td>
<td>14.43</td>
</tr>
<tr>
<td>FeOt</td>
<td>8.86</td>
<td>11.54</td>
</tr>
<tr>
<td>MgO</td>
<td>4.54</td>
<td>3.19</td>
</tr>
<tr>
<td>CaO</td>
<td>4.51</td>
<td>4.28</td>
</tr>
<tr>
<td>Na2O</td>
<td>2.48</td>
<td>3.80</td>
</tr>
<tr>
<td>K2O</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>MnO</td>
<td>0.17</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The obviously out-of-place block that constitutes STOP 6 is quite unrepresentative of the Tamarack tuff, in that it exhibits size sorting of tephra into several distinct beds. Most Tamarack tuff is structureless and poorly sorted, presumably the result of deposition by a turbulent mass flow. The white-weathering, originally puniceous blocks and lapilli are supported by a darker, chloritic matrix of originally microvesicular ash and fine lapilli. Puniceous blocks and lapilli, the largest of which are 35-45 cm long, are square or rectangular; rounded, and usually equant. They seldom are deformed; at this locality, and inferted spindle also are rare. Your hand lens will reveal tiny round quartz amygdules in both puniceous blocks and matrixes, and both also contain sparse small quartz phenocrysts, some subhedral.

**Thin-section petrography**

A block has finely granular epidote concentrated in patches and streaks that parallel original flow lamination, the latter marked by aligned, tiny, reticled plagioclase microlites and relatively large (e.g., 2-mm-long), elongated amygdules. Most puniceous blocks in the Tamarack tuff exhibit close-packed, spheroidal, reticulated mesostasis averaging about 0.07 mm across (51-68% vesicles in eight point-counted blocks), and this block has abundant, round to elliptical microvesicles averaging about 0.05 mm long. All amygdules in this block consist of relatively coarse granular quartz, sometimes accompanied by prehnite, sometimes by pumpellylite (pleochroic, pale yellow-brown to bright green (+V); anomalous blue and red-brown interference colors). Rare plagioclase microphenocrysts were replaced by mixtures of albite and highly irregular quartz. A solitary plagioclase phenocryst 1.5 mm long now consists mostly of quartz and prehnite. Two reticulate quartz phenocrysts are present in the largest one 1.85 mm across. Tiny prehnite subhedral, some replaced by iron oxide, pervade the sample, and spherule occupies huge spherules only about 0.006 mm in diameter.

Lapilli-size, originally microvesicular and microlitic fragments are easily recognized in the Tamarack tuff matrix at STOP 6, but recrystallization has obliterated details of ash-size fragments. The vesicles, now occupied and overgrown by chlorite, quartz, prehnite, and epidote, typically are elongated in a direction parallel to aligned retic plagioclase microlites, tiny fibers averaging 0.035 mm long. Lapilli also contain scattered quartz and plagioclase phenocrysts 0.3 to 1.75 mm in maximum dimension. The larger of the embedded quartz phenocrysts have been shattered in situ into many fragments. The matrix sample is rich both in prehnite and epidote, both of which may be kbroplastic. Prehnite (2VZ large, 2P very weak, distinct 001) cleavage, tabular parallel to (001) occupies grains as large as 0.55 mm, and often comprises aggregates with epidote. Finely granular spheres also are abundant. Small unoriented prehnite tablets occur with quartz in veins. Elsewhere, matrix samples are seen to consist of well-sorted coarse ash and fine lapilli that are equant or elongated and often blocky or three-cornered; subsequent eruption of tephra is indicated.

**Directions to STOPs 7-17**

Drive southeastward on California Highway 70 to its junction with California Highway 89. Turn right (south) on Highway 89 and drive 2.7 miles through Graeagle to the intersection with the Gold Lake Highway (U.S.F.S. Highway 24). Turn right (west) on the Gold Lake Highway and drive 11.6 miles to the junction with the Salmon Lake Road. Turn right (west) on the Salmon Lake Road and go 1 mile to its end at Upper Salmon Lake, crossing several recessional moraines associated with the later post-Siogemian advance of the "Salmon Creek Canyon Glacier" (Mathieson, 1981). Park at Upper Salmon Lake. There will be a 15-minute hike to STOP 7.

**STOPs 7-17** are linked by a clockwise circuit south, southwest, and east of Upper Salmon Lake, in the Gold Lake 1/2 quad (Fig. 11). STOPs 7-10 and 14 are in the Taylor Fm., STOPs 11, 13, 15, and 17 in the Eloow Fm., and STOPs 12 and 16 along the contact between the two formations (Fig. 11). We will be mostly in lower-greenschist rocks in this area, though some rocks containing prehnite + actinolite also occur.

Scramble south on a narrow, rough fisherman's path along the east side of Upper Salmon Lake. Note the glacial strie trending 55°E at the lake outlets at the dam. The strie are developed on plagiolepidoblastic, puniceous lapilli tuff in the Taylor Fm. Continue southward along the south end of Upper Salmon Lake. Where the path becomes tangent to the overhand power line, note that the Taylor lapilli tuff underfoot contains widely scattered blocks, some amygdaloidal quartz and chlorite amygdules. Similarly shaped lapilli and talus-vreccia underlie the knob you just passed on your left (to the south). At least 95 m of such rocks are exposed there, without obvious depositional break. How did these materials originate, and how did they accumulate in such great thicknesses?

**STOP 7 (FIGURES 1 and 11)**—Debris-flow deposit and ash turbidites in the Taylor Fm.

The origin of some of the coarser debris in these thick-bedded volcanioclastic rocks is obvious here: broken pillows (Fig. 12).
This nice broken-pillow breccia (Brooks and Gerout, 1972) is interpreted as the basal part of a normally graded debris-flow deposit produced by slumping of the oversteepened flank of a pile of pillows onto contemporaneously erupted sphenic (represented by the lapilli tuff supporting the pillow fragments). We are standing on a bedding surface. The pillow fragments are distinguishable from feldspar-phyric and also exhibit sparse, small clinopyroxene phenocrysts and quartz xenocrysts, some elongated perpendicular to pillow margins. They have prominent, pale (epidote-rich) outermost rims followed abruptly inward by dark brick-red (actinolite-rich) selvages which grade into the pillow interior (Fig. 12). The pale outermost rim represents part of the original glassy pillow rim. Note that the broken edges of pillows are irregular; these pillows were not prismatically jointed (Fig. 12). The derivation of the large, rimless, clinopyroxene- and plagioclase-phyric blocks containing abundant, large quartz xenocrysts is unknown, but they might be disrupted sills. The broken-pillow breccia displays normal grading of blocks and lapilli, and comprises the lowest exposed 1.2 m of the debris-flow deposit (the bottom of the deposit was cut away by the presently layered sills). The overlying 1.2 m consist of structureless lapilli tuff just like that forming the matrix of the broken-pillow breccia, and this passes upward into the final 0.6 m of vaguely stratified tuff and lapilli tuff.

The strikingly bedded rocks which overlie the debris-flow deposit are upward-fining ash turbidites. The finest ash always weathers white. Evidence of scour (and resulting cross-stratification) is present, and possible Tubs. Bouma sequences can be found (Tv=3, T1=3, T2=3, T3=3), massive lapilli tuff or coarser tuff, T2=finer, plane-parallel-laminated tuff; T3=uppermost, fine, rippled tuff. Most interesting is the curious bedding feature called "sled structure". This is the local involvement of indistinctly stratified, coarse and fine tuff, and occurs in groups at the same horizon (representing the edge of a laterally migrating channel?). I have seen similar features in turbidites in the Ordovician. Bedded Pyroclastic Fm. on Snowdon, Wales, where they are termed "birds-foot laminae" by Peter Nicol, and occur in cataclastic incursions of unconformable sediment; deposition was from high-density turbidity current, and Sr/Sr and Th/Th divisions are characteristic (Orton and others, 1990). Figure 13 is a sled structure photographed some distance south of us, since the incorporated pillow fragment is standing on end, deposition from a high-density turbidity current, or even more-cohesive flow, is indicated.

**Thin-section petrography**

The interior of a pillow fragment, just within the 1-cm thick epidote-rich rim, exhibits prominent, sharply euhedral, reflect phenocrysts and glomerocrysts of plagioclase and clinopyroxene. Individual crystals of plagioclase reached 1.65 mm in maximum dimension, those of clinopyroxene 1.05 mm. Plagioclase also formed euhedral microphenocrysts and sparse, oriented microlites, and reflect clinopyroxene microlites can be found as well. Plagioclase now consists mostly of albite with undulatory extinction, variously oriented sheaves of parallel to radiating actinolite fibers, sphenic granules, and some epidote and chlorite. As the epidote-rich rim is approached closely, airiaous films of hematite appear and the abundant actinolite coarsens to bundles of parallel, more-birefringent fibers, and individual prisms as long as 0.1 mm that are sometimes simply twinned. This coarsening is accompanied by loss of dark "clast" and sphenic granules.
The matrix in the epidote-rich rim certainly consisted originally of glass, for curved, relict perlitic and/or thermal-contraction cracks are apparent where highlight is hematite. Relict plagioclase microphenocrysts and microclines are jacketed by gray "dust" present in the original glass, as are occasional small (e.g., 0.4 mm), round to elliptical amygdules occupied largely by radiating sprays of actinolite brecciated from the original vesicle walls. The glassy matrix was largely replaced by xenoblastic to idiomorphic epidote of widely variable grain size; some chlorite, at least, also is present.

The pillow fragments are supported by massive lithic-crystal lapilli tuff of similar composition (basalt to basaltic andesite). Lapilli tuff adjoining the epidote-rich, originally glassy pillow rims contains no obvious pillow-rim spall; instead, the richly phytic (but not prominently glomerophytic) ash and lapilli generally were more vesicular than the pillow rims (amygdaloids consist mostly of chlorite and actinolite). Plagioclase phenocrysts again were replaced by albite, riddled by white-mica inclusions, clinopyroxene mostly by coarse actinolite (minor chlorite, epidote, and quartz); a little clinopyroxene, rimmed by actinolite, survived. The matrix of ash and lapilli now consists of actinolite (variably oriented needles and bundles of parallel needles or fibers) and very dark, "cloudy" sphaeres, and lacks the albite with undulatory extinction present in pillow (fragments calcite-rich samples appear to lack the actinolite, as well). Some lapilli are so charged with amygdules as to have been scoraceous. Round to elliptical vesicles at least as small as 0.05 mm were filled with chlorite (the smallest ones) or with chlorite, calcite, epidote, and quartz in various proportions (the larger ones, which average perhaps 0.3 mm in diameter). The largest amygdules (e.g., 2.75 mm long) are quite irregularly shaped. Many ash-size fragments consist simply of broken plagioclase phenocrysts.

STOP 8 (FIGURE 11) - Pillow lava in the Taylor Fm.

Walk southwestward uphill from STOP 7 to a plagioclase-and clinopyroxene phytic, basaltic dike that trends N80°W. Walk westward along the dike until it intersects pillow lava present near the base of the Taylor Fm.

These discrete, unconnected, elliptical pillows are embedded in a relatively voluminous, locally stratified, tuffaceous matrix; this is as close-packed as they get (Fig. 14). The pillows reach approximately 3 m in maximum dimension. A few are broken. The small plagioclase glomerocrysts are characteristic of Taylor pillow lavas; small clinopyroxene phenocrysts are rare. When present, large (to nearly 4 cm) quartz amygdules usually occur near pillow margins and may be elongated perpendicular thereto (Fig. 14). The complex mineralic zoning of pillow margins is interesting. The gradual reddening toward a pillow...
marg in is due in part to outward increase in the amount of metamorphic actinolite (or actinolite and chlorite), and the pale outer rim is epidote-rich, as already mentioned. In places, an outermost, brick-red, chlorite-rich rim is preserved; together with the epidote-rich rim, it represents the original glassy pillow rim (Fig. 14). It often was granulated by thermal contraction, the fragmented glass preserved in situ or partially or wholly stripped away.

![Image of close-packed pillows with complex mineralogical zoning rim: Stop 8 in the Taylor Fm. Scale is 16.5 cm long.](image)

**FIGURE 14.** Close-packed pillows with complex mineralogical zoning rim. Stop 8 in the Taylor Fm. Scale is 16.5 cm long.

The chemical analysis of the slumbrous core of a basaltic andesite pillow collect ed just south of us appears in Table 3 below (Sample C36), together with the average analysis of 19 Taylor lavas collected between Sierra City and Long Lake (second column). The standard deviation divided by the mean is over 25 wt. % for all oxides save SiO2, TiO2, and FeO*, partly reflecting element mobility during metamorphism.

**Thin-section petrography**

A thin section cut near the core of a pillow shows that pillow interiors are less recrystallized than pillow rims: actinolite is almost non-existent, and abundant clinopyroxene microcrystals are unaltered, even where adjacent to clinopyroxene phenocrysts.

**TABLE 3. Composition of basalt and basaltic andesite lavas in Taylor Fm.**

<table>
<thead>
<tr>
<th></th>
<th>C36</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO2</td>
<td>56.0</td>
<td>53.8</td>
</tr>
<tr>
<td>TiO2</td>
<td>0.41</td>
<td>0.47</td>
</tr>
<tr>
<td>Al2O3</td>
<td>20.31</td>
<td>15.98</td>
</tr>
<tr>
<td>FeO*</td>
<td>9.12</td>
<td>9.07</td>
</tr>
<tr>
<td>MgO</td>
<td>4.08</td>
<td>5.94</td>
</tr>
<tr>
<td>CaO</td>
<td>3.91</td>
<td>7.50**</td>
</tr>
<tr>
<td>Na2O</td>
<td>4.15</td>
<td>3.17</td>
</tr>
<tr>
<td>K2O</td>
<td>nd</td>
<td>0.36**</td>
</tr>
<tr>
<td>MnO</td>
<td>0.15</td>
<td>0.18</td>
</tr>
<tr>
<td>Sum</td>
<td>97.13</td>
<td>96.48</td>
</tr>
</tbody>
</table>

**Note:** Of the 12 analyses, CoO was not detected by INAA in one sample.

**Note:** Of the 12 analyses, K2O was not detected (nd) by INAA in one sample. The detection limit was about 0.1 wt. % K2O.

that have been wholly recrystallized to chlorite, quartz, and epidote. The clinopyroxene microcrystals occur as stout prisms often 0.1–0.2 mm long, and display weak hourglass color-zoning (brown to nearly colorless) and some simple (100) twins. The pillow core also is relatively rich in plagioclase microcrystals. These are of widely variable size, from tiny slivers to laths 0.25 mm and more long, and, together with the clinopyroxene microcrystals, exhibit haphazard arrangement. Abundant plagioclase glomerocrysts, each consisting of many unoriented euhedra, range up to about 4 mm across; one individual crystal is 3.9 mm long. These sometimes incorporated clinopyroxene crystals, and clinopyroxene also formed a few glomerocrysts unaccompanied by plagioclase. Plagioclase glomerocrysts mostly are replaced by albite single-crystal pseudomorphs riddled by inclusions of epidote. Some clinopyroxene glomerocrysts are pristine, some completely replaced as described above. Scattered, relatively large (often 0.75 mm), round amygdules largely consist of quartz, which bears apatitic prisms near original vesicle walls; very narrow linings of chlorite and a little actinolite may intervene between the quartz fillings and vesicle walls. A few of these amygdules are filled with radiating epidote prisms.

Relatively large epidote crystals occur frequently in the matrix of this pillow-core material, as do rounded to irregular patches of chlorite at least as small as 0.03 mm that represent tiny amygdules. The remainder of the matrix consists of sphenic granules and delicate radiating sprays of fibers which now, at least, consist of albite with undulatory extinction. The latter are most apparent adjacent to relict vesicles, and must have originated by crystallization of glass (during sea-floor alteration?). The gradual widening of the edges of pillows just inside the pale, epidote-rich rims may be partly the result of loss of this albite.

A thin section cut across the outer 17 mm of another pillow intersected all three of the selvages that sometimes are present:
the innermost, dark brick-red selvage; the medial, pale selvage, here c 1 mm wide; and the outermost, brick-red rim, up to 7 mm wide in this sample. Not until one is within a few millimeters of the pale, c 1-mm selvage does actinolite first appear abundantly in the pillow-lava matrix and as pseudomorphs of clinopyroxene microlites. Also, red iron oxide gradually increases in amount over this interval, eventually becoming concentrated, with very dark brown leucosomes, in sinuous, anastomosing films coinciding with the c 1-mm selvage. The films, together with increased amounts of chlorite, comprise a foliation parallel to the edge of the pillow. The c 1-mm selvage consists of granoblastic epidote with red-brown pigment that encloses delicate silver- to lath-like plagioclase microlites originally enclosed in glass; most microlites display the characteristic jackets of dark "dust". Outboard of this selvage is the final rim, undulated in this sample, which originally was particularly glass-rich, encasing many fewer microlites. The glass now consists largely of almost isotropic chlorite (banded green and white interference colors) charged with biotite and small spheres of dark brown, cloudy patches of leucosome, at least some of which originally enclosed tiny microlites. Relatively coarse, idiomorphic actinolite and epidote (the angle between Z and a is at least 29°) are scattered throughout this material, and chlorite amphiboles outlined by necklaces of granular leucosomes also appear. The latter often are shaped like biconvex lenses and parallel to the pillow margin. A sample in which the glass was affected by cooling-contraction crystallization has angular reticulate glass fragments to 8 mm long bounded by flat to smoothly curved conchoidal fractures.

The matrix between pillows consists of tuff largely replaced by fine-grained, granoblastic epidote (hence the pale color of the matrix material.) Coarse-ash grains bear actinolite, as well.

STOP 9 (FIGURE 11) - Pillow lavas, ash turbidites, and debris-flow deposits in the Taylor Fm. West west to STOP 9.

Taylor pillow lava here is overlain by well-bedded (N10W, 30° E) crystal-lithic-tuffitic tuffs, which in turn are surmounted by lithic-tuffitic lapilli tuffs containing pillow fragments and china-white lumps of pumice (look for tiny round quartz amygdules with the hand lens). (Remember that the facing direction is easiest.) Detailed mapping discloses that the Taylor pillow flows have flat bases, steep flanks, and highly irregular upper surfaces (Brooks and Gehrke, 1972). The tuffs were emplaced contemporaneously with the pillows, and thereby comprise their matrix. When pillows were not being formed, tuffs with tabular stratification continued to be deposited from turbidity currents (evidence for this depositional mechanism is discussed at STOP 7 and 10). The interbedded lapilli tuffs and tuff-breccias containing pillow fragments and pumice lumps (broken-pillow breccias) are debris-flow deposits; debris flows evidently were initiated by slumping of the oversteppled flanks of the pillow lavas.

Note worthy in this outcrop are: 1) the apparent differential compaction of tuff where it grades into large pillows; 2) pillows broken in situ and vexed by tuffaceous matrix; 3) the pinching out of the bedded tuff sequence against the underlying pillow lava (surface unconformity); 4) traces of fossils in the bedded tuff; and 5) pillow fragments in the lithic-tuffitic lapilli tuff, some with quartz amygdules elongated perpendicular to pillow margins, some with pale, epidote-rich rims.

A large slab lying on the ground nearby shows the well-bedded (N10W, 30° E) crystal-lithic-tuffitic tuff, which in turn is surmounted by lithic-tuffitic lapilli tuffs containing pillow fragments and china-white lumps of pumice (look for tiny round quartz amygdules with the hand lens). The tuffs were emplaced contemporaneously with the pillows, and thereby comprise their matrix. When pillows were not being formed, tuffs with tabular stratification continued to be deposited from turbidity currents (evidence for this depositional mechanism is discussed at STOP 7 and 10). The interbedded lapilli tuffs and tuff-breccias containing pillow fragments and pumice lumps (broken-pillow breccias) are debris-flow deposits; debris flows evidently were initiated by slumping of the oversteppled flanks of the pillow lavas.

Note worthy in this outcrop are: 1) the apparent differential compaction of tuff where it grades into large pillows; 2) pillows broken in situ and vexed by tuffaceous matrix; 3) the pinching out of the bedded tuff sequence against the underlying pillow lava (surface unconformity); 4) traces of fossils in the bedded tuff; and 5) pillow fragments in the lithic-tuffitic lapilli tuff, some with quartz amygdules elongated perpendicular to pillow margins, some with pale, epidote-rich rims.

Noteworthy in this outcrop are: 1) the apparent differential compaction of tuff where it grades into large pillows; 2) pillows broken in situ and vexed by tuffaceous matrix; 3) the pinching out of the bedded tuff sequence against the underlying pillow lava (surface unconformity); 4) traces of fossils in the bedded tuff; and 5) pillow fragments in the lithic-tuffitic lapilli tuff, some with quartz amygdules elongated perpendicular to pillow margins, some with pale, epidote-rich rims.

Finally, note the draping of pillows one over another in the adjacent outcrop. The upper pillow apparently sagged downward between the two underlying, already-solid pillows, which themselves were draped over subjacent, solid pillows. Quartz amygdules in the upper pillow coalesce upward: some are elongated perpendicular to the upper margin of the pillow, suggesting continued growth of vesicles on a crystallographic front as it moved toward the pillow center.

Thin-section petrography

The lithic-tuffitic lapilli tuff contains two kinds of lapilli: one was pumiceous, lacking, or nearly lacking, plagioclase microlites; the other was microlite-rich
and generally poorly vesicular. Though relict plagioclase microclasts consist of albite, plagioclase phenocrysts may consist largely of aggregates of quartz, some quite fine-grained, and these evidently masquerade as quartz phenocrysts under the hand lens, millimeter-scale silica metasomatized clearly took place. The matrix of the microcline-rich lapilli always contains abundant actinolite as tiny sheaves of fibers or as relatively coarse, acicular crystals having rhombic cross sections. The few vesicles present are filled, in various combinations, by apatite-bearing quartz, chloride, epidote, and subhedral, pleochroic brown almandine. In contrast, the matrix of the originally pumiceous lapilli is olivine-richest. Chlorite both replaced glass and filled vesicles, so that the latter would not be apparent. Veins were distorted (elongated) next to plagioclase phenocrysts. The olivine-rich matrix contains unoriented, acicular actinolite crystals and xenoblastic to idiomorphic epidote.

Some pumiceous lapilli have the matrix largely replaced by acicular actinolite, with chlorite apparently confined to amygdules, and, in other such lapilli, relatively very large crystals of epidote (e.g., 0.65 mm) and quartz (e.g., 1.3 mm) have replaced glass. Individual crystals of such growing across many vesicles in the process. Where quartz replaced glass, it contains acicular actinolite, but chlorite again is relegated to amygdules. One pumice fragment was replaced by granoblastic epidote containing a little actinolite and the usual brown sphene/eucorrenes marking relict vesicles. The analbite-white pumice lens so conspicuous in outcrop probably were replaced mostly by quartz and epidote, but their pale color actually may be due largely a dark brown, sphene/eucorrenes pigment.

In less recrystallized samples, preserved edges of lapilli are seen to be scalloped whose vesicles were broken across, and a few ash grains largely bounded by concave-outward vesicle walls have the form of sharply pointed chards. Lapilli range up to about 9 mm long in thin section.

