Gold-Bearing Gravel of the Ancestral Yuba River, Sierra Nevada, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 772

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By WARREN E. YEEND

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A restudy of the unmined Tertiary placer deposits in a historic hydraulic mining region

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GOLD-BEARING GRAVEL OF THE ANCESTRAL YUBA RIVER, SIERRA NEVADA, CALIFORNIA

By Warren E. Yeend

ABSTRACT

Enormous quantities of unmined gold-bearing gravel are present on the interstream divides between the Middle Yuba River and the North Fork of the American River. This gravel was deposited by a major Paleocene(?) and Eocene river system (ancestral Yuba River) that flowed into a marine basin to the west from a highland to the east. A mining method using extensive systems of water canals and large iron pipes with huge nozzles, termed hydraulic mining, was used to mine cheaply the gold from this thick gravel from 1855 to 1884. In 1884 a court injunction, obtained by the agricultural interests in the Central Valley of California to prevent the dumping of the mined gravel into the modern rivers, halted hydraulic mining. Owing to this injunction large quantities of gold-bearing gravel remain.

The gravel was restudied with geochemical and geophysical techniques in order to learn more about the occurrence, distribution, characteristics, source, and resource of the placer gold. It is hoped that this new knowledge will encourage the development of economic methods for exploiting the enormous resource believed to remain.

The channel of the ancestral Yuba River and its tributaries cuts into bedrock that is composed of low-grade metamorphic rocks such as Paleozoic phyllite and slate of the Calaveras and Shoo Fly Formations and Mesozoic igneous rocks, primarily granodiorite. Gold-bearing milky-white quartz veins intruding the metamorphic rocks and most prevalent in and adjacent to serpentines served as the primary source for the gold in the gravel.

The gravel, partly covered by the remains of an extensive sheet of volcanic rocks, crops out at a number of places on the broad ridge crests between the major river canyons of the Middle and South Yuba, Bear, and North Fork of the American Rivers.

The gravel is divisible into a lower and an upper unit on the basis of lithology and texture. The lower gravel contains abundant cobble-size clasts, boulders to 10 feet in diameter near the base, many rock types—primarily slate, phyllite, greenstone, granodiorite—and most of the gold. The lower gravel is 70–140 feet thick. It is commonly blue gray and was referred to as the "blue gravel" by miners. The blue-gray color is due to the presence of unoxidized slate and phyllite clasts preserved below the water table.

The upper gravel is distinguished from the lower by an abundance of silt and clay beds, by the presence of clasts predominantly of milky-white quartz and quartzite, and by its low gold content. A leaf flora from clay beds within the upper gravel is correlative with the Chalk Bluffs flora that has been dated as late early Eocene.

Three holes were drilled in the North Columbia diggings in 1968 to obtain samples of an entire section of gravel. The gravel thicknesses ranged from 300 to 455 feet. The gravel in the lower 80–100 feet of all three holes contained most of the gold. Rarely do values in the lower gravel exceed $1.00 per cubic yard ($35.00 per oz); the richest interval was a 2-foot section that contained gold equal to $6.35 per cubic yard. Most of the gravel above the lower rich zone contains gold in amounts generally worth less than $0.02 per cubic yard. Values were at a maximum on bedrock for two holes and at a position 12–15 feet above bedrock for the third hole. Average gold values obtained in the 1968 drilling project were approximately 50 percent of those obtained from drilling by private interests in the same area in 1939. Most of the particles of gold in the lower gravel are 1–2 mm in diameter and 0.1–0.2 mm thick. Gold coarser than 1 mm in diameter was not observed more than 80 feet above bedrock in the drill holes.

Published and unpublished reports containing information on gold values derived from production records and drilling (sampling) in the area give the following averages: Lower gravel, $0.59 per cubic yard, upper gravel, $0.13 per cubic yard.

Four rotary drill holes on San Juan Ridge penetrated 500–650 feet of volcanic breccia above sand, clay, and minor amounts of fine gravel. Gold values from the prevolcanic sedimentary deposits were less than $0.01 per cubic yard. It appears that all four holes were drilled parallel to and along the margin or flood plain of the channel as it passes beneath the volcanic rocks on San Juan Ridge.

It is estimated that within the area studied the exposed parts of the ancestral Yuba River channel contain gold valued at about $188,100,000 distributed in 977,400,000 cubic yards of gravel, the equivalent of an average value of $0.193 per cubic yard. More than 75 percent of this total resource is contained in the vast deposit between Malakoff and Badger Hill Diggings.

On the basis of heavy mineral suites derived from the drill samples obtained in the North Columbia diggings, the gravel can be separated into four zones: (1) a lower zone of ilmenite, zircon, pyrite, amphibole, epidote, and chlorite; (2) a lower middle zone of ilmenite, zircon, pyrite, siderite, amphibole, and epidote; (3) an upper middle zone of ilmenite, zircon, pyrite, and siderite; and (4) an upper zone of ilmenite and zircon. All of these minerals can be derived from local bedrock sources. The zonation reflects differences in degree of physical and chemical weathering on the surrounding slopes. Physical weathering was dominant during the early history of the channel development, and chemical weathering became prominent during the late aggradational stage of the river. Pyrite and siderite are secondary minerals because they were formed after deposition of the gravel. Abundant vegetation trapped

and buried during deposition of the gravel together with the ubiquitous iron-bearing minerals, provided an ideal environment for sulfide development.

The drainage pattern of the ancestral Yuba River and its tributaries can be reconstructed by using existing gravel outcrops, water-current indicators such as imbrication and cross-bedding, and bedrock elevations on the channel floor. Tributaries of the ancestral Yuba River extend beyond the mapped area to the north, east, and south. Original gradients of 17–65 feet per mile are obtained for the ancestral Yuba River drainage upon removing effects of postgravel faulting along the channel and postgravel tilting of the Sierra Nevada. The gradient of the northwest-trending segment from Little York Diggings to North Columbia probably was not affected by tilting, as it would parallel the tilt axis. A gradient of 17 feet per mile seems reasonable for this stretch. From North Columbia to Smartville, the gradient probably was originally 20–25 feet per mile, greater than for the stretch above because the river was flowing perpendicular to the regional slope west of North Columbia. The upstream parts, American Hill to North Columbia and Liberty Hill to Little York Diggings, flowing down a highland front, had gradients of 60–65 feet per mile. The direction of flow from Little York Diggings to North Columbia is interpreted as parallel to the base of this highland.

By comparing known characteristics of the ancestral Yuba River with modern river systems in the Western States, the unknown parameters of drainage basin size and river length can be postulated. Such a study reveals that the ancestral Yuba River may have had a drainage basin as large as 2,000 square miles above the area studied and a length of 150 miles. This would put the headwaters no farther east than western Nevada.

The early Tertiary history of the area was characterized by active river downcutting, high relief, and physical weathering predominating over chemical weathering. Gold was continually being supplied to the rivers but was not transported beyond the drainage basins like the bulk of the rock detritus in the rivers. As the rivers continued to downcut, predominantly during times of flooding and vigorous runoff, the 50- to 100-foot-thick veneer of coarse gravel flooring the river valley would be moved downvalley only to be replaced by new material from upstream. By middle or late Eocene time, the rivers had extended their basins eastward, the steep slopes of the earlier landscape had given way to gentle slopes, and chemical weathering played the prominent role in the breakdown of the rocks. Because of the intensity of the weathering, only the most resistant minerals and rocks survived the journey to the rivers. The valley fill increased in thickness, the rivers continued to aggrade, and extensive flood plains were formed. The climate was probably similar to the present climate on the lower slopes of the Sierra Madre in the State of Vera Cruz, Mexico.

A date of 37.9 ± 1 m.y. was determined by potassium-argon method on biotite from a volcanic tuff lying above the gold-bearing gravel section near North Columbia. A few of the older prevolcanic channels were filled with the volcanic detritus, and a thin veneer of clastic rocks covered parts of the old land surface.

Widespread volcanic mudflows of andesitic composition covered most of the surface during the Miocene and Pliocene. Between successive mudflows, incipient river systems were born, and waterworn boulders and cobbles of andesite were deposited in restricted channels. A rhyolitic biotite-rich tuff dated 8.7 ± 0.5 m.y. is present near the town of Alta.

Probably in late Pliocene time, as volcanic activity subsided, the Sierran block was uplifted and tilted toward the west. During and following the uplift, much of the volcanic cover was eroded and vast areas of the prevolcanic surface exhumed.

Colluvial deposits accumulated near the base of the volcanic cliffs in Pleistocene and recent time because clays in the upper gravel and volcanic section repeatedly failed.

Operators of recent small-scale placer mines along the ancestral Yuba River have been hard pressed to make a profit. Of three mining ventures operating at various times from 1966 to 1970, one remains in operation.

INTRODUCTION

A restudy and evaluation of known gold-producing districts, together with the search for new gold deposits, was initiated in July 1966. The Tertiary gravel in the foothills of the Sierra Nevada in California, from which 14,500,000 ounces of gold was produced, was selected as a promising deposit for restudy. Because of the court injunction of 1884, which virtually put a stop to the hydraulic mining industry, large quantities of gravel remained unmined.

PURPOSE AND OBJECTIVES

A large resource of gold remains in the unexploited alluvial gravels of the ancestral Yuba River owing to an inability in earlier times to extract the gold without degradation of the downstream environment. Assessment of this untapped resource, and, hopefully, the development of acceptable techniques to extract the gold were the main foci of this study. The amount, distribution, and physical character of the gold in these placers had not been fully known, and the bedrock source of it needed additional study. These deposits record an important chapter in the history of the Sierra Nevada region. The deposits constitute an unevaluated potential source of construction material and water resources for nearby growing urban areas. Thus, this study in its broader context provides a geologic framework for the evaluation of the land and mineral resources occurring therein.

METHODS AND CONCLUSIONS

Mapping was done directly on U.S. Forest Service aerial photographs (1:20,000, 1948, 1955, 1966), and the contacts were transferred to topographic quadrangle maps (1:24,000 and 1:62,500). Surface samples were screened and panned in the field, and the panned concentrates transferred to the laboratory for detailed study. In addition to noting textures and lithologies of the gravel where exposed, current indicators (cross-bedding and pebble imbrication) were measured and plotted. Fieldwork was carried on during the fall months of 1966, 1967, and 1969 and during the spring months of 1968 and 1969. In addition to myself, Donald W. Peterson worked on the project from July 1966 to July 1968.

In addition to the conventional geologic field methods of mapping and sampling, many geophysical techniques were employed in an effort to learn more about the subsurface characteristics of the gravel. The techniques used include seismic refraction, ground and airborn magnetic and electromagnetic (EM) surveys, gravity and resistivity surveys, and induced polarization. The geophysical field studies were conducted during the summers of 1967 and 1968 under the supervision of H. W. Oliver.

During the fall and winter of 1968 and January 1969, rotary and churn drilling was done to check the validity of the geophysical interpretations and to obtain samples from the gravel for determination of gold values and for heavy-mineral study. The results of that drilling are presented here.

In 1968 the U.S. Bureau of Mines, under the guidance of the U.S. Geological Survey, selected the Badger Hill hydraulic pit as a focus area. A rather thorough study of the old hydraulic diggings ensued that involved many of the branches of the Bureau of Mines, including the mining research group from Denver, Colo. Extensive geophysical surveys were made, numerous holes were drilled with both rotary and large bucket drills, and large samples were taken for the purpose of concentrating gold and other heavy minerals. It was originally hoped that efficient mining techniques might be developed to extract gold and other metals from the gravel at this locality. The "mining research" phase of the project, however, did not progress beyond the sampling program.

The study has revealed that the early work of Lindgren (1911) was quite complete and thorough in locating and describing the gold-bearing gravel.

The major remaining placer gold resource appears to be on San Juan Ridge between Badger Hill and Malakoff State Park. A liberal estimate indicates that 800,000,000 cubic yards of gravel at this locality could contain recoverable gold worth $140 million ($35.00 per oz). Drilling in the North Columbia diggings in 1968 produced samples that rarely contain gold value in excess of $1.00 per cubic yard; this value is considerably less than obtained from earlier drilling in 1939 by private interests. Estimates of total volume and values of unmined gravel in the entire area studied indicate that gold worth $188 million ($35.00 per oz) could be present. This estimate does not include the gold in gravel beneath the thick (500–700 ft) volcanic breccia on San Juan, Washington, and Harmony Ridges.

Vertical distribution of heavy minerals within the gravel implies an early history of physical breakdown of the source rocks with limited chemical weathering. Most of the gold, in highest concentration in the lower 80 feet of immature gravel, was supplied to the river during its early downcutting stage. The river in later Eocene time was characterized by a low gradient, a wide flood plain, large meanders, and a sediment load indicative of intensive chemical weathering. During this time, gold either was not carried into the rivers or was flushed into the marine environment to the west.

MINING HISTORY

Placer gold first discovered and mined along the deep valleys of the youthful streams and rivers in the Sierran foothills was, in time, traced to sources high above the streams on the drainage divides. What we now call the "gold-bearing Tertiary gravel" was found to contain large amounts of gold, but in relatively low concentrations. The simple small-scale mining techniques employing a pan, a sluice box, or a rocker, used by the lone miner along the present streams, gave way to the land-destroying methods of hydraulic mining. First used in 1852 in Yankee Jims in Placer County and near Nevada City (Clark, 1965), it was during the 29 years from 1855 to 1884 that the great bulk of gravel was washed by this simple but devastating method. Nozzles with openings as large as 9 inches in diameter directed water with enormous force at the gravel beds, breaking apart the generally poorly cemented conglomerate. Large quantities of gravel could be washed with little effort by playing the jet of water back and forth across the gravel exposures. The manmade rivers carried the great bulk of the sand and gravel into the natural drainages, while the gold was trapped in the riffles and sluices, which were often heavily charged with mercury. The natural drainages carried most of this displaced gravel to the edge of the Central Valley, where, because gradients in river channels were lower, it was deposited, filling and choking the channels. Flooding and silting repeatedly destroyed vast amounts of farmland and frequently threatened to destroy property in the large cities of Marysville and Sacramento. Litigation between the miners and farmers continued more than 10 years, culminating in the famous court case Woodruff vs. North Bloomfield Gravel Mining Co. (Kelley, 1959, p. 237–240). Judge Lorenzo Sawyer issued an injunction in 1884 against the company, now often referred to as the "Sawyer decision," that prohibited the dumping of debris into the Sacramento and San Joaquin Rivers and their tributaries. A precedent was set, and hydraulic mining nearly ceased. Some companies constructed debris dams and made a pretext of storing the washed gravel, but the big hydraulic mining effort was finished.

Drift mining along the gravel-bedrock contact continued after the shutdown of the hydraulic mines, but only the richest gravel was mined. Gilbert (1917) estimated that 30 million cubic yards of gravel was mined by drifting.

In an attempt to revive the hydraulic mining industry, the California Debris Commission was created in

1893 to aid and oversee the mining. This effort proved unsuccessful, and with the inflation following World War I, gold production dropped further. In 1930 public funds were allotted for the construction of large debris dams on the major rivers draining the foothills. Englebright dam on the Yuba River and North Fork dam on the North Fork of the American River were built for storing hydraulic tailings. The California Debris Commission obtained assurances from the mining people that the dams would be used for these purposes and that the costs of construction would be repaid by the mining industry. However, hydraulic mining never again flourished, and less than 3 percent of the storage capacity of the dams was utilized. What little "gold fever" remained in the hydraulic mining industry was discouraged by the high costs of water and equipment, and by increasing governmental regulation. Even the increase in gold price from $20.67 to $35.00 per fine ounce in 1934 did not provide the economic incentive to revive hydraulic mining.

Following the shutdown of the hydraulic mines in 1884, most of the California gold was produced by floating bucket dredges, which operated in the vast gravel deposits along the major drainageways at the junction of the mountain front and the Central Valley.

Pine trees and manzanita bushes have since sprung up in the hydraulic pits. Most of the old access roads are overgrown, except where frequented by the bottle collector, hunter, motorcyclist, or trash disposer. Little remains in the way of mining artifacts. Even the old rusty hydraulic pipes are gone; they were carted off for road culverts.

AREA OF STUDY

The area of study is roughly that part of the Sierran foothills between the North Fork of the American River and Middle Yuba River (fig. 1). The mapped area comprises parts of the Emigrant Gap, Alleghany, Colfax, and Nevada City quadrangles (1:62,500 scale). It contains a part, but not all, of the ancestral Yuba River drainage basin. This particular area was selected for study because: it contains the largest remaining deposits of Tertiary gold-bearing gravel in the Sierra Nevada; a significant portion of the total Tertiary placer gold produced from California has been derived here; a fairly large gold resource was believed to still exist; and exposures and access are relatively good.

PREVIOUS WORK

The comprehensive report by Lindgren (1911) stands as a classic in its complete and thorough coverage of the Tertiary gravels of the Sierra Nevada. I have drawn extensively from this work because much of the information that was available in Lindgren's day, particularly concerning gold values, has vanished. Whitney's discussion of the gravel (1880) is of interest because it was written during the height of the mining activity. A rather exhaustive quantitative study of the hydraulic mining debris that was made by Gilbert (1917) is useful when figuring average gold values. Early folio maps by Lindgren (1900) and Lindgren and Turner (1895) show the distribution of Tertiary gravel as well as bedrock (scale 1:125,000). The study area is covered by the more recent map compilation of Burnett and Jennings (1962). Good discussions of the geology of the gravel and information on potential gold resources are in Jenkins (1946), Averill (1946), Haley (1923), Hammond (1890), and Turner (1891). The Jarman (1927) report on the feasibility of resuming hydraulic mining contains a rather thorough summary of unmined gravel quantities. A report on the fossil flora contained in the gravel (MacGinitie, 1941) is still our best evidence for establishing age and climatic conditions of deposition of at least the upper part of the gravel. Clark's reports (1965, 1970) are handy useful references on the gravel and its occurrence throughout the Sierra Nevada. An informative up-to-date summary of the regional geology of the Sierra Nevada, including a discussion of both the bedrock and overlying rock units, is given by Bateman and Wahrhaftig (1966). An early publication derived from the studies by the Geological Survey concerns the area on San Juan Ridge, particularly the gold resource and geophysical investigation of the gravel (Peterson and others, 1968).

ACKNOWLEDGMENTS

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GENERAL GEOLOGY

Unmined gold-bearing gravels are mapped on plate 1, which also shows the distribution of the overlying volcanic rocks and adjacent underlying metamorphic and igneous rocks. Only those areas known or believed to contain gold-bearing gravel were mapped for this study.