A sample of the well-bedded tuff contains several of the white-weathering laminae representing the originally finest ash. These are 2- to 5-mm thick and consist almost wholly of cloudy (brown pigment), finely granoblastic epidote, and plagioclase grains. Actinolite needles and quartz also may be present. None of the ash has been disintegrated. Three of these laminae, but no relict plagioclase crystals are present, the ash may have been weathered. Repliact ash and lapilli up to 2.8 mm long can be recognized in the coarser interbeds; however, many of these are not vesicular, possess relict plagioclase microclasts, and are actinolite-rich. Many others comprise relict plagioclase phenocrysts from their nonvesicular, microclitic matrix. A few sparsely vesicular fragments have a matrix rich in lithic fibers and laths, the latter clearly relict plagioclase microclasts. Large, xenoblastic to idiomorphic epidote crystals replaced much of this coarser tuff, and may occasionally enclose relict plagioclase microclasts, also present are quartz, sphene, and considerable chlorite.

Other samples of tuff contain no relict plagioclase crystals of any sort, contain many richly vesicular ash grains, and doubtless represent utricol tuff. Ash grains are roughly equant to elongated.

STOP 10 (FIGURE 11) - Ash turbidites and debris-flow deposits in the Taylor Fm.

Walk northeast down hill to STOP 10.

Thinly stratified tuffs here are characterized by repeated, string-upward packages thought to represent Tabbs tenses, and accordingly they are considered to be ash turbidites deposited from low-density turbidity currents. The coarsest, structureless sili (a-S3 of Lown, 1982) division of a turbidite is followed upward by the plane-parallel-laminated sili division, which in turn is succeeded by the finest (white-weathering), rippled Tc division (Fig. 16). Creasts of Tc ripples commonly are truncated at the base of the next higher turbidite (Fig. 16). A colleague asserts that the finest tiffs represent Tc instead of Tc divisions. What do you think? Tc divisions may be normally graded, with respect to little tuffs, or reverse graded, with respect to pumice.

Trace fossils again appear, in the finest, rippled Tc (Tc?) divisions of turbidites. According to W.C. Miller III (personal communication, 1989), the branching forms are Chondrites, the meandering ones I hemicyclina; and the entire assemblage is characteristic of upper bathyal to supratidal depths. The joint-controlled outcrop surface intersects bedding at a very small angle, so that the amplitudes of ripples are greatly accentuated. Actual amplitudes and wavelengths average about 1.5 cm and 10 cm, respectively. We have never seen storm-weather ripples.

Interbedded (N20°E, 25°NE) with the ash turbidites are relatively thin (e.g., about 90 cm) beds of lapilli tuff containing pillow fragments. A fallen slab shows two such debris-flow deposits, separated by a little stratified tuff. Pillow fragments project from the top of the lower debris-flow deposit, which is reversely graded with respect to the pillow fragments, and load casts occur at the base of the upper one.

STOP 11 (FIGURES 11 and 17) - Arctico and basalt sills and volcanogenic sandstones in the Elwell Fm.

Walk westward to join the trail to Horse Lake. Beyond Horse Lake, leave the trail above several switchbacks and walk westward uphill to STOP 11.

The ridge forming the skyline to the north again displays the stratigraphic section nicely; the foresteled saddle is underlain by the Elwell Fm.; the core, gray and red outcrops to the left (west) belong to the Sierra Buttes Fm.; and the darker outcrops to the right make up the upper part of the Taylor Fm.

A thick sill of Elwell andesite intruded the Sierra Buttes Fm. a few hundred meters north of us, then became dike-like and climbed stratigraphically until it turned on its side to become sill-like again at this location, the stratigraphic horizon occupied by the Elwell Fm. (Fig. 17). The orientation of the sill here is revealed by the steeply plunging columnar structure (75° N30°W). The sill overtops up to 12 cm of epilithic volcanic sandstone interwзвтшш with black phosphatic chert (note the white phosphatite nodules). Some sandstone beds, rich in gray quartz and white plagioclase derived from dacite in the Sierra Buttes Fm.
are quite coarse (sand grains up to 1.5 mm in diameter). Appearing beneath the Elwha sedimentary rocks is the top of another sill of quite a different kind. This one is capped with large (to 1 cm long), unaltered, light green clinopyroxene phenocrysts. Sills of this type occur volumetrically at and near the stratigraphic horizon of the FF, and are thought to represent cumulates complementary to the aphyric andesite sills. They are basaltic, and reach thicknesses of at least 34.5 m. This sill is about 2 m thick nearby, where its base is exposed, and most of the top one meter is exposed here. The 10-cm-thick, clinopyroxene-rich edge of the sill gives way downward to a 15-cm-thick, clinopyroxene-free but originally relatively vesicular zone (angulates of quartz and chlorite to 5 mm); this zone passes back to 60 cm or so of generally clinopyroxene-rich basalt. Such interlayering presumably is the result of extrusion during sill emplacement. No chemical analysis is available for this sill, but the average analysis of three other of these richly clinopyroxene-phyric intrusions follows. (The tetragonal $\mathbb{F}$).

The modes of the three analysed samples contain from 12 to 35% clinopyroxene phenocrysts and from 0 to 16.5% plagioclase phenocrysts. All three samples are classified as subalkaline, tholeiitic, and basaltic by all major-element and norm criteria recommended by I. I. Castagnola and Y. R. Crabb (1971). All three are hypnormative, and one is ol normative (Ca 15.3%), the other two are weakly Q-normative (Q 1.27, 2.70). Abundances of the immobile elements Ti, Zr, Y, Cr, and La show that these basalts belong to the tholeiitic rock association of island arcs (Barnes and Coles, 1980). An island-arc tholeiitic origin also is indicated by the concentrations of heavy to intermediate rare earths ($\text{Sm-La}$), which range from 3.5 to 6 times chondritic abundances. Zr values are low, probably because of dilution by accumulation of clinopyroxene phenocrysts, and Cr values are high for the same reason.

<table>
<thead>
<tr>
<th>oxide wt. %</th>
<th>immobile trace element ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>49.5</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.44</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>13.74</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>1.73</td>
</tr>
<tr>
<td>FeO</td>
<td>8.60</td>
</tr>
<tr>
<td>MgO</td>
<td>9.54</td>
</tr>
<tr>
<td>CaO</td>
<td>9.09</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>1.58</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.87</td>
</tr>
<tr>
<td>MnO</td>
<td>0.20</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.05</td>
</tr>
<tr>
<td>H$_2$O$^+$</td>
<td>2.96</td>
</tr>
<tr>
<td>H$_2$O$^-$</td>
<td>0.17</td>
</tr>
<tr>
<td>C$_{CO}_2$</td>
<td>0.09</td>
</tr>
<tr>
<td>Sum</td>
<td>99.25</td>
</tr>
</tbody>
</table>

$\text{FeO}^+ = 16.16$
quartz and albite grains were derived from phenocrysts of quartz and plagioclase, the limy granular grains from the matrix—now recrystallized—in which these phenocrysts originally were embedded. Indeed, some limy granular grains bear relict quartz phenocrysts rounded by magmatic corrosion, some euhedral, relict plagioclase phenocrysts, and a few, lath-shaped, relict plagioclase microcrysts. Some quartz grains are highly angular. All of these materials evidently were eroded from dacite in the underlying Sierra Buttes Fm. Films of nearly isotropic chlorite separate the sand grains, and spherule and epidote also are concentrated there.

The black chert laminae consist of granular quartz and epidote, and black, dust-like carbonaceous material, as well as scattered detrital grains; radiolarians are not apparent.

Although almost nothing can be told about the original condition of the matrix of the euhedral clinopyroxene-plagioclase silt rock, the clinopyroxene phenocrysts themselves are nearly pristine. They comprise stout prisms considerably rounded by magmatic corrosion (colorless, 100° polysynthetic twinning, birefringence about 0.027, the angle between Z and c = 41°). Optically continuous, irregular actinolite grains fill interiors of the clinopyroxene phenocrysts, and actinolite may form serrated hinges along their margins. Though much actinolite is colorless, some individual crystals are color-zoned, with Z colorless to rather deep brown, or brown to blue-green. The matrix of the basaltic silt rock is rich in actinolite (bands of parallel fibers and coarser prisms), granular spherule, and xenoblastic epidote. Many relatively large (e.g., 0.4 mm) quartz, augen to elongated, round or ellipsoidal to irregular, single crystals or crystal aggregates of quartz are present, some of these probably represent amphiboles, but others appear to contain relict plagioclase microcrysts, as in the andesitic silt rock. Relict magnetite microcrysts also occur. The matrix in addition exhibits irregular patches of black iron oxide and lenticular bodies—probably deformed amygdules—of chlorite+/calcite+/-quartz.

STOP 12 (FIGURE 17) - Elwell andesite sill and overlying debris-flow deposit

Walk downhill to the southeast, approximately along the contact between the andesitic and clinopyroxene-rich Elwell sills, reappraising the trail; andesitic silt rock along the way contains exceptionally abundant, large, chlorite- and quartz-filled amygdules. Walk northward toward Home Lake.

This sill is the same, andesitic one examined at STOP 11, here with magnificently displayed columnar structure in its lower part (Fig. 18). Look for the poorly exposed black phosphiite chert that concordantly underlies the sill. The sill rock here is unusual in that it exhibits scattered small gnomon crystals of plagioclase and clinopyroxene. It also contains unusually abundant gray quartz megascopics that greatly resemble large quartz phenoocrysts which choke some dacitic rock units in the Sierra Buttes Fm. Are these crystals xenocrystals or phenoocrysts? The hand lens shows that they commonly are deeply embayed and highly irregularly shaped.

The top of the sill is missing, having been eroded, together with overlying rocks, and replaced by an epiclastic debris flow charged with large clasts of phosphiite Sierra Buttes dacite, Elwell silt rock, black phosphiite chert, etc. Many sand grains in the matrix of the debris-flow deposit consist of anhedral quartz derived from phosphiite Sierra Buttes dacite. Such debris-flow deposits make up the basal member of the Taylor Fm., as I define it. The contact between the decapitated sill and debris flow is very sharp and highly irregular: it intersects vesicles flattened in the plane of the sill during its emplacement. Look for steeply dipping, tabular, black chert veins that the sill below the contact; stiff fluid chert injected columnar joints as they opened during shrinkage of the solidifying sill. The tabular chert veins have to be distinguished from nodular xenoliths of chert picked up by the sill during its emplacement, which also are present.

Thin-section petrography

Relict euhedral plagioclase phenocrysts in the sill range up to 1.35 mm long and commonly form clusters of 2 or 3 individuals. They have been completely replaced by an array of minerals—epidote, calcite, albite, quartz, actinolite, chlorite, and white mica—in various combinations and proportions. Subhedral to euhedral, prismatic, clinopyroxene microphenocrysts and phenoocrysts up to 1.5 mm long (colorless, mammiform, twinning, birefringence about 0.025, 2VZ moderate, angle between Z and c = 40°), again commonly clustered, have been partially replaced by chlorite, actinolite, epidote, quartz, calcite, and
sphene, in a seemingly endless variety of combinations. Relict clinopyroxene, plagioclase, and magnetite microfibers occur in the sill rock matrix. The former comprise poorly terminated prisms typically twinned on 1101 which may display a second composition plane oriented normal to c, resulting in interesting lineations. Many clinopyroxene microfibers have been replaced along their edges, or throughout, by parallel fibers of actinolite. The quartz megacrysts were extensively corroded, with rounded edges and smooth, straight to gently curved “lenses”, both convex and concave outward. They display narrow, optically continuous quartz overgrowths, which in places polikablistically enclose olivine and sphene pseudomorphs of plagioclase and magnetite microfibers originally present in adjacent glassy matrix.

STOP 13 (FIGURES 17 and 18) - “Dispersed” peperite in the Ewell Fm.

Rejoin the trail and walk northeastward toward Horse Lake. Leave the trail south of Horse Lake, skirt the west side of the lake, and climb Hill 6717 north of the lake.

Much of the top of this hill consists of aphyric sill rock and peperite in the Ewell Fm. (Fig. 19) has the details. Here, trending andesite magma encountered relatively wet black phosphatic chert and was quenched drastically, producing “dispersed” peperite: relatively well-sorted, fine-grained peperite, the voluminous chert matrix of which contains phosphatic nodules, both whole and broken, and chert fragments (Brooks and others, 1982). The phosphatic nodules must have formed diagnostically prior to lithification of the chert, and been shattered, together with locally lithified chert, by steam explosions. The drastic quenching of magma is indicated by relict quartz microfibers of plagioclase in andesite fragments (Fig. 20). One may search with the hand lens among the finer andesite fragments for those bounded by the characteristic conchoidal fractures representing thermal-contraction cracks developed in rapidly freezing, glassy lava. Spectacular examples of “dispersed” peperite may be collected from talus as we descend the southeast flank of Hill 6717 on our return to the trail.

Also notable at this locality are: 1) large deformed chert xenoliths enclosed in sill rock without intervening peperite, representing chert that was lithified when intact; 2) peperite containing small pillows that were deformed ductily during disposal of the peperite by steam explosions (some leptyn-size andesite fragments at this locality also initially exhibited ductile behavior); and 3) the rarely observed passage of sill rock into peperite, where they adjoin once-hot chert.

Thin-section petrography

Ash- and leptyn-size, aphyric andesite fragments in the “dispersed” peperite are charged with strongly flow-aligned, prismatic, relict plagioclase microfibers; flow lines may be folded. Straight to smoothly curved fragment boundaries, the result of thermal-contraction cracking of glassy andesite, frequently terminate flow lines. Fragments may have correspondingly simple shapes, produced by the intersection of these shrinkage cracks, or may exhibit complex outlines suggestive of fluidal behavior. Some fragments contain scattered, tiny (e.g., 0.15 mm long), elliptical amygdales.

The relict plagioclase microfibers are embedded in green chlorite subbed by sphene spherules, commonly 0.01 mm in diameter. Coarse epidote idioblasts also occur, such polikablistically enclosing several of the aligned plagioclase microfibers. Calcite and relatively coarse quartz occur infrequently. Near fragment margins, plagioclase microfibers served as nuclei for forming overgrowths of additional albite.

Andesite fragments are rimmed (e.g., 0.2 mm wide) by extremely fine, acostic intergrowths of chlorite and epidote(?); these nucleated on plagioclase microfibers, as well as on the bounding shrinkage fractures. Acostic rims may be followed inward by narrow bands of dark gray, cloudy leucosome or red-brown, granular sphere. Cloudy leucosomes also may appear between plagioclase microfibers and encrusting acostic intergrowths. The acostic intergrowths probably originated during sea-floor metamorphism, when fibrous quartz replaced fibrolapogonite formed earlier at the edges of glassy fragments (Dimroth and Lichtblau, 1979). Such alteration would have been facilitated by the relatively copious quantities of heated pore water that apparently were present at this location following peperite formation.

The chert matrix of the peperite contains poorly preserved radiales, and consists, besides microgranules: quartz and carbonaceous material, of chlorite and epidote. Andesite fragments at least as small as 0.35 mm long are recognized in the chert.
STOP 14 (FIGURE 11) - Pillow lava in the basal Taylor Fm.

Rejoin the trail just after crossing the outlet of Horse Lake and follow it northward to the wooden bridge that crosses the outlet near Salmon Lake Lodge. Leave the trail soon and continue northward up the ridge to STOP 14 near the water-storage tank.

Here is the lowest pillowed lava flow in the Taylor Fm. at this latitude (Fig. 21). The spheroidal pillows are closely packed, with only minor sulfurous mixtures evident at pillow junctions. They are characterized by elongated quartz-epidote amygdalae that tend to occur all the way around a pillow, like the spokes in a wagon wheel (Fig. 21). Pillows frequently exhibit minor in situ fragmentation. Patches of green epidote is much in evidence, especially in the pillow rims.

The pillows are richly clinopyroxene-phryic and possibly contained some olivine phenocrysts as well. Cleavage flakes that extend completely across phenocrysts reveal igneous clinopyroxene. A chemical analysis of the central part of a large pillow, recalculated to 100 wt. %, volatile-free, follows.
TABLE 5. Analysis of the central part of a mafic Taylor fm pillow.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56.10</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.24</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>9.62</td>
</tr>
<tr>
<td>FeO⁺</td>
<td>10.46</td>
</tr>
<tr>
<td>MgO</td>
<td>8.92</td>
</tr>
<tr>
<td>CaO</td>
<td>11.76</td>
</tr>
<tr>
<td>Na₂O</td>
<td>2.19</td>
</tr>
<tr>
<td>KO</td>
<td>0.15</td>
</tr>
<tr>
<td>MnO</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Although in the basaltic andesite range in terms of silica content, this sample is otherwise very mafic, containing 842 ppm Cr but only 4 ppm Zr. Ti also is unusually low, and the values of all three elements doubtless were affected by accumulation of the mafic phenocrysts. Also, the rare-earth abundance pattern is the most primitive of all 19 of the Taylor lavas analysed, the concentrations of Sm and Eu being only 2 times their chondritic abundances. The pattern shows substantial relative depletion of REE; La and Ce were not even measurable by INAA. A model analysis recalculated to exclude amphiboles resulted in 14.3% clinopyroxene phenocrysts, 2.9% relics olivine and/or plagioclase phenocrysts, and 82.8% matrix.

Thin-section petrography

Euhedral clinopyroxene phenocrysts and microphenocrysts are rimmed and veined by chlorite and uniformly oriented, finely prismatic actinolite. Chlorite tends to be in direct contact with ragged remnants of clinopyroxene, actinolite occupying central parts of veins and outermost parts of rims. The clinopyroxene has properties like that in the richly clinopyroxene-phryic sill at STOP 11; viz., stout, 8-sided prism; polysynthetic twinning; colorless; 2V̈ about 65° (pov, weak); the angle between Z and c at least 41°.

Clusters of relatively coarse, mostly euhedral epidote crystals in some cases clearly have filled vesicles, in others just as clearly have completely replaced phenocrysts. Chlorite commonly accompanies the epidote, which is then idiomorphic against it. Epidote amphiboles are elliptical (e.g., 0.6 mm long) and exhibit haloes of dark gray, cloudy leucoclace. Epidote pseudomorphs display straight to curved, relict crystal faces, some concave outward, and rounded corners. These relict phenocrysts reach a maximum dimension exceeding 3.5 mm, and have shapes sometimes suggesting plagioclase, sometimes olivine. The epidote is weakly pleochroic (X=colorless, Y-Z=pale yellow), displays simple (100) twins, and has 2V̈ large (>40°, strong), birefringence about 0.03, and the angle between Z and c about 25°.

The matrix consists largely of unoriented bundles of parallel actinolite fibers, granular sphefite, and relatively coarse, highly irregular epidote grains darkened by leucoxene; length-fast albite lamina representing relict plagioclase microlites get lost in the actinolite but are not uncommon.

STOP 15 (FIGURE 11) - Pillowed sill at top of Elwell Fm.

Continue up the ridge to STOP 15.A thick sill of aphyric Elwell andesite, columnar-jointed at the bottom and layered in its central portion, has a pillowed top. It overlies black chert, and penecontemporaneous chlorite can be found in its base. The prominent columnar structure involves 5- and 6-sided prisms that are curved in places, plunging less steeply than the dip steepens northeastward (Fig. 22). Cross fractures are present perpendicular to the long axes of the columns, which are, for example, 20 cm in diameter (Fig. 22). The columnar structure dies out upward in layered (flow-layered?) andesite, which is sparsely amygdaloidal near the top (chlorite amygdaloids). Metamorphic cleavage, dipping more steeply northeastward than the layering, is apparent in the finer, thinner (2.5-5 cm), red-brown weathered layers which separate the 20-30-cm-thick, pale gray-green layers. The darker, red-brown layers appear to represent a transition to the darker, purplish weathered pillow lava above, into which the layered andesite passes through a thin zone of relatively small, deformed pillows broken in situ. The overlying, larger, close-packed pillows exhibit distinctive curved fractures concentric to the pillow margins. These developed parallel to closely spaced, very thin shells of microvesicles which appear to be equivalent to the vesicle sheets present at the edges of aphyric andesite sills (STOPS 3 and 5). Additionally, some pillows are divided by irregular, crudely prismatic shrinkage fractures. Neither the concentric nor the radially oriented fractures are found in Taylor pillows. It is worth emphasizing that the pillowed sill, together with nearby Elwell pillow lava (STOP 17), occur in the same area as dykes containing small pillows and ductilely deformed frag-
ments (STOP 13); all emplacement was essentially at the sediment-water interface, where sea-floor sediments were water-saturated.

Refer again to the rare-earth abundance patterns in Figure 8. Sample 43 was collected from a pillow about 0.75 m long in the pillow ed top of this sill, sample 43A from the prominent curved column beneath the ledge just left of the center of Figure 22. The rare-earth patterns for these two samples essentially coincide, to accord with my belief that there is no physical break between the pillow ed and un-pillow ed parts of this rock mass. The chemical analyses of the two samples, recalculated to 100 wt. %, volatiles free, appear below.

The large differences in MgO, CaO, Na2O, and K2O doubt least reflect the mobility of these oxides during metamorphism.

Thin-section petrography

Thin sections cut from basal, columnar-jointed and central, layered parts of the pillow ed all show that the plagioclase anes
ti te originally possessed intergranular texture, being charged with plagioclase microclases. Although these at first appear to be ar ranged randomly, a closer look reveals that they actually display a limited number of definite orientations, perhaps determined by the structure of the conglomerate melt. The lamellar-twinned plagioclase laths and fibers average 0.1 mm or less in length, and may be clustered in bundles of parallel laths.

The interfaces between olivite laths are occupied by relatively dark-green chlorite, granular sphene, epidote, and quartz. Some samples contain calcite as well. The epidote is pleochroic, color less to pale yellow, and has a birefringence greater than 0.025, indicating a fairly iron-rich epidote. A particularly strong re-
crystallized sample has the original plagioclase microclases com pletely replaced by epidote single crystals or crystal aggregates, their ghostly outlines marked by parallel rows of red-brown, dust-
like inclusions. This sample also contains coarse actinolite (Z=light blue-green).

Irregular strings of widely spaced amygdaloids probably repre sent vesicle sheets. In one sample, elongated (probably flattened) microcrystalline epidote (e.g., 0.2 x 0.7 mm) consists of epidote and have gray haloes of sphene/talcoclase. Rare chlorite amygdaloids in the same sample (e.g., 2.4 mm long) display necklaces of epidote only one grain (i.e., 0.1 mm) wide, and seem to be in dependent of the sheets of microcrystalline epidote. In another sample, amygdaloids consist largely of xenoblastic calcite.

STOP 16 (Figure 11) - Pillow ed top of Ewe ll sill over lain by Taylor dolomite-flow deposit.

Continue northward along the ridge to STOP 16, crossing a light-gray dike of deuteronically altered hornblende anes
ti te along the way. This unmetamorphosed anes
ti te dike is Early Cretaceous (122 Ma) and originated from a tonalite pluton ex posed at the northeast end of Gold Lake (Lull and Brooks, 1963).