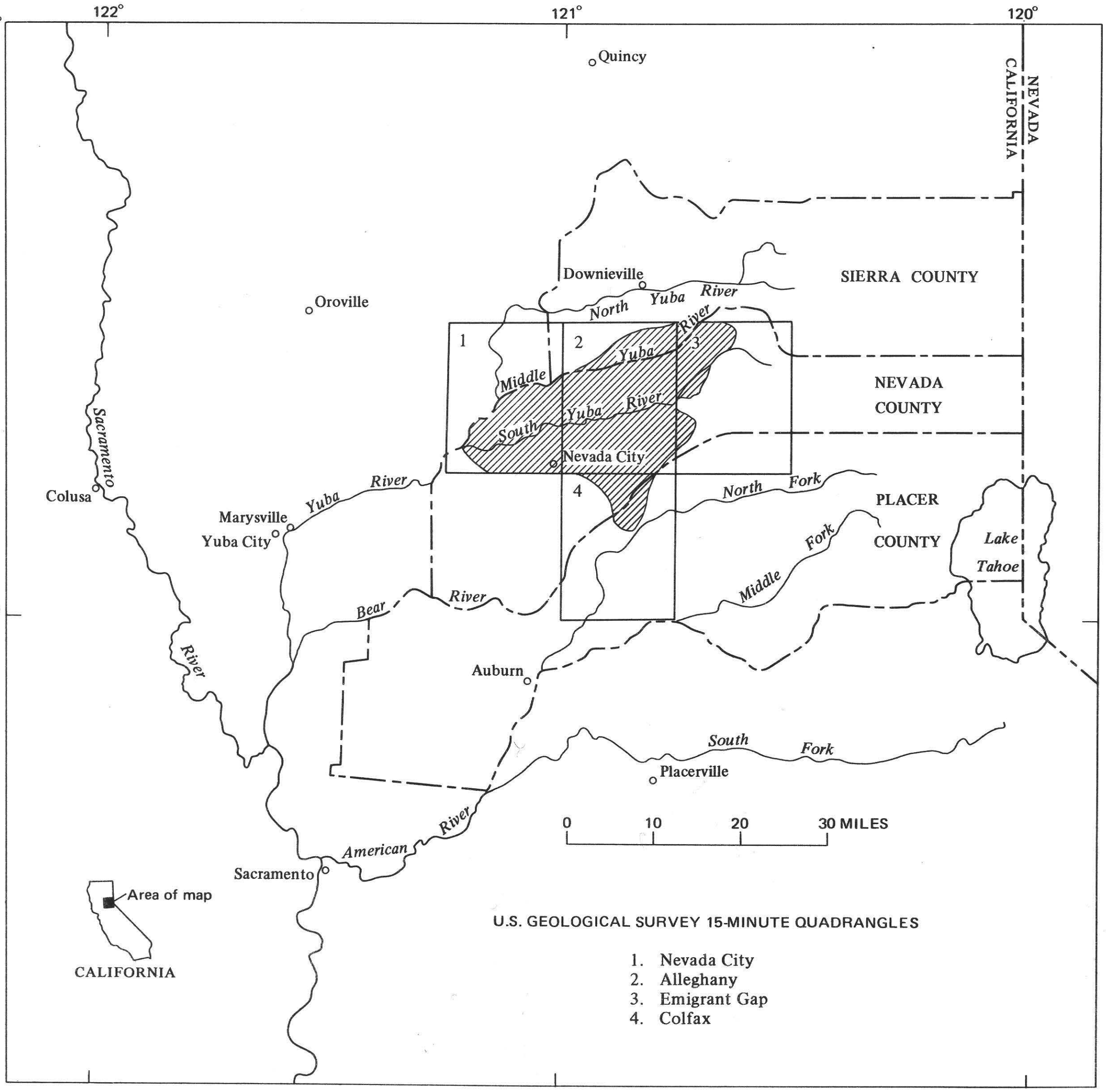


FIGURE 1.—Index map showing location of study area (patterned).

BEDROCK

Two types of bedrock are shown on the geologic map: igneous and metamorphic. The distribution of serpentines and of some quartz veins is shown in figure 2.

The metamorphic rocks are all low grade. They occur in a wide north-west-trending belt across the central part of the mapped area. Commonly referred to as the Calaveras Formation (Lindgren, 1900; Ferguson and Gannett, 1932) of late Paleozoic age, they consist mostly of fissile slate, siliceous phyllite, hornfels, quartzite, and greenstone. In the eastern part of the area are dark-gray slates of the Silurian(?) Shoo Fly Formation (Clark and others, 1962, p. B16, B17). Metamorphism has been so slight that many of the metasedimentary rocks still show well-preserved sedimentary textures and structures such as crossbedding, graded bedding, lenticular and wavy bedding, and alternating silt and clay beds. The slates and phyllites are locally rich in pyrite. A typical phyllite contains detrital quartz and feldspar in a groundmass of quartz, sericite, and chlorite. Mesozoic metavolcanic rocks typical of the western Sierra metamorphic belt (Bateman and Wahrhaftig, 1966, p. 113) occur in the extreme western part of the area.

Mesozoic igneous rocks intrude the metamorphic rocks throughout the area. Biotite-hornblende granodiorite constitutes the two largest intrusive bodies in the eastern and western parts of the area. Smaller intrusive bodies consist of diorite, serpentine, gabbro, and diabase. A saussuritic granitic rock rich in epidote

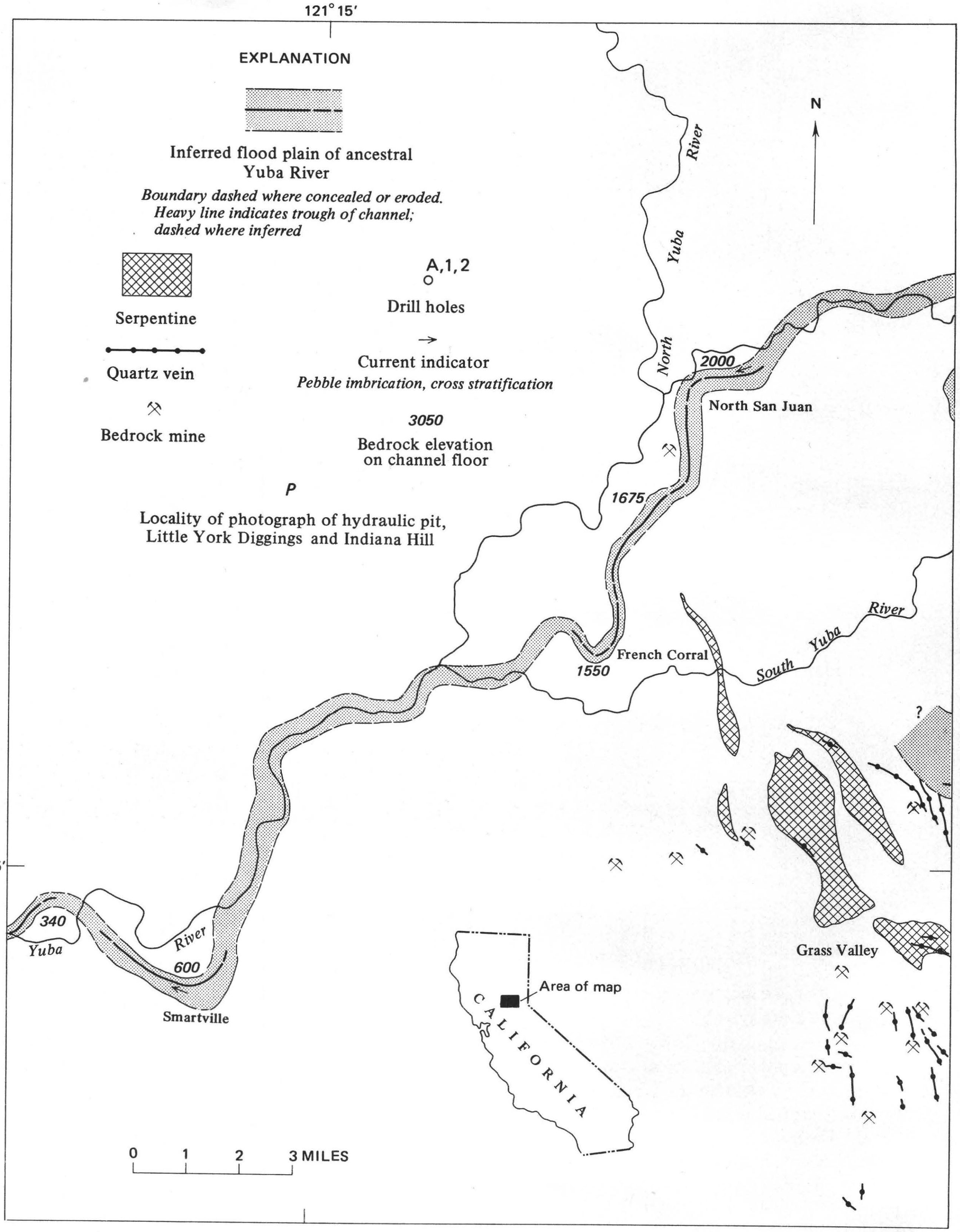
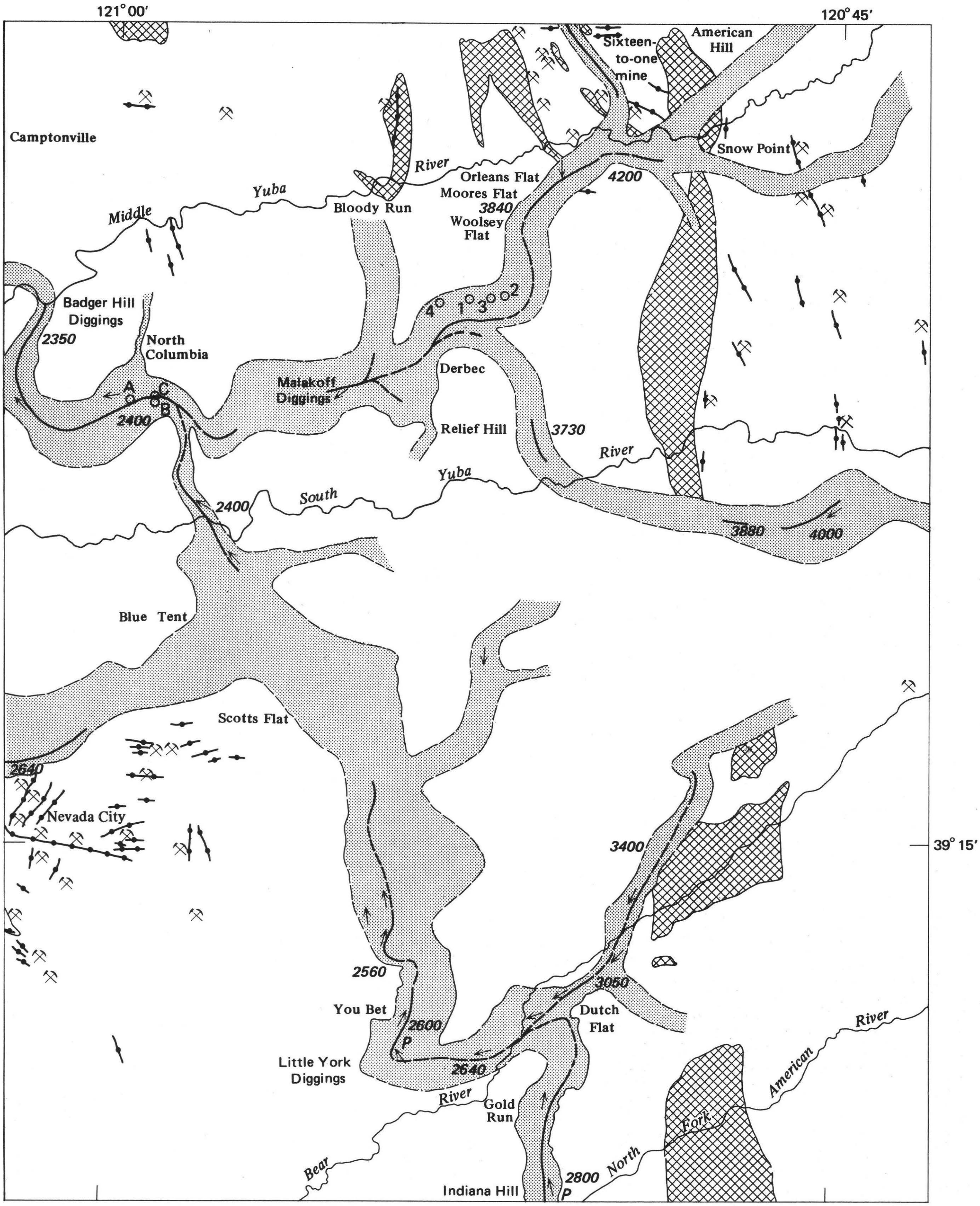


FIGURE 2.—Trace of part of ancestral Yuba River



drainage. Sierra, Nevada, and Placer Counties, Calif.

and allanite(?) was encountered in drilling below the volcanic rocks on San Juan Ridge. A small outcrop of a megascopically similar granitic rock is present in the middle reaches of Bloody Run Creek, just north of the San Juan Ridge. Milky-white quartz veins locally intrude the older metamorphic rocks (fig. 3) and are most prevalent in and adjacent to serpentine bodies (fig. 2). Siliceous zones and quartz veins within the metamorphic rocks commonly resist weathering and remain as ridges that stand above the surrounding land surface.

In this part of the Sierra Nevada, only the uppermost levels of the granitic plutons have been exposed; large volumes of geosynclinal sediments still exist as a "roof" covering the igneous intrusions. Farther south in the range, the geosynclinal sedimentary "roof" rocks have been largely removed, leaving large areas of the plutons exposed.

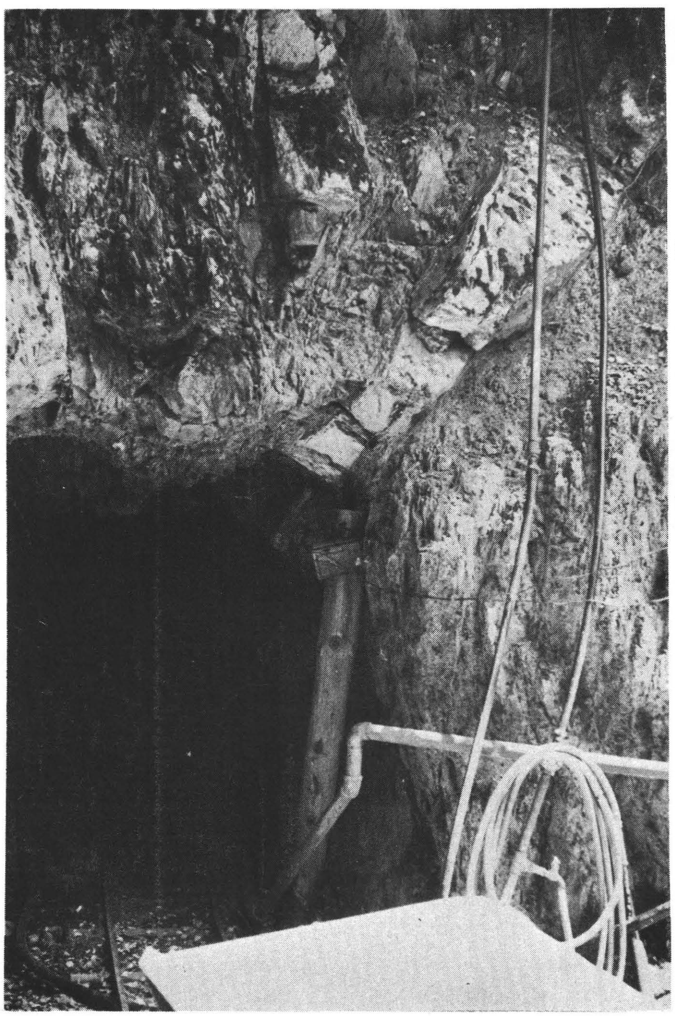


FIGURE 3.—Portal of the German Bar mine, located between Snow Point and the Middle Yuba River. Slate and greenstone of the Calaveras Formation are intruded by gold-bearing(?) quartz, a rock type common in prevolcanic gravel, and the source for much of the gold contained in the gravel.

The regional structure consists of a large homocline dipping steeply to the northeast. The rocks strike north-northwest, essentially parallel to the trend of the Sierra Nevada at this latitude. Locally the rocks dip steeply southwest. Cleavage is well defined within the slates and moderately to poorly defined within the phyllites. Generally the cleavage parallels the bedding in the metasedimentary rocks. The general structural grain of the metamorphic rocks seems to have controlled the emplacement of the serpentine, as shown by the long linear serpentine bodies that trend parallel to the general strike of the enclosing metamorphic rocks. The north-northwest-trending bedrock structures seem to have exerted limited control on the early Tertiary drainage system. Much of the ancestral Yuba River drainage parallels the strike of the bedrock from the North Fork of the American River to the present location of the Middle Yuba River, roughly 20 miles. Other major portions of the drainage flowed at right angles to the strike of the rocks, from east to west.

A major fault north-striking, probably an extension of the Melones fault (Burnett and Jennings, 1962), crosses the east end of San Juan Ridge, where it forms the boundary between slates and serpentine. Small faults cut the ancestral Yuba River channel at several places. The evidence for these faults, though not always conclusive, consists of bedrock scarps, disrupted zones in bedrock, geophysical magnetic anomalies, and abrupt changes in channel floor elevations. Vertical offsets are seldom more than 100 feet.

GRAVEL

Remnants of gravel deposits containing detrital gold are present on the interstream divides. Generally these deposits occur within well-defined channels cut into the older igneous and metamorphic bedrock complex. In a few areas, the enclosing bedrock channel has been eroded, leaving isolated patches of gravel capping low hills.

The channel-fill deposit is here called a "gravel," following the firmly established tradition of using this textural term when referring to the deposit, for example: Tertiary gravels (Lindgren, 1911; Merwin, 1968; Wells, 1969), auriferous gravels (Whitney, 1880; Hammond, 1890), and gold-bearing channel gravel (Peterson and others, 1968). It should be emphasized, however, that the bulk of the deposit, particularly the upper part, is not composed of gravel, but is predominantly sand, silt, and clay. The unit is distinguished from younger gravel, which may or may not contain detrital gold, by the absence of unmetamorphosed volcanic clasts. Younger gravel contains abundant clasts of rhyolite, andesite, and their weathering products.

Such vast amounts of gravel were removed by hydraulic mining that at some places bedrock is now exposed where thick gravel deposits formerly lay. In other localities, for example, North Columbia and the southern part of the Badger Hill pit, large amounts of gravel remain. The hydraulic pits are outlined on the geologic map (pl. 1), and the areas where gravel was stripped all the way to bedrock are shown.

Although many of the gravel exposures have been isolated by erosion, the major drainage system can be reconstructed with reasonable certainty. (See section entitled "Trace of Restored Channel.")

LOWER AND UPPER CONTACTS

The basal gravel rests with pronounced angular unconformity on the steeply dipping slate and phyllite. Where the lower contact is well exposed, as on the floor of hydraulic pits, the bedrock surface is smoothed, polished, grooved, and fluted (fig. 4). Both igneous and metamorphic bedrock show the typical erosional features associated with active river scour. The old erosion surface is generally intact on the granitic bedrock. In metamorphic bedrock, the surface was commonly broken up and destroyed during mining. Rock cleavage, joints, and associated fractures that are more common within the slates and phyllites acted as natural traps for the lodgment of detrital gold particles. This fact was clearly evident to the early miners, who typically would tear up 1–5 feet of the old channel floor in their search for the entrapped gold. The granitic surface, generally smooth, presented a poor environment for the lodgment of gold particles.

Outside the pits, the precise position of the lower contact at the margin or lateral boundary of the channel is generally obscured by thick soil, and subtle evidence had to be used to locate the contact. In some places a topographic break indicates the contact position. Elsewhere, resistant rounded alluvial quartz pebbles indicate underlying gravel, and angular siliceous rock chips in the soil signify underlying bedrock (figs. 5, 6). The channel rim or edge, as evidenced by the contact of gravel and bedrock, could generally be correctly mapped to within 50 feet. Cuts showing weathered bedrock below the gravel were observed only near the margins of the old river channels. At these localities the weathered bedrock was preserved by the overlying gravels. It seems doubtful that weathered bedrock could survive active fluvial scour, as would have been common near the center of the river channel.

The rocks overlying the gold-bearing gravel have only one unifying characteristic: they are rich in fresh

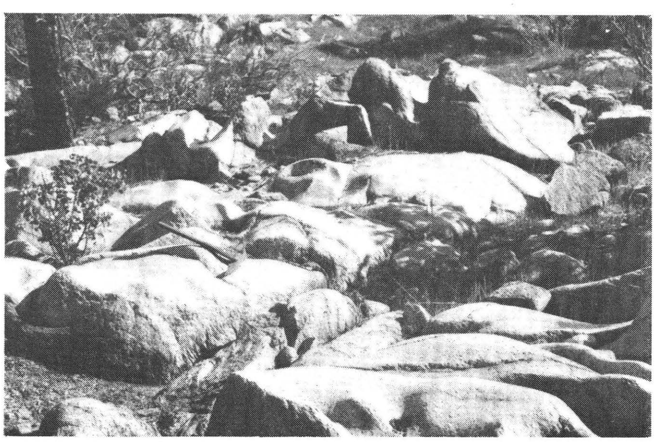


FIGURE 4.—Fluted and scoured granitic bedrock floor of the once gravel-filled channel exposed in a hydraulic pit near Peterson's Corner 2 miles southwest of North San Juan. The overlying gravel was removed by hydraulic mining in the late 1800's. The river flowed toward the observer.

FIGURE 5.—Surface of soil developed on phyllitic bedrock. Note angular bedrock chips remaining as a lag on soil surface.

FIGURE. 6—Surface of soil developed on gold-bearing gravel. Note subrounded pebbles of quartz and siliceous phyllite weathering out of the alluvial gravel. Such subtle evidence as differences in degree of roundness or angularity (compare fig. 5) is used in locating gravel-bedrock contacts. Eyeglass case indicates scale.

volcanic material. These younger rocks include: bentonite and tuff beds at North Columbia; volcanic cobble gravel at Scotts Flat, Chalk Bluffs, and Malakoff Diggings; andesite breccia at Woolsey Flat; and colluvium at numerous localities.

In contrast to the overlying rocks, the upper part of the auriferous gravel lacks volcanic detritus and is everywhere characterized by fine-grained alluvial material such as sand, silt, and clay. In places where tuff and bentonite overlie the gravel, the contact seems gradational, and it does not look like erosion took place between the deposition of the two units. Where the gold-bearing gravel is overlain by material such as volcanic cobble beds, andesite breccia, or colluvium, the contact is quite clearly an erosional unconformity.

LITHOLOGY AND TEXTURES

Close examination suggests that the gold-bearing gravel can be divided into an upper and a lower unit. Although the units are lithologically and texturally distinct, no distinct contact can be selected. Consequently, the gravel was mapped as a single unit. For text description, however, the gravel is divided into two units.

Pebble counts were made at selected localities along the channel in both the upper and lower gravel units. At similar sampling points, percentages of the different size clasts were measured by screening and weighing the various size fractions. Field descriptions of measured gravel sections at Woolsey Flat, Malakoff Diggings, North Columbia, Badger Hill, and Chalk Bluffs are given with sections on plate 2 and figures 7 and 8. Descriptive gravel sections of the drill holes on San Juan Ridge and in the North Columbia hydraulic pit are shown on plate 2.

Results of the studies of the heavy minerals and detrital gold obtained from the gravels are discussed under the sections "Placer Gold" and "Other Heavy Minerals."

LOWER GRAVEL

The lower gravel contains most of the gold and consequently was the unit most sought by the early miners. Relatively few exposures of the lower gravel can be found, as it was either completely mined out or, because of the thick cover of overlying gold-poor upper gravel, was never exposed. Localities where the lower gravel could be seen in 1968 include the hydraulic pits at French Corral, Birchville, Badger Hill, Moore's Flat, Sailor Flat, Little York, Dutch Flat, and the unnamed hydraulic pit 1 mile northeast of Edwards Crossing near Spring Creek. Even fewer exposures can be found of undisturbed lower gravel resting on bedrock. One such exposure is near the northwest edge of the hydraulic pit at Moore's Flat (fig. 9). Granitic boulders more than 6 feet in diameter are not uncommon at this locality, and some are as much as 10 feet in diameter. These boulders must have been transported at least 8 miles, the distance to the nearest upstream bedrock exposure of similar porphyritic granite. Large boulders 6–10 feet in diameter lie along the south side of the Malakoff pit (fig. 10). The boulders probably have been disturbed by mining activities and are not in place; but as they probably were not moved very far, they do give some idea of the maximum boulder size in the lower gravel. These rocks are siliceous phyllite similar to the bedrock in the Malakoff area. At Badger Hill and French Corral, the lowest gravels are not exposed, and the clasts are smaller than those at Malakoff and Moore's Flat. Most of the lower gravel unit is exposed at these localities and is predominantly of cobble size. At Badger Hill, good exposures of the lower gravel unit are seen in the walls of the lower hydraulic pit (fig. 11). Imbrication within the cobble gravel is moderately well developed and indicates a south-to-north current flow.

Size analyses of 26 samples of lower gravel collected throughout the area give the following averages (using Wentworth's size classification): cobble and boulder (>64 mm), 13 percent; pebble (64 to 4 mm), 56 percent; granule and sand (4 to $\frac{1}{16}$ mm), 28 percent; and silt and clay (<$\frac{1}{16}$ mm), 3 percent. Because of the great variability in texture of the lower gravel both vertically and laterally along the channel, these figures may be meaningless when applied to any one area. However, they can be useful in a general comparison of texture of the total unit with the textures of the upper gravel. Sorting in this lower unit, as would be expected in a coarse gravel, is poor.

Pebble counts of the 16- to 32-mm size fraction give the following averages from 26 samples: bluish-black siliceous slate, 52 percent; weathered igneous rocks, 31 percent; milky quartz, 12 percent; other, 5 percent. The compositionally immature nature of the lower gravel indicated by the pebble count is substantiated by the heavy minerals present. Chlorite, amphibole, and epidote are common within the lower gravels, whereas they are conspicuously absent from the upper gravel.

The lower gravel varies in thickness from 70 to 140 feet, depending on where one places the upper boundary. Generally the boundary is placed where pebble and cobble gravel is replaced upward by beds that are predominantly pebble and sand. The lower 130 feet of measured section at Malakoff Diggings probably corresponds to the lower gravel (pl. 2). Most of this part of the section consists of cobbles and pebbles; boulders

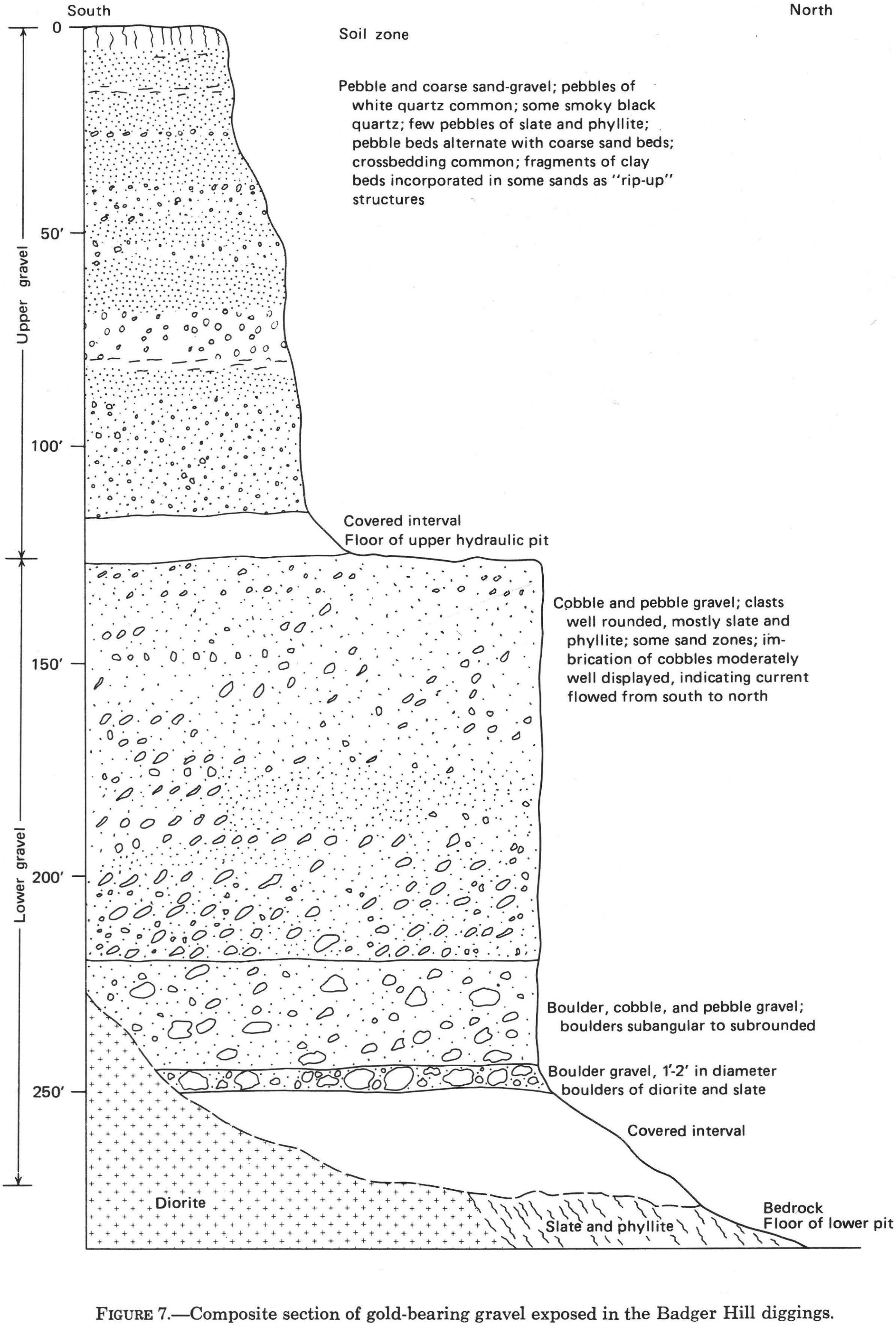


FIGURE 7.—Composite section of gold-bearing gravel exposed in the Badger Hill diggings.

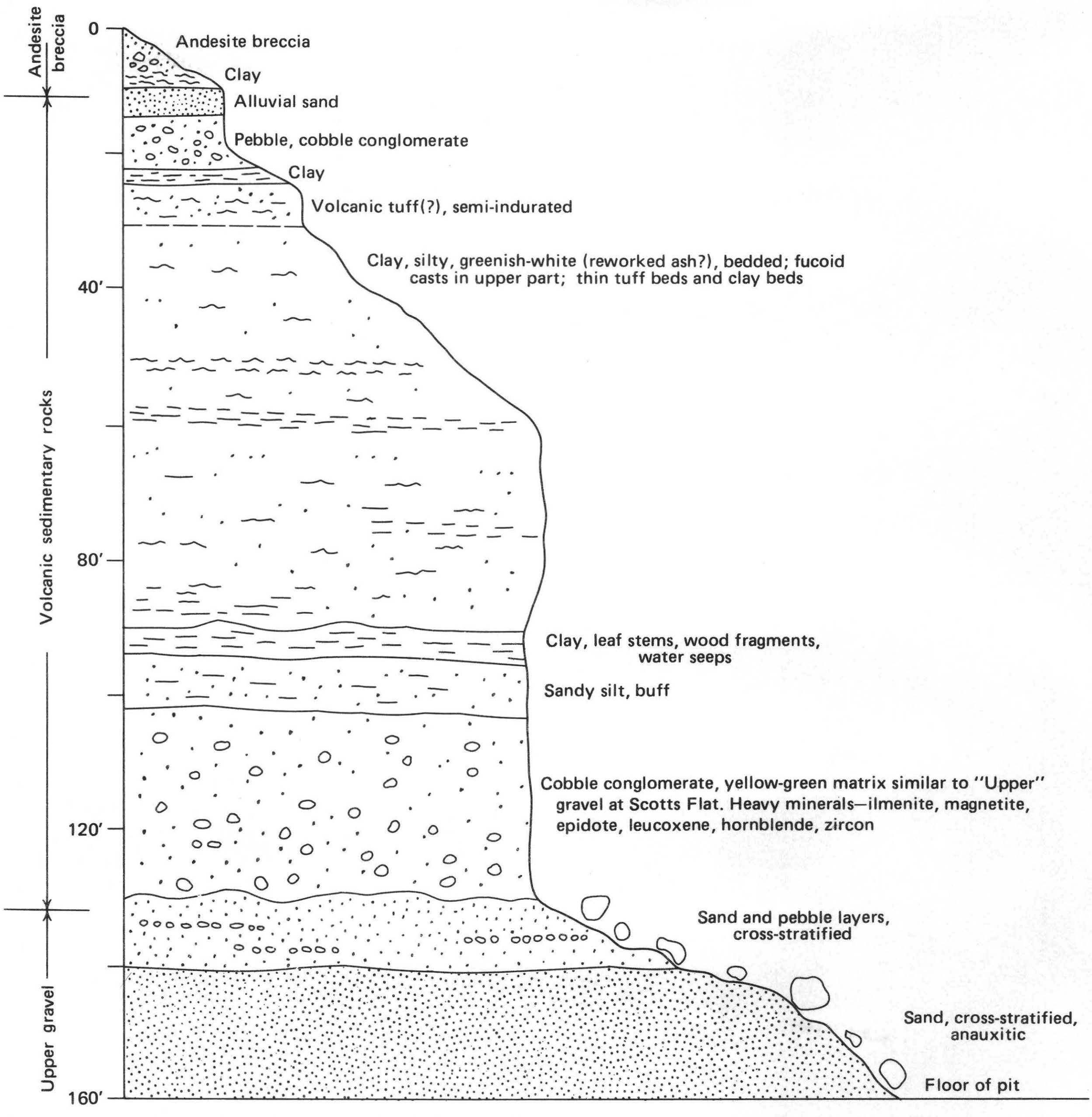


FIGURE 8.—Section measured at Chalk Bluffs showing the change from the upper gold-bearing gravel to volcanic sedimentary rocks and andesite breccia. The section is located on the east side of the large hydraulic pit near You Bet.

appear in only the lowest 30 feet. All exposed gravel measured at Woolsey Flat is in the upper gravel. The lower 75 feet of section is covered but presumably would contain the lower gravel unit (pl. 2). The gravel section measured at North Columbia is part of a composite section shown on plate 2 as hole A. The description of the upper 50 feet and lower 260 feet of this section was obtained from drill-hole data. The description of the middle part of the section (260 feet) was made from outcrops within the hydraulic pit. A great deal more information could be obtained about textures from the actual exposures than from the drill data. The churn drill shattered all the coarse constituents of the gravel to sand size and smaller and made reconstruction of original textures and lithologies exceedingly difficult. On the basis of such drilling characteristics which can be useful indicators of boulders and cobbles, it would appear that the lower 90–100 feet of gravel drilled is of the lower gravel unit, roughly corresponding to the heavy mineral zones III and IV as discussed in the section "Other Heavy Minerals." The lower gravel at Badger Hill is approximately 140 feet thick.

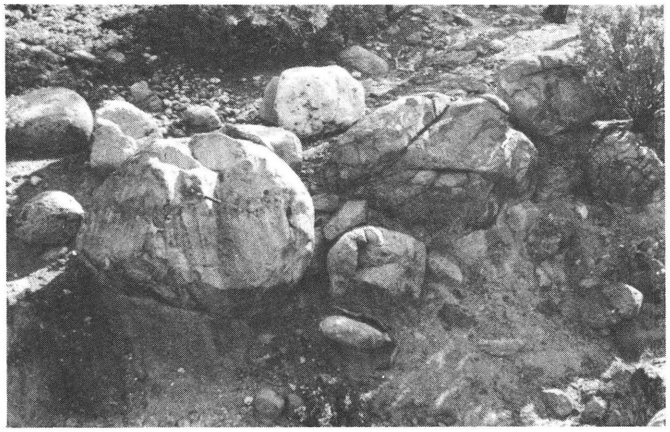


FIGURE 9.—Lower gravel exposed in the hydraulic pit at Moore's Flat. Boulders 6 feet in diameter (note rock hammer on left boulder) are porphyritic granite. Bedrock is below bottom of picture.

At this locality, hydraulic mining proceeded on two levels corresponding to the upper and lower gravel units (fig. 7).