The pillow ed top of the sill at STOP 15 here is over lain abruptly by pebbly sandstone rich in debris derived from the Sierra Buttes Fm. Indeed, pillows were decapitated in places prior to deposition of this epiclastic sediment, perhaps by slump ing of pillows (Fig. 23). The contact between pebbly sandstone and pillow lava is very sharp and irregular, with fragment projections—partly bounded by reticulate fractures—extending from decapitated pillars into the base of the pebbly sandstone (Fig. 23). The pebbly sandstone contains fragments of the subjacent pillow ed, and displays reverse grading of the coarser, mostly clastic clasts (Fig. 23). Smoky-gray quartz and white feldspar grains derived from quartz and plagioclase phenocrysts chokes the sand-size fraction of this debris-flow deposit (Fig. 23). Among the coarser clasts are, besides Sierra Buttes dacite and Ewe ll pillow fragments, probable quartz-phryic pumice, likely derived from the immediately underlying Sierra Buttes Fm.
which is pumiceous in this area. Again, as at STOP 12, a debris-flow deposit rich in Sierra Buttes detritus marks the base of the Taylor Fm.

The large Elwell pillows, up to at least 2 m in diameter, are very closely packed. Large, pleochroic-green, epidote-rich patches commonly dominate the interior parts of pillows. Crudely radially oriented, relict shrinkage fractures in the Elwell pillows are filled by dark reddish gray, porous material rich in magnetite and hematite, and, locally, by red jasper (hematite-rich chert). Also, masses of jasper at least 8 cm long appear in the pillow lava, and these may be separated from the lava by 5-10 mm of magnetic, dark gray, porous, magnetite-rich chert. Hematite in pillow lava in the Josephine ophiolite may have been formed by hot-spring activity on the sea floor (Harper, 1991), but Elwell pillow lavas were formed in an anoxic (black phosphatic chert) environment, and formation of the jasper has to be attributed to a subsequent hydrothermal event.

Thin-section petrography

The fine to coarse sand and fine pebbles in the Taylor pebbly sandstone consist of 1) former phenocrysts of embayed, bipyramidal quartz and euhedral plagioclase seemingly little affected by sedimentation processes (although fine quartz sand grains frequently exhibit sharply angular corners resulting from breakage); and 2) two kinds of relict groundmass in which the quartz and plagioclase phenocrysts were embedded, one now feldspathic, the other chloritic. Also, leucocene grains representing former magnetite microphenocrysts are present.

FIGURE 23. Close-packed, decapitated Elwell pillows overlain by debris-flow deposit rich in Sierra Buttes detritus at stop 16. Fine stipple is interpillow matrix, coarse stipple is quartz sandstone, and long dashes indicate color banding at edges of pillows. Grains smaller than about 0.5 mm are not shown. All fractures except the two labelled "T" (for tectonic) probably are relict shrinkage fractures. Same as Fig. 7 in Brooks and others (1982).
The very finely granular, feldspathic (quartz/feldspar?) type of rhyolite groundmass contains some relic plagioclase microlites and spherulites up to 0.3 mm in diameter, both of which now consist of albite. The chloritic groundmass type, presumably also derived from the Sierra Buttes Fm., contains only relic quartz and plagioclase phenocrysts. Sand-size grains of this material consist of chlorite abundantly pockmarked by tiny (0.02 mm feldspar?) spherulites, and pebbles of it comprise chlorite locally developed in the feldspar(s) spherulites, finely granular feldspar, idiomorphic quartz and stilpnomelane (X-light yellow, Y=2-deep olive green), white micas, etc. Spherulite spherulites generally a bit larger than the feldspar(s) spherulites are scattered throughout the chlorite, which doubles itself usually glass.

Where one can be sure that the matrix of this poorly sorted pebbly sandstone is being examined—between the angular grains of fine quartz sand—it is too finely granular to work with, but consists largely of quartz and/or feldspar.

The magnetite-rich chert that separates from adjacent Ewell pillow lava displays parallel, discontinuous streaks of virtually solid magnetite. The magnetite comprises sharp, hexagonal cubes and octahedrons from 0.01 to 0.1 mm across. There are also a few small flakes of muscovite and/or stilpnomelane, and a little white mica is present. The Jasper originally contained much less magnetite than the magnetite-rich chert, present as uniformly distributed small patches and strings now largely replaced by hematite. Only irregular bands of magnetite remain, and the original form of most of it is not clear. Considerable fine-grained leucoxene accompanies the altered magnetite, so that it must have been titaniferous. Very finely divided hematite is concentrated in much larger, cloud-like masses separate from the small patches of altered magnetite, and it is the material that accounts for most of the red pigment in the Jasper. The quartz comprising the bulk of the Jasper exhibits a relatively coarse (grains to 0.04 mm across), granoblastic fabric suggestive of strong recrystallization; many straight grain boundaries—hence polygonal quartz grains—occur.

STOP 17 (FIGURE 11) - Pillow lava in the Ewell Fm.

Walk westward down-section to STOP 17.

The spheroidal geometry of Ewell pillows here is revealed in three dimensions. A brief search discloses that these discrete, 1-2-m, tightly packed pillows are separated by thin films of black chert. The roughly radially oriented fractures within pillows here are filled with black chert—weathered gray to white—indicating that they originated as prismatic shrinkage fractures that were injected by fluid chert as they opened. Some chert veins even were flow-dominated during this process (see below).

Thin-section petrography

Fluid chert injecting shrinkage fractures opening in the pillows resulted in irregular black chert veins that may pinch and swell, changing thickness rapidly. One vein, so rich in black carbonaceous material that no quartz is apparent, has a maximum thickness of only 0.25 mm; others are even thinner. A vein up to 4 mm thick displays flow laminae adjacent to both walls; these are made conspicuous by varying amounts of finely divided carbonaceous material and are surprisingly planar, considering the very irregular vein walls. Most of the chert is very fine, quartz grains averaging only about 0.01 mm across.

The pillows originally were rich in the usual plagioclase microcrysts, and contained a few plagioclase microcrysts. The former now consist mostly of albite, the latter the aggregates of epidote and chlorite. Vein walls quenched by fluid chert contain fewer relics plagioclase microlites. Small (e.g., 3.5 mm) volumes of the anodes of the anodes were completely replaced by relatively coarse, xenoblastic quartz containing sphene and anatase, and smaller (e.g., 0.5 mm), spheroidal volumes were similarly entirely replaced by reddish-brown epidote aggregates. Tiny (e.g., 0.25 mm) formless patches of chlorite-/epidote may represent microamorphous, others consist of epidote or quartz.

We will retrace our steps down the ridge to the trail and follow it around the north side of Upper Salmon Lake, thereby returning to the parking area. I hope you enjoyed the trip!

ACKNOWLEDGEMENTS

Some of the chemical data appearing here have never been published, so I must acknowledge those institutions instrumental in their acquisition. Most data were obtained while I held an Associated Western Universities-Department of Energy faculty participation appointment at the Lawrence Livermore National Laboratory; analytical costs were borne by the Earth Sciences Division, Lawrence Livermore National Laboratory. Silica analyses were paid for by a grant from the Committee on Research, California State University, Hayward, and FeO, P2O5, H2O, and CO2 analyses (Table 4) were provided by the Branch of Analytical Chemistry, U.S. Geological Survey, Menlo Park.

I wish to pay tribute to the more than 400 students who have completed the California State University, Hayward, summer field geology course since it was instituted in 1970. They, together with the many teaching assistants and, especially, my colleagues Mike Wood and Phil Garbutt, have influenced many ways my ideas about these often enigmatic rocks. For the same reason, I am greatly indebted to June Legler, John Lull, and Steve Silve, California State University, Hayward, students whose M.S. thesis I supervised in the Eastern Belt. Christine Nashbak, chiefly responsible for the outcrop map comprising Figure 19, was an undergraduate student in the 1980 field geology course.

I thank Peter Schifman for getting me involved in these IGCP Project 294 field excursions, and Judy Hannah and Dave Harwood for extremely thorough and useful reviews of this chapter.
REFERENCES


Matheson, S.A., 1981, Pre- and post-Sangamon glacial history of a portion of Plumas and Sierra Counties, California [M.S. thesis]: Hayward, California State University, 250 p.


TECTORIC SETTING AND METAMORPHISM OF
THE SIERRA NEVADA, CALIFORNIA

HOWARD W. DAY
Department of Geology
University of California
Davis, California 95616

INTRODUCTION

It is an article of faith among petrologists that the tectonic setting of metamorphic rocks is an indicator of the process or controls on metamorphism, but the link between tectonic setting and the details of thermal history is poorly defined. Most Phanerozoic metamorphic belts are exposed in orogenic belts that were originally at continental margins. Continental collision zones and ocean-continent subduction zones, such as the Alps and the California Coast Ranges, are perhaps the most familiar examples. The nature of metamorphism and the thermal history in arc-continent collision zones, intra-oceanic subduction zones, and transform margins has been little studied, however, and even the basic characteristics have not been examined systematically. The Sierra Nevada of California (Fig. 1) have been the site of active continental margin tectonic processes since the early Paleozoic and offer an opportunity to study the relationship among tectonic setting, metamorphism and thermal processes at a long-lived continental margin.

The broad outline of the history of the continental margin in California is reasonably well-established (Burchfiel and Davis, 1972; Dickinson, 1981) [Fig. 1]. Precambrian igneous and metamorphic rocks are exposed in southeastern California and the limits of Precambrian basement have been inferred from the western and northern limits of Mesozoic igneous rocks having initial $87^{Sr}/86^{Sr}$ ratios of 0.706 or greater (Fig. 1) (Kistler and Petterman, 1973). A continental margin was probably first established during the late Precambrian when miogeoclinal sedimentary rocks were deposited unconformably across the trends of all major Precambrian age belts (Dickinson, 1981). In southeastern California, a miogeoclinal sequence of Lower Paleozoic sedimentary rocks was deposited, but in the northern Sierra Nevada, pre-Upper Devonian metasedimentary rocks were deposited in continental rise or slope-rise environments (Bond and DeVay, 1980). The pre-Upper Devonian metasedimentary rocks are overlain by three younger volcanic-plutonic complexes that were formed in continental or near-continental marine settings during the Devonian, Permo-Triassic, and Middle Jurassic periods (Hannah and Moores, 1986). Triassic truncation of the continental margin has been inferred from the abrupt termination of Precambrian-Paleozoic structural, sedimentary, and geochronological trends by Mesozoic thrust-tectonic belts, but the nature of that truncation remains controversial (Burchfiel and Davis, 1972; Saleeby, 1981). During the Jurassic, marine sedimentary and volcanic rocks, and arc-ophiolite suites were added to the continental margin and occupy the inferred zone of Triassic truncation. Whether these rocks formed near the continental margin or are far-traveled terranes remains an open question (Burchfiel and Davis, 1981; Moores and Day, 1984; Schweickert and Cowan, 1975). Jurassic and Cretaceous glauconite schists in the coastal Franciscan Complex mark the onset of oceanic subduction and continental accretion that persisted into the Tertiary Era. The Sierra Nevada batholith was emplaced mostly during that time and is commonly regarded as a magmatic arc overlying the Franciscan subduction zone (Miyashiro, 1973). However, granitoid intrusions are also important elements of the Paleozoic, Triassic and Jurassic history of the continental margin. Eocene surficial gravels and Miocene and Pliocene volcanic rocks mantle much of the Sierra Nevada. Tertiary sedimentary
and volcanic rocks in coastal California record the transition from subduction to transform tectonics at the continental margin.

Much of the history of the active continental margin is recorded in the Western Sierra Nevada Metamorphic Belt (Fig. 1), which contains all metamorphosed and deformed rocks west of the Sierra Nevada batholith and east of the sedimentary rocks in the Great Valley (Clark, 1964). At least three orogenic events are recorded in the deformation of the Western Metamorphic Belt, which correspond to the Devonian "Antler," Permian-Triassic "Sonoman," and Jurassic "Nevadan" Orogenies (Dickinson, 1981). Each is marked by a profound angular unconformity. In the Eastern Belt of the Sierra (Fig. 2), pre-late Devonian and pre-late Triassic unconformities are well-documented (Hannah and Moores, 1986; Harwood, 1983; Harwood, 1988; Varga and Moores, 1981). In the Western Belt, at the eastern edge of the Great Valley (Fig. 2), undeformed, Upper Cretaceous and Tertiary sedimentary rocks unconformably overlie penetratively deformed, Upper Jurassic and older metamorphic rocks (Whitney, 1865). The major regional faults that control the present distribution of rocks in the Western Metamorphic Belt (Fig. 2) are known collectively as the Foothills Fault System (Clark, 1960) and are largely artifacts of the Jurassic Nevadan deformation.

The purpose of this contribution is to introduce the tectonic setting, age and conditions of metamorphism in the Western Metamorphic Belt north of latitude 39° N, where the pre-batholithic rocks are exposed over a wide expanse. Although the tectonic history remains controversial and the metamorphic history of the Sierra is poorly known, several major points emerge from the available data: (1) Major regional faults tectonically juxtapose rocks of significantly different age and metamorphic grade; (2) The Western, Central and parts of the Feather River Belts (Fig. 2) contain late Paleozoic and Mesozoic volcanic arc, ophiolitic and marine sedimentary assemblages that were amalgamated with the Eastern Belt during the Jurassic Nevadan deformation; (3) There have been several episodes of Paleozoic and Mesozoic low grade metamorphism; (4) Much of the low grade metamorphic character of Sierran rocks may have been acquired in volcanic arc or other oceanic settings prior to, and modified during, the latest phases of Nevadan deformation; (5) There is little unambiguous regional metamorphism associated with the Cretaceous intrusion of the Sierra Nevada batholith.

GEOLOGIC SETTING

The Western Metamorphic Belt (Fig. 3) is bounded on the east by Tertiary rocks and Mesozoic granitoid batholiths, on the north by Tertiary and Quaternary volcanic rocks and is overlain unconformably on the west by unmetamorphosed, Upper Cretaceous and Tertiary sedimentary rocks in the Great Valley. Steep faults of the Foothills Fault System define at least four lithotectonic belts that extend along strike for about four hundred kilometers in the Sierra and may have counterparts in the Klamath Mts. of northern California and Oregon. The faults deform Upper Jurassic rocks, but their history, sense of movement, and tectonic significance are poorly known and controversial (Burchfiel and Davis, 1981; Clark, 1960; Day, et al., 1985; Edelman, et al., 1989; Moores and Day, 1984; Salesky, 1981; Schweickert and Cowan, 1975; Tobisch, et al., 1989).

The Eastern Belt (Fig. 3) comprises early Paleozoic siliciclastic sedimentary rocks on which Devonian-Mississippian, Permian-Triassic, and early-middle Jurassic volcanic rocks were deposited (D'Aluia, et al., 1977; Hannah and Moores, 1986; Harwood, 1988). Although the sedimentary basement rocks are exposed throughout the length of the belt, the volcanic sequences are restricted to regions north of latitude 39° N. The early Paleozoic sedimentary rocks were probably deposited in a continental slope or rise environment (Bond and Devay, 1980) and the Paleozoic-Mesozoic section may have been at or near the continental margin throughout its history. In the northern Sierra, the continental margin assemblage in the Eastern Belt is separated from primarily Mesozoic oceanic rocks to the west by the fault-bounded Feather River Belt (Day, et al., 1985), which contains Paleozoic metaperidotite, serpentinite, and associated mafic rocks as well as Mesozoic blueschist. The Feather River Belt apparently passes southward into the so-called Calaveras-Shoo-Fly thrust (Schweickert, 1981).
The Western and Central Belts (Fig. 2) contain primarily Jurassic assemblages of ophiolites and marine volcanic and sedimentary rocks that were added to the continental margin during Jurassic time. The Western Belt is dominated by Middle and Upper Jurassic volcanic and volcanoclastic rocks with associated intrusive complexes. These rocks are interbedded with and overlain by Upper Jurassic, fine-grained, siliciclastic sedimentary rocks with subordinate volcanoclastic detritus. The Western and Central Belts are separated by a poorly understood, steep fault zone known as the Big Bend-Wolf Creek fault in the north and the Bear Mts. fault zone in the south.

The Central Belt (Fig. 2) is a structurally complex association of primarily Mesozoic ophiolite, volcanic arc assemblages, and marine sedimentary rocks that is split into eastern and western halves by the Dogwood Peak - Gillis Hill - Melones fault zone (Clark, 1969; Hietanen, 1976; Hietanen, 1981). The western half of the Central Belt is characterized by abundant early Jurassic ophiolite and volcanic arc assemblages and early Jurassic (?), fine-grained volcanoclastic sedimentary rocks and chert-argillite. In the south (Fig. 2), Middle and Upper Jurassic rocks similar to those in the Western Belt are exposed in the so-called Mother Lode Belt. The eastern half of the Central Belt contains the late Paleozoic - early Mesozoic Calaveras Complex in which a tripartite sequence of metavolcanic rocks, siliciclastic sedimentary rocks, and chert-argillite has been recognized at least since the early work of Turner (Turner, 1897). Some workers prefer to assign the volcanic rocks to a separate, fault-bounded terrane (Schweickert, et al., 1988) but there is no consensus on the matter (Peterson et al., 1991).

The Western, Central, and Eastern Belts can be recognized throughout the length of the Western Metamorphic Belt and have played a major role in applying concepts of terrane tectonics to the Sierra Nevada (Edelman, et al., 1989; Edelman and Sharp, 1989; Schweickert, et al., 1988). The belts are widest in the north and quite attenuated in the south, which may have contributed to significant differences among tectonic interpretations of workers who have concentrated their efforts in the south or in the north. This contribution emphasizes studies that have been completed in the area north of latitude 39° N, with which I am most familiar, and where preservation of some of the lithotectonic elements may be more complete (Fig. 3).

Western Belt

The Western Belt in the northern Sierra (Fig. 3) is occupied by the Jurassic Smartville Complex, including a rifted volcanic and plutonic arc, fragments of its sedimentary cover, and, perhaps, its basement (Beiersdorfer, et al., 1991; Day, et al., 1985). It is bounded on the west by undeformed Upper Cretaceous and Tertiary sedimentary rocks and, on the north and east, by the Big Bend and Wolf Creek faults (Day, et al., 1985; Hietanen, 1977). Abundant isotopic and sparse fossil data suggest that the volcanic and intrusive rocks as well as their sedimentary cover were formed during a short interval near the Bathorian - Callovian or Kimmeridgian - Oxfordian boundaries (Harland, et al., 1990). The former estimate is based on numerous isotopic ages of about 161.2 Ma (Bickford and Day, 1988; Edelman, et al., 1989; Salseby, et al., 1989) and the most recent time scale of Harland et al. (1990), whereas the latter is based on the fossils (Creely, 1965; Markett, et al., 1979; Xenophontos, 1984).

The main part of the Smartville Complex is composed of basaltic to andesitic volcanic and volcanoclastic rocks (Kv, Fig. 4) intruded by hypabyssal and plutonic rocks (Beard and Day, 1987, Beard and Day, 1988). The volcanic units include a lower unit of pillowd and massive flows and a widespread upper unit of distinct dipyroxene - pyric pyroclastic and epipletic breccias (Xenophontos, 1984). The hypabyssal rocks include exposures of 100% diabase dikes, which may be “sheeted” or “unsheeted”, and areas in which the diabase appears to be massive and no dike structures can be detected (Kd, Fig. 4). Two unrelated suites of plutonic rocks appear to be coeval with the intrusion of the sheeted and unsheeted dikes. Elongate plutons of hornblende-biotite tonalite, granophyric tonalite and granodiorite (Jk, Fig. 4) are parallel to the strike of diabase dikes. Gabbro-diorite plutons (Jgb, Fig. 4) range greatly in size and also tend to be parallel to the strike of diabase dikes. The largest gabbronodiorite plutons are zoned continuously from olivine gabbro core to quartz diorite rim (Beard and Day, 1988).

The basement on which the Jurassic volcanic arc was constructed has not been documented unambiguously anywhere in the Western Belt (Fig. 3). However, the oldest intrusive rocks in the Smartville Complex are massive metabasalts and metabasalt dikes associated with metagabbro screens and intrusions exposed in and north of a half-window on the southeastern margin and in the central parts of the Complex (not distinguished from Jd in Fig. 4) (Beard and Day, 1987). These units are cut by all other major intrusive bodies and they may be part of the basement on which the volcanic arc was constructed (Beiersdorfer, et al., 1991), but their relationship to the volcanic rocks is not exposed. In the eastmost Smartville Complex, 161 ± 2 Ma tonalite dikes and a related tonalite pluton, also dated at 161 ± 2 Ma, intrude 198 ± 2 Ma tonalite (the earliestmost body of Jt, Fig. 4) (Bickford and Day, 1988; Edelman, et al., 1989; Souter and Day, 1991) suggesting that the basement of the volcanic arc included fragments of earlier volcano-plutonic complexes similar to those in the Central Belt. Edelman et al. (1989) suggested that the basement of the 160 Ma volcanic arc might include sedimentary rocks of the Central Belt similar to those exposed along its margin (Js, Fig. 4), similar to earlier suggestions of Salseby (1981) and Schweickert (1981).

Jurassic sedimentary cover (Js, Fig. 4) of the volcanoplutonic complex is exposed only in the northwestern part of the area (Day, et al., 1985) where it is known as the Monte de Oro Formation (Creely, 1965). The rocks are lithic quartz sandstones containing fragments of monocrystalline quartz, chert, slate, and volcanic detritus. Most of the rocks form a single volcanic unit are faults, but an overturned depositional contact was reported in the northwestern Smartville Complex. Rocks equivalent to the Monte de Oro and the upper volcanic unit (Vmt, 1980). This sedimentary cover appears similar in age, lithology, and stratigraphic position to Upper Jurassic sedimentary rocks in the southern part of the Western Belt (Fig. 2).
Fig. 3. Geological Sketch Map of the Western Metamorphic Belt, Sierra Nevada.
Central Belt

The Central Belt is bounded on the west by the Big Bend - Wolf Creek Fault and on the east by the Feather River Belt (Figure 2) (Day, et al., 1985). The Belt is divided into eastern and western halves by the Dogwood Peak - Gillis Hill Fault. Although it is structurally and lithologically complex and has been termed “melange” (Schweickert and Cowan, 1975), recent mapping has revealed large, relatively intact volcanic arc - ophiolite complexes (Edelman, 1986; Tuminas, 1983; Zigan, 1981) that may be keys to unraveling the Mesozoic tectonic history of the Sierra Nevada.

Western Half of the Central Belt: The western half of the Central Belt contains two Jurassic volcanic arc - ophiolite complexes that appear to overlie tectonically a complex sedimentary and ophiolitic basement of similar or slightly older Mesozoic age. The Slate Creek and Lake Combie Complexes are Jurassic volcanic arc - ophiolites (SCC, LCC; Fig 5). Tectonically underlying these units are fine grained sedimentary and volcanic rocks (chert-argillite) with locally abundant serpentinize bodies (EJs, Fig. 5). In the northwestern part of the area, disrupted ophiolite, ophiolitic melange, are summarized as Older Ophiolite (OO, Fig. 5) and may be overlain by and structurally interleaved with the chert-argillite unit.

The Slate Creek Complex (SCC, Fig. 5) (Day, et al., 1985; Edelman, et al., 1989) is a pseudostratigraphic sequence of serpentinitized ultramafic rocks (um, Fig. 5), overlain and apparently intruded by tonalite bodies (Jp, Fig. 5) that, in turn, intrude upward into overlying volcanic and volcaniclastic rocks (Jv, Fig. 5). The ultramafic unit may also include some cumulate rocks related to the overlying plutonic unit. Hypabyssal intrusives and dikes are a minor part of the sequence that occur near the contact between the plutonic and volcanic rocks. The ultramafic unit overlies deformed metasedimentary rocks along a fault that dips steeply east. The sequence is interpreted, therefore, as a volcanic arc and its ultramafic basement that were thrust over underlying metasedimentary rocks and deformed by later steep faults and folds (Edelman, et al., 1989).