Where recent mining activities have exposed fresh, unweathered lower gravel, as at French Corral and Birchville, two units can be recognized within the lower gravel, a blue and a red. The lower unit, referred to by the older miners as blue gravel, blue lead, or blue clay, is water saturated, appears to be unoxidized, and is bluish gray. These colors are especially noticeable when wet. The color is clearly due to the high content of bluish-gray-colored slates and phyllites derived from the ubiquitous Calaveras Formation. The blue-gray gravel contrasts markedly with the overlying oxidized gravel, the upper unit, sometimes called the red gravel. The differences between the two appear to be those produced by oxidation. The general textures and lithologies of the clasts are similar. As Lindgren (1911, p. 76) pointed out, the blue gravel is a zone below the water table in which reducing conditions prevail and is not a distinct lithologic unit different in composition and origin from the overlying oxidized gravel. Secondary pyrite coats pebbles and is disseminated through the matrix of the blue gravel at many localities. The origin of the pyrite is discussed in the section "Second-

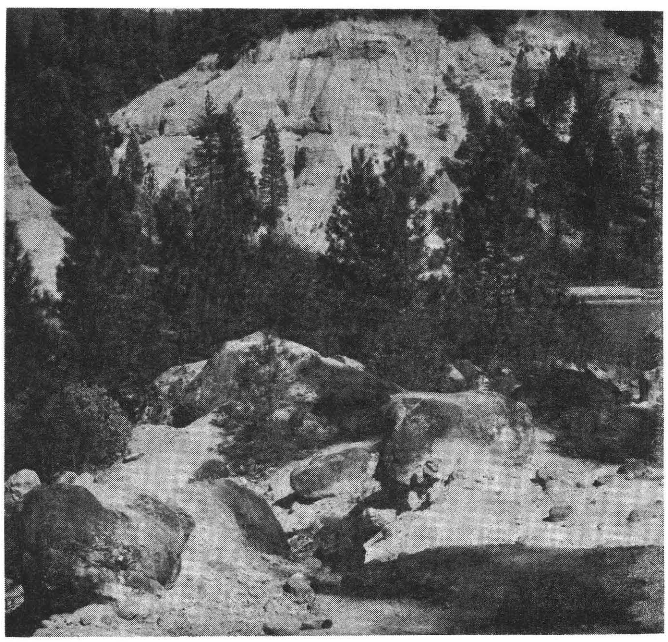


FIGURE 10.—Boulders are as much as 10 feet in diameter near the floor of the Malakoff hydraulic pit. View is north across lake in west end of pit. Boulders are siliceous phyllite similar to bedrock in area.

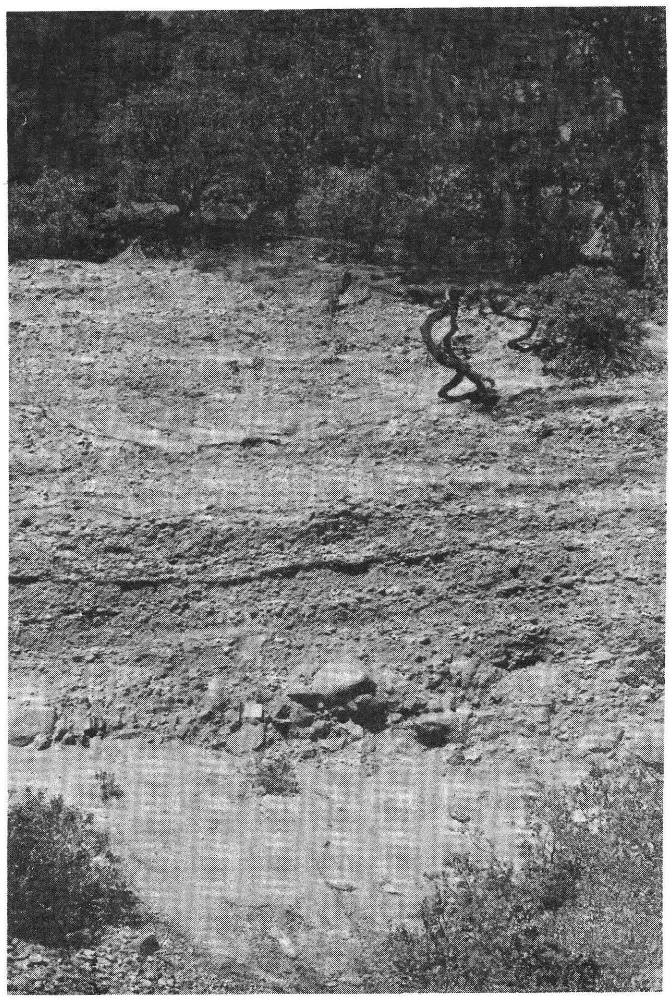


FIGURE 11.—Lower gravel in the Badger Hill hydraulic pit. View is west near northernmost part of pit. Gravel is exposed on side of pit, and bedrock slopes up steeply beneath gravel. Gravel-bedrock contact is not exposed but probably is 20–30 feet below lowest exposure of coarse gravel. Largest boulders exposed are 3 feet in diameter. Note aluminum notebook for scale.

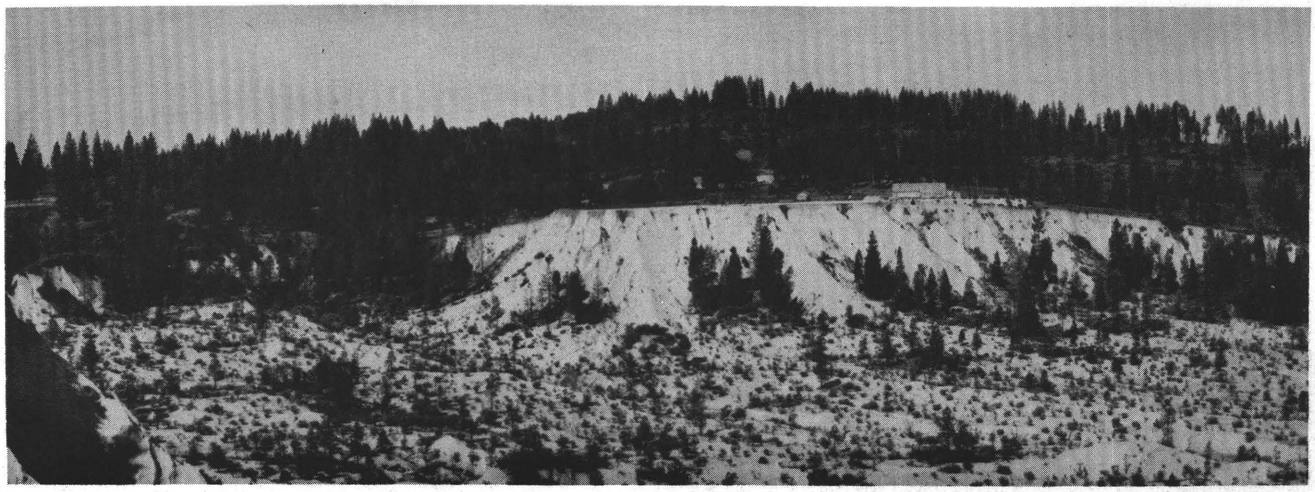


FIGURE 12.—Upper hydraulic pit at Badger Hill Diggings. Upper gravel is exposed in pit walls. View is west across pit.

ary Sulfides." At those places where the water table is within the upper gravel as at North Columbia, all the lower gravel is blue (zones III and IV, pl. 2).

UPPER GRAVEL

The upper gravel, unlike the lower, is exposed more or less continuously along the old river channel. It is commonly exposed in cliff faces and constitutes the bulk of the deposit in most areas. Figure 12 shows typical exposures in the hydraulic pit at Badger Hill Diggings.

Features that help distinguish the upper gravel from the lower are: (1) the generally finer grain, clasts rarely being larger than pebble size; (2) the abundance of clay and silt beds; (3) compositional maturity of the clasts—milky-white quartz and quartzite are very abundant and sand and silt-size grains are predominantly quartz; (4) the heavy-mineral content, almost exclusively zircon, ilmenite, and magnetite.

Crossbedding and cut-and-fill features are common sedimentary structures within the upper gravel. Large, sweeping crossbeds 8 feet across are observed in places. Associated with the finer grained character of this gravel is pronounced bedding and fair to good sorting. Pebble beds are most prevalent in the lower part of the upper gravel, and clay beds are common in the upper part of the section. Commonly the clay is greenish gray and weathers to brown. Thin sand and silt zones, generally less than a foot thick and heavily impregnated with iron oxide, occur sporadically throughout the upper gravels. These zones are possible evidence of old water tables within the gravel. Five such zones were noted in the upper gravel at Malakoff in 325 feet of section (pl. 2).

Size analyses of the upper gravel determined from 35 different localities give the following averages: cobble and boulder, 1 percent; pebble, 41 percent; granule and sand, 53 percent; and silt and clay, 5 percent. These averages do not reflect the total amount of clay in the section, because the samples generally were collected from sand and pebble units for the purpose of studying the detrital gold and other heavy minerals. Pebble counts of the 16- to 32-mm size fraction show: white quartz, 52 percent; siliceous slate, 40 percent; quartzite, 7 percent; other constituents, 1 percent. The figure of 52 percent white quartz contrasts markedly with the 12 percent obtained as the average within the lower gravel and points up one of the major lithologic differences between the two units. The gold value of the upper gravel, as discussed in detail in section "Gold Values Old and New," is generally low, rarely more than $0.02 per cubic yard.

The maximum measured thickness of upper gravel, 400 feet, is in the North Columbia pit (pl. 2). In this pit, the lower 160 feet of the upper gravel is below the water table, and sulfides and carbonized wood are common within it. As the upper gravel at North Columbia grades upward into bentonitic clay and tuff of volcanic origin with no apparent depositional break, the section here probably is more or less complete. The overlying volcanic rocks at North Columbia are thin and of spotty occurrence and could not be mapped at the scales used. For mapping purposes, they have been included in the prevolcanic gravel unit. At Malakoff Diggings (pl. 2) there is at least 325 feet of the upper gravel unit. Many of the clay beds exposed in the hydraulic cliffs have failed and mud and earth flows are common in the pit. Here also some of the clays in the upper part of the section are probably of volcanic origin. At Woolsey Flat (pl. 2) there is approximately 200 feet of upper gravel. The lower boundary is not exposed. Carbonized wood in the lower part of the upper gravel marks a position below the water table.

At Badger Hill about 125 feet of upper gravel remains (fig. 7). Silicified wood, distributed sporadically throughout the upper gravel, is particularly abundant. At Chalk Bluffs (fig. 8), only the uppermost part of the upper gravel was measured. Here the upper boundary is distinct and is marked by a cobble conglomerate with abundant volcanic clasts resting with erosional unconformity on sand of the upper gravel unit.

CHANNEL CONFIGURATION

The diagrammatic sections of figure 13 show an idealized Tertiary channel covered by volcanic rocks and an example of land surface that develops when the volcanic cover is eroded away. The porous and permeable gravel, once exposed, is more resistant to erosion than the bordering bedrock, be it granitic or slate. At the few localities where the gravel has not been mined, the channel is expressed as a low ridge, a topographic reversal of what originally was a linear depression. Rainwater tends to percolate into the gravel instead of running off and thus causes little physical erosion. The quartz and quartzite rock types common in the upper gravel further resist chemical breakdown. A short stretch of the channel between French Corral and Birchville is a characteristic gravel ridge marking the channel location (fig. 14).

In the North Columbia area, the channel is very broad and the gravel thick; 15 miles downstream, the gravel is much thinner and occupies a narrower channel (fig. 14). The channel configuration at North Columbia is determined from five holes drilled to bedrock across the channel in the early 1900's by private interests. Exposures of bedrock throughout much of the area from Birchville to French Corral allow an accurate depiction of the configuration of the channel floor. An adequate explanation for the marked difference in channel size between the two areas is not apparent. The gravel in the French Corral area belongs to the lower unit; one explanation for the absence of the upper unit is that it has been eroded away. The French Corral area lies farther from the existing volcanic covering rocks than the North Columbia area; most likely the gravel at French Corral has been exposed to erosion for a longer period of time.

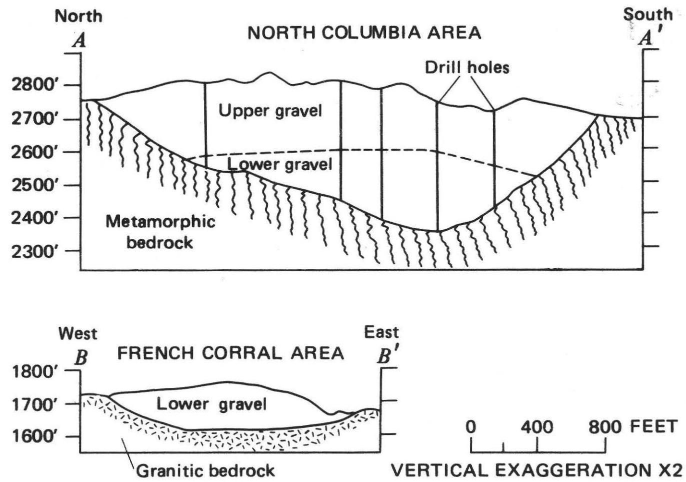


FIGURE 14.—Cross sections of gravel-filled channels near North Columbia and French Corral. French Corral is approximately 15 miles downstream from North Columbia along the ancestral Yuba River. Lines of sections are shown on plate 1.

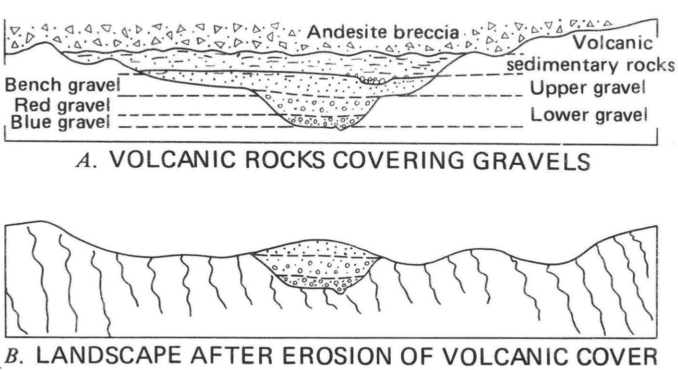


FIGURE 13.—Diagrammatic cross section of an idealized gravel-filled Tertiary channel showing rock relations before, (*A*), and after (*B*), erosion of covering volcanic rocks.

AGE

Fossil leaves were found at only one locality within the study area, within clay beds in the lower pit at North Columbia (pl. 2, index map). The composite stratigraphic section measured in the North Columbia area (pl. 2, hole A) shows that the leaf horizon is near the middle of the upper gravel. The flora in this horizon is similar to that described and dated by MacGinitie (1941) as late early Eocene (Bateman and Wahrhaftig, 1966, p. 135). The stratigraphic horizon at Chalk Bluffs, for which MacGinitie named the Chalk Bluffs flora (MacGinitie, 1941), is below the lowest part of the section shown in figure 8.

While drilling along the margin of the hydraulic diggings at North Columbia, several biotite-rich tuff beds were found. These beds lie within 25 feet of the ground surface and within 20 feet of the contact between the gravel and the volcanic sediment (pl. 2, hole A). The biotite, generally fresh looking, was dated by potassium-argon analysis at 37.9 ± 1 m.y. (million years). (Analyses were by Lois Schlocker and Jarel von Essen, U.S. Geol. Survey, Menlo Park, Calif.) This date, roughly the Eocene-Oligocene boundary, suggests that the upper half of the upper gold-bearing gravel was deposited during the late Eocene.

Approximately 18 airline miles north of the study area, in the vicinity of the town of La Porte, a dacite tuff is preserved in one of the channels containing gold-bearing gravel. The tuff was deposited in a depression cut into the upper prevolcanic gravel unit and a coarse volcanic gravel (fig. 15) that may be correlative with the coarse volcanic gravel exposed in the Chalk Bluffs (fig. 8). The dacite tuff at La Porte has been dated by potassium-argon methods at 32.4 m.y. (Evernden and James, 1964). A leaf flora within the tuff is dated as early Oligocene (Wolfe and others, 1961). These dates at La Porte nicely fit the age determined for the rocks in the North Columbia pit and indicate that volcanism began in the general area near the beginning of the Oligocene. The Chalk Bluffs flora further indicates that most of the gold-bearing gravel, including all the lower gravel and some of the upper gravel unit, was deposited prior to the middle Eocene. This period of deposition may have taken all of the early Eocene and perhaps part of the Paleocene.

The Ione Formation of Eocene age (Merriam and Turner, 1937, and Bowen, 1962), exposed sporadically along the east margin of the Great Valley, has been correlated with the gold-bearing quartz gravel (Allen, 1929). The formation has been shown to consist of two members (Pask and Turner, 1952), the lower of which is compositionally more mature than the upper. If there is a correlation between the Ione Formation and the prevolcanic gold-bearing gravel, it would seem that the lower member of the Ione would correlate with the upper member of the gold-bearing gravel. The primary basis for this correlation would be the approximate equivalence of age and similarities of gross lithology, including the heavy-mineral suites. Compositionally immature sedimentary rocks underlying the Ione, informally called lower Eocene deposits of the Foothills by Bateman and Wahrhaftig (1966, p. 129), may then correlate with the lower gold-bearing gravel unit.

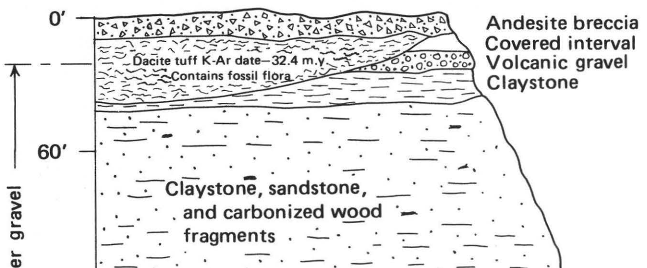


FIGURE 15.—Section of rocks exposed in hydraulic pit near La Porte.

SEDIMENTARY AND VOLCANIC ROCKS

Capping the ridges between the major drainages is a blanket of sedimentary and volcanic rocks of diverse textures. These rocks have been divided into two units for mapping purposes—a lower unit composed of sedimentary rocks rich in volcanic detritus and an upper unit made up of a coarse andesite breccia, andesite cobble gravel, and rhyolitic tuff.

VOLCANIC SEDIMENTARY ROCKS

The unit mapped as volcanic sedimentary rocks comprises coarse gravels, sands, silts, clays, and tuffs, all characterized by a high percentage of volcanic-derived clastic material. The contact with the underlying gold-bearing gravel has been discussed. Sections containing volcanic sedimentary rocks are shown on plate 2 and figures 8 and 15. These rocks occur discontinuously below the overlying andesite breccia. The upper contact with the breccia characteristically is erosional; and it is presumed that, although originally widespread, the rocks were eroded from many areas prior to deposition of the andesite breccia. The only subunit within this map unit that appears to be at all persistent across the region is a coarse cobble gravel, observed at Chalk Bluffs (fig. 8), Scotts Flat, Malakoff Diggings (pl. 2), and La Porte (fig. 15). At Chalk Bluffs and La Porte, it occurs as the lowest subunit. The gravel contains both andesite and nonvolcanic cobbles and pebbles. The volcanic gravel at Scotts Flat, about 20 feet thick, contains gold equal to $0.20 to $0.30 per cubic yard, as determined from two large pans of gravel.

Rhyolitic tuffs, both fresh and reworked, are present at Chalk Bluffs and below the Columbia Hill lookout on San Juan Ridge, north of Nevada City. Chalk Bluffs derived their name from a massive white tuff that forms a prominent cliff bordering the hydraulic pits near Red Dog and You Bet. A thin tuff bed overlying the gravel near North Columbia contains the biotite dated at 37.9$\pm$1 m.y.

The volcanic sedimentary rocks reach a maximum thickness of 120 feet at Chalk Bluffs and along the Graniteville Road below the Columbia Hill Lookout.

Part of this section may correlate with the Valley Springs Formation (Piper and others, 1939), which is composed of rhyolite tuffs and associated clastic rocks, but the date of 37.9 m.y. for the tuff at North Columbia suggests that these rocks may be somewhat older than the Valley Springs, which was dated as 20–30 m.y. (Dalrymple, 1964).

ANDESITE BRECCIA AND GRAVEL

The upper unit is composed primarily of andesite breccia with intercalated cobble and boulder gravel. The breccia is poorly sorted and fragments are angular; some blocks are as much as 6 feet in diameter; commonly the fragments are 6 inches to a foot in diameter.

The moderately well indurated light-gray matrix is composed of fine sand-size andesitic debris. At several localities, zones containing rounded, apparently water-worn cobbles and boulders are intercalated with the breccia. A typical gravel horizon is present within the breccia on San Juan Ridge exposed along the road leading down to Bloody Run Creek (fig. 16). Several such horizons were encountered 400–500 feet below the top of the breccia on San Juan Ridge. These boulder zones are good aquifers, and springs are common where they crop out, particularly in a moderately thick section of andesite gravel along the Relief Hill Road above the old mining town of Relief.

Thick deposits of andesite gravel, formerly believed to belong to the older volcanic unit, cap Montezuma Hill, Bunker Hill, and Round Mountain. The exposures at Round Mountain show stratigraphic continuity with the andesite breccia and are mapped as part of the younger volcanic unit.

FIGURE 16.—Exposure of andesite breccia overlying andesite boulder gravel on San Juan Ridge along road to Bloody Run Creek. Largest boulder in photo is 3 feet in length.

The four drill holes on San Juan Ridge penetrated 510–650 feet of volcanic breccia and intercalated gravel. The thickness varies markedly on Washington and Harmony Ridges, where the breccia was deposited across the boundary of a highland surface extending to the east and a somewhat flatter, lower surface occupied by the ancestral Yuba River to the west.

The breccia seems to be made up of a series of mudflows separated by a few preserved soil horizons. The flows eventually filled most of the depressions in the land surface, forming a broad, fairly flat surface. Remnants of this constructional surface are preserved as the west-sloping interfluves of the northern Sierra. The concordant elevation and slope of this surface across the drainages is easily mistaken for an old erosion surface.

A rhyolitic, biotite-rich tuff is present in the southern part of the area along the Southern Pacific Railroad tracks between Alta and Dutch Flat. Samples of the tuff were collected from a roadcut along the paved highway leading to the California Division of Forestry Headquarters near the town of Alta, where the tuff overlies both bedrock and a thin section of cobble gravel. A potassium-argon date on biotite from the tuff was determined at 8.7±0.5 m.y.; this date indicates that the tuff correlates with latites that are farther south in the Sierra Nevada which are dated 8.8 to 9.0 m.y. (Dalrymple, 1963).

This upper unit of andesite breccia and gravel resembles the Miocene and Pliocene Mehrten Formation described from other areas in the Sierra Nevada (Piper and others, 1939; Curtis, 1954), as well as the Miocene and Pliocene Disaster Peak and Relief Peak Formations of Slemmons (1966) of the central Sierra Nevada. Direct correlation with these formations has not been established. Andesitic mudflows and conglomerates deposited in this same stratigraphic interval, above the Valley Springs Formation, have been dated at 19 to 5 m.y. (Dalrymple, 1964).

COLLUVIUM

A blanket of landslide debris termed "colluvium," composed predominantly of andesite breccia, borders many of the steep slopes capped by the breccia. The colluvium has an irregular, hummocky, and sometimes blocky surface, indicating little modifications since its formation. It is thickest near the steep slopes of the undisturbed volcanic breccia, where it commonly grades into talus. Generally, the colluvial mantle is several tens of feet thick and may extend as much as 2 miles from the volcanic cliffs.

The colluvium is perhaps thickest and most widespread at the locations where the prevolcanic-gravel-filled channels disappear beneath the volcanic rocks capping the ridges. The weak clay in the upper unit of the prevolcanic gravel is probably instrumental in the common slope failure at this location. Slope failure might be expected where a thick layer of relatively porous, water-saturated volcanic rocks overlies weak clays. Consequently, the presence of colluvium can be used as an indicator of buried gold-bearing gravel that might otherwise be unsuspected.

Colluvium undoubtedly accumulated as soon as erosion began to remove the volcanic breccia, and as the breccia scarp retreated, a mantle of colluvium continued to form at its base. The rate of erosion and colluvium accumulation probably reached a maximum during the wet periods of the Pleistocene, and most of the present colluvium probably formed at that time.

PLACER GOLD

Any study of the characteristics and distribution of gold in the Tertiary gravel must be undertaken with the realization that the most accessible and readily attained gold has been removed by the mining methods of the late 19th and early 20th centuries. Information on gold values of the mined-out deposits can be obtained only from scanty information recorded by the early miners, some mining companies, and an occasional geologic report. Only in those areas where the gold-rich portion of the gravel is covered by thick deposits of low-grade gravel, volcanic breccia, and colluvium is it now possible to obtain first-hand information about the occurrence of the Tertiary placer gold.

One of the major objectives in drilling three holes in the thick gravel in the North Columbia diggings was to obtain samples of a complete unmined gravel section in order to study the gold characteristics and vertical distribution and to compare values with gold values determined from earlier (1939) drilling in the same area. It also made possible a comparison with gold values reported for gravel elsewhere within the ancestral Yuba drainage.

DRILL HOLES, NORTH COLUMBIA DIGGINGS

Three churn drill holes in the North Columbia diggings penetrated 308–455 feet of gold-bearing gravel (pl. 2). Hole A was drilled on the upper bench at a position determined from earlier (1939) drilling to be near the channel center as based on the lowest elevation of bedrock. Holes B and C were drilled on the lower bench, also near the channel center. Hole B was drilled to establish the validity of a geophysical interpretation of depth to bedrock—an interpretation that did not fit the information derived from the earlier drilling. Hole B also provided data useful in comparing gold values over a short interval (<200 feet) laterally across the channel. All three holes were drilled 10 feet from earlier drill holes, a distance that permits comparison of gold values without the hazard of encountering cave-in material and disturbed ground associated with the uncased holes.

All the holes were drilled with a cable-tool drill, also termed a churn drill, placer drill, or keystone drill, using a 6-inch drive pipe and a 7.5-inch drive shoe. Casing was driven to a depth of 398 feet in hole A, 232 feet in hole B, and 226 feet in hole C, at which depths the drill encountered boulders or cemented gravel sufficiently hard to prevent further driving. The gravel was well cemented below the bottom of the casing, allowing an open hole to be drilled without fear of caving. All the material drilled in all three holes was collected, and the samples separated every 5 feet in the upper, gold-poor gravel and every 1–3 feet in the lower high-value gravel. Drilling of hole A was begun September 4, 1968, and hole C was completed December 9, 1968.

METHODS OF GOLD RECOVERY AND VALUE DETERMINATION

Samples were panned at the drill sites as they were "bailed" from the drill hole (fig. 17). Gold colors were noted from each panned concentrate and the concentrate dried and stored in glass vials. As a check to determine the effectiveness of recovering fine gold from the drill hole, eight distinctive gold flakes ranging in diameter from 2 mm to 0.25 mm were dropped and washed down the hole when drilling at a depth of about 150 feet within the gold-poor section. It was reassuring to recover all eight gold flakes within the next two samples collected, following each drive of 5 feet.

In the laboratory, gold values were determined for each panned concentrate by handpicking and weighing the detrital gold fragments. Amalgamation with mercury was not done for several reasons. It seemed important not to destroy the original size and surface characteristics of the gold fragments useful for further study, and it was discovered that as much as 20 percent of the gold in some of the lower samples would not amalgamate. "Roughing up" the gold in the pan, cleaning with the ultrasonic probe, and boiling in separate acid solutions of HCL and HNO_3, although improving the amalgamating properties, did not allow recovery of all the gold. Using a binocular microscope and a large hand magnifying glass, it was possible to effect a clean separation rather quickly. As most of the gold fragments were larger than 1 mm in diameter, the grains were easily seen and quickly removed with the aid of a fine camel's-hair brush. The gold from each sample was weighed to the nearest tenth of a milligram. Knowing the diameter of the drill hole and the length of hole represented by each sample, it was a simple matter to

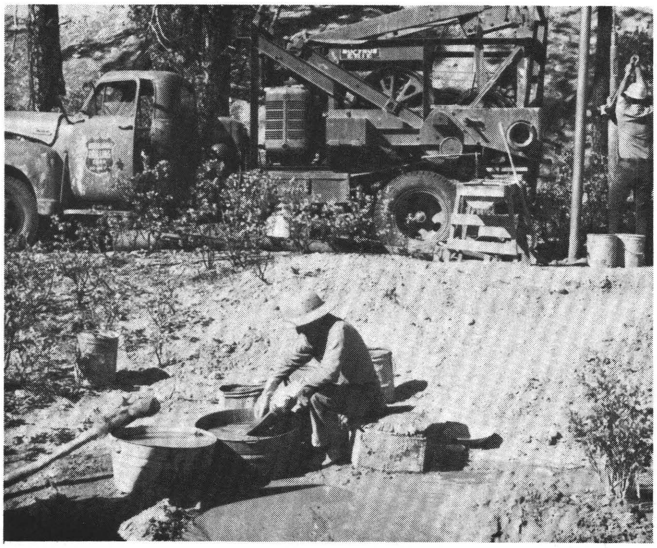


FIGURE 17.—Panning churn drill samples from hole A in the hydraulic pit near North Columbia. Panner, August Ebbert, is a former hydraulic miner.

calculate gold values. The value of gold in cents per milligram was determined using a price of \$35.00 per ounce and a fineness of 885, the average fineness of placer gold obtained in California (Wells, 1969, p. 99). The following formula was used to determine gold values, V, in cents per milligram

$$V=\frac{\$\text{Price} \times \text{fineness} \times 0.1}{31{,}103} \quad \text{(Wells, 1969, p. 121),}$$

substituting values

$$V=\frac{35 \times 885 \times 0.1}{31{,}103}=0.0996 \text{ c per mg.}$$

This figure was sufficiently close to 0.10 cent to round off for subsequent value calculations.

The "Radford" factor (Wells, 1969, p. 35) was used in computing hole volume. Theoretically a 7.5-inch drive shoe should cut 0.3068 square feet of material, but because of rounding and abrasion, it probably cuts less. The "Radford" factor implies a 7.5-inch drive shoe will cut, on an average, 0.27 square feet of material. A 1-foot drive would include a sample volume of 0.27 cubic feet or 1/100 cubic yard. Using the "Radford" factor, gold values can be computed by the following formula

$$\text{cents per cubic yard} = \frac{W \times V \times 27}{A \times D} \quad \text{(Wells, 1969, p. 34),}$$

where

W = weight of gold in milligrams,
V = value of gold in cents per milligram,
A = effective area of drive shoe in square feet,
D = length of sample in feet, and
27 = cubic feet in cubic yard.

For example, value calculations for a 2-foot section of the lower part of hole A (422–424 ft.), if

W = 45 milligrams of gold,
V = 0.1 (as just calculated),
A = 0.27 (Radford factor), and
D = 2,

$$\text{cents per cubic yard} = \frac{45 \times 0.1 \times 27}{0.27 \times 2} = \$2.25.$$

GOLD VALUES OLD AND NEW

Gold values in dollars per cubic yard are shown for holes A, B, and C on plate 2. In all three holes, the lower 80–100 feet contains the bulk of the gold. The richest sample consisted of a 2-foot interval in hole B (277–279 feet), which contained gold equal to a \$6.35 per cubic yard. A 5-foot section of hole C (289–294 feet) gave a value of \$2.80 per cubic yard, the highest for that hole; and the interval 420–422 feet in hole A produced values of \$2.60 per cubic yard, the highest for hole A. Above the high-value zone in the lower part of each hole, values do not exceed 12 cents per cubic yard and rarely exceed 2 cents per cubic yard.

The upper 10 feet of bedrock in holes B and C contain appreciable gold, probably gold lodged in the fractures of the bedrock by fluvial processes and not lode gold. The values drop off rapidly as the holes penetrate deeper, and presumably fresher, less-weathered bedrock. The old adage that gold values are always highest on the bedrock does not seem to obtain here. In hole A gold values are quite low on the bedrock and increase upward to a maximum at 12–25 feet above bedrock. Clay beds in the lower gravel, if correctly placed as interpreted from drilling characteristics, do not seem to act as barriers or false bedrock horizons, for gold values do not seem to be in any way related to them.

Although holes B and C are separated by no more than 200 feet horizontally, there is considerable variation in gold content between the two. Other than the lower bedrock contact, it would be difficult to correlate any overlying zones solely on the basis of gold values. However, the 1939 drilling indicates high values near the 250–260-foot level (fig. 18) for all three holes.

Samples from the 1939 drilling yielded considerably higher values than samples from the 1968 drilling for holes at the same locations (fig. 18). Hole B was drilled to a depth of only 145 feet in 1939, at which point the clay-rich material penetrated was interpreted to be weathered bedrock. A refraction seismic profile that was run across the location of hole B in 1967 indicated deeper bedrock, and the 1968 drilling program proved this interpretation to be correct. Real differences in gold values due to the slight shift in position of the drill holes would be expected to balance. Weighted averages show that the differences do not balance; rather, values obtained by the 1968 drilling are approximately 50 per-

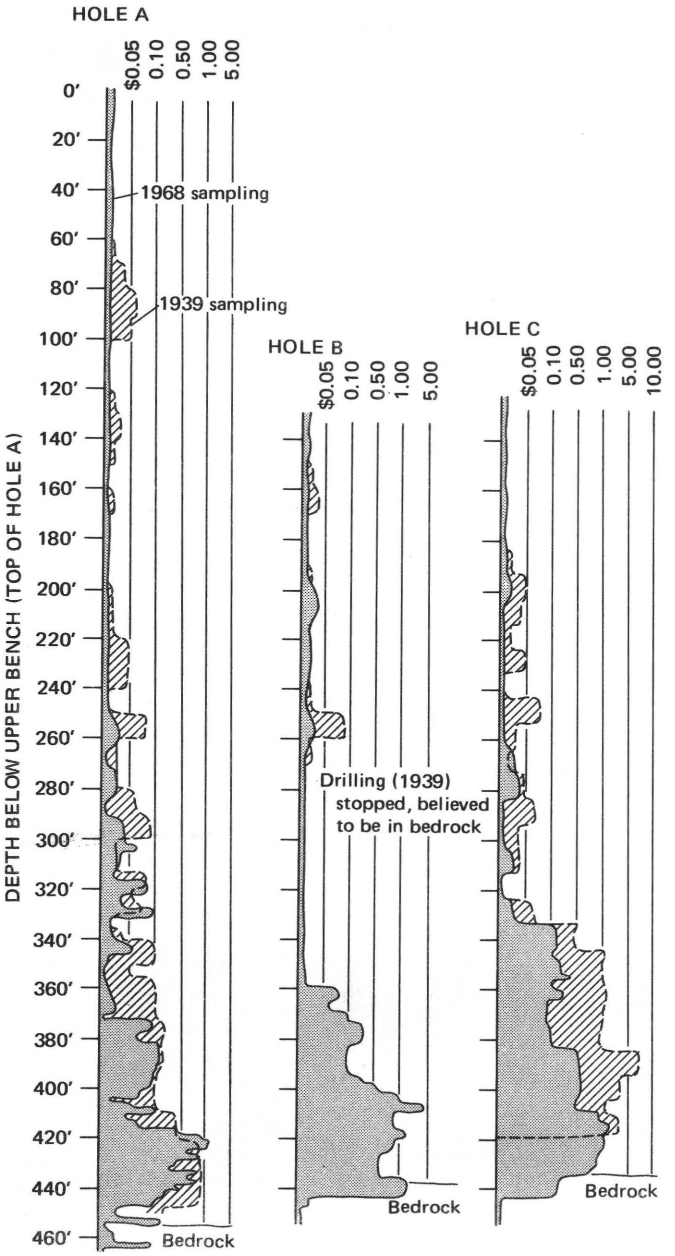


FIGURE 18.—Comparison of gold values (per cu yd) obtained by drilling, 1939 and 1968, North Columbia hydraulic pit.

cent of those obtained from the 1939 drilling (table 1). Different methods of recovery, sample concentration, and value calculation must be responsible for the consistent difference in evaluation. It is impossible to say with the information available which evaluation is more correct.

A total of 61 holes were drilled and sampled in the North Columbia diggings in 1939. Using the drill records from these holes (made available by the property owners), it was determined that 21.8 million cubic yards of the lower gravel contained $17.7 million in gold at an average grade of 81.2 cents per cubic yard (Peterson and others, 1968, p. 10). To conservatively evaluate the gold-producing gravel, we should probably consider reducing the total figure obtained from the 1939 drilling by as much as 50 percent (table 1). This gives a total of $8.6 million. It must be kept in mind that this figure is more correct only if the gold values obtained from our 1968 sampling program are more accurate than those obtained in 1939.

Gold values for upper and lower gravel at selected localities obtained from both published and unpublished reports on the production records and drilling (sampling) in the area are given in table 2. Some caution is advisable in evaluating the data, for much of this information, before being permanently recorded, existed as hearsay or speculation passed by word of mouth. If, however, it is assumed that these figures are approximately correct, it is apparent that the values vary widely from place to place along the channel. The relatively high values at Liberty Hill, French Corral, and Smartville probably can be attributed to the almost exclusive presence of the lower gravel at those places. The thick low-grade upper gravel prevalent in many of the other areas was virtually absent at these localities.

In figuring the averages, the abnormally high values of the lower gravel at Derbec and in the area from Dutch Flat to Indiana Hill were excluded because these values were determined from the unusually rich gravel mined within only a few feet of bedrock. The averages of $0.13 and $0.59 per cubic yard for the upper and lower gravel, respectively, probably are representative values in generalizing about the vast amount of gravel along the major tributaries of the ancestral Yuba River.