The age of the plutonic unit in the Slate Creek Complex is early Jurassic (205 ± 3 Ma; U-Pb, zircon) (Bickford and Day, 1988; Edelman, et al., 1989; Saleeby, et al., 1989). The fault contact between the volcanic unit and the underlying sedimentary rocks of the chert-argillite unit (EJs, Fig. 5) is intruded by younger plutonic dated by U-Pb (zircon) as 165 ± 3 Ma and 152 ± 2 Ma (Bickford and Day, 1988; Edelman, et al., 1989). Saleeby et al. (1989) reported an age of 193 +4/-7 Ma from a keratophyre on strike with the volcanic unit of the Slate Creek.
Complex, north of the S. Fork Feather River (Fig. 5). Thus, the age of the Slate Creek Complex is early Jurassic and it was thrust into place no later than about 165 Ma.

The Slate Creek Complex is well-defined southwest from the S. Fork Feather River (Fig. 5), but there is no consensus about which rocks to the north, if any, should properly be included in the Complex (Bickford and Day, 1988; Dilek, et al., 1990; Edelman, et al., 1989; Hacker and Goode, 1990; Saleeby, et al., 1985) because the area is structurally complex and has not been mapped since the early work of Hetanen (Hetanen, 1973; Hetanen, 1976; Hetanen, 1981). For the purposes of this overview, rocks mapped by Hetanen as Franklin Canyon Formation have been included in the Slate Creek Complex (Fig. 5).

The Lake Combie Complex (LC, Fig. 5) (Day, et al., 1985; Tuminas, 1983) is a relatively intact volcanic arc complex, similar in many respects to the Smartville Complex to the west and the Slate Creek Complex to the north (Fig. 4). It is bounded by the Wolf Creek fault zone on the west and the Gillis Hill fault on the east. It is intruded by the Yuba River pluton on the north, but its southern termination has not been mapped. It consists of a pseudotachylite sheet that overlies the late Jurassic, tectonic contact with no evidence of contact metamorphism. The contact between the Lake Combie Complex and the chert-argillite unit has been interpreted as a thrust fault modified by late Tertiary and Quaternary faulting and folding (Day, et al., 1985; Tuminas, 1983).

The age of the Lake Combie Complex is shown in Figure 3. The complexes form a linear belt of metavolcanic and metasedimentary rocks and mafic intrusive rocks that are considered to be of late Jurassic age. The metavolcanic rocks consist of a variety of volcaniclastic and sedimentary rocks, including volcanic ash, tuff, and breccia. The metasedimentary rocks consist of conglomerate, sandstone, siltstone, and shale. The metavolcanic rocks are characterized by the presence of volcanic glass and volcanic clasts. The metasedimentary rocks are characterized by the presence of thin-bedded sedimentary structures.

The northwest part of the Central Belt is underlain by a melange of ultramafic, metavolcanic, metatelluric, and metasedimentary rocks. The area containing abundant fragments of disrupted ophiolite is summarized as Older Ophiolite (OO, Fig. 5). The unit contains numerous bodies of serpentinite and metavolcanic rocks, fragments of serpentinite-matrix ophiolitic melange up to 10 km long. A large body of Paleozoic serpentinitized metasedimentary and related mafic rocks occupy the north end of the Feather River Belt (Fig. 5). The older ophiolite has been studied in detail only near the N. F. Feather River (Dilek and Moones, 1986). Portions of the unit have been interpreted as a fossil transform fault system (Dilek and Moones, 1986).
preted as the lower part of an ophiolite based on the presence of peridotite tectonite, cumulate ultramafic rocks, and both layered and massive gabbro (Moore, 1972; Standley, 1978). South of the S. Pl Flat. Feather River, the belt comprises early Mesozoic (?) metasedimentary and volcanic rocks (Elba, Fig. 5), and Paleozoic amphibolites (Pa, Fig. 5). In addition to serpentized ultramafic rocks. All contacts among the three units are faults. The early Mesozoic metasedimentary and volcanic rocks are especially notable because they contain the only known occurrences of lawsonite and glaucophane-croissite in the Sierra Nevada (Ferguson and Gannett, 1932; Hietanen, 1981; Schwerdtfeger et al., 1980). Amphibolite and mafic rocks between the S. Pl Flat. Feather and North Yuba rivers are interpreted as a fragment of the Paleozoic Devils Gate ophiolite based on the discovery of sheared dikes and pillow structures (Edelman et al., 1989).

Isotopic data reflect a poorly understood Paleozoic igneous and metamorphic history. Igneous rocks intruding the metapelitic appear to be middle Paleozoic or older. Standley (1978) reported an 40Ar/39Ar hornblende age of 387±7 Ma from a dike that intrudes mafic rocks associated with the metaperidotite. Saleeby et al. (1978) determined an U-Pb zircon, upper intercept age of 388±7 Ma on a granite that intrudes amphibolite. Late Paleozoic igneous and metamorphic events are also reflected in the data. Saleeby et al. reported an U-Pb age (upper intercept) of 314±10 Ma for zircon from plagiogranite in a mafic dike complex (Saleeby and Moore, 1978).

Fig 5. Geological Sketch Map of the Central and Feather River Belts. Abbreviations: GT - Quaternary and Tertiary sedimentary and volcanic cover; Kgr - Late Jurassic and Cretaceous granitoid intrusives; Jc - Late Jurassic clastic sedimentary rocks; Jp - Early Jurassic and younger (?) plutonic rocks in the State Creek (SCC) and Lake Combie Complexes (LCC); Jd - Jurassic diabase and dikes in the Lake Combie Complex; Jv - Jurassic volcanic and volcaniclastic rocks in the State Creek, Lake Combie and related complexes; Elba - Early Jurassic (?) or older (?) chert-argillite and tuffaceous rocks (called Riddle Creek Complex by Edelman et al., 1989); Oo - Older Ophiolite comprising highly disrupted volcanic, plutonic, sedimentary and ultramafic rocks and including undifferentiated chert-argillite; Elba - Early Jurassic or older metasedimentary and volcanic rocks with blueschist assemblages; Pa - Paleozoic amphibolite in the Feather River Belt, including both Peronian (?) rocks to the north, and Devonian (?) rocks to the south of the N. Yuba River; Cs - chert and phyllite of the Carboniferous or younger Colavera Complex; Cv - volcanic rocks associated with the Carboniferous or younger sedimentary rocks of the Colavera Complex; un - undifferentiated ultramafic rocks, LCC - Lake Combie Complex; SCC - State Creek Complex; YRP - Yuba River Pluton.
1979), but K-Ar ages of amphibole from mafic rocks range from 236 - 345 Ma and suggest late Paleozoic metamorphism (Bohle and McKee, 1984; Hietanen, 1981; Standliee, 1978; Weisenberg and Ave Lallement, 1977).

The metasedimentary and metavolcanic blueschists are early Jurassic or older, based on K-Ar ages of 174 Ma in white mica (Schweickert, et al., 1980). These rocks may be the southernmost exposure of blueschists better exposed in the Klamath Mountains of northern California (Hacker and Goode, 1990).

**Eastern Belt**

The Eastern Belt (Fig. 6) is bounded on the west by a complex fault zone and the Feather River Belt, on the north by the Tertiary and Quaternary volcanic rocks, and on the east by Mesozoic granitoid intrusive rocks and Tertiary volcanic and sedimentary rocks. It marks the continental margin during Mesozoic time and comprises the early Paleozoic Shoo Fly Complex, and three younger volcanic sequences that mark periods of significant volcanism during Devonian-Mississippian, Permian, and Jurassic periods (D'Allura, et al., 1977; Hannah and Moore, 1986; Harwood, 1988). Each of these sequences is separated by a marked erosional interval or unconformity.

Sedimentary rocks of Shoo Fly Complex (ODsf, Fig. 6) are exposed along the entire length of the Eastern Belt and form the basement on which three distinct volcanic sequences were deposited. The metasedimentary rocks are include quart sandstone, shale, chert and melange that have been mapped as three or four, comprovesent, lithotectonic units. In the south, four units have been mapped as thrust - bounded allochthons (Schweickert, et al., 1984), whereas only three units were recognized in the north and were interpreted to define regional scale folds (Hannah and Moore, 1986). The lowest unit is the Lang sequence, which is composed of quartz sandstone and shale turbidites that formed in a near continental setting (Bond and DeVay, 1980). The Duncan Peak and Kelborn Lake allochthons contain abundant chert and argilite where they were defined in the southern half of the belt (Schweickert, et al., 1984). The structurally highest unit is the Sierra City melange, which consists of blocks of serpentinite, gabbro, basalt and sedimentary rocks in a matrix of slate and sandstone.

The age of the Shoo Fly Complex is not well known but must be early Paleozoic. The faults that bound the allochthons are intruded near the Yuba River by the Devonian Bowman Lake Batholith (Girty, et al., 1984; Hanson, et al., 1988) and truncated by a pre-Upper Devonian unconformity (Fig. 6) for a recent review, (Harwood, 1988). The maximum age of the Shoo Fly is not well constrained, but the unit is known to contain Ordovician fossils (Girty and Wardlaw, 1985; Hannah and Moore, 1986), late Cambrian or early Ordovician detrital zircons (506 ± 22 Ma) (Girty and Wardlaw, 1984), and Proterozoic detrital zircons (Girty and Wardlaw, 1985).

Devonian - Mississippian volcanic and sedimentary rocks (Grizzly, Sierra Buttes, Taylor and lower Peale Fm) overlie the Shoo Fly Complex unconformably and constitute a regionally extensive volcanic arc (D'Allura, et al., 1977; Varga and Moore, 1981). The arc is characterized by rhyolitic to dacitic composition and abrupt variations of stratigraphic thicknesses and both volcanic and sedimentary facies (Brooks, et al., 1982; Hannah, 1980; Hanson, 1983). Volcanic activity extended into Mississippian and was followed by deposition of Carboniferous ribbon chert (Upper Member of the Peale).

Volcanic activity was renewed during the Permian (Arlington, Goodhue and Re service Formations) with the deposition of basalt and andesite, and volcaniclastic rocks unconformably on the older Devonian-Mississippian volcanic arc. The Permian volcanic sequence, in turn, is overlain unconformably by Upper Triassic limestone and Jurassic volcaniclastic rocks near the N. Fork of the American River (Fig. 6) (Harwood, 1983).

Jurassic volcanic and volcaniclastic sedimentary rocks extend the entire length of the Eastern Belt from the Mt. Jura area in the north to the North Fork of the American River (Fig. 6). The volcanic rocks are no older than Middle Jurassic (Lmbay, 1961) and are dominantly andesitic and dacitic flows, tufts, breccias, and volcaniclastic sedimentary rocks. In the south, the sequence is thin, overlies the Upper Paleozoic rocks on a tilted surface and is set into abundant Jurassic and Cretaceous granite plutons of the Sierra Nevada batholith (Harwood, 1983). In the north, the Jurassic rocks are overlain by the Paleozoic section along the Taylorville fault, but the basement on which they were deposited is not exposed (Diller, 1892; Diller, 1908).

**Age of Deformation**

The geologic relations in the Eastern Belt provide evidence for pre-late Devonian, pre-late Triassic and middle Jurassic or younger deformations that may correspond to the Antler, Sonoma and Nevedan orogenesis, respectively (Dickinson, 1981). The pre-late Devonian and pre-late Triassic unconformities are profound, but high grade metamorphism is not associated with either event. Middle Jurassic or younger deformation is indicated by the thrust faults that deform the Jurassic rocks in the vicinity of Mt. Jura. Other faults, such as the Grizzly fault, which repeats the Paleozoic section, may also reflect Jurassic deformation.

The regional scale faults and penetrative fabrics of rocks in the Western, Central and Feather River Belts are primarily the result of Jurassic deformation. The earliest systematic surveys of California established that the steeply dipping "auriferous slates" contained Jurassic fossils and were overlain unconformably by nearly flat-lying, unmetamorphosed Cretaceous sedimentary rocks (Whitney, 1865). That Jurassic deformation is now known as the "Nevedan Orogeny" but the tectonic significance and duration of that deformation remains subjects of considerable interest.

Blackwelder (1914) used the term "Nevedan" to describe the Jurassic deformation that affected the Sierra Nevada and much of the western margin of North and South America and the term was later modified to "Nevedan" (Hinds, 1932, 1935). Tafersferro (1942) provides a good historical overview and his definition of Nevedan is still in use today.
"...an orogeny...which deformed the late Jurassic Mariposa and older beds and resulted in tight folding, overturning, thrust faulting and formation of dynamically metamorphosed rocks over wide areas in the Sierra Nevada." (Talaferrro, 1942) (p. 92).

The tectonic significance and duration of the Nevadan orogeny are still debated. The principal structural features of the Nevadan orogeny are the Foothills Fault System of regional scale faults and associated folds and penetrative cleavages (Fig. 2, 3) (Clark, 1960; Clark, 1964). Strike-slip movements on these faults are implied by the reconstruction of plate movements (Salseby, 1981), but only steep, reverse, dip-slip structures have been recognized (e.g., Day, et al., 1985; Miller and Paterson, 1991). Many workers in the Central Sierra have proposed that the steep faults are steepened west-vergent thrust faults. In the northern Sierra, we have proposed that the steep faults may truncate or deform earlier east-vergent thrust faults (Day, et al., 1985; Edelman, et al., 1989; Moores and Day, 1984).

Because the youngest rocks deformed by these steep faults are Kimmeridgian, the Nevadan is considered by many workers to be a short lived, late Jurassic event (Knopf, 1929; Smith, 1909; Talaferrro, 1942), perhaps at about 155 ± 3 Ma (Schweickert, et al., 1984). However, a considerable body of evidence suggests that deformation commonly considered as Nevadan began during early or middle Jurassic (Day, et al., 1985; Edelman, et al., 1989) and continued into the Cretaceous in some areas (Tobisch, et al., 1989).

Fig. 6. Geological Sketch Map of the Eastern Belt. Abbreviations: Q & T - Quaternary and Tertiary sedimentary and volcanic cover; KJgr - Cretaceous and Jurassic granoid intrusives; Jvs - Jurassic volcanic and sedimentary rocks; PT - Permo-Triassic volcanic rocks; C - Carboniferous Chert; DM - Devonian - Mississippian volcanic rocks; SDI - Siurion - Devonian intrusive rocks; ODs1 - Ordovician (?) - Devonian(?); Shoo Fly Complex, primarily siliciclastic sedimentary rocks.
The presence of 174 Ma, or older, blueschists in the Feather River Belt implies early Mesozoic subduction (Schweickert, et al., 1980). The thrust fault between the ~205 Ma Slate Creek Complex and its underlying basement is cut by a ~165 Ma pluton (Edelman, et al., 1989) and by younger steep faults. Both observations imply first order convergent deformation during the early Jurassic and possibly earlier. The relationships of the Yuba Rivers Pluton (159 Ma, U-Pb, zircon (Edelman, et al., 1989)) (Fig. 5) to the adjacent rocks in the Western and Central Belts suggests that some steep faults must be older than about 160 Ma. The pluton intrudes and is deformed by the Wolf Creek fault (Day, et al., 1985) and its contact aureole overprints earlier fabrics (Clark, 1960). Furthermore, it cuts steep fault contacts among units in the Older Ophiolite unit and the Lake Combie Complex (Fig. 5), implying that at least some of the steep faults were active before intrusion. Finally, hornblende barometry of Jurassic plutons from both sides of the Wolf Creek - Big Bend fault zone (Fig. 4, 5) limits the amount of vertical offset on the fault since 160 Ma to no more than two or three kilometers (McLeod and Day, 1991). Further south in the vicinity of the Cosumnes and Mokelumne rivers, Duffield and Sharp (1975) recognized a belt of melange that is summarized in Figure 3 as early Jurassic sedimentary rocks. They suggested that most faulting occurred before late Jurassic tilting of the present steep dips and that the melange was formed before the deposition of Callovian volcanic rocks (Lofton Ridge Formation). Edelman et al. (1989) suggested that "suspect terranes" in the Central and Feather River Belts must have been amalgamated prior to about 163 Ma and that many of the steep faults of the Foothills Fault System reactivated older, cryptic terrane - bounding faults during late Jurassic deformation.

These observations and interpretations suggest that large scale transport and convergent deformation of Mesozoic rocks began no later than early Jurassic (174 Ma?); that some presently steep faults and associated penetrative cleavages are older than ~160 Ma; and that fault movements, folding and cleavage formation continued into the late Jurassic, or possibly, early Cretaceous. The angular unconformity of Upper Cretaceous sedimentary rocks on steeply dipping, late Jurassic slates suggests that the major exhumation or orogenic phase of the deformation took place during the Cretaceous. In the absence of evidence that deformation subsided for a significant interval, it seems unjustified to restrict the notion of " Nevadan" to a brief interval during the late Jurassic. Rather, we adopt a broader connotation that may be useful to indicate the Jurassic and younger deformation that occurred prior to deposition of Upper Cretaceous sediments unconformably on the "anteriorous slates."

Summary of Mesozoic Tectonic History

The Mesozoic rocks of the Western Metamorphic Belt have been the focus of renewed interest during the past twenty years, but no consensus about the tectonic significance of these rocks has been reached. Jurassic rocks in the Western and Eastern Belts have been attributed to either one or two magmatic arcs (Burchiel and Davis, 1972; Moores, 1972; Schweickert and Couw, 1975). The major faults of the Foothills Fault System have been viewed as west-vergent thrust faults that may or may not have been related to east-dipping subduction (Emst, 1983; Schweickert, et al., 1988), east-vergent thrust faults (Day, et al., 1985; Moores and Day, 1984), west-vergent faults followed by east-vergent faulting (Edelman, et al., 1989), and as the result of strike-slip and transpressional tectonics (Saleeby, 1981). What is clear is that no simple tectonic model is likely to explain the diverse structural and stratigraphic relationships that have been observed along the entire length of the Western Metamorphic Belt.

The Western Belt contains extrusive, intrusive, and sedimentary products of a rifted volcanic arc. The basement of this arc is exposed only in the north and appears to be disrupted portions of a 200 Ma volcanic arc and associated sedimentary rocks in the Central Belt. The Central Belt itself is composed of fragments of late Paleozoic and Mesozoic oceanic, volcanic-plutonic complexes and sedimentary sequences. The western half of the Central Belt contains one or more late Triassic - early Jurassic volcanic terranes that were juxtaposed at least in part by thrust faulting no later than middle Jurassic (~165 Ma). The eastern half contains a Carboniferous or younger, chert-argillite sequence and volcanic rocks of unknown provenance and age. The Feather River Belt juxtaposes Paleozoic ultramafic and mafic rocks of uncertain origin with Mesozoic, blueschist facies metasedimentary and metavolcanic rock. Finally, the Eastern Belt displays an intact record of Paleozoic through Mesozoic sedimentary and volcanic activity that appears to have taken place at or near the margin of the North American continent.

Late Jurassic deformation is evident in the folding, faulting, and penetrative fabrics of late Jurassic rocks in the Western Metamorphic Belt. Some of this deformation may have continued into the early Cretaceous. The importance of active tectonic environments during middle and early Jurassic, however, is becoming increasingly apparent, especially in the Central and Feather River Belts. Some of the tectonism, and presumably coeval metamorphism, undoubtedly took place in an oceanic setting and should be distinguished from orogenic deformation.

Most workers agree that the Jurassic history of the Sierra records the complex processes by which volcanic arcs and associated marine sedimentary assemblages are added to the continental margin. Progressively younger, marine volcanic and sedimentary rocks were added to the continental margin during late Paleozoic - Triassic and Jurassic time. Jurassic volcanic complexes were formed in a dynamic tectonic setting and were amalgamated no later than about 165 Ma (Edelman and Sharp, 1989). It is not clear, however, whether the added material was exotic or " near-continental. " Continental influence is evident in the provenance of late Jurassic siliciclastic sedimentary rocks, xenocrysts, Precambrian zircon in mid - late Jurassic plutonic rocks (Bickford and Day, 1988), and the provenance of mid-Jurassic or older quartz conglomerates in the Central Belt - south of the Cosumnes River (Fig. 3) (Duffield and Sharp, 1975), but there is no direct evidence for the distance from a true continental margin. Evidence for polarity of one or more subduction zones is circumstantial. Both directions may have operated at different times during the Jurassic.
METAMORPHISM – AN OUTLINE

Although there has been a substantial amount of interest in contact aureoles and ore deposits associated with the intrusion of the Sierra Nevada batholith, there has been very little systematic work on the regional metamorphism and thermal history of the Sierra Nevada. Most of the available information comes from observations that were incidental to the main focus of structural or stratigraphic studies. Notable contributions include the early work of Best and Baird in the Central Sierra and of Hietanen in the northern Sierra (Baird, 1962; Best, 1962; Hietanen, 1951; Hietanen, 1973). No detailed regional metamorphic map of the area has ever been made, but Ernst presented a metamorphic map of California in which the northern Sierra was included (Ernst, 1983). Day et al. (1988) discussed the metamorphism of the northern Sierra based on a review of the literature and preliminary field and petrographic observations. Much of the following is summarized from that review.

Several different views of the regional metamorphism have emerged from these incomplete studies. The Sierra Nevada is regarded as a greenschist facies metamorphic belt punctuated by contact aureoles related to the Sierra Nevada batholith. The low-grade regional metamorphism has been explained as: (a) an effect of Neovadnian deformation (Talalay et al., 1942); (b) a Cretaceous, low P/T belt paired with the Franciscan high P/T blueschists (Miyashiro, 1961; Miyashiro, 1973); (c) a Jurassic subduction complex (Ernst, 1983); (d) a collage of tectonically juxtaposed metamorphic terranes (Day et al., 1988); (e) the thermal consequence of the construction and burial of volcanic arcs (Day et al., 1988). Recent work suggests that the metamorphic history may be as rich and complex as the tectonic history outlined above and that no single model is likely to accommodate all the observations.

Figure 7 (modified after Day et al., 1988) summarizes our current understanding of the ages and conditions of metamorphism in the northern Sierra. Volcanic rocks in the Smartville Complex of the Western Belt are relatively undeformed and only weakly recrystallized, except in contact aureoles. Prehnite and pumpellyte are widespread, but actinolite is also abundant (Springer et al., 1992). Contact aureoles of ca. 161 Ma plutons overprint the prehnite and pumpellyte assemblages in volcanic rocks of approximately the same age. Some of these contact aureoles contain granulite facies, two-pyroxene assemblages and evidence for partial melting (Beard, 1990).

Greenschist facies assemblages, actinolite + albite + epidote + chlorite, are common in the hypabyssal dike complex and may be the result of autometamorphism or deuteric alteration (Day et al., 1988). Epidotes are probably the result of hydrothermal processes associated with the intrusive activity. The regional metamorphism must be synchronous with or slightly older than the main intrusive episode, implying that the regional, contact, autometamorphic and hydrothermal metamorphic processes are all part of the construction and burial of the Smartville volcanic complex.

Much of the Central Belt (Fig. 7) contains greenschist facies assemblages and actinolite and biotite are much more widely reported than in the Smartville Complex. However, post-tectonic plutons are abundant in the northern part of the Central Belt and it is not yet clear whether the regional assemblages might be related to the plutonism. The Older Ophiolite unit contains assemblages of the greenschist and epidote amphibolite facies (actinolite + albite; bluish-green hornblende + albite, hornblende + actinolite + albite-oligoclase; actinolite + oligoclase). Pumppellyte has not yet been confirmed in the Slate Creek Complex, but the preservation of delicate quartz textures in some volcanic rocks suggests that recrystallization is weak in some areas and that pumpellyte may have been overlooked. Alternatively, low-grade assemblages may have been overprinted by greenschist facies assemblages in some places. Springer (unpublished) has identified pumpellyte in hypabyssal intrusives in the Lake Combie Complex, and prehnite has been reported from tuffaceous rocks in the chert-argillite unit (Edelman et al., 1999).

The ages of metamorphic events in the Central Belt are poorly constrained, but must be early Jurassic or younger because the mafic rocks in the western part of the Central Belt are no

---

**Figure 7:** Metamorphism as a Function of Age and Lithotectonic Belt.
older than ~200 Ma. In the Older Ophiolite unit, the assemblage actinolite + oligoclase is found in the deformed outer margin of a flaser diorite that is interpreted to have formed during the late- or post-magmatic cooling of the pluton (Day, et al., 1988; Mazaheri, 1982) at about 204 Ma (Saizely, et al., 1989). North of the N. Yuba River, greenschist and epidote amphibolite assemblages are found in foliations and fault zones that are truncated by the ~159 Ma Yuba Rivers Pluton.

The Feather River Belt (Figure 7) contains the highest grade rocks exposed in the northern Sierra, outside of contact aureoles. Amphibolites yielding Permian and Devonian argon ages on hornblende contain typical lower amphibolite facies hornblende+ oligoclase (Bohlen and McKee, 1984; Hieteranen, 1981) and metaperidotites contain anthophyllite (Ehrenberg, 1975). Peak metamorphic temperatures in amphibolites and intercalated metasediments were 600 ± 50 °C at 5 ± 3 kbar and they appear to have been overprinted by Jurassic(?)+ pumpellyite + actinolite assemblages (Hacker and Peacock, 1990). Greenschist facies actinolite + albite + epidote appear to be lower than the amphibolite facies recrystallization, especially in shear zones. Metasedimentary and metavolcanic blueschists occur in fault contact with the high grade mafic and ultramafic rocks. Glaucophane - bearing amphibolites in the Feather River Belt were first described by Ferguson and Gannett (Ferguson and Gannett, 1932) in the Alleghany gold district near the Middle Yuba River and lawsonite + albite was later reported from the same area by Rosenbaum (unpublished). Glaucophane + lawsonite + epidote blueschists were described by Schwerdfeger and others and Hieteranen near the North Yuba River (Hacker and Goodge, 1990, Hieteranen, 1981; Schwerdfeger, et al., 1980). The metamorphism of the blueschists was 174 Ma or older (Schwerdfeger, et al., 1980), but the geological relationships are occurring north and south of the N. Yuba river are not clear. More detailed petrological work suggests that glaucophane + lawsonite and crossite + epidote formed at 6 - 7 kbar, 300 ± 50 °C and that the blueschist assemblages are overprinted by pumpellyite + actinolite (Hacker and Goodge, 1990).

The Eastern Belt (Figure 7) contains widespread lower greenschist and sub-greenschist facies assemblages. The pre-Devonian Shoo Fly Complex contains the common assemblage quartz + chlorite + white mica. Biotite and stilpnomelane are reported as less common accessory minerals but detrital biotite has been reported (D’Allura, 1977) and it is not clear that all biotite is neoblastic. Recent studies of illeite crystallinity in the Shoo Fly suggest that the Complex is in the "epizone," comparable to the lower greenschist facies (Robinson and Bevin, personal communication). The Devonian-Mississippian volcanic rocks of the northern Sierra contain widespread prehnite and pumpellyite (Hannah, 1980). (Brooks, unpublished; Schifflinan, unpublished) that appear to be overprinted by greenschist assemblages near Cretaceous granite plutons. Permian-Triassic volcanic rocks also contain pumpellyite and prehnite (Bevin and Robinson, personal communication). Jurassic volcanic and sedimentary rocks near Mt. Jura show only evidence of very low grade metamorphism. Prehnite and pumpellyite have not been reported and recrystallization of the rocks is minimal except in narrow deformation zones or in obvious contact aureoles near Cretaceous intrusions.

It is especially notable in the Eastern Belt of the northern Sierra that there is no regional increase of metamorphic grade toward the Sierra Nevada batholith on the east. In particular, the lowest grade rocks appear to be the Jurassic metavolcanic and metasedimentary rocks immediately adjacent to the large Cretaceous granitoid intrusions in the vicinity of Mt. Jura (Fig. 6). The highest grade (biotite) grade rocks are most abundant in the Shoo Fly Complex on the western margin of the Eastern Belt. The highest grades of regional metamorphism in the northern Sierra, in fact, occur in the Feather River Belt to the west.

The time(s) of low-grade metamorphism in the Eastern Belt are unclear. Some of the metamorphism is clearly pre-Upper Devonian because foliated metasedimentary clasts of Shoo Fly lithologies occur in the lower part of the overlying Devonian units (Varga and Moores, 1981). Harwood attributed most of the metamorphic alteration to a late Jurassic metamorphic overprint (Harwood, 1988; Day, et al. 1998) suggested that prehnite + pumpellyite assemblages might be the result of alteration during the construction and burial of Paleozoic volcanic arcs, in much the same way as documented in the Jurassic Smartville Complex to the west. No definitive evidence has yet been offered to resolve the issue.

Late Neovadian shear zones in the northern Sierra are everywhere associated with greenschist facies metamorphism. In late Neovadian shear zones truncating or bounding the Smartville Complex, actinolite + albite + epidote + chlorite is a common assemblage. Upper greenschist or epidote amphibolite assemblages are common in the northern parts of the Central Belt, where metamorphic foliations and contact aureoles are nearly ubiquitous. Retrograde greenschist assemblages are commonly associated with faults and cleavages in the Feather River Belt. Likewise, fault zones in the Eastern Belt also contain greenschist facies assemblages.

Contact metamorphism occurred in aureoles surrounding Paleozoic and younger gabbroid and granitoid plutons in all except the Feather River Belt of the northern Sierra. All known metamorphic assemblages suggest low pressures of intrusion and contact metamorphism. Andalusite, andalusite + cordierite, and andalusite + staurolite assemblages are known from several contact aureoles and suggest pressures of metamorphism of about 3 kbar (Bobbit, 1982; Day, et al., 1988; Hieteranen, 1973, Hieteranen, 1976; McMath, 1958; Swanson, 1970). This estimate is supported by hornblende barometry on plutons in the Central and Western Belts (Lang and Manduca, 1991; McLeod and Day, 1991).

DISCUSSION

The northern Sierra Nevada is primarily a low grade metamorphic terrane composed of both sedimentary and volcanic protoliths. The thermal history of low-grade terranes such as this are notoriously difficult to determine because of the poor sensitivity of the major lithologies to metamorphic recrystallization at low temperatures and because of the complex and incompletely understood tectonic history. Despite the near absence of systematic and detailed studies of the metamorphism, some broad features of the thermal and tectonic history are beginning to emerge.
Conditions of Metamorphism

The pressures and temperatures of metamorphism in the Sierra Nevada metamorphic belt are only broadly constrained, in part because we are only beginning to recognize multiple events and, in part because data are sparse. Figure 8 (modified after Day et al., 1988; Liou et al., 1985) illustrates estimates of the conditions of metamorphism based on the limited petrological information available and estimated equilibrium conditions for iron-free phases. The presence of prehnite and pumpellyite in the Smaritite Complex, Western Belt, suggests temperatures of about 275-300°C and pressures of about 2.5 - 3.0 kbar (Day et al., 1988; Springer et al., 1992). Recent hornblende barometry of syn- and post-metamorphic plutons in the Western and Central Belts, likewise, suggests that pressures were in the range of 2.5 - 3.5 kbar (Lang and Manduca, 1991; McLeod and Day, 1991). Actinolite is abundant in late "Nevadan" shear zones everywhere in the northern Sierra and probably formed at 350°C - 400 °C at about the same pressure. Both actinolite + olivine and hornblende + aësite are found in the Older Ophiolite unit of the Central Belt suggesting lower pressures, perhaps as low as 1.5 - 2 kbar (Fig. 8). The pressures at which amphibolite facies assemblages in the Feather River Belt formed are not constrained in a significant way, but the coexistence of epidote + glaucophane in the Feather River blueschists appears to require significantly higher than "normal" pressures. Based on the iron-free system (Fig. 8), pressures may have been above 8 kbar, whereas estimates based on analyses of the natural phases are about 6 kbar (Hacker and Goode, 1990).

Times of Metamorphism

Most of the metamorphism in the northern Sierra Nevada occurred before the main phase of Cretaceous intrusions in the Sierra. Indeed, there is little unambiguous regional metamorphism associated with the emplacement of the Sierra Nevada batholith in the northern Sierra. In general, narrow contact aureoles of Cretaceous plutons overprint regional metamorphic fabrics and, outside the aureoles, regional metamorphic grade seems to increase from east to west across the Eastern Belt, away from the main exposures of the batholith.

Although late Jurassic metamorphism is clearly evident in the greenschist facies assemblages of late Nevadan shear zones, the sparse data available suggest also that there have been several earlier episodes of Paleozoic and Mesozoic low grade metamorphism. In the Western Belt, contact aureoles of 161 ± 2 Ma plutons overprint Prh + Pmp assemblages in late middle Jurassic volcanic rocks, implying middle Jurassic low grade metamorphism (Day et al., 1988). Pumpellyite in intrusives of the Lake Combie Complex, Central Belt, similar to occurrences in the Western Belt (Springer et al., 1992), suggest that low grade metamorphism is related to the igneous activity by which the arc was constructed, but the age is uncertain. In the Older Ophiolite unit of the Central Belt, early and middle Jurassic metamorphism is suggested by upper greenschist facies metamorphism, which appears to be associated with intrusions emplaced in an oceanic fracture zone at about 204 Ma, and greenschist assemblages in the fault zones, which must be older than the 159 ± 2 Ma Yuba River Pluton. In the Feather River Belt, rocks of widely differing metamorphic grade and age are tectonically juxtaposed by faults in the foothills Fault System that, elsewhere, deform fossiliferous late Jurassic rocks. Ar ages of amphibole in amphibolites require minimum ages of metamorphism that are Permian and Devonian. Blueschist metamorphism is unrelated to the amphibolite facies metamorphism, but must be early Jurassic or older. The age of metamorphism in the Eastern Belt is not directly constrained. It is very likely that some of the low greenschist facies metamorphism of the Shoo Fly Complex is pre-Upper Devonian. We have proposed that the prehnite + pumpellyite facies assemblages of the Paleozoic volcanic rocks may be related to the construction and burial of the volcanic complexes in much the same way that we observe in the Smaritite Complex (Day et al., 1988) (Beiersdorfer and Day, this volume).

Tectonic Implications

The Western, Central and parts of the Feather River Belts (Fig. 2) contain late Paleozoic and Mesozoic volcanic arc, ophiolitic and marine sedimentary assemblages that were amalgamated with the Eastern Belt during the Jurassic Neva- dan deformation. The major regional faults of the Foothills Fault System juxtapose rocks of significantly different age and metamorphic grade and the amalgamation of the lithotectonic belts separated by these faults may have occurred largely before ~165 Ma (Edelman et al., 1989; Edelman and Sharp, 1989). The deformation of late Jurassic rocks along these faults may represent, therefore, reactivation of earlier, cryptic faults (Edelman et al., 1989). The evidence for early, middle and late Jurassic, as well as early Cretaceous, deformation sug-
suggests that the Nevadan was not an event of short duration. Rather, a broader view of Jurassic deformation may be more appropriate, as suggested previously for the Klamath Mountains (Wright and Fahan, 1988).

There have been several episodes of Paleozoic and Mesozoic low-grade metamorphism and much of the low-grade metamorphic character of Sierran rocks may have been acquired in volcanic arc or other oceanic settings prior to, and modified during, the latest Nevadan deformation. Overprinting of low-grade regional assemblages by contact aureoles of Jurassic and Cretaceous plutons gives only broad constraints on the ages of regional metamorphism. The tectonic juxtaposition of rocks with significantly different metamorphic grade during late Jurassic deformation, especially in the Feather River Belt, testify to the pre-late Jurassic age of some of the metamorphism. Late Jurassic metamorphism occurred primarily in relatively narrow deformation zones, but implies that rocks were buried at conditions appropriate to the greenschist facies at that time. There is no documented regional metamorphism associated with the Cretaceous intrusion of the Sierra Nevada batholith. In fact, Cretaceous must have been a time of major exhumation, because the late Jurassic and early Cretaceous contact aureoles formed at approximately 3 kbar and are overlain by Eocene and younger sedimentary and volcanic rocks.

The picture that is emerging, therefore, is that metamorphism in the Sierra occurred in a variety of oceanic, volcanic arc, and subduction environments prior to the later Jurassic phases of the Nevadan orogeny. Greenschist facies metamorphism overprinted the earlier assemblages and fabrics during the latest phases of the Nevadan deformation, followed by contact aureoles of post-tectonic plutons. Consequently, metamorphism is perhaps best viewed as a collage of various, pre-orogenic tectonic settings overprinted by the greenschist facies thermal effects of the final amalgamation and exhumation.

ACKNOWLEDGEMENTS

Over the past 15 years, I have benefitted immensely from the hard work and stimulating discussion of my colleagues and students. Eldridge Moores introduced me to the geology and tectonics of the Sierra and much of my early work was done jointly with him. Our former students J. S. Beard, S. H. Edelman, J. L. Hannah, A Turnins have been major influences on my thinking and our progress owes much to their efforts and insights. I am most grateful to P. Schiffman, D. Robinson, and R. Bevis for permission to cite unpublished data. Critical reviews of the manuscript by J. S. Beard, T. Fagan, D. Robinson, and X. Zhai were greatly appreciated. This review has been supported by NSF grants EAR-9119390 and EAR-9017844.

REFERENCES


Bobbitt, J. B., 1982, Petrology, structure and contact relations of part of the Yuba Rivers Pluton, northwestern Sierra Nevada foothills, California [M.Sc. thesis]: Davis, California, University of California, 160 p.


McLachlan, V. E., 1958, The geology of the Taylorville area, Plumas County, California [Ph.D. dissertation]: Los Angeles, California, University of California, 199 p.


NORTHERN SIERRA NEVADA - GEOLOGICAL ROAD LOG
(WILKESON AND LAWLER 1997)

auburn to north san juan - geologic map 8

Between Auburn and the Bear River, Highway 49 traverses rolling open grassland broken here and there by patches of brush and scrub trees. The somewhat monotonous landscape to the north of Auburn gives no inkling of the splendid scenery soon to be in evidence from Grass Valley to the end of Highway 49. The bedrock between Auburn and Grass Valley is mainly green metavolcanics of doubtful age which have been intruded by irregular bodies of serpentine and by basic dikes of several types. Between the forks of Dry Creek a narrow belt of Calaveras metasediments begins which rather closely parallels Highway 49, on its west side, as far north as Rattlesnake Creek. The Calaveras rocks are mainly mica schist, chert, and limestone. There are large granodiorite intrusions near Grass Valley and the bedrock from Nevada City to North San Juan is principally of plutonic igneous rock approaching granodiorite in average composition. All the Quaternary stream and bench gravels have been worked for gold. Tertiary deposits are absent between Auburn and Grass Valley along the route of Highway 49. There are no mines of any consequence south of the Grass Valley district of which the Bullion claim of the Idaho-Maryland Mines Company, Ltd., is the southernmost member (49).

0.0 Highway 49 underpass with Highway 80. Head north toward Grass Valley on Highway 49. The rocks in this area are greenstones, serpentine and Calaveras Group schist.

0.3 Pulweller Road to right. To the right (east) is an ultrabasic mass. On the immediate right (east) is metavolcanic rocks of a melange terrain and to the west are metavolcanic rocks that are not part of a melange complex.

3.2 De Witt Center. The roadcuts for the next 3 miles expose metavolcanic and metasedimentary rocks.

3.3 OPHIR MINING DISTRICT

Three miles west of Auburn near Highway 40 is the Ophir mining district. Ophir, first known as Spanish corral, was one of the main placer camps of Auburn ravine and has since been the main gold-quartz mining center of Placer County. Although little is left of the town, the orchard and vineyard landscape is attractive (49).

3.2 Bell Road to airport.

4.2 Elder's Corner at Dry Creek Road. An ultrabasic mass on the right (east) lies between Bell Road and Dry Creek.

4.4 Marguerite Mine Road to small hardrock mine.
South Fork of Dry Creek. At this point there is serpentine to right (east) and Calaveras Group rocks to left (west) along a fault that runs parallel to Highway 49.

HOTALING (CLIPPER GASP)

Six miles northeast of downtown Auburn at Hotaling, near Clipper Gasp, one of the earliest iron mining operation in California was locate. Clipper Gap and Hotaling can be reached via Highway 20 east from Auburn. The Hotaling iron mine was located in 1857 but no ore was shipped until 1869. The deposit was in the form of lenses at the contact of granodiorite and a metamorphic series of probable Paleozoic age. The ore minerals were magnetite and hematite containing from 40 percent to 65 percent iron. A blast furnace was operated on the property between 1880 and 1885 using charcoal made locally and limestone mined near by. It produced thirty to thirty-five tons of pig iron daily. Although red and yellow ocher were shipped from the vicinity in the late 1920's for mineral paint, no attempt to exploit the lower grade ores for their iron content has been made since the turn of the century (49).

The Honor Camp No. 7 iron mine is northeast of Hotaling in Section 10 of Road Map 32.

North Fork Dry Creek in Calaveras Group rocks.

BEAR RIVER BRIDGE

Highway 49 crosses the Bear River and the Placer-Nebraska County line 8.7 miles north of Auburn. The vicinity of the Bear River bridge is of considerable geologic interest and is an attractive spot for fishing enthusiasts and pleasure seekers. A major thrust fault diagonally crosses the Highway in a NW-SE direction and the crumpled rocks along its trace are an interesting study. West of the bridge along the eastern bank of the river, the sheared and crumpled meta-volcanics of the Lake Combie Complex are in places, a lattice-work of silica-carbonate veinlets. Discontinuous, irregular bodies of serpentine appear along the contact, and the crumpled volcanics include fragments of chert and limestone. East of the bridge a few hundred yards, the massive greenstones contain amygdaloidal horizons and represent quiet lava flows rather than the pyroclastic beds seen to the west (49).

U-name-it ranch with placer workings.

Combic Road in metavolcanics.

Pillow basalt metavolcanic rocks.

Serpentine in roadcut
11.8 South Fork of Wolf Creek with Overland emigrant trail Historical marker #799.

12.0 Higgins Corner with Combie Road leading to Combie Dam on the right (east).

HIGGINS CORNER

Two miles north of Bear River is Higgins Corner. A road connecting with the hamlet of Wolf leads off to the west and another to the east leads to the Combie Dam and Reservoir on Bear River. A prominent outcrop of Calaveras chert forms a reef just west of the highway 2.3 miles north of the south fork of Wolf Creek. This reef is almost vertical in attitude and is associated with greenstones of uncertain age. This is one of the few exposures of chert to be seen close to Highway 49 south of the Yuba River (49).

12.5 Vertical bed of Calaveras Chert.

12.6 Carriage Road goes to Cottage Hill.

13.5 Contact between green metavolcanics and granodiorite.

14.0 Cherry Creek Road and Holcomb Road in metavolcanics. The Stockton Hill Mine is on the left. This intersection marks the north end of an fault contact between Paleozoic metasediments and an ultrabasic mass in the Wolf Creek Fault Zone. Highway 49 follows this zone most of the way to Grass Valley.

14.1 Donner Party emigrant trail.

15.3 Lime Kiln Road

LIME KILN (JONES RANCH)

The Lime Kiln or Jones ranch was the site of a series of limestone quarries and kiln where limes for mortar was prepared at a very early date. Traces of the old workings have been almost obliterated, but partially burned limestone marks the old kiln sites. The limestone bodies are small and are now largely masked by the soil mantle. Chemical analysis of the limestone shows it to be of excellent grade. The Lime Kiln ranch is located three miles west of Highway 49 via dirt road. The turnoff is 5.3 miles north of Higgins Corners and is marked by a white sign (49). Modern development has obliterated the kilns, but limestone outcrops can still be seen.

18.6 Forest Springs Drive.
18.7 GRANODIORITE INTRUSIVE CONTACT

Three miles beyond the chert reef the greenstone bedrock is invaded by granodiorite. The contact is plainly visible in a roadcut on the west side of the highway. The dark minerals in the granodiorite near the contact have been altered to chlorite and green amphiboles, and the granodiorite is almost as green as the meta-andesite aeries which invade. A feldspar porphyry is present close to the contact which does not appear to be related to either the meta-volcanic series or the granodiorite, and may have been brought up from below by the intrusion. The porphyry is composed of abundant large plagioclase phenocrysts averaging 3 mm in diameter set in a fine-grained black groundmass (49).

20.1 Granodiorite in roadcut at Bethel Way.

20.4 LA BARR MEADOWS in granodiorite with manzanita and ponderosa pines on a bypass to the east of Highway 49.

The change in bedrock from meta-volcanics to granodiorite is almost immediately reflected by the vegetation. Heavy growths of manzanita cover most of the granodiorite bedrock with a dense gray-green mantle. The manzanita thickets are most conspicuous in the vicinity of La Barr meadows.

20.5 Deep weathering profile of granitic rocks.
21.2 Hansen Brothers Gravel Operations.

21.7 GRASS VALLEY CITY LIMIT

Grass Valley is one of the most beautiful historic mining town in the Northern Sierra. Mining camps the world over are notoriously ugly and uncomfortable places to live, but Grass Valley is set in a well watered coniferous forest of great beauty. Many stands of large trees have been spared the loggers axe and tower in dark green borders about broad meadowlands. The entire aspect of suburban Grass Valley is park-like. Even the mine dumps and buildings are more or less masked by trees so that the scenery suffers little by their presence. The business district of town is much like that of other Sierran towns (49).

Grass Valley is connected to the overland route through Reno via Highway 20 which joins Highway 40. A railroad once connected Nevada City and Grass Valley to the transcontinental route of the Southern Pacific but the tracks have been removed. Aside form explorations of Spanish Americans of which there is no record, Grass Valley was first visited by French emigrants in 1846. Gold miners from Oregon spent considerable time there in 1848 but the first permanent settlers who were emigrants from the east arrived in 1849. Historical spots in Grass Valley are numerous. The careers of such
famous names as Lola Montez and Lotta Crabtree are closely associated with the history of the town. Its lode mines constitute the most productive group of gold properties in California and rank among the richest in the nation (49).