SIZE, SHAPE, AND SURFACE CHARACTERISTICS OF THE GOLD

The unamalgamated detrital gold recovered from drill holes A, B, and C was studied with the aid of a

TABLE 1.—*Comparison of gold values obtained from drilling, 1939 and 1968, in North Columbia hydraulic pit at approximately the same location*

[Values expressed as dollars per cubic yard at gold prices of $35 per oz]

Drill hole	Sections	Depth (ft)	Dollar value 1939	Dollar value 1968
A	Upper	375	0.036	0.016
	Lower	80	.62	.49
	Entire	455	.14	.10
B	Upper	230	.017	.007
	Lower	78	....	.81
	Entire	308	.017	.21
C	Upper	210	.031	.013
	Lower	100	2.43	.668
	Entire	310	.805	.223
Average	Upper		.028	.012
	Lower		1.53	.66
	Entire		.32	.17

TABLE 2.—*Gold values in dollars, obtained from mining records and drill sampling for selected areas along the ancestral Yuba River*

[Values adjusted to a $35.00 per oz gold price]

Location	Upper gravel	Lower gravel	Undifferentiated	Source
Gold Run	0.08	0.30	0.24–0.32	Hydraulic Mining Comm. of Calif.
Dutch Flat to Indiana Hill	.19	(up to 15.00)	....	Lindgren, 1911, p. 71.
Dutch Flat	.185	.68	.43	Hydraulic Mining Comm. of Calif.
Liberty Hill	.24	1.40	.24–.39	Do.
Christmas Hill, Little York Diggings	.115–.17	.34	.27	Do.
You Bet, Red Dog	....	......	.15	Do.
Hunts Hill, Quaker Hill, Buckeye Hill	.11	......	.255	Do.
Scotts Flat	.10	......	......	Lindgren, 1911, p. 43.
Sailor Flat, Blue Tent	.034	......	.12–.24	Hydraulic Mining Comm. of Calif.
Blue Tent	.042	.255	......	Lindgren, 1911, p. 71.
Omega	......	......	.23	Do.
Relief Hill	......	......	.15–.22	Hydraulic Mining Comm. of Calif.
Snow Point	......	......	.19	Do.
Orleans Flat, Woolsey Flat	......	......	.254	Do.
Derbec	......	6.30 (lowest gravel)	......	Lindgren, 1911, p. 71.
Malakoff Diggings	.049–.067	.56	......	Do.
Malakoff Diggings	.065	.56	.165	Hydraulic Mining Comm. of Calif.
Malakoff Diggings to Badger Hill Diggings	......	......	.15–.20	Do.
North Columbia to Cherokee	.17–.25	......	......	Lindgren, 1911, p. 71
North Columbia to Badger Hill Diggings	.18	.39	.20	Do.
Badger Hill Diggings	.06	.26	......	Unpub. mine records.
North San Juan to Smartville	......	......	.51–.63	Lindgren, 1911, p. 71.
French Corral	.24	.70	.50	Unpub. mine records.
Smartville	......	1.05	......	Do.
Averages	.13	.59	.27	

binocular microscope, and the following generalizations were made. Most of the fragments in the lower rich gravels are 1–2 mm in diameter and 0.1–0.2 mm thick. The largest flake was 3.0 mm in diameter, the smallest 0.3 mm. Grains smaller than 1.0 mm diameter are generally 0.1–0.05 mm thick. Approximately 80 percent of the gold weight for hole B and 50 percent for hole C within the lower rich parts of the holes is derived from gold fragments of a diameter greater than 1 mm. Gold coarser than 1 mm in diameter was not observed more than 80 feet above bedrock in the holes. This fact seems to imply that during deposition of the upper gravel either (1) the source region was supplying only fine gold; (2) active reworking in the rivers was physically breaking down the gold, or (3) only the fine gold was being transported to the rivers, the coarse gold lagged behind in the regolith. Flour gold, if present, was likely lost during the drilling and panning procedures. However, Lindgren (1911, p. 67) states that, "flour gold *** is not abundant in the Tertiary or present gravels of the Sierra Nevada." He believed the flour gold was swept out into the sedimentary rocks that fill the Great Valley.

Generally the gold flakes are shiny and rough; some show coatings of iron oxide and silica. The grains are flattened with rounded edges that show general abrasion (fig. 19). Some grains have particles of magnetite, ilmenite, and quartz adhering to them.

DRILL HOLES, SAN JUAN RIDGE

Between the Malakoff Diggings and Woolsey Flat, the gravel-filled ancestral Yuba River channel is buried beneath a cover of colluvium and volcanic breccia which is as much as 650 feet thick. Seismic refraction techniques were employed in 1967 and 1968 to locate the position of the buried channel midway between the exposures at Malakoff Diggings and Woolsey Flat (Peterson and others, 1968). Interpretations of the seismic data indicated that the channel center was in the vicinity of the Upper Derbec Spring along the Graniteville Road and was covered by approximately 900 feet of volcanic breccia. A drilling program was set up to drill through the thick volcanic breccia and the suspected underlying gravel to bedrock. During the late summer and fall of 1968, four holes were drilled (rotary drill) along the Graniteville Road in an attempt to prove the geophysical interpretation of the channel center location and to sample the suspected rich lower gravel. "Ditch" samples separated from the mud by a shaker with a 30-mesh screen were collected every 5–25 feet for the purpose of noting lithologic characteristics and concentrating heavy minerals, gold particularly. Silt and clay-sized cuttings that filtered below the shaker were also collected and examined. Plate 2 shows

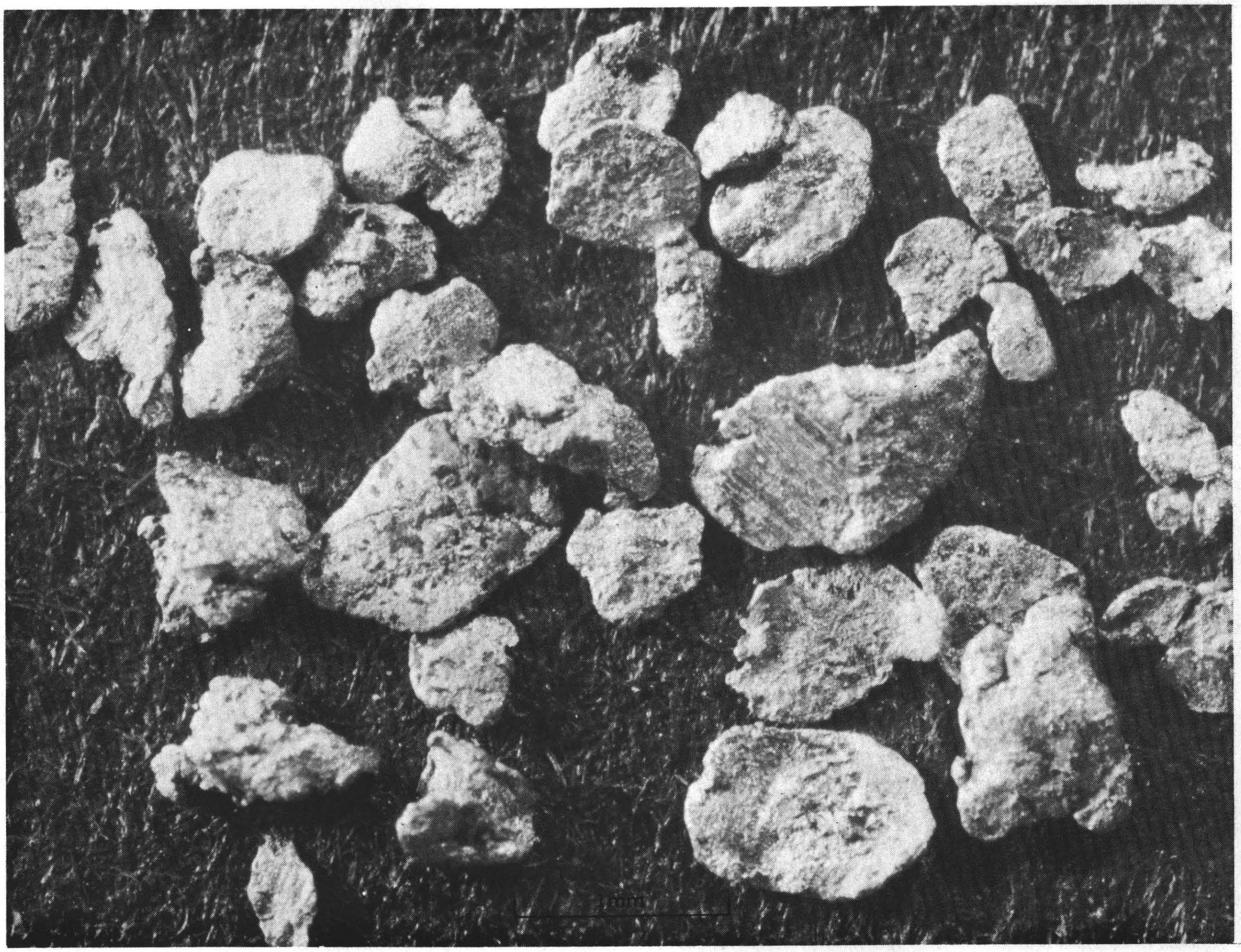


FIGURE 19.—Typical placer gold derived from lower gravel in North Columbia hydraulic pit.

the logs for all four drill holes as well as measured sections of the bounding gravel exposures at Malakoff Diggings and Woolsey Flat. Electric logs run in the holes subsequent to their drilling allowed a more precise "pick" of the boundaries of the lithologic units. All four drill holes penetrated sands and clays below the volcanic breccia and above the bedrock. Thickness of the volcanic breccia ranged from 500 to 650 feet. The samples collected from the gravel section were panned by hand and examined for gold. As gold was absent in most samples and rare in others, it was not worthwhile to construct plots of gold content similar to those produced for holes A, B, and C in the North Columbia diggings. Values determined were less than $0.01 per cubic yard. The heavy-mineral plots are discussed under the section "Other Heavy Minerals." The disappointingly low gold values, together with the fine-grained textural characteristics of the section, clearly suggest that the part of the gravel drilled through correlates with the upper sections as exposed at Malakoff Diggings and Woolsey Flat (pl. 2). It seems that all four holes were drilled parallel to and along the margin or flood plain of the channel as it passes beneath the volcanic rocks on San Juan Ridge. In the light of the information obtained from the drilling, the suspected trace of the buried channel center was redrawn (fig. 2).

GOLD SOURCE

Evidence suggests that the bulk of the gold in the Tertiary gravel has been derived from the gold-bearing quartz veins occurring within the low-grade metamorphic rocks of the Sierras. The gravel that has the highest gold values also contains abundant detrital fragments of white "vein" quartz and blue-gray siliceous phyllite and slate common throughout the foothill region. Furthermore, high concentration of gold in the gravel is essentially restricted to the areas where the ancient rivers crossed the gold-bearing quartz veins in the bedrock of the foothills region (Lindgren, 1911, p. 65–66).

In order to compare the composition of the placer gold with the lode gold of the Sierra Nevada, trace-element contents were determined for 20 samples of native gold (table 3). Nineteen of the samples were selected from detrital gold flakes recovered from drill holes A and C within the North Columbia hydraulic pit. The analyses of these samples can be compared with the analyses of a small nugget from the bedrock lode mines of the Alleghany district, a likely source for the gold in the gravel at North Columbia. Except for the silver common in nearly all samples of native gold, only copper is present in all samples; the copper content ranges from 100–1,000 parts per million. Small amounts of lead and iron are present in some samples. These data show that the placer gold is indeed similar to the lode gold indigenous to this part of the Sierra Nevada and suggest that the gold was derived locally.

The bedrock gold mines in the northern Sierra Nevada included in this study show a distinct spatial relation to outcrops of ultrabasic rocks (fig. 2). Most of the quartz veins and mines are either adjacent to the ultramafic rock bodies or within several miles to the east of them, a relation recognized by the early miners and reported in more recent studies (Ferguson and Gannett, 1932). These areas probably provided a rich source for much of the gold within the ancestral Yuba River drainage. Of course, much of the gold in the gravel was derived from higher level rocks that have been completely removed by erosion. The principal gold-producing quartz veins in the Alleghany district dip 25°–40° north to northeast (Ferguson and Gannett, 1932, p. 29) and project at higher eroded levels several miles to the south and southwest. These veins may have provided the bulk of the gold produced from the gravel at Moore's, Orleans, and Woolsey Flats, and the Derbec and Malakoff Diggings areas; they may have provided a significant portion of the gold in the hydraulic diggings farther down the channel as far as Smartville. The vein system in the Nevada City–Grass Valley area probably contributed a significant portion of the gold recovered from the gravel in that area as well as in the Blue Tent and Sailor Flat diggings. Rich gravels in the You Bet to Dutch Flat area may have been derived from a source south of the mapped area as well as from northeast of Dutch Flat.

TABLE 3.—*Trace-element content of native gold from placers and lode deposits, San Juan Ridge, Calif.*

[Analyst: A. L. Sutton; analyses by standard six-step spectrographic analysis. Elements looked for but not detected: B, Ba, Be, Bi, Cd, Co, Ga, La, Mn, Mo, Pd, Pt, Se, Sn, Ti, V, Y, Yb, Zn, Ir, Os, Rh, Ru. N=not detected, at limit of detection or at value shown; L=detected, but below limit of determination or below value shown]

Sample No.	Weight (mg)	Fe (percent)	Ag (ppm)	Cr (ppm)	Cu (ppm)	Pb (ppm)
Detrital gold from drill holes in North Columbia hydraulic pit						
A126–128	5.88	L.003	120,000	N	300	N
A138–142	9.85	.005	270,000	N	200	N
A142–145	6.01	N	92,000	N	300	N
A157	5.60	N	31,000	N	100	N
A158	6.62	N	71,000	N	100	N
A159	6.48	.007	73,000	20	100	N
A160	6.87	L.033	64,000	N	150	L
A161	6.95	L.003	86,000	N	150	N
A162–164	9.75	L.002	92,000	N	100	N
C75–77	4.60	L.005	62,000	N	1,000	N
C92–96	7.34	.003	56,000	N	500	N
C97–101	9.96	L.002	90,000	N	500	N
C104	9.80	N	59,000	N	300	L
C105	7.60	N	94,000	N	300	L
C106	9.38	L.002	64,000	N	1,000	L
C107–108	6.56	L.002	52,000	N	1,000	L
C109	7.00	L.002	76,000	N	300	20
C110–112	7.69	L.002	64,000	N	500	L
C101A–109A	6.86	L.002	130,000	N	200	L
Lode gold from Alleghany district						
W.Y.–S26–69	5.37	L.002	170,000	N	150	L

GOLD OCCURRENCE

Why does the bulk of the placer gold occur in the lower 80–100 feet of gravel? It is worthwhile to examine several possible explanations.

It is presumed that a lower, relatively thin layer of compositionally and texturally immature gravel was always present on the river channel floor during the long interval of downcutting. This thin veneer of gravel represented the coarse material being transported by the river much as does the gravel in the bottom of the Colorado River today (Berkey, 1935). While most of the constituents of the gravel were undergoing lateral transport along the river during times of flooding and high runoff, the gold that was constantly being added to the gravels was lagging behind, much as it does in a sluice box. As the volume of gravel in the river bed essentially remained the same through additions of new detritus and removal of old, the gold concentrations gradually increased. Most of the gold that was eroded during the early downcutting history of the ancestral Yuba River ended up within this giant sluice box. Certainly some gold was flushed beyond the river and wound up in the marine sediments to the west. As the river ceased to downcut and began aggrading, the nature of the weathering and erosion of the surrounding hill slopes changed. Whereas physical weathering was predominant in breaking up and moving the coarse detritus on the steep side slopes, chemical weathering became common as the slopes became less steep and thick soils were able to develop. Only the most resistant minerals survived the intense weathering process. Judged by the amount of vein-quartz pebbles in the upper gravel, a great deal of potential gold-rich bedrock was eroded. What happened to the gold? Certainly the low gold content of the upper gravel does not reflect all the gold that was ultimately released. Several possibilities come to mind: (1) the gold was physically and chemically broken down to a size small enough to be transported by the river and was deposited offshore in the marine environment; (2) the prevailing conditions of chemical weathering facilitated the removal of the gold in solution; or (3) the gold became concentrated in the soil zone and, because of the low slope gradients, was not transported in high concentrations into the rivers. If indeed the gold was not moved into the rivers (3), it should still be present where the old soil zones are preserved, primarily beneath the volcanic cover. Perhaps much of the gold that became concentrated in the younger rivers (intervolcanic and recent) was derived from this old gold-rich regolith.

A more definitive solution to this problem will have to await (1) exploration for gold in the upper Eocene sediments in the Great Valley and (2) laboratory study of physical and chemical resistance of gold in a variety of environmental conditions.

GOLD RESOURCES

Since the days of the famous Sawyer decision in 1884, when most of the hydraulic mining ceased, people have calculated volumes and values of minable gravel remaining along the Tertiary river courses. As the costs of mining, water, and gold changed, these figures were reevaluated, recalculated, and somewhat refined. It has long been known that a sizable gold resource remains dispersed in the gravel. Whereas equipment and labor costs markedly increase oweing to inflation, the price of gold remains virtually the same, thereby greatly reducing the incentive to mine this tremendous resource. With the presently known and allowable mining techniques, it is understandable that in recent years few mining ventures have been attempted and that only a small percentage of these have survived.

Lindgren (1911, p. 81) estimated that approximately $507 million ($35 per oz) in gold was produced from the Tertiary gravel. Estimates of the gravel yardage removed in deriving this $507 million in gold was subsequently calculated at 1,585 million cubic yards (Gilbert, 1917), an average yield for the entire body of mined gravel gives $0.32 per cubic yard. This figure is probably too high a value to use in computing total gold content of the remaining gravel, as much of the unmined gravel is the gold-poor upper gravel.

Probably the most detailed and complete determinations of volume of unmined gravel were made by Arthur Jarman (1927) in his report of the Hydraulic Mining Commission to the California State Legislature. This report is on the feasibility of resuming hydraulic mining by construction of debris dams. Table 4 draws on much of the information contained in Jarman's report. Figure 20 shows where gold-rich lower gravel is believed to lie along the ancestral Yuba River channel.

The $0.193 per cubic yard average obtained by dividing the estimated total gold value of $188,085,000 by the total volume of unmined gravel, 977,440,000 cubic yards. This figure is substantially lower than the $0.32 per cubic yard value obtained by using Lindgren's (1911) and Gilbert's figures (1917) and presumably reflects the lower tenor of the remaining gravel.