The geology of the Grass Valley mines differs greatly from that of the Mother Lode mines. Very little large scale faulting is in evidence in the Grass Valley district. The Mariposa slate is largely absent and even Calaveras rocks usually do not contain ore. The main veins dip on an average of $35^\circ$ whereas most Mother Lode veins are steeply dipping. The minor cross veins are usually not mineralized except at their intersections with main veins. The wall rocks of the Idaho-Maryland and Spring Hill mines are principally gabbro and serpentine; those of the Empire Star and Golden Center are granodiorite, meta-andesite, diabase, and Calaveras schist. Vein forming minerals from the Grass Valley district include ankerite, native arsenic, arsenopyrite, chalcopyrite, chromite, epidote, galena, gold, magnetite, mariposite, pyrite, pyrrhotite, sphalerite, and rarely molybdenite, scheelite, hessite, and altaite. The latter two are tellurides of gold and lead respectively. Wall rocks in the district are heavily watered above the 1500 foot level and water flows into the lowermost workings necessitating use of elaborate pumping systems. Pumps which handled 3000 gallons per minute are used in the wettest spots. Although exceedingly humid, Grass Valley mines were among the coolest in the world. The temperature increase or geothermal gradient below ground is less than 1° F. per 100 feet of depth (49).

22.5 Highway 20 East turn off to West Empire Mine Street.

22.7 West Empire Mine Street. Turn right at the stop sign and go east on Empire Street to the intersection of South Auburn Street and West Empire Mine Street.

23.0 The Empire Market is on the SW corner of the intersection. Go straight (east) toward the Empire Mine. The rocks in this area are metavolcanics and granodiorite.

23.8 Borne Mansion on the right (south).

23.9: EMPIRE MINE STATE PARK AND VISITOR'S CENTER

EMPIRE-STAR MINES
The largest mining operation in Grass Valley was that of the Empire-Star Mines Company, Ltd. The Empire-Start is a consolidation of the major North Star, Pennsylvania, and Empire mines and a host of lesser workings. The Empire began operations in 1851. During World War II most of the shafts have been shut down. The mine workings had gold in them, but they filled with water and have remained so ever since. The workings of the Empire-Star total more than 200 miles in length making it one of the most widespread mines in existence. It has been mined to an inclined depth of more than 11,000 feet or a vertical depth of over a mile. The total production of the
Empire-Star group has been in excess of 4,800,000 oz ($120,000,000). For the locations of the various shafts of the Empire-Star and other Grass Valley mines see the accompanying map (49).

Guided tours of the Empire mine are available and highly recommended.

Return to Highway 49. Reset odometer

0.0 Highway 49 and West Empire Mine Street. Go straight over the Highway 49 overpass to Mill Street.

0.1 Mill Street turnoff. Take the turnoff and circle back to the right to North Star Powerhouse Road.

0.4 Turn left at Stop Sign to go through Old Town Grass Valley.

GOLDEN CENTER MINE

The Golden Center mine is located in the heart of the business district of Grass Valley. Although the surface extent of the Golden Center property is not great the mine was rich and ore worth more than 100,000 oz ($2,500,000) was taken from it before litigation forced a shut down. The Golden Center is currently idle. The deepest shaft is 1900 feet as measure along the incline (49).

SPRING HILL MINE

The Spring Hill mine northeast of Grass Valley is a small but promising operation which was active in 1949. It was one of the neatest, best maintained properties in the gold county and its headframe and mill have been photographed repeatedly for various publications. The main shaft is about 1900 feet deep in diabase and serpentine wall rocks. The recorded production, most of which has been between 1928 and 1948, is 120,000 oz ($300,000) (49).

1.0 Downtown Grass Valley. Turn right on Main Street east to Business Highway 49.

1.2 Stop sign. Go straight toward Nevada City.

1.6/0.0 Go under Highway 49 then take the on-ramp that curves to the right. Get on freeway, head north toward Nevada City. Reset odometer. To the east of the on-ramp is Idaho Maryland Road.

IDAHO-MARYLAND MINES

Another major gold-mining operation in Grass Valley active in 1949 was that carried on
by the Idaho-Maryland Mines Corporation. Its holdings include the Old Brunswick, New Brunswick, Idaho, and Eureka mines and many smaller workings. The New Brunswick shaft is 3450 feet deep and the Idaho is 2700 feet deep via shaft and winze. A successful attempt at shaft sinking by core drilling was made by the Idaho-Maryland. Part of the core can be seen at the Museum and in downtown Grass Valley. The Idaho No. 2 shaft was sunk 1000 feet into serpentine by this method using a Newsom drilling machine developed at the Idaho-Maryland. The drill cores are five feet in diameter and weigh several tons each. Many of these cores are piled about the entrance to the shaft. Although the Idaho-Maryland is not as large an operation as the Empire-Star, it is still among the six largest gold mines in California, and has a recorded production of 2,570,000 oz ($64,240,543). Ore-treatment plants at one time connected with both Idaho-Maryland and Empire-Star mines (49).

0.9 Brunswick Ave. Exit: TOWN TALK

Midway between Grass Valley and Nevada City was the old mining camp of Town Talk. Little remains to mark the site because it has been overrun by urban development of Grass Valley. Historian Glasscock has it that Town Talk came about partly as an act of God and partly as a practical joke. An old saloon sign bearing the words Town Talk is supposed to have been stranded in the vicinity of the camp by flood waters of Deer Creek. Someone fished the sign out and stuck it up on the hill and the camp was thereafter known by that name.

2.0 Gold Flat Road.

2.6 Nevada City limits.

3.1 Broad Street exit. Take this to the South Yuba Canal Office with its display of 5 stamp mill, water wheel and 5-ft diameter drill core of serpentine gabbro. Then turn left, go west into Nevada City.

3.3 Downtown Nevada City

NEVADA CITY

Nevada City, four miles northeast of Grass Valley, has been a famous lode-gold mining center although the mines there are currently idle. James Marshall passed through there seeking a placer bonanza in the summer of 1848 but missed making a strike. The first settlers arrived in 1849 and the placers attracted a large population within a few months. Known originally as Coyoteville, because of the local method of tunneling called coyoteing, the name Nevada City was evolved after a dispute with the state of Nevada over priority rights to that name. A total of 320,000 oz ($8,000,000) in placer gold is said to have taken from the vicinity. Nevada City is county seat of Nevada County and, like
Grass Valley, is full of pioneer landmarks such as the Wells-Fargo Express Office site established in 1853, fire-houses built in the 1869's and a remnant of Chinatown. It is situated on Highway 20, which connects with Reno and, like Grass Valley, was once connected to the transcontinental rail route of the Southern Pacific (49).

The Principal lode mines of Nevada City are the Lava Cap, Murchie, Champion, and Providence. The Nevada City assay office is credited with assaying the first ore taken from the Comstock lode (49).

3.4 Hydraulic workings on Cement Hill Ridge along skyline at 12:00

3.5 Pioneer Park on right.

3.5 Broad Street exit with granodiorite exposed in roadcut

3.6 Street splits at "Y". Stay to the left on Broad Street.

3.8 Nevada City cemetery.

5.0 Hydraulic diggings on right (north) on Cement Ridge.

LAVA CAP MINE

The Lava Cap mine has a recent history dating from 1933. In its ten years of operation it grossed about 360,000 oz gold and 40,000 oz silver ($12,000,000). The mine is 2700 feet deep and has over five miles of lateral workings. The Murchie was worked in a small way in the 1890's but major production took place in the 1930's. The mine is now owned by the Empire Star Mines Company, Ltd., and is currently idle. It was an exceedingly productive mine before the last World War but few figures on it are available. The Champion and Providence mines have been worked discontinuously, with indifferent success, since the early day lode-mining period of the 1860's and 1870's. The Nevada City mines lie at the fringe of the Grass Valley district and the ore shoots have not persisted at depth as have those in the heart of the district.

West from Nevada City, Highway 49 passes through a thick series of tertiary gravels which lie at the southern base of a ridge or rhyolite tuff and andesite. These deposits have been extensively hydraulicced and placered. Hydraulic pits and faces of moderate size can be seen on both sides of the highway. West of the gravels the granodiorite outcrops are full of dark inclusions or enclaves. These vary in size from fractions of an inch to one foot in diameter. Enclaves are common in many granitic batholiths and are formed either by magmatic segregation of various mineral constituents of by inclusion and partial assimilation of wall rocks caught in the invading magma. In most cases they carry a greater proportion of dark minerals than the matrix rock and have a somewhat
different pyrite. Pyrite occurs only in the enclaves, not in the matrix rock, and probably was a constituent of the assimilated rock from which the enclaves formed. The texture is granitic but the crystals are finer than those in the matrix rock, which is essentially a biotite-hornblende granodiorite. Excellent exposures of these rocks may be seen in roadcuts 1.2 miles west of Nevada City (49).

Immediately west of the enclave locality is the contact between the granodiorite and meta-volcanic greenstones. Lindgren’s map shows these to be in the Calaveras formation but separate from greenstones lying a quarter of a mile to the west. Two miles farther to the northwest is a narrow belt of serpentinite and related basic intrusive rocks which are not particularly well exposed along the highway except in deeply weathered roadcuts. Deeply weathered areas and dark-red soil mark remnants of the old Eocene surface. The remainder of the route into North San Juan lies on a granitic bedrock ranging in composition from quartz diorite to granodiorite. A small roof pendant or remnant of overlying wall rock of dark green amphibolite can be seen in road cuts 1.2 miles south of the Yuba River bridge. The greenstone is cut by aplite and pegmatite dikes. A good locality for collecting hornblende crystals is to be seen close to the amphibolite contact (49).

7.9/0.0 Cement Hill Road and Highway 49. Turn right and go east on Highway 49 past the County Government Center to North Bloomfield Road.

From Nevada City to Tyler Foote Road this field guide departs from the route of the original Highway 49 field guide. Descriptions of the geology and history of Yuba River Bridge on Highway 49 and of Sweetland, Bridgeport and Bitney Corner are found in Appendix IV.

0.4 North Bloomfield Road and Highway 49. Turn left, go north past the California Division of Forestry station.

0.7 Cement Hill Tertiary tributary channel gravels and red soil.

0.9 North Bloomfield and Lake Road "T" shaped intersection. Turn right, go east on North Bloomfield Road.

1.5 Tertiary Mehrten Mudflow outcrops on right.

3.2 Normandie Mine to left (north).

3.3 Hoge Mine to the right.

4.3 Old narrow concrete bridge.

4.7 Blue Tent School Road.
6.1 Diamond Center Conference Grounds, formerly Kirkham Ranch

6.9 South Yuba Recreational Area.

7.4 Granodiorite exposures.

7.7 Site of historic stage coach robbery.

7.9/0.0 EDWARDS CROSSING

Edwards Crossing is a popular recreational site on the South Yuba River. The area is good place for gold panning. Rocks are basic intrusives with Paleozoic metasediments to the north.

Enormous amounts of hydraulic tailings were deposited along this stretch of the Yuba river. The tailings extended from this bridge to Malakoff diggings several mines to the east. In some places these tailings were over 150 feet thick and completely choked the river channel. The main southern tributary of the Ancestral Yuba river crosses present canyon of the South Fork of the Yuba river 1 to 2 miles upstream from Edwards Crossing (49).

After the suction dredging demonstration, we cross the Bridge and proceed east toward Malakoff Diggins.

0.5 Caved adit (tunnel) on the left.

0.6 Paleozoic metasedimentary marine rocks.

1.5/0.0 Junction of the Grizzly Hill Road and North Bloomfield Road. Turn right on North Bloomfield Road. Reset odometer.

0.2 South Yuba Trail and camp on the right.

0.9 Kenebec Creek in Paleozoic metasediments.

2.5 Lake City Junction. Turn right and continue east on North Bloomfield Road.

3.1 Lake City historic townsite (circa 1860-1880).

3.4 Views of Malakoff Pit at 12:00.

3.8 Malakoff Diggins on left toward the Eastern Channel Deposits. These sand, gravel and
clay layers exceed 600 feet in thickness in this area.

4.1 North Bloomfield Drainage Tunnel on left. Humbug Creek on the right.

**MERCUry AMALGAMATION**

In order to get as much gold as possible from the sluicing operations, mercury was added to the ore slurries. Several hundred pounds of mercury were recovered from the North Bloomfield tunnel after hydraulic mining ceased. Mercury can be found in the gravels of the South Yuba and other Mother Lode streams to this day.

4.5 Diggins overlook on left (north). Placer tailings on right.
4.7 Crystal Hill Mine on right. This is administered by the Bureau of Land Management and is under claim. You must obtain permission from the mine owner to examine the old hydraulic workings in this area. The Crystal Hill is used by the Bureau of Land Management as a training area for its geologists and mining engineers.

4.8 Cemented gravels on the left (north). Sometimes these gravels are cemented by iron oxides, in which case they are called "Ferrocrete". The hardness of these layers make them difficult to mine, even though locally they may contain considerable quantities of gold.

5.0 School house on left.

5.4 Entering Malakoff historic townsit.

**NORTH BLOOMFIELD**

The immensity of the North Bloomfield pits must be seen to be believed. Although excavated entirely by powerful jets of water, the pits compare favorably in size with many of the open pit copper and iron mines of other states which have been excavated by modern mechanical means (49).

5.5/0.0 Malakoff Diggins at Relief Road and North Bloomfield Road.

**MALAKOFF DIGGINS**

The Malakoff pit west of North Bloomfield resembles a miniature Bryce Canyon. The soft clay and gravel walls have been fluted and otherwise sculptured by erosion into "badlands" of great charm. The pastel-colored horizons in the pit gravels contract strikingly with the deep red soil mantle and the dark-green backdrop of forest trees. Some ideas of the achievement of the nineteenth-century hydraulic miners in moving such great quantities of material without modern equipment may be had from the
following figures: 20,000,000 cu. yds. were excavated at North Bloomfield; and 25,000,000 cu. yds. from North Columbia. Only 14 percent of the gravel reserves at North Columbia had been removed by the time hydraulic mining was stopped by court injunction in 1884. The problem of the debris from such operations was, of course, a great one. It choked the rivers below and ruined riverbottom lands for farming purposes. In some places the problem has been solved by building debris dams; in others by selective spreading of waste on already valueless areas. A few hydraulic mines such as Relief and Omega situated southeast of North Bloomfield were active in 1948, but most have been idle since the 1880's (49).

Malakoff diggings visitor center has a museum and interpretive lectures are available.

PALEOENVIRONMENTAL STUDIES

The study of paleobotanic fossils and depositional environments in the Eocene gravels of Malakoff and other Tertiary channels indicates that they formed in a very near-tropical environment, similar to the Amazon River today. It was a hot, moist climate that encouraged deep chemical weathering. It was this climatic condition that caused the release of disseminated gold into the fluvial system and later concentration in placer deposits. (See Ancestral Yuba River Gold Map - Lawler 1997)

0.0 Head out of Malakoff on North Bloomfield Road going east.

0.2 Bair Pond, site of a freakish 1992 drowning.

0.4 Eastern limit of the North Bloomfield townsite.

0.7 Shoot Hill campground to the left.

1.4 Intersection of Derbec Road and North Bloomfield Road. Turn left and go north toward North Columbia. Rocks in this area are of the Valley Springs formation (Miocene-Pliocene pyroclastic deposits).

1.5 Malakoff School on right (east).

1.6 Derbec Meadows on left (west).

2.1 Intersection of Blackbone Road and Derbec Road. Turn left and go west on Blackbone Road. Blackbone Road becomes the Graniteville Road, which is paved.

3.1 Intersection of Cruzon Grade Road and Blackbone Road to Lake City.
6.1 Miocene-Pliocene pyroclastic rocks (mudflows of Valley Springs Formation) in roadcuts.

6.3 Tyler Foote Road and Backbone Road.

6.9 Red soils in weathered Paleozoic metamorphic rocks.

7.4 Tyler Foote and Lake City Roads.

7.9 North Columbia Schoolhouse on right (north).

8.1 Jackass Flats Road. Turn left.

8.8 Center of San Juan Ridge Eocene channel gravel deposits. Excellent view of east side of San Juan Mine project encompassing over 2000 acres and nearly five linear mile of the Tertiary age Ancestral Yuba River fluvial deposits that are currently being exploited using state-of-the-art underground (drift) mining methods and technologically advanced processing equipment. Portions of the Kennebec Hill, North Columbia, and Cherokee hydraulic mines can be viewed from this vantage point.

SAN JUAN RIDGE TERTIARY GRAVELS.

These deposits show the effects of hydraulic mining on the environment in a spectacular way. The deposits are also among the few deposits that have not been thoroughly developed. Drill testing of this deposit have revealed high volumes of minable gravel, even using expensive underground mining methods.

The present owners have conducted an extensive revegetation testing program to see what can be done to accelerate reforestation and revegetation of San Juan Ridge.

Return to Tyler Foote Road

0.0 Jackass Flats and Tyler Foote roads. Go west toward North San Juan and Nevada City.

0.4 Roadway crosses the northern rim of the Ancestral Yuba River Tertiary Channel. There are extensive hydraulic workings in this area.

1.0 to 1.2 Blue Canyon Formation in roadcuts. These are metasedimentary rocks of Paleozoic age.

1.9 to 2.1 Ancestral Yuba River Channel crosses the roadway to the northwest and strikes toward the Badger Hill area.

2.7 Historical location of Cherokee townsite.
CHEROKEE, NORTH COLUMBIA, NORTH BLOOMFIELD, RELIEF, OMEGA MINES

One mile northwest of Shady Creek bridge Tyler Foote Road intersects Highway 49 which connects with the hydraulic mines of Cherokee, North Columbia, North Bloomfield, Relief, Omega and many others. The Cherokee diggings are six miles northeast of the above intersection, North Columbia, is a little over nine miles, and North Bloomfield is about 19 miles, respectively.

3.0 Ananda Retreat Center turnoff to the right.

3.4 View of hydraulic tailings on Shady Creek drainage to the left at 10:00

SHADY CREEK BRIDGE

In the vicinity of Shady Creek bridge extensive deposits of Quaternary gravels choke the river bed. These are partly the result of placer operations connected with Tertiary gravels situated upstream (49).

3.7 Granodiorite contact.

4.3 Intersection of Pardon Road, Oak Tree Road and Tyler Foote Road. This place is called "Mother Truckers".

5.4 Eroded granodiorite terrain from this point to Highway 49.

7.7/0.0 Highway 49 and Tyler Foote Road. Turn left and go North San Juan. Reset odometer.

ALTERNATE ROUTE: NEVADA CITY TO SWEETLAND (TYLER FOOTE ROAD)

This route bypasses Edwards Crossing, Malakoff Diggins, San Juan Ridge, and North Columbia.

0.0 Intersection of Highways 49 and 20, north of Nevada City.

0.3 California Division of Forestry Fire Station.

0.7 Government Center on right in granite.

1.2 Indian Flat Road follows a lens of Paleozoic limestone.
2.4 Road to Newtown and Empress Mine on the left (south).

1.7 Triassic-Jurassic metavolcanics.

2.7 Ultrabasic rocks

2.9 Road follows Rush Creek in Triassic-Jurassic metavolcanics.

3.2 Basic intrusive (diorite) at headwaters of Rush Creek.

5.0 Hilliard Ranch in basic intrusive rocks.

6.1 Independence trail. This is a mining-era water diversion ditch which has been converted into a trail for wheelchairs.

6.9 Jones bar is below the bridge on the South Fork of the Yuba River. One-fourth mile downstream is a contact between basic intrusive rock and granite. Bunker Hill is to the right (east).

7.4 YUBA RIVER BRIDGE ON HIGHWAY 49

Close to the south abutment of the Yuba River bridge, a broad roadcut and quarry in granodiorite afford an excellent close-up view of the intruding batholith. The coarse matrix is full of large inclusions or enclaves and several prominent joint systems prevail which have aided in quarrying the rock for fill. The river water is often discolored by tailings from hydraulic workings upstream.

The road cuts up the grade along the north wall of the Yuba River canyon expose granitic rocks of at least two separate intrusive bodies. Contacts between the intrusions are indistinct, granodiorite grading into darker hornblende diorite which is cut by light-colored dikes of variable texture (49).

10.0 Shady Creek

10.1 Roadcuts in granite.

10.3 Old Highway 49 is on the right (east).

10.6/0.0 Highway 49 and Tyler Foote Road. Reset odometer.

1.0 PETERSON'S CORNER (Now named Sweetland) and road to French Coral.

Peterson's Corner, 1.2 miles northwest of the North Columbia-Highway 49 intersection is the terminus of a paved road connecting with the hydraulic-mining towns of Sweetland,
Birchville, French Corral, and Bitney Corner. An interesting and a scenic side trip on this road will bring one out on Highway 20 at Bitney Corner a few miles west of Nevada City. The route lies principally through granitic basement rocks which have been deeply weathered into a lateritic red clay in many places. An occasional belt of black or green meta-volcanics may be seen bordered on either side by granitic rocks. The many Tertiary gravel deposits lying on this surface are the basis for the once thriving hydraulic mines (49).

SWEETLAND

Sweetland, of which Peterson's Corner is a part, was originally a placer-mining camp first settled in the early 1850's. Together with adjoining towns to the southwest, Sweetland was a going and prosperous town of the region. Sweetland is now a handful of frame swellings set in a quiet country landscape. Birchville, 1.5 miles southwest of Sweetland, is located principally by the hydraulic pits to the north of the old town site. Several are filled with water and form small lakes (see - Ancestral Yuba River Gold Map - Lawler 1995).

Three miles below Birchville is French Corral which dates from 1849. The town is located in an attractive valley on a tributary to the South Fork of the Yuba River. Several well preserved stone and brick buildings remain along the main street. French corral was at one end of the first long distance telephone line ever built. It connected with Birchville, Sweetland, North San Juan, Cherokee, North Columbia, North Bloomfield and Bowman or French Lake, a distance of 58 miles (49).

BRIDGEPORT AND BITNEY CORNER

Very little remains at the Yuba River site of Bridgeport, three miles southwest of French Coral. A covered wooden bridge spans the river and grown graveyard is located beside the road a short distance south of the river. There is little of particular geologic or historical interest between Bridgeport and Bitney Corner on Highway 20, but the landscape is an attractive one and the side route will draw travelers who like to keep off the beaten track (49).

North along Highway 49 from Peterson's Corner, remnants of the exhumed Eocene surface are evident in several places. This flat surface is particularly noticeable in the vicinity of North San Juan. Large hydraulic diggings can be seen to the west. The granitic basement rocks are a dark or melanistic phase of the ordinarily light-colored granodiorite, being rich in biotite mica (49).

1.9. Hydraulic workings on the left. These are the San Juan segment of the Ancestral Yuba River.
3.0 North San Juan town limits.

3.3 NORTH SAN JUAN

North San Juan is one of the largest and best preserve of the northern gold towns. The iron grill work on the old brick buildings resembles the grilled balconies of the are 'Vieux Carre' or French quarter of New Orleans. North San Juan was founded about 1853 not by Spanish Californians, as the name suggests, but by Christian Kientz, an immigrant of German ancestry. He thought the hill resembled another known as San Juan and named the new spot accordingly (49).

NORTH SAN JUAN TO DOWNIEVILLE - GEOLOGIC MAP 9

The topography along Highway 49 north of North San Juan becomes increasingly rugged and more and more typical of the higher Sierra. The northward trend to the highway changes north of Camptonville and the route follows the bottom of the tremendous canyon of the North Fork of the Yuba in a broad northeasterly arc. Remnants of the Eocene surface become more and more restricted in areal extent and are commonly perched well over a thousand feet above present main-stream gradients. Calaveras meta-sediments and thick sections of greenstones reappear south of Camptonville and granitic rocks outcrop in only one area between Camptonville and Downieville. Except for logged-off areas of limited extent in the vicinity of North San Juan and Camptonville, the entire region is heavily forested with coniferous trees. The fauna and flora are typical of the upper transition and lower Canadian life zones. The dominant forest trees are yellow pines and Douglas firs (Oregon pines) with lesser numbers of white firs, incense cedars, and western hemlocks. Alders and other water-loving trees grow along the water courses (49).

From the turnoff to Alleghany (Celestial Valley) to Goodyears Bar this part of the field guide does not follow Highway 49. Along this stretch of Highway 49 are Camptonville, Frog Hollow, Joubert Hydraulic Diggins, Indian Valley Campground and Bald Top Mountain. Geologic and historic descriptions and a road log for these areas are found in Appendix IV and Road Maps 54 yo 56.

3.5 East end of North San Juan.

3.9 Tahoe National Forest Boundary. Area is underlain by granodiorite.

4.5 Clear Creek Bridge in granodiorite.

6.2/0.0 MIDDLE FORK OF YUBA RIVER AT YUBA COUNTY LINE

Two and eight tenths miles north of North San Juan the highway crosses the Middle Fork of the Yuba at the Yuba County line. The granodiorite near the bridge is prominently jointed into rectangular blocks. One tenth of mile beyond the bridge, a dirt road branches
off to the east at an acute angle to the highway recrosses the Yuba over a covered wooden bridge much like the one at Bridgeport. It is covered as a protection against the winter snow pack and the tunnel-like appearance is typical of old mountain bridge in this region. The road connects with the famous mining district of Alleghany, located 24 miles northeast of the turnoff. Alleghany can also be reached via dirt road from Goodyears Bar, a few miles west of Downieville. Lode, drift, and hydraulic mines are located in the vicinity of Alleghany many of which have fine production records (49).

0.1 Turnoff to Covered Bridge on Oregon Creek and day-use area. We will drive through the bridge and then return to Highway 49.

1.7 Turnoff to Alleghany on Ridge Road. Turn right and go east.

1.8 Road to Celestial Valley to the left. We stay to the right on Ridge Road which climbs the west flank of Pliocene Ridge between Celestial Valley and the Forest/Alleghany/Bald Mountain area. The ridge is misnamed. It is covered not by Pliocene, but by Miocene rock formations. There are several high-grade lode and placer properties in the Alleghany Mining District.

3.8 Exposure of slates in the Calaveras Formation.

4.2 Badger Hill hydraulic mines and Tertiary channel on the right (south) across the Middle Fork of the Yuba River. Badger Hill contains the stratigraphically lower (and richer) "Blue Gravels" of the Ancestral Yuba River.

4.6 Gabbro dikes (?) in roadcut on left (north).

5.4 Sierra County line.

5.6 Pike. The historic townsites is to the west of this point.

5.8 Turnoff to historic townsites of Pike.

5.9 Granodiorite

6.4 View of Middle Fork canyon of the Yuba river is to the right (south).

6.7 Metasediments of the Calaveras Group.

7.3 Pliocene Ridge Schoolhouse. Pliocene Ridge is covered with a deep soil mantle and pluvial forest cover.

8.7 Squirrel Creek turnoff to the right. Paleozoic metasedimentary rocks in roadcuts.
9.4 Cross section of volcanic channels. This roadcut is a textbook example of this type of feature. The volcanic mudflow cut into and then filled metasedimentary "basement" rocks.

9.5 Back road to the Pike townsite and the Tippacanoe and Mount Pleasant hydraulic drift mines on the left (west).

9.6 Road to Blue Goose Mine on the right (south).

9.9 Plumb Valley baseball diamond. This area was a historic placer and drift mining center.

10.5 Deformed and weathered metavolcanics in roadcuts.

11.2 Tree plantation on Slayville Ridge.

11.3 Mudflows deposited on eroded metasediments on the west (left) side of the roadway.

12.3 Road ascends through lava and volcanic mudflows. These form a cap on a portion of Pliocene Ridge.

14.2 360-degree view of the Sierras.

15.5 Intersection of the Henness Pass Road, Forest and Alleghany roads. There is a historical marker at this junction. We stay to the left (south) and head toward Alleghany.

15.9 Wolfie Flat hydraulic mine across the Middle Fork canyon of the Yuba River is on the right (south). This is the eastern part of the San Juan Ridge portion of the Ancestral Yuba River Channel.

15.8 to 16.4 Intervolcanic channel exposed as cross section in road cut.

17.7 Wet Ravine on the right represents the site of the earliest placer and lode mining activity in the Alleghany District.

18.0 Town limits of Alleghany.

18.1 Road forks. Turn left (north) to go on upper town road.

18.4 Hydraulic workings can be seen across canyon to the right (south).

18.6 "Downtown" Alleghany. Turn to the right at the town bell and commemorative plaque. Take this road to double back and go through lower Alleghany.
18.8 Alleghany cemetery.

18.9 Alleghany community park.

19.0 Turnoff to the 16-to-1 mine. This is private property and permission must be obtained prior to going through the gate.

19.6 Outcrops of the Tightner Formation capped by white quartz gravels of the Ancestral Yuba River.

19.8 Fork in road. Stay to the right, go east toward the 16-to-1 mine.

19.9 16-to-1 Mill Building. Kanaka Creek is on the right (south) as is Chips Flat. Remnants of the Tertiary Ancestral Yuba River Channel is exposed on LaFayette Ridge which forms the skyline to the south.

**ALLEGHANY DISTRICT: 16-TO-ONE AND OTHER MINES**

The best known lode mines in the Alleghany district are the Sixteen-to-One, Oriental, Plumbago, Rainbow, and Bush Creek, all of which have recorded productions in the millions of dollars. Dozens of smaller workings have been profitable from time to time. The Brush Creek and Yellow Jacket mines were operation early in 1948 as well as the major Sixteen-to-One (49).

The sixteen-to-One, located a short distance downhill toward Kanaka Creek from the town of Alleghany, has been the principal producer of the district. It was discovered in 1876 and, as now operated, is a consolidation of the Twenty-One and Tightner mines and several miscellaneous properties. The main vein system lies along a reverse fault in was rocks of hornblende schist and other metamorphosed sediments of the Tightner and Kanaka members of the Calaveras formation. Serpentine dikes cut the Calaveras and both are cut by the thrust system. Vein minerals from the Sixteen-to-One include arsenopyrite, mariposite, sphalerite, gold, graphite, chalcopyrite, quartz, ankerite, tetrahedrite, galena, pyrrhotite, and pyrite. The deepest part of the mine is 3300 feet form the surface as measured along the inclined Tightner shaft. The total recorded production of the Sixteen-to-One to 1949 is slightly in excess of 644,000 oz ($16,100,000) (49).

The mine is now active with a work force of 5 to 10 persons, depending on the time of year. The mine uses metal detectors to help find the gold-rich portions of its quartz veins. This mine is noted for the purity of its ores (all gold and quartz with no other minerals). The owners sell specimens at wholesale prices.
Hydraulicking in the Alleghany district was confined to a few favorable locations on the Ancestral Yuba fluvial deposits as well as younger auriferous alluvial deposits where the gravels were not deeply buried under the Tertiary lava cap. Ferguson has estimated that between 83,300 and 166,700 oz ($2,000,000 and $4,000,000) were extracted from the district by hydraulic means. Something is excess of 400,000 oz ($10,000,000) was produced from drift mines such as the Ruby and about 1,120,000 oz ($28,000,000) from lode mines. Placer gravels, principally of Quaternary age added over 40,000 oz ($1,000,000) to the above totals, giving a grand total of over 1,520,000 oz ($38,000,000) for all gold mines in the district. Ferguson and Gannett give another interesting sidelight on the richness of the Alleghany lodes. They compiled, from various authorities, a table of the probable amounts of gold eroded from the Alleghany lodes and redeposited in channel gravels below. These estimates ranged from 72,000 ($18,000,000) to 2,080,000 oz ($52,000,000). (49).

RETURN TO JUNCTION OF HENNESS PASS AND FOREST ROAD (ROAD MAP 45)

0.0 Junction of Henness Pass Road and Forest Road. Turn right, go north toward the town of Forest.

0.1 Henness Pass Road is to the east. Keep going north on Forest Road.

0.7 Mud flows are exposed for the next mile on the right (east) side of the roadway. The volcanic cover in the Forest area exceeds 1000 feet in thickness.

1.9 Oregon Creek at historic Forest City townsite. The Bald Mountain drift mine to the north produced over $60 million in gold.

2.0/0.0 Road intersection at Forest. This town retains many historic buildings that are still in residential use.

0.0 Cross Oregon Creek bridge and head west toward Goodyear’s Bar.

2.4 Forest City cemetery on right (north).

3.1 Sandusky Creek crossing.

3.3 Unmarked road to the left (south) leads to the Kate Hardy Mine.

3.8 Tightner Formation metasediments.

4.0 Mudflow on right.
4.3 Serpentine on right. This is the same rock unit that hosts the veins at the Kate Hardy mine.

4.8 Ramshorn Fault Zone and Serpentine Belt.

6.1 Road to right is an alternate route to Forest. It is the lower Mountain House Road.

6.2 VIEW OF RAMSHORN FAULT ZONE IN WOODRUFF CREEK AND GOODYEARS CREEK.

The Ramshorn Fault is a major structural suture zone extending for 10 miles north and 4 miles south of this point. It is a highly mineralized zone and contains rich lode gold deposits (e.g., Brush Creek Mine). There are also several rich placer deposits in this area: the Magnolia, Newkirk and Colony mines. The fault zone follows both Woodruff Creek and Goodyears Creek. These are south and north of the North Fork Yuba river respectively. The Yuba river cuts across the Ramshorn Fault Zone at a 90-degree angle.

Ramshorn Fault zone has created a broad valley over one mile wide.

Fir Cap Peak is at the head of Goodyears Bar to the north.

6.3 Road to left at Mountain House Junction goes to Pioneer Dark graveyard. This is the Slaysville Ridge Road.

7.0 Road descends to Woodruff Creek.

7.2 Gate for upper Brush Creek Mine and Mill site.

9.8 View of Grizzly Peak at 12:00.

9.9 Rock Creek is to the right. This is a tributary to Woodruff Creek and is rich in modern placer deposits that have formed from modern rivers cutting through and enriching older Ancestral Yuba River gravels.

10.3 Serpentine of the Ramshorn Fault Zone.

11.2 Junction with the lower Brush Creek Mine Road to the right.

11.4 Road parallels Woodruff Creek. There has been a small amount of historic placer production from this area.

11.7 Woodruff Creek Bridge.
11.9 Historic townsite of Goodyears Bar.

GOODYEARS BAR

Goodyears Bar, located near the junction of Woodruff and Goodyear Creeks with the Yuba four miles west of Downieville, was settled in the summer of 1849. It prospered during the 1850's before its rich placers were exhausted, but a fire which virtually destroyed the town in 1864 culminated a steady decline which had begun some years earlier. A good dirt road from the Alleghany mining district joins highway 49 in the vicinity of Goodyears Bar (49).

RUBY DRIFT MINE

The Ruby drift mine is below the Ruby Bluff near the headwaters of a north-south trending tributary to Rock Creek, southeast from Goodyeas Bar. It is famous for its coarse gold nuggets and its large quartz crystals. It is one of but few mines in the district which are still operating. The workings are principally tunnels in the bedrock from which raises are put up to the channel gravels above. There are several miles of tunnels and drifts and several vertical access and escapeway shafts. Ore is hauled out along the main tunnel level and run through sluices. More than 123 nuggets valued at over $100.00 (4 oz) each had been removed from the Ruby by 1941. The largest weighed 52.3 ounces and was worth $1,758.00 (49).

12.0 Stop sign. Turn left.

12.1 Cross North Fork of the Yuba River. Terrace gravels can be seen at the west end of the bridge.

12.2/0.0 Junction of Highway 49 and Mountain House Road. Turn right on Highway 49 and go east toward Downieville. Serpentine is exposed in the road cut east of this intersection.

SERPENTINE

There is a geometric relationship between gold deposits and serpentine belts. The California Mother Lode and South African gold deposits are classic examples. The processes that create serpentine are associated with those that concentrate gold in orogenic/continental accretion processes. Serpentine is a mineral. Serpentinite is the scientific word for a rock made up of serpentine. However, the California legislature took it upon themselves to make Serpentine the State Rock, prompting this soliloquy:
A scholar I resent a mite
Calls SER-pentine ser-PENT-inite
I know full well this self-same gent
Might call a SER-pent a ser-PENT

If the English language you would not demean
Please call this green rock SER-pentine

0.1
Cross section of Ramshorn Fault Zone metasediments.

Three-tenths of a mile east of Goodyears Bar is a prominent outcropping of serpentine
which is associated with fine-grained dark intrusive rocks. Half a mile east of the
serpentine belt is a small area of meta-gabbro. The fine-grained basic rocks are cut by
quartz veins (49).

A broad zone of faulting and deformation is visible along the highway 1.4 miles west of
Downieville. The meta-volcanics there are much contorted and, in many places, are
impregnated with pyrite. In the stream bed below, deep circular depressions known as
potholes or kettles spinning action of rapid water over uneven, bare rock. Gravel and
pebbles caught in the depressions are spun by the currents and aid in the circular
downcutting effect. They are a common feature along streams of considerable gradient
(49).

0.2
Serpentine.

0.4
Gravels lie atop metamorphic rocks of the Calaveras Complex.

0.8
Metavolcanics of the "Yuba Terrain" are part of the Calaveras Group of rocks outcrop for
the next 3 miles.

2.3
Rosassco Ravine to the left (north). City of Six Ridge is to the southeast.

2.4
Old Toll House Road crossing is on the right (south).

3.0
Coyoteville historic site. This is now a resort.

3.4
Slug Canyon on right (south).

3.6
Turnout to right at Canon Point. Overview of Downieville.
Downieville, county seat of Sierra County, is situated at the junction of the north and east branches of the North Fork of the Yuba River. Lofty tree-covered mountains surround it on all sides and it is a fitting location for the center of a well-named county. There is very little flat land in the county and this is located either along river bottoms or on upland remnants of the Eocene surface. Like Goodyears Bar, Downieville was found in 1849 by a party of gold seekers. Originally known as The Forks, the name was changed to Downieville in honor of William Downie, one of the initial settlers. More than 5000 people jammed the town in 1851 and some rich strikes were made. So determined were the miners to get the gold from the bed of the Yuba that they flumed and diverted the river from its bed between Downieville and Goodyears Bar. This worked beautifully as long as summer held out, but winter floods quickly wiped out the project. After the placer mines were exhausted, gold mining went on in hydraulic, drift and a few lode mines. Very few historical buildings remain, the County Courthouse and St. Charles Hotel having burned in 1947. The Pioneer Museum, a well-built stone building with iron doors and window shutters, was restored by the heirs of pioneer J.M.B. Meroux and dedicated to the Pioneers of Sierra County by the Native Sons and Daughters of the Golden West in 1932. Costa's grocery store, also of stone, dates from 1852 (49).

DOWNIEVILLE TO SATTLLEY - GEOLOGIC MAP 10

The northeastern end of Highway 49 lies along the headwaters of the North Fork of the Yuba and then climbs out of the Yuba drainage system and over Yuba Pass to the broad upland of Sierra Valley. Yuba Pass does not show the tremendous alpine landscape that is so typical of the passes to the south such as Tioga and Sonora. The greatest relief to be seen on Highway 49 is along the route form Camptonville to Sierra City. However, the end of the route is through heavily forested country full of streams, and the beauty of the woodlands partly compensates for the comparative lack of alpine features (49).

0.0 Downtown Downieville, underlain by Calaveras Complex and Mesozoic-Paleozoic metasediments. The Melones Fault Zone crosses Highway 49 0.5 miles east of Downieville. This fault separates undifferentiated Mesozoic and Paleozoic rocks to the west from Shoe Fly Complex sandstones, siltstones and slates to the east.

0.8/0.0 Bridge over North Fork of the Yuba River. The confluence with the Downie River is 150 yards downstream. Reset odometer at this bridge.

0.1 Black Slates

Immediately east of Downieville the roadcuts are in a belt of black slates which have been quarried for local use as a building stone. The slates are full of quartz veinlets which have invaded the series along the bedding planes. These slates closely resemble the Mariposa slate of the Mother Lode but have been assigned to the Calaveras formation.

25
by H. W. Turner. Quartz veins varying in width from fractions of an inch to two feet cut the country rock in many places along the road from Downieville to Sierra City. Although barren for the most part, some of these veins have been found to carry pocket gold. Several prospect holes close to quartz veins can be seen on the south side of the river. Granodiorite outcrops in several places in this vicinity and the quartz veins were undoubtedly derived from adjacent or underlying granitic intrusion (49).

These rocks are now recognized as part of the Shoc Fly Complex.

0.7 Hungry Month Canyon to right (south).

0.8 Placer workings on right (south), between highway and river.

1.0 Resort on the right (south).

1.2 Vertical beds of slate on right (south).

2.6 North Fork Terrain rocks of the Show Fly Group. Placer workings to the right (south).

2.8 Sierra Shangrala Resort and confluence of Jim Crow Canyon and San Juan Canyon. The Arizona Mine is above the headwaters of San Juan Canyon atop the ridge.

POCKET MINES

This region has many "pocket mines". These are small concentrations of rich paleoplacers, often having only a few hundred tons of material in them. Careful study of the rocks, veins, soils and sediments around the pockets sometimes leads to short-lived discoveries.

3.0 Jim Crow Canyon on right (south).

3.8 North Yuba modern placers were heavily worked historically between this point and Sierra City. Placer workings on stream benches are seen along both sides of the Yuba River.

4.9 Metal footbridge over Yuba River.

5.8 CAMP YUBA (now Union Flat Campground) in Show Fly complex rocks. Union Flat is the site of a north-south striking thrust fault with the upper plate to the east. The fault places tonalite of the Bowman Lake batholith against Paleozoic Shoe Fly sandstones.

Camp Yuba, 5.4 miles east of Downieville, is another of the very fine public camps situated on the banks of the river. This camp is near the old placer camp site of China
Flat. Several lode gold mines are located both to the northeast and southeast of Camp Yuba and the Ladies Canyon bridge include a small body of weathered granodiorite which looks as if pre-existing wall rocks had been assimilated by it. It is a dark, impure rock resembling a granite in texture only. Excellent examples of hill creep or false folding in platy meta-sediments may be seen along the roadside in several places. Hill creep is produced on steep slopes by gravitational bending of inclined strata in a downhill direction and is usually the result of downhill movement of the soil mantle which lies above the tilted edges of the stratified bedrock (49).

7.0 Road to Gold Point Road is on the left (north).

7.2 LADIES CANYON Creek with rich placers upstream.

Between Ladies Canyon and Sierra City a wide variety of interbedded meta-sediments, meta-volcanics and dike-like intrusives are exposed in the many roadcuts. Slate, phyllite, schist, chert, quartz porphyry, serpentine, and green meta-volcanics can all be collected at various places along the highway. Terrace alluvium perched high above the present stream channel may be seen in the vicinity of Fournier Ranch and Loganville (49).

7.6 Negro Canyon on right (south). The Cleveland mine is on the east side of Negro Canyon.

8.0 Small turnout with placer workings to the right (south) on the south side of the North Fork of the Yuba River.

8.4 Fournier Ranch. Over the past few years, placer operations at Fournier Ranch have produced up to 100 ounces of gold a week for several seasons. Al Dupree was the operator.

8.6 Charcoal Ravine on the right.

9.5 Keystone Mountain on right (south).

10.1 View of Keystone Mine on the right (south). The lower portion of the canyon is not visible from this point and is the location of the Lucky Boy Mine.

10.2 Loganville (Shanen's Cabins). Northwest of Loganville are the Primrose, Buffalo, Monarch, Sovereign, and Columbo mines.

10.9 Forest Service Loganville campground.

11.0 Big Avalanche Ravine to the right (south).

11.3 4,000 ft elevation sign.
11.8 Metavolcanics and metasediments are exposed in roadcut.

12.0 West end of Sierra City

12.5 Sierra Buttes and Sierra Buttes Mine to the left (north). These are composed of rhyolitic to andesitic flows, breccias, tuffs and cherts of the Devonian Sierra Buttes Formation

At this point another thrust fault crosses the roadway, about a mile west of Sierra City.

13.4/0.0 West end of Sierra City at road milage sign.

Remnants of glacial moraines lie between the highway and the river in this area. Here, also is a sliver of metavolcanic rocks 0.5 miles west of town. On the east end of town is a contact with quartz porphyry volcanic rocks of the Sierra Buttes Formation. East of Sierra City are thin (0.5 mile wide) slivers of marine conglomerate, sandstone and chert of the Devonian Grizzly Formation.

SIERRA CITY

At the edge of Sierra City, a road leads off to the north which connects with Sierra Buttes mining district. As mentioned in preceding paragraphs, the Sierra Buttes district is noted for the many large nuggets recovered there in early days. There is little or no activity in the district at present. The columnarly jointed lava cap of Sierra Buttes can be seen in many places along the highway in the vicinity of Sierra City (49).

Sierra City, located at the foot of towering peaks on a narrow river terrace, was first settled in 850 by gold miners. The vicinity was full of Indian rancherias or camp sites and apparently was one of the most heavily populated Indian districts in California. The new settlement was destroyed by an avalanche in 1852 and the present buildings date from the 1860's or later. The main street of Sierra City resembles those of many other towns of the gold country. The brick-and-frame Busch Building has the same iron doors and shutters that are so typical of fire-conscious towns built in the 60's and 70's. Sierra City is famous for being the birthplace of a roisterous society known as E. Clampus Vitus. The organization has the reputation of being principally a perpetrator of practical jokes upon the uninitiated. At any rate, name and reputation are colorfully connected with the history of Sierran gold mining from Sierra City far down the Mother Lode. The society was reorganized several years ago by the California Historical Society, apparently with satisfactory results to all concerned (49).

0.1 Wild Plum Road to right (south).

0.4 View of Haypress Canyon.
KENTUCKY MINE AND MUSEUM

This restored mine and mill are well worth the $4.00 entrance fee. Reset odometer. The mine entrance and mill rest on metavolcanic rocks of the Shoe Fly complex.

0.0 Kentucky Mine Turnoff. Go east toward Sattley. East of the Kentucky Mine, Highway 49 crosses tuff, red slate, quartzite, limestone and conglomerate of the Milton Formation.

0.8 GLACIAL DEBRIS resting on andesite breccia, tuff and slate of the Carboniferous Taylor Formation.

East of Sierra City, Highway 49 passes close beside an east-west contact between the quartz-porphyry bedrock and overlying glacial moraine detritus. This is the first appearance of glacial debris along Highway 49 but morainal deposits can be seen in a great many places between Sierra City and Bassett at the foot of Yuba Pass. The most obvious characteristic of the glacial deposits is their extreme variability or heterogeneity. Clays, gravel, and huge boulders both stratified and unstratified are dumped together in irregularly shaped deposits. Some of the fragments or clasts have been planed off or faceted by the ice. Others have been grooved or striated by being ground against resistant bedrock. Most of the boulders and smaller stones are merely rounded or subangular and one must examine many of them to find any which have characteristic glacial markings. The quartz porphyry east of Sierra City is a light-buff rock with a very fine-grained groundmass and numerous small, rounded, quartz crystals or phenocrysts and less numerous rectangular or lath-shaped feldspar phenocrysts. The rock is probably close to a dacite in over-all composition. East of the quartz porphyry belt of green porphyritic meta-andesite breccia much like the Logtown Ridge formation along the Mother Lode.