As can be seen from table 4, the gravel and gold resource between Malakoff and Badger Hill Diggings accounts for more than 75 percent of the total from all areas considered. The figure of $0.175 per cubic yard (from estimates by Jarman (1927) on the Hydraulic Commission of California), which is used to obtain the $140 million total gold value, is similar to the average value of $0.17 per cubic yard obtained from the 1968 drilling in the North Columbia diggings (table 1). The mapping for this study did not include all the Tertiary gold-bearing gravels known to exist throughout the foothill region of the Sierra Nevada. From field reconnaissance checks and a study of published and unpublished accounts of the unmined gravel, however, it is doubtful that an area exists in which gravel quantities and gold values exceed those in the Badger Hill–Malakoff region. It would seem, therefore, that the deposit between Badger Hill and Malakoff would be the most likely target for a resumption of large-scale mining of the Tertiary gravel.

The figures for unmined gravel in table 4 do not include deposits beneath the volcanic cover on San Juan, Harmony, or Washington Ridges. Our knowledge of the occurrence and gold values of gravel beneath the volcanic rocks is meager at best, but it is doubtful

TABLE 4.—*Areas containing appreciable unmined gravel with estimated gold content along the ancestral Yuba River drainage*

[Gravel volumes from Jarman (1927) gold values (per cubic yard) from table 2]

Area	Volume of unmined gravel (cubic yards)	Estimated average gold value per cubic yard ($35 per oz)	Estimated total gold content ($35 per oz)
Gold Run	75,000,000	$0.28	$21,000,000
Liberty Hill	4,500,000	.315	1,400,000
Dutch Flat	28,500,000	.43	12,000,000
Christmas Hill, Little York Diggings	3,440,000	.27	930,000
You Bet, Red Dog	20,000,000	.255	5,100,000
Hunts Hill, Quaker Hill, Buckeye Hill.	5,000,000	.255	1,275,000
Omega	24,000,000	.225	3,240,000
Relief Hill	15,000,000	.185	2,780,000
Sailor Flat, Blue Tent.	2,000,000	.18	360,000
Malakoff Diggings to Badger Hill Diggings	800,000,000	.175	140,000,000
Totals	977,440,000	.193	188,085,000

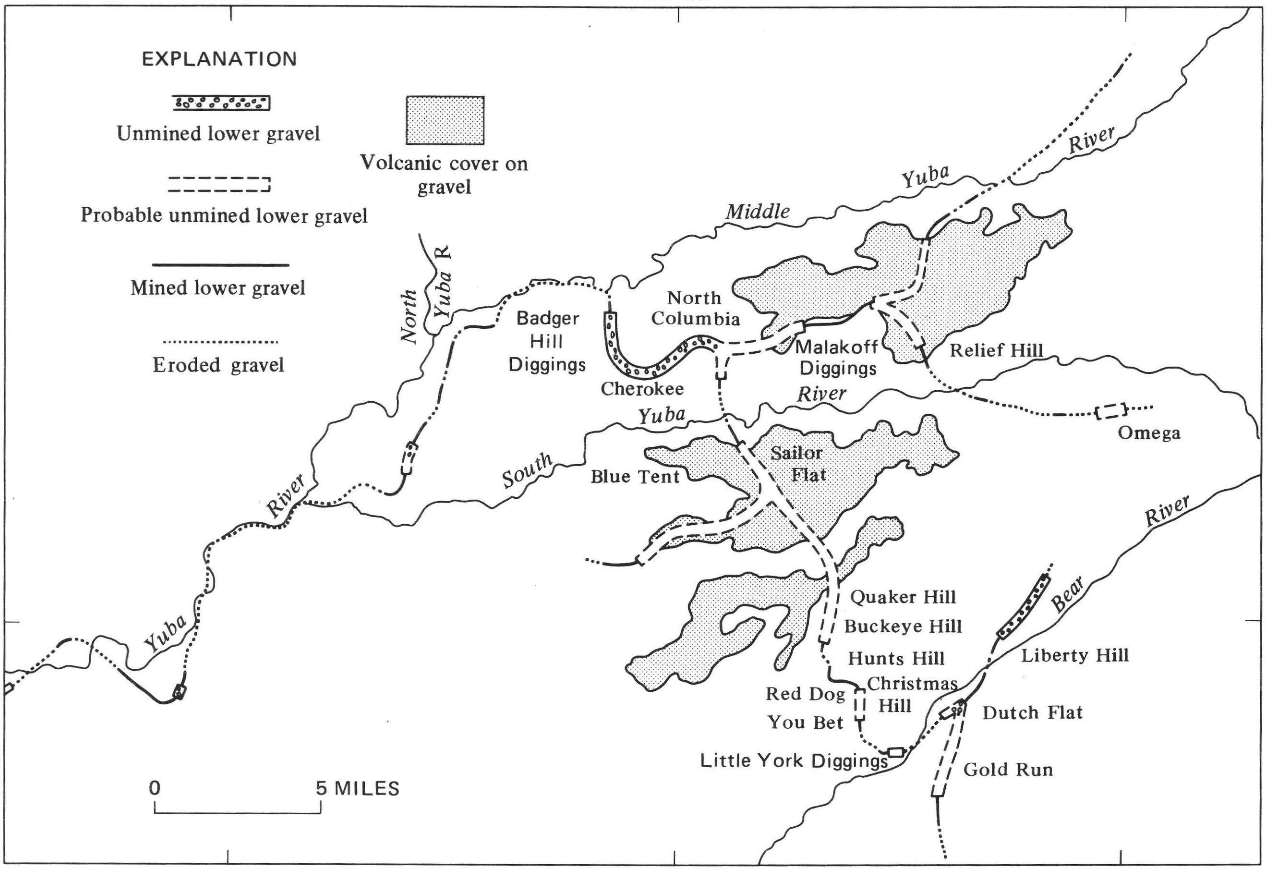


FIGURE 20.—Part of the ancestral Yuba River drainage showing areas of mined and unmined relatively rich gravel along the river channel.

that the total volume of material would increase the calculated totals by as much as 50 percent.

No method has yet been devised for recovering the gold from the Tertiary gravel more efficiently than the hydraulic. In referring to the rich deposit on San Juan Ridge, Jarman (1927) wrote, "It does not appear to be possible to work this gravel profitably by any other method than that of hydraulicking," and that statement seems appropriate today. Even "in place" leaching, now receiving some consideration by various groups, was discarded by Jarman as a poor method of removing the gold from the gravel. The economic recovery of the gold dispersed through the widespread Tertiary gravel remains a challenge to the keenest minds in the mining industry. It is not unreasonable to foresee the day when the gold will be removed as a byproduct of the gravel used principally for construction and decorative uses. Current prices (1970) in the San Francisco Bay area for decorative rock of the type most common throughout the "upper" Tertiary gravel is $19-$28 per cubic yard!

SECONDARY SULFIDES

Common throughout much of the lower "blue gravel" are sulfides, primarily pyrite. They occur within the sandy matrix, form coatings on pebbles and cobbles, and are most plentiful in areas marked by an abundance of carbonized wood. The fresh and shiny crystals are quite clearly of a secondary nature, having formed after deposition of the gravel. The pyrite accumulations are restricted to gravel zones below the water table. A deep-red color of the overlying gravel is produced by oxidation of the contained pyrite as a result of lowering of the water table and exposure to the air. Pyrite accounts for more than 50 percent of the heavy-mineral fraction within portions of the lower and middle exposures of gravel in the North Columbia pit (pl. 2). X-ray diffraction patterns of heavy-mineral concentrates derived from drill cuttings in the North Columbia diggings reveal that all the sulfide is pyrite and not marcasite or arsenopyrite.

One small mining venture in the vicinity of Birchville in 1967 reported that lower blue gravel was yielding 10 pounds of sulfides per cubic yard of gravel processed. This concentrate, however, was far from being pure sulfide; it contained other heavy minerals.

Nodular and granular pyrite from a gravel mine in Butte County yielded gold at the rate of \$173 to the ton (Lindgren, 1911, p. 76). At \$20 to the ounce this would be equal to 8.65 ounces of gold per ton of sulfide or approximately 270 ppm. This figure seems abnormally high when compared with atomic absorption gold analyses of pyrite obtained during this study. Seven separate samples of pyrite all showed less than 0.10 ppm gold.

The pyrite within the gravel is most often closely associated with carbonized wood. It exists as nodules, coatings, and thin seams as much as ⅛ inch thick. The genesis of the pyrite is probably similar to that occurring within coal deposits (Newhouse, 1927). An ideal environment for the production of low-temperature pyrite was probably created during and following deposition of the gravels. The prevailing subtropical climate (MacGinitie, 1941, p. 73) very likely promoted development of thick, lush vegetation that was periodically carried into the major drainages where it formed temporary local dams along the channel. Sediment would fill in behind such "log jams" and eventually cover them, thereby preventing their destruction by oxidation. A moderately warm mean annual temperature of 65°F (MacGinitie, 1941, p. 78) may have promoted the growth of anaerobic bacteria active in producing hydrogen sulfide from the buried trees and shrubs. Hydrogen sulfide would have readily reacted with the iron-rich ground water producing FeS that was subsequently changed to FeS_2 (Edwards and Baker, 1951; Galliher, 1933). Eventually, as the water table dropped, much of the pyrite in the upper and middle sections of the coarse gravel layers was oxidized and leached. Siderite and limonite-rich cemented zones a few inches to several feet thick, common throughout much of the middle section of the gravel, probably record the water table positions at various times in the postdepositional history of the gravel.

OTHER HEAVY MINERALS

Other heavy minerals in the panned concentrates were studied to better understand the depositional environment of detrital gold.

METHODS OF CONCENTRATION AND IDENTIFICATION

Bromoform (sp gr 2.85) was used to separate the few light minerals not removed in the hand-panning process. A small magnet was useful in removing drill steel from the samples, and with it the magnetite abundant in a few samples. A relatively nonmagnetic heavy mineral fraction ranging in size from 0.50 to 0.0625 mm (medium sand to coarse silt) was thus produced for study.

Minerals were identified by optical methods and checked occasionally by X-ray diffraction techniques. Because percentages of minerals were estimated, they are not to be regarded as precise figures. Samples selected for examination generally were taken at intervals of 10–15 feet in the churn drill holes, and closer intervals where significant mineral changes were occurring. More widely spaced samples were selected for examination from the rotary drill holes on San Juan Ridge where heavy-mineral contents were relatively uniform.

CHURN DRILL SAMPLES, NORTH COLUMBIA DIGGINGS

Vertical distribution of heavy minerals is plotted along the section for drill holes A and C in the North Columbia diggings (pl. 2). The heavy minerals plot of hole A is based on examination of 41 samples, that for hole C on 20 samples. Pyrite, ilmenite, zircon, siderite, amphibole, epidote, and chlorite are present in quantities large enough (>5 percent) to plot. The category "other" includes rock fragments, sphene, garnet, tourmaline, zoisite, rutile, leucoxene, and pyroxene.

Pyrite, of secondary origin, is present in significant quantities. It seems quite likely that the first appearance of pyrite marks the water table or boundary between oxidation (red gravel) and reduction (blue gravel). This horizon is at a similar level, 2,675 to 2,685 feet elevation, in all three holes, as would be expected if it represents a water table. Ilmenite and zircon make up most of the heavy minerals in the upper (oxidized) part of the gravel (fig. 21). This might be expected because ilmenite is more stable under oxidizing than reducing conditions, and zircon is a very durable mineral both physically and chemically. The lower gravel is characterized by a variety of both stable and unstable mineral types including gold (fig. 22). Amphibole, primarily actinolite, and epidote are restricted to the lower 100 feet of gravel, chlorite to the lowest 30 feet. Authigenic siderite, present in the lower part of hole A, would be expected in a reducing environment (Pettijohn, 1957, p. 460) such as produced the pyrite.

On the basis of the heavy-mineral suites and detrital gold, the gravel can be separated into four zones, each succeeding lower zone characterized by the addition of one or more new minerals: (1) an upper zone characterized by the presence of ilmenite and zircon, (2) an upper middle zone distinguished by the appearance of pyrite, possibly siderite, less zircon, and increasing gold, (3) a lower middle zone where amphibole and epidote are present with less pyrite and gold values are highest, and (4) a lower zone characterized by the appearance of chlorite. Although holes A and C are

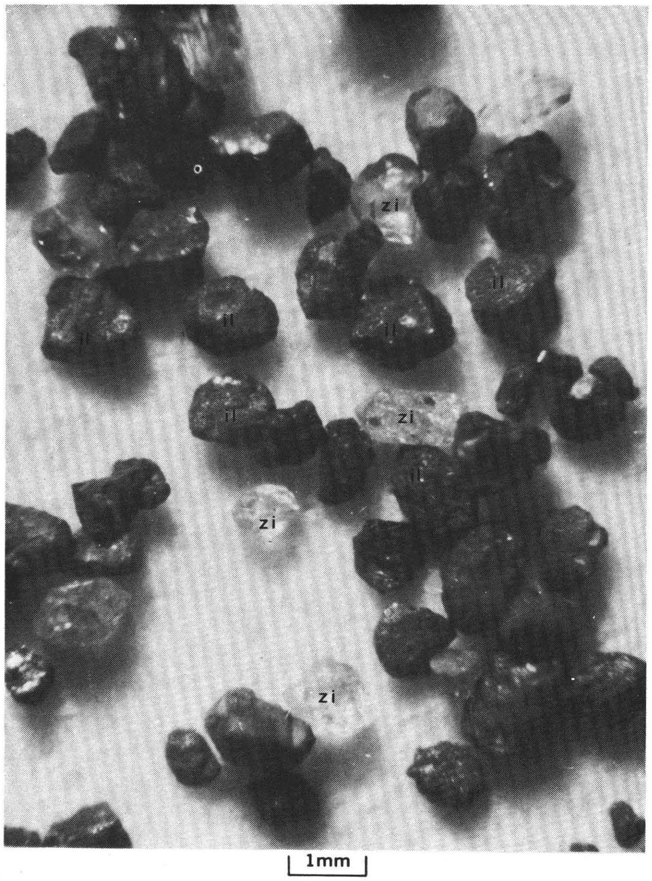


FIGURE 21.—Heavy minerals from upper gravel of hole A in the North Columbia Diggings. Sample collected from a depth of 15 feet. zi, zircon; il, ilmenite.

FIGURE 22.—Heavy minerals from lower gravel of hole A in the North Columbia Diggings. Samples collected from a depth of 365 feet. zi, zircon; il, ilmenite; py, pyrite; si, siderite; ep, epidote; ac, actinolite; G, gold.

separated by no more than half a mile, there is no reason to believe that roughly the same zonation would not be continuous throughout most of the drainage basin.

Detrital platinum was not found in any samples, including surface samples. Chemical analysis of the heavy-mineral concentrates from the lower part of hole A revealed that platinum, palladium, and rhodium were present in negligible amounts varying from 0.1 to 0.02 ppm.

Whitney (1880) reported that "quite a number of diamonds" has been recovered from the gravel in the vicinity of French Corral, the largest 7¼ carats. The occurrence of diamonds within Tertiary gravel from Placer County have also been reported (Mining and Scientific Press, 1870) although the precise location of their occurrence is not known. With this knowledge in mind, the heavy-mineral concentrates obtained for this study were carefully searched for diamonds, but with negative results.

DEPOSITIONAL HISTORY

Even though postdepositional solution and weathering effects have altered some minerals in the gravel, the vertical changes in the heavy minerals can be used to reconstruct the history of deposition. Since the lowest gravels contain the same heavy minerals as the bedrock and in somewhat similar percentages, local source areas probably contributed the bulk of detritus in the early history of the river. Deposition probably was rather rapid, with a minimum of winnowing and reworking, and the rather large percentages of amphibole, epidote, and chlorite indicate only slight chemical weathering. The coarse and poorly sorted texture of the lowest gravel supports this conclusion. The boundary between zones two and three is rather abrupt and seems to represent a major change in depositional characteristics. Only the most resistant and durable heavy minerals, primarily zircon and ilmenite, were deposited in these younger sediments. Euhedral and subhedral zircon and quartz grains are fairly common, implying little transportation and reworking. Rather, chemical weathering is thought to have become a dominant factor in the breakdown of the rocks. As slope gradients were lowered, soil formation was allowed to continue for longer periods of time without removal by sheetfloods or mass-wasting processes. Only the most physically and chemically resistant minerals would have survived the intense weathering of the subtropical climate believed to have prevailed at that time (MacGinitie, 1941, p. 73).

The presence of pyrite and siderite in zone two does not tell us much about the depositional history of the gravel, because these minerals are postdepositional in origin; however, their presence does imply that organic matter was somehow trapped and buried in the gravel before destruction by oxidation.

Zone two is gradational with zone one. In zone one gold values are the lowest. The amount of zircon increases, and compared to zone two, overall grain size decreases, as clay, silt, and sand are predominant. Source rocks of the sediments deposited here have undergone extensive physical and chemical breakdown.

ROTARY DRILL HOLE SAMPLES, SAN JUAN RIDGE

Heavy minerals are plotted for the gravel portion of holes No. 2, No. 3, and No. 4 on San Juan Ridge (pl. 2). These holes were drilled primarily in an attempt to intersect the deepest, gold-rich part of the gravel; it can be readily seen from the textures and heavy minerals found in all four holes that the objective was not achieved. The textures, for the most part, are typical of the upper bench gravel, similar in some respects to the upper gravel section exposed at Woolsey Flat and Malakoff Diggings (pl. 2). The heavy minerals, with some exception, are also typical of the upper gravel. Ilmenite is ubiquitous; zircon is present in hole No. 3 only. Pyrite and siderite are secondary in origin, as in the drill holes in the North Columbia diggings, and are accounted for by a reducing environment. The entire gravel section is below the water table, because 500–650 feet of volcanic breccia overlies the gravel on San Juan Ridge. The amphibole in all three holes is mostly hornblende, which is similar to that in the overlying andesite breccia (upper part of holes No. 2 and No. 4). The hornblende in these samples is believed to have been derived from higher in the hole by caving, sloughing, and circulation of the mud; therefore, it should not be considered an inherent mineral of the gravel. Other than confirming the "upper bench" character of the gravel in these drill holes, the heavy minerals are not particularly useful. Only a few flakes of gold were found in the samples, and values are less than 1 cent per cubic yard.

SURFACE SAMPLES

Surface exposures of Tertiary gravel were sampled throughout the area in an effort to see if there was a systematic change in mineral suites along the river channel. Generally each sample consisted of two or three 15-inch pans of gravel. Whenever possible samples of both upper and lower gravel were collected at each locality. Heavy-mineral suites from representative samples are shown in figure 23. Generally the heavy minerals are similar to those found in the drill samples in the North Columbia diggings with some exceptions. Magnetite in minor amounts was removed with a hand magnet. As with the drill samples from the North Columbia diggings, the upper gravel is high in ilmenite and zircon, whereas the lower gravel has significant amounts of the less stable minerals, epidote, hornblende, actinolite, pyrite, and sphene. Pyrite was missing in many of the lower gravel samples because the exposures had been oxidized following the mining activities of the past century. Wherever fresh exposures of the lower gravel could be found, pyrite was present. X-ray patterns of samples collected near outcrops of ultramafic intrusive rocks (Liberty Hill and Little York) revealed both chromite and magnesian-chromite ($FeCr_2O_4$ with $MgAl_2O_4$) in the heavy-mineral suite.