1.4 to 1.7 Reworked glacial material.

1.9 Springs on hillside to the left.

2.0 Elevation sign: 5000 ft.

2.3 Andesite breccia and basalt flows of the Taylor Formation and talus slopes to the right.

2.5 Salmon Creek bridge.

2.6 Folded bedded cherts of the Elwell Formation.

2.9 Glacial moraine (reworked) with talus.
3.5 Ruin with chimney on right

3.9 Bassett townsite at Howard Creek and road to Sierra Buttes Recreational Area. This area is underlain by granodiorite.

3.9 BASSETT

From the vicinity of Bassett to the summit of the pass, the basement rocks are weathered granodiorites of the main pluton or batholith which forms the core of the Sierras. Spheroidal decay boulders can be seen weathering out of the main granitic mass in many places. Preservation of more or less unaltered spheroids in an almost completely weathered matrix is typical of granitic masses in a great many other places as well as the Sierras, and is a phenomenon which has never been adequately explained. Local differences in grain size and mineral composition sometimes account for it. In other instances the effect has no apparent local control (49).

The main rock type between Bassett and Sattley is granodiorite.

4.3 Intersection of Highway 49 and Sardine Pond road.

5.0 San Francisco State University Field Camp (Camp Leonard) to right. Vehicles proceed to main camp area on dirt access road. NCGS Field Trip participant shall spend the evening at the camp and attend dinner and presentation by Dr. Elwood Brooks on geology of the Sierra Buttes - Gold Lakes basin.

GOLD LAKE AND SARDINE CAMPGROUND

A road connecting with Gold Lake, Sardine Creek public camp and other parts of the Plumas National Forest joins Highway 49 4.3 miles northeast of Sierra City. Sardine Lake and others in the vicinity are cirque lakes of glacial origin. Except for the moraines to be seen along the North Fork of the Yuba, glacial features are few along Highway 49 and it is necessary to take side trips in order to see examples of glacial topography. A road passable in summer connects with the glacial Packer Lake and resorts. Sardine Lake must be reached by foot from Sardine Creek public camp (49).

6.3 Sierra campground on left.

6.4 Haskell Creek bridge.

7.2 Chapman Creek campground.

7.4 Elevation sign: 6,000 ft.
8.6 Clark Station and road to Chapman Saddle.

9.1 Yuba Fire Camp at right.

10.9 YUBA PASS and Sno Park

The summit of Yuba Pass, at an elevation of 6701 feet, lies in a broad, upland valley which is slowly being dissected at either end by streams of opposing watersheds. The California Sno-Park Camp is to the right (south). The winding grade from Yuba Pass to Sattley affords fine views of Sierra Valley which opens out to the northeast from the vicinity of Sierraville. Sierra Valley is a graben or depressed fault block part of which has been masked by volcanic mountains extruded since the depression of the block. Subsequent erosion and glaciation has greatly dissected the disrupting lave. William Morris Davis believed Sierra Valley to be a continuation of the graben which is partly occupied by Lake Tahoe. The Fault which roughly corresponds with the western edge of the valley crosses Highway 49 immediately west of Sattley. Andesitic gravels can be seen faulted against the granodiorite in places where the contact is not masked by alluvium (49).

13.4 View of Sierra Valley to the east.

13.8 Leaving Tahoe National Forest.

14.8 Vista Point on right has a small but informative display on the geology of this area.
Tectonic Belts of the Sierra Nevada
June 10 and 11, 1995
Northern California Geological Society

Road Log
Timothy Fagan, Jason Mayfield, Howard W. Day
Department of Geology
UCDavis

Acknowledgements. At the outset, we would like to thank the Northern California Geological Society for this opportunity to expound upon some of our favorite geologic problems in some of our favorite places. Among the many geologists who have influenced our notions of northern Sierra Nevada tectonics, we feel compelled to recognize James Beard, Raymond Beiersdorfer, Elwood Brooks, Steven Edelman, and Eldridge Moores.

Saturday, June 10, 1995

YUBA RIVERS TRAVERSE

Directions to stop 1
From the intersection of Rts. 70 & 20 in Marysville, follow Rt. 20 east toward Grass Valley for 17 miles to Parks Bar Bridge over the Yuba River. Cross the bridge and make an immediate right turn which will loop back beneath Route 20 to the east. About one-quarter mile from the road, there is a small paved parking area on the left. Park and walk down to river level. Watch out for poison oak.

Stop 1. Smartville pillow volcanics at Parks Bar Bridge. Beneath the bridge at the southern abutment is a well exposed section of pillowed flows of the lower volcanic unit of the Smartville Complex. The pillowed basalts trend north-northwest and dip approximately 70 degrees west. Pillow morphology indicates stratigraphic up is to the west. Most pillows are concentrically zoned from an aphanitic, black to green, glassy rind several centimeters thick to a vesicle rich zone and a massive vesicle poor core. Relict igneous mineralogy consists of plagioclase and pyroxene with magnetite and phene. Plagioclase and pyroxene occur as microlites in the fine grained groundmass and as euhedral phenocrysts. Oscillatory and sector zoning of the clinopyroxenes is common. Interpillow material consists of chloritized and epidotized glass shards, plagioclase crystals, and rare recrystallized radiolaria in a matrix of microcrystalline quartz. Metamorphic minerals present at this outcrop include pumpellyite, chlorite, quartz, calcite, albite, white mica, prehnite, sphene and an
opaque phase. This outcrop is mapped within the prehnite-
pumpellyite zone.

<table>
<thead>
<tr>
<th>miles cumulative</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0</td>
<td>From Stop 1 we will get onto Route 20 West, toward whence we came. This portion of the road log starts at the left turn onto Rt. 20 (west) from stop 1 on the south side of the Yuba River.</td>
</tr>
<tr>
<td>5.1 5.1</td>
<td>Intersection of Rt. 20 with Marysville Road (Yuba County Road E21). Turn right (north) on Marysville Road.</td>
</tr>
<tr>
<td>9 14.1</td>
<td>Convenience store on left, road is leading uphill</td>
</tr>
<tr>
<td>9.2 14.3</td>
<td>Stop 2. Smartville sheeted dikes at Stanfield Hill. The roadcut at Stanfield Hill is one of the best exposures of sheeted dikes in North America. The outcrop is composed of dikes and minor plutonic screens. A majority of the dikes are subparallel and strike approximately N10W with dips ranging from 65 to 80 degrees northwest (Day, 1977). The average dike thickness is between one and two meters. Numerous chilled margins, including one-way chilled margins, are present. This outcrop was studied in detail by S. D. Day (1977). By use of cross-cutting relationships he has documented a sequence of five intrusive events. From oldest to youngest they are: 1) medium grained quartz albitite, diabase and altered screens of porphyritic basalt with phenocrysts of plagioclase; 2) dikes of diabase, basaltic andesite, and dacite; 3) complete diabase dikes showing less alteration and epidotization than earlier intrusive phases; 4) thin non-porphyrritic basalt dikes; 5) a 3.5 meter thick dike of rhyolite porphyry with plagioclase phenocrysts. The metamorphic phases calcite, chlorite, actinolite, epidote, quartz and pyrite occur in amygdules and veins. This outcrop is mapped within the greenschist zone. From Stop 2 continue north on Marysville Road.</td>
</tr>
<tr>
<td>1.6 15.9</td>
<td>Intersection of Marysville Road with LaPorte Road—turn to the right to stay on Marysville Road. Follow Marysville Road through Dobbins.</td>
</tr>
</tbody>
</table>
| 9.0 24.9         | Stop 3. Smartville layered gabbros on Marysville Road. Park on the wide shoulder on the right. This outcrop is an inconspicuous road cut on the left side of the road. This outcrop of olivine gabbro and clinopyroxenite is the only known exposure of well-developed "cumulate" layering in the entire Smartville Complex. (Please do not hammer on the layered gabbro. Samples of layered gabbro can easily be found on the ground, among the manzanita bushes, behind the roadcut.) The areal extent of the layered gabbro body is rather small,
only one square km. Cumulus phases in the gabbro are augite and anorthitic plagioclase. The western part of the outcrop consists of an olivine clinopyroxenite dike (Ol = 78 Fo, Cpx = 46.3 En, 7.0 Fs, 46.7 Wo).

From Stop 3 continue on Marysville Road toward the east

4.7 29.6 Stop 4. LUNCH! and Smartville deformed metavolcanics and epidote blobs at Bullards Bar Dam. Bullards Bar Dam will come into view. Take the left turn up off of Marysville Road following the sign for Emerald Cove parking. Abundant road cut occurs adjacent to the parking lot, and down next to Marysville Road as well.

This stop occurs within a shear zone related to the Big Bend-Wolf Creek fault zone along the eastern margin of the Smartville Complex. We interpret these rocks to be penetratively deformed volcanoclastic rocks of the Upper Volcanic Unit. The matrix of the volcanoclastic rocks was preferentially altered to epidote prior to deformation. During the deformation the epidote rich zones formed into boudins and lozenges of various sizes and shapes. The more competent epidote lozenges have quartz and chlorite filled tension gashes. The schistosity strikes at N15W and dips 75° to the east. Metamorphic minerals present at this outcrop and include chlorite, epidote, amphibole, biotite, quartz, plagioclase and sphene. This outcrop is mapped within the greenschist zone.

After lunch we will continue eastward on Marysville Road approx. five miles to Route 49. Turn left (north) on Rt. 49. Route 49 will take us north and east for the remainder of the day.

<table>
<thead>
<tr>
<th>miles cumulative</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Junction of Rt. 49 and Marysville Road. Reset mileage log.</td>
</tr>
<tr>
<td>9.7</td>
<td>Rt. 49 crosses North Yuba River. River outcrops of metavolcanic rocks of the Slate Creek Complex are accessible from a small parking area on the left on the north side of the bridge.</td>
</tr>
<tr>
<td>1.6</td>
<td>Gravel turnout on the right (southeast) side of the road. A road cut exposing the Indian Valley pluton is present on the opposite side of the road.</td>
</tr>
<tr>
<td>0.1</td>
<td>Indian Valley Campground</td>
</tr>
<tr>
<td>3.7</td>
<td>Stop 5. Chert/argillite along the North Yuba River. Small gravel turnout on the right (southeast). The quality of this outcrop will depend on the water level of the North Yuba River. Lithologies are</td>
</tr>
</tbody>
</table>
best exposed toward the upstream end of the outcrop where steeply
dipping dark gray chert beds and boudins occur with dark gray to
black fine-grained argillite. Many chert lozenges are cut by closely-
spaced white veins of carbonate and/or quartz. Beds generally strike
to NNW and are vertical to steeply NE-dipping, except near rare fold
hinges (an irregular small-scale synform plunges moderately to the
NW near the upstream end of the outcrop). The other main rock-type
consists of fine-grained green-gray (tuffaceous?) fragments in a dark
gray matrix of chert/argillite. This outcrop is included in the Clipper
Gap Formation of the Fiddle Creek Complex by Edelman et al., (1989).

3.5 18.6  

Stop 6. Serpentinized ultramafic rocks of the Feather River
Peridotite at Goodyears Bar. Serpentinites at Goodyear's Bar. These
serpentinites are thought to be remnants of the Feather River Peridotite
farther north and represent the first outcrops of the Feather River Belt,
bounded on the west by the Goodyear's Creek Fault. Chrysotile fibers
are abundant on the slickensided surfaces, but massive serpentinite
probably contains antigorite. Edelman et al. (1989) suggested that a
large body of quartzite in this outcrop is similar to rocks in the
Paleozoic Shoo Fly formation, the nearest exposures of which are east
of Downieville.

4 22.6  bridge over the Downie River, Downieville.

0.2 22.8  

Stop 7. Deformed sandstones and cherts of the Shoo Fly Formation.
Turn left (north) just before Rt. 49 curves to the left, and park along a
small street parallel to Rt. 49. Cross to the south side of Rt. 49 (Be
careful of traffic!). The outcrop is along the North Yuba River.

The Shoo Fly Formation here consists of thinly bedded gray to gray-
green, quartz-rich sandstones with medium gray to black chert
interbeds, and minor argillite. The beds strike NNE and dip steeply
SE. Boudins of sandstone are apparent on sub-horizontal surfaces and
suggest that these rocks have undergone sub-horizontal extension.
Isoclinal fold hinges occur in the Shoo Fly Formation near the Melones
Fault Zone, and we should be able to see at least one synform at this
outcrop.

18 40.8  intersection of Rt. 49 with Gold Lake Highway at Bassetts

1.1 41.9  San Francisco State Sierra Nevada Field Campus (SNFC). A wide
gravel parking lot is present on the right. Park here, and walk across
the bridge over the North Yuba River to the SNFC for dinner and
lodging.
Sunday, June 11, 1995

<table>
<thead>
<tr>
<th>miles</th>
<th>cumulative miles</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>SNFC</td>
</tr>
<tr>
<td>1.1</td>
<td>1.1</td>
<td>intersection Rt. 49 &amp; Gold Lake Highway at Bassetts</td>
</tr>
</tbody>
</table>
| 1.4   | 2.5              | Stop 8. Clinopyroxene-rich volcaniclastic breccias of the Taylor Formation. The outcrop is a road-cut on the right (east) side of Gold Lake Highway just before the intersection with the road to Sardine Lake. Make the left turn onto the Sardine Lake Road and cross the bridge to park. We'll walk back and cross Gold Lake Highway to the outcrop.

Most of this outcrop consists of clinopyroxene-rich volcaniclastic breccias of the Taylor Formation, a part of the late-Devonian volcanic arc system which formed on Shoo Fly basement. Lithic clasts in the breccia include cpx-phyric, plag-phyric, cpx+plag-phyric volcanics and fine-grained granodiorite. A fine-grained green-gray tuffaceous bed underlies the breccia near the north end of the outcrop. The proportion of clast vs. matrix and the size of the clasts increase within the breccia upward from the bedding contact at this exposure.

If the Gold Lake Highway is open (as of May 30 it was snowed in), we will continue north to the intersection with Rt. 89 near Graegle. If the Gold Lake Highway is still closed, we will return to Rt. 49, turn left (eastward) at Bassetts, and follow Rt. 49 to its intersection with Rt. 89 near Sattley. One way or another, we will head north on Rt. 89, continue north and westward where 89 merges with Rt. 70 near Blairsden, and proceed through Quincy. The road log resumes where 89 diverges from 70 near Indian Falls.

From this intersection, we have planned two traverses: the Taylorsville traverse following Rt. 89 to the north and east, and the North Fork Feather River traverse following Rt. 70 to the south and west. The Taylorsville traverse includes rocks from the Devonian and Jurassic arc sequences of the Eastern Belt, whereas the North Fork Feather River traverse offers a different look at some of the same tectonic units we examined yesterday. We will not have enough time to make all of the road stops listed. We decided to leave all of the stops in this guide for your reference.

TAYLORSVILLE TRAVERSE

<table>
<thead>
<tr>
<th>miles</th>
<th>cumulative miles</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>intersection of Rts. 89 &amp; 70 near Indian Falls. Follow Rt. 89 to the northeast.</td>
</tr>
</tbody>
</table>
**Stop 9.** Grizzly & Sierra Buttes Formations. Stop 9. The Grizzly and Sierra Buttes Formations are discontinuous and lie unconformably above Shoo Fly Complex. According to Harwood (1992), the Grizzly is an epiclastic unit comprising polymict conglomerates, sandstone and pelite. The Sierra Buttes Formation lies in gradational contact above Grizzly or unconformably overlies Shoo Fly, where the Grizzley Formation is missing. The Sierra Buttes Formation consists of quartz-bearing pyroclastic and volcaniclastic rocks of andesitic to rhyolitic composition.

**Stop 10.** Taylor Formation cpx-rich breccia. The Taylor Formation comprises much of the Upper-Devonian to Lower Mississippian volcanic sequence that overlies the Shoo Fly Complex. Here, the Taylor is composed of very coarse tuff-breccia; coarse andesitic fragments contain bright apple-green augite. In what environment and by what processes do you suppose these rocks were deposited?

3 6.3 right turn on A22 toward Taylorsville

5.4 11.7 left turn @ Taylorsville Park & Rodeo

**Stop 11.** Jurassic rocks in the Taylorsville area. Harwood (1992) has given a recent summary of the Mesozoic stratigraphy in this area. Fossils are abundant in these Jurassic rocks compared to most localities in the Sierra Nevada. Volcaniclastic and tuffaceous sandstones, conglomerates and shales reflect broadly andesitic to dacitic volcanism throughout much of the Jurassic Period in what was probably a subareal environment, at least locally and episodically. Andesitic dikes intrude fossiliferous sandstones a few hundred feet north of this locality.

From Stop 11 turn around and return on A22 and Rt. 89 southwesterly to the intersection of Rts. 89 and 70 south of Indian Falls.

**NORTH FORK FEATHER RIVER TRAVERSE**

<table>
<thead>
<tr>
<th>miles</th>
<th>cumulative miles</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Intersection of Rts. 70 &amp; 89 near Indian Falls.</td>
</tr>
<tr>
<td>1.2</td>
<td>1.2</td>
<td>Bridge over Soda Creek.</td>
</tr>
<tr>
<td>0.6</td>
<td>1.8</td>
<td>(landmark: a turnout on the north side)</td>
</tr>
</tbody>
</table>
Stop 12. Inclined sandstones and phyllites of Shoo Fly Complex. Pull off to the right (north) side of the road where the road bends from east to southeast. The outcrop will be behind us from the wide area on the road shoulder.

The Shoo Fly complex here consists of evenly bedded metasandstones and phyllites with a bedding orientation of N79E, 37NW. Sandstone layers ranging in thickness from approximately 0.5 to 1.5 meters are separated by 0.3 to 0.5 meter thick phyllite layers. The bedding is most prominent high on the outcrop to the east of the wide shoulder. The lithologies can be examined from abundant float. Rounded gray quartz grains approx. 2 mm in diameter are abundant in the sandstone and provide one piece of evidence that the Shoo Fly was derived, at least in part, from a continental provenance. The phyllite is evenly grained, light gray-green in color, and has cleavage parallel to bedding.

7.2 9.7 Rush Creek Road

Stop 13. Feather River Peridotite Belt, partially serpentinized ultramafic rock. There is a wide shoulder and plenty of road-cut outcrop along this stretch.

The extent of serpentinization is much less here compared with the Goodyears Bar outcrop where we stopped yesterday. Tremolite occurs as a metamorphic mineral in the ultramafic rocks in this area. Mafic protoliths are present in the FRPB, as well, and typically contain amphibolite facies mineral assemblages. However, occasional Na-rich amphibole is present in the mafic rocks and suggests high-P, low-T metamorphic conditions, possibly related to subduction.

2.7 14.6 Rich Bar Road

0.6 15.2 (landmark: turnout on south side)

0.2 15.4 Stop 14. Calaveras complex, folded chert w/ argillaceous interbeds. Pull over to the right (north) at a wide gravel turnout. A small seasonal waterfall is in the center of the turnout area. Abundant outcrop along the margin of the turnout area will allow us to take a look at the rocks without traffic at our heels for a change.

The Calaveras complex here is chert-rich. The chert occurs in rhythmically bedded, medium-gray layers 0.5 to 2 cm thick, separated by argillaceous interbeds. The beds here are essentially vertical and strike approx. N55W. Fold hinges can be identified along the western bluff of the outcrop. Broken chert beds and pinch and swell features in the chert are common near the fold hinges.
Sketch map of the Western Metamorphic Belt, northern Sierra Nevada, showing major lithotectonic belts and cross-cutting Jurassic-Cretaceous granitic plutons. Uncircled numbers indicate field trip stops. Circled numbers are highway routes.
20.1 35.5 Stop 15. Lunch and granodiorite of the Grizzly pluton. Pull over to the right at the Forest Service picnic area. Abundant boulders of granodiorite are typical of the felsic plutonic rocks we have been driving through. This stop is located within the Grizzly pluton. The Grizzly pluton is typical of the northern Sierra plutons: it is a medium to coarse-grained, light gray granodiorite containing hornblende and biotite. Ages of the plutons range from approx. 165 Ma to 140 Ma (the Grizzly pluton is ~140 Ma) based on U/Pb zircon data (Saleeby et al., 1989). When the zircon data are combined with Ar/Ar and fission track cooling ages, a pattern of pluton emplacement followed by rapid cooling to ~200°C becomes apparent (Rowe and Day, 1994). Geochronologic data and field relationships indicate that this suite of plutons was emplaced during and after juxtaposition of the Western, Central, Feather River Peridotite, and Eastern Belts.

7.2 42.7 (landmark: power lines cross road)

0.4 43.1 Stop 16. Flaser diorite of the Central Belt. There is not much room here. We will pull off to the right at a small gravel turnout where the road curves to the left (from west to south). This flaser diorite exhibits a variety of deformational fabrics from weakly foliated to well foliated to banded gneissic and nearly migmatic. How much of the deformation is syn-magmatic and how much is post-magmatic? The gneissic fabric is cross-cut by abundant felsic veins, many with dark reaction rims. The diorite is intrusive into the surrounding serpentinitized ultramafic rocks and is considered to be ~200 Ma based on unpublished U/Pb zircon data (Saleeby, pers commun.).

5.2 48.3 Stop 17. Central belt dikes, serpentinites, and intrusives at Jarbo Gap. Again, there is not much room to park here and traffic will be very close. The outcrop is a prominent road-cut on both sides of Rt. 70. This outcrop is instructive because in many ways it is a microcosm of the Central Belt. It contains serpentinites, serpentinite-hosted breccias, individual dikes, dike sets that resemble sheeted dikes, and small plutonic bodies. Dilek and Moores (1986) interpret this complex assortment of rocks as an oceanic fracture zone.

5.6 53.9 Stop 18. Central Belt melange on the east side of the West Branch of the Feather River. We will park in a small gravel parking lot on the left (southeast) side of the road as we come down the slope toward the bridge over the Feather River West Branch. The outcrop consists of road-cuts on the opposite (northwest) side of the road. The rocks here consist of Central Belt melange. The melange matrix consists of a dark gray slate with cleavage oriented N50W/90. The cleavage becomes more widely spaced and somewhat more diffuse as
it passes through clasts of the melange. The melange clasts have apparently been flattened parallel to the slaty cleavage. Clast types include cherts, epidotomite, metasiltstone, serpentinite, partially serpentinized ultramafic rock, and quartzite.

1.1 55

Stop 19. Smartville Complex (Western Belt) clinopyroxene-rich breccias on the west side of the West Branch of the Feather River. As Rt. 70 curves to the right (from south to west) we will pull over on the right shoulder to look at some small outcrops on a grassy slope that leads down to the road from the north. These rocks consist of cpx-rich metavolcanics from the Smartville complex (Western Belt). Toward the southwestern end of the exposure, the texture is massive; toward the northeastern end of the outcrop, the texture is volcaniclastic with breccia-sized fragments. Clinopyroxene crystals are abundant here, although some clasts in the breccia are aphyric.

References