No obvious systematic change in the heavy minerals is apparent along the channel in the area studied. The intrusive granitic and ultramafic rocks and the low-grade metamorphic phyllite, slate, quartzite, and schist cropping out in the foothills region most probably were the source for the heavy minerals found.

Heavy minerals from three superimposed textural units within the gravel along Interstate Highway 80 near Gold Run were examined; they are plotted in figure 24. All three units fall within the upper gravel stratigraphically, although the finer grained middle unit contains heavy minerals more characteristic of the lower gravel. It seems that at this particular locality, the normal depositional characteristics of the upper gravel were interrupted and a temporary return to conditions of more rapid deposition of unweathered detritus occurred. During times of heavy precipitation or landsliding, relatively fresh unweathered materials could have been carried into the rivers and locally overwhelmed the more normal sediments being deposited. It seems quite probable that this took place repeatedly throughout the history of the gravel deposition at various places along the length of the river channel.

TRACE OF RESTORED CHANNEL

The trace of the gravel-filled channel as it may have existed near the close of the Eocene is shown in figure 2. The flood-plain width indicated probably represents a minimum width. The flood plain was probably wider than shown in the western half of the area downstream from Badger Hill; this part of the flood plan has undergone more erosion than the part farther east, such as at North Columbia, where the retreating cover of volcanic rocks has more recently exposed the channel gravels. The wide expanse of gravel marking the position of alluvial deposition should be thought of as a valley fill developed in an area that had a fairly well integrated drainage system. The rivers were not as wide as the gravel fill, except perhaps in times of extraordinary floods; their channels meandered back and forth across the fill material.

Only that portion of the drainage is shown for which there is reasonably clear evidence for its reconstruction. Several isolated, outlying exposures of gravel cannot be tied definitely into the drainage system.

EVIDENCE FOR RECONSTRUCTING DRAINAGE

The evidence for reconstructing the drainage is primarily the location of preserved gravel deposits. Extensive drilling by private companies in the 1930's between North Columbia and Badger Hill Diggings provided the evidence for the positioning of the channel center in this locality; the center indicated in figure 2 is meant to correspond to the lowest or deepest position within the bedrock channel. In some places, as between North San Juan and French Corral, it is actually an incised trough sometimes referred to as a "gut." Elsewhere, it is merely the lowest point in the overall broad channel depression.

Rotary drilling on San Juan Ridge between Malakoff Diggings and Moore's Flat, together with information from the underground drift mine, the Derbec, provided data for the channel restoration in this area.

Pebble imbrication and crossbedding made possible a reconstruction of the drainage pattern in the southern part of the area mapped. It can be quite clearly shown that gravel in the Gold Run–Dutch Flat area was deposited by water flowing in a northerly direction and that this channel was definitely part of the same drainage system existing farther north in the vicinity of Nevada City and North Columbia. This conclusion was advanced earlier by Lindgren (1911) and Hudson (1955). Imbrication of cobbles and boulders in the lower gravel at Indiana Hill (fig. 25) and Little York (fig. 26) clearly indicate this pattern of current flow.

The present bedrock elevations on the floor of the channel, where exposed, provide further clues for restoration of the drainage system. These data must be tempered with the realization that tilting of the Sierra Nevada and local faulting of the channel gravel have appreciably altered the original slope of the river floor.

MAJOR TRIBUTARY EXTENSIONS BEYOND MAP AREA

Evidence for extension of the drainage system beyond the map boundaries to the northeast is scanty. The high parts of the Sierra Nevada have undergone deep erosion and the volcanic cover on the gravel has been removed from all but a few narrow ridge tops. The main channel, traced only as far as American Hill in this study, is shown by Lindgren (1911) to extend beneath the thin volcanic cap to the northeast, then bend around to the southeast much as the Middle Yuba River does today. The tributary coming in from the vicinity of the Sixteen-to-one mine at Alleghany is covered by volcanic rocks farther north but probably extends as far north as the town of Forest.

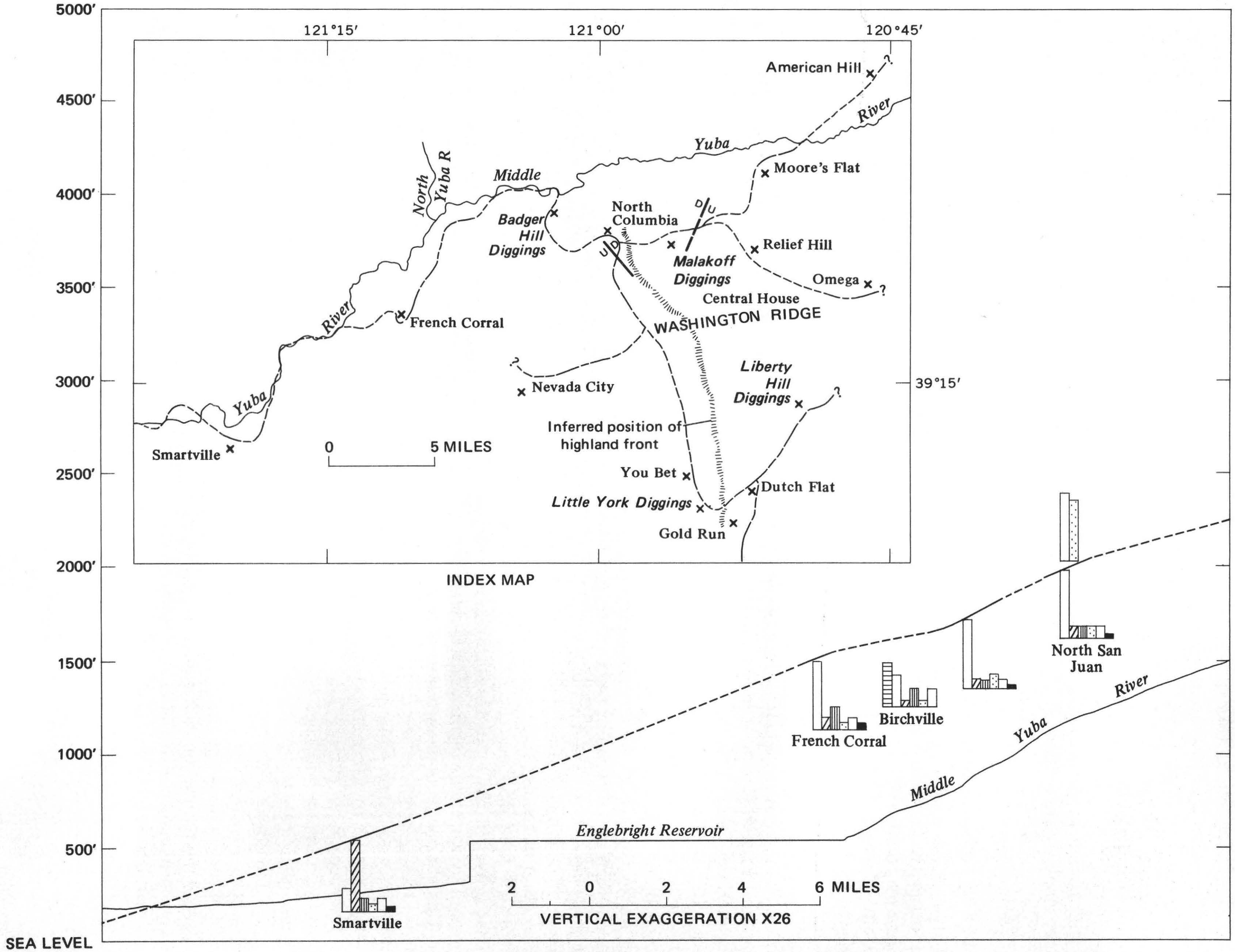
The mapping of this study was not extended south of the North Fork of the American River, although the gravel of this region would allow a much longer drainage restoration (Lindgren, 1911). Below Smartville, west of the map area, the gravel was traced to the present flood plain of the Yuba River. Projecting the present gradient of the ancestral Yuba River farther west places the channel beneath the land surface (fig. 23). Where last exposed near the present Yuba River flood plain, the gravel contains cobbles and boulders that are as much as 8 inches in diameter. From this fact, the river mouth is inferred to have been some distance farther west.

The location of the headwaters and size of the total drainage basin of the ancestral Yuba River will be discussed in a subsequent chapter.

DIFFERING INTERPRETATIONS

Lindgren (1911) showed a major tributary entering the main channel near North San Juan but I do not because the mapping did not reveal evidence for such a tributary. If such a tributary did enter here, the critical area of confluence has been destroyed. Mapping did not extend north as far as Camptonville, the nearest exposure of gravel in this direction.

In the area of the Malakoff hydraulic pit, Lindgren (1900) shows two drainages coming together—one from the north in the Bloody Run Creek area and one from the east, from the Relief Hill tributary. Lindgren's reconstruction shows the channel coming in from Bloody Run Creek bending around to the east and connecting with the exposed gravel at Woolsey, Moore's, and Orleans Flats. Field mapping in 1967 and 1968 revealed that only thin, isolated gravel deposits were present in the Bloody Run Creek area. It was concluded, therefore, that this gravel was deposited by a small tributary rather than by the main river. Furthermore, drilling in 1968 and 1969 established the presence of a thick section of sand and clay beneath the volcanic rocks on San Juan Ridge. As these sediments were believed to represent the marginal or flood-plain deposits of the main river channel, the channel is shown extending from the Malakoff pit beneath the volcanic cover to Woolsey Flat (fig. 2). The Derbec mine (Lind-



5000′
4500′
4000′
3500′
3000′
2500′
2000′
1500′
1000′
500′
SEA LEVEL
121°15′
121°00′
120°45′
39°15′
American Hill
Yuba
River
Middle
North
Yuba R
Moore's Flat
Badger Hill Diggings
North Columbia
Relief Hill
Malakoff Diggings
Omega
Central House
WASHINGTON RIDGE
French Corral
Nevada City
Liberty Hill Diggings
Inferred position of highland front
Smartville
0
5 MILES
You Bet
Dutch Flat
Little York Diggings
Gold Run
INDEX MAP
North San Juan
Birchville
French Corral
Middle
Yuba
River
Englebright Reservoir
2
0
2
4
6 MILES
VERTICAL EXAGGERATION X26
Smartville

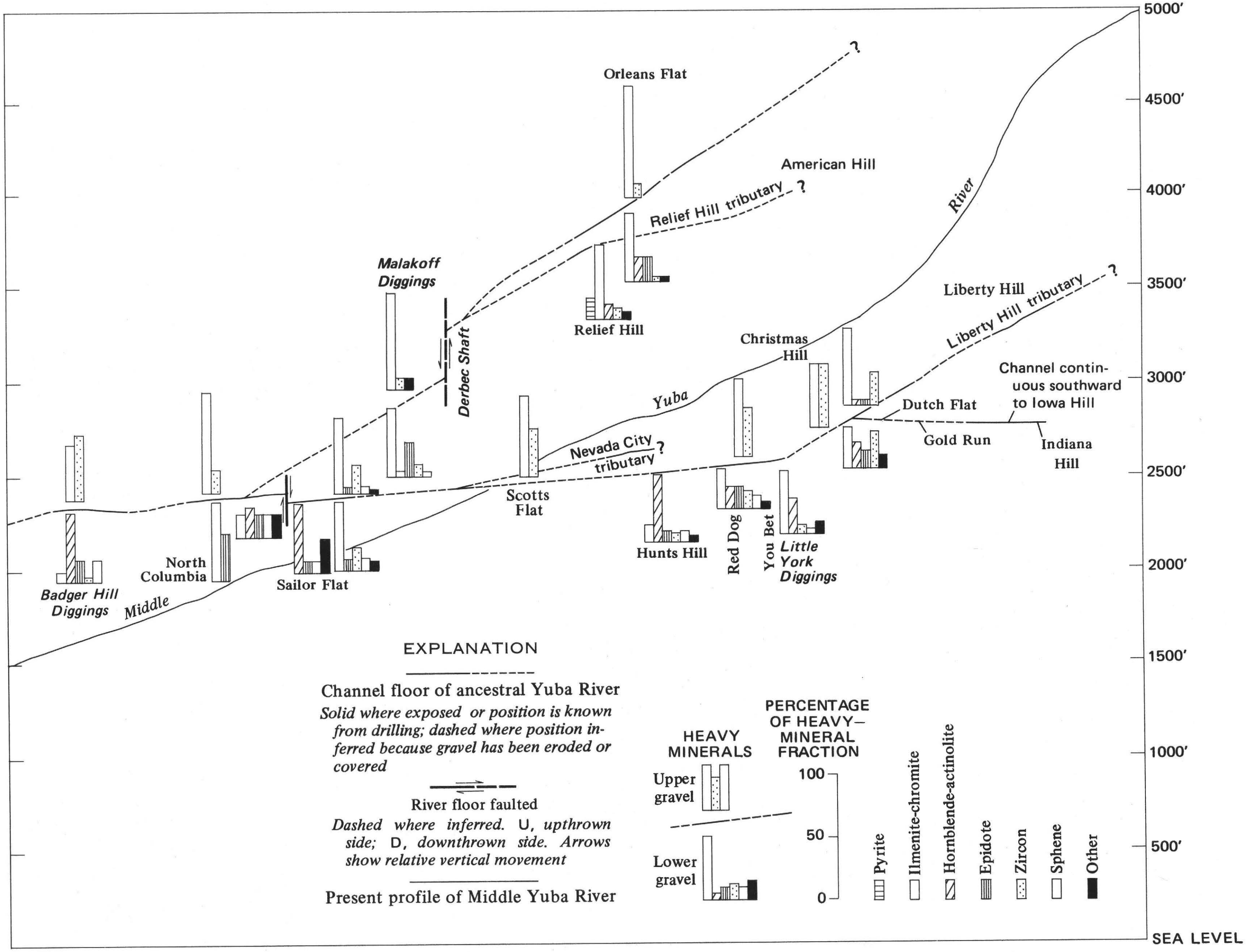


FIGURE 23.—Profiles of ancestral and present Yuba Rivers, with graphs of heavy-mineral suites from gravels of the ancestral Yuba River.

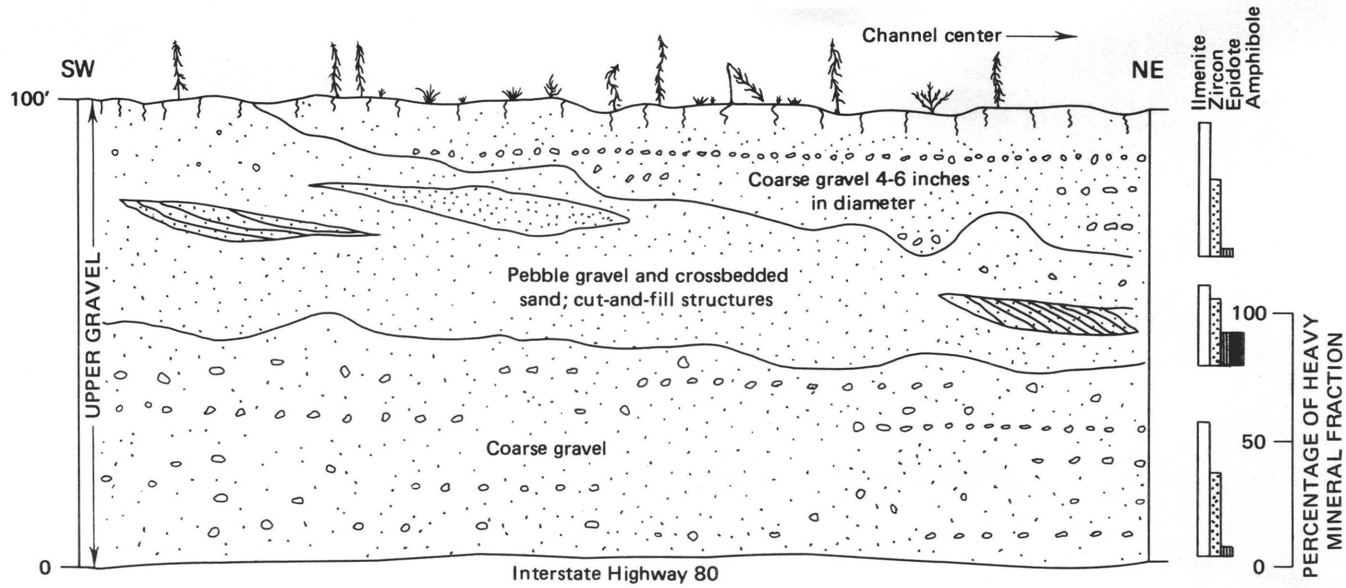


FIGURE 24.—Tertiary gravel (upper gravel) exposed along Interstate Highway 80 near Gold Run. Heavy minerals shown at right.

gren, 1911) allows the positioning of the channel center in that area south and southwest of the drill holes (1–4) on San Juan Ridge (fig. 2). A separate channel is shown entering from the east through Snow Point because the rock types in the Snow Point diggings are all of local bedrock types—siliceous phyllites and slates. The rock types in the hydraulic pits at Orleans, Moore's, and Woolsey Flats include granite, diorite, amphibolite, and phyllite, implying a source area different from that of the Snow Point area. The exact position of the confluence of the Relief Hill tributary entering from the south is uncertain.

The reconstruction of the channel or channels in the Nevada City area is difficult. Lindgren (1911) describes a channel configuration much different from the one shown here in figure 2. A westerly direction of flow is indicated by Lindgren with two separate tributaries originating in the Nevada City–Grass Valley area. Except for two narrow occurrences of volcanic colluvial cover, the gravels at Nevada City are traceable into gravels exposed between Scotts Flat Reservoir and Blue Tent. It is therefore concluded that the wide tributary at Nevada City is connected with the main river channel extending between Scotts Flat Reservoir and Blue Tent. Detailed mapping did not extend southwest of Nevada City; consequently, the complete restoration of this tributary is not shown.

GRADIENTS AND PALEOGEOGRAPHY

The present gradient of the ancestral Yuba River channel can be determined from the data compiled in figure 23. Removing the effects of the local faulting after the gravel deposition, the following gradients can be measured:

1. The downstream, southwest-trending segment, Badger Hill Diggings to Smartville, 79 feet per mile.
2. The middle, northwest-trending segment, Little York Diggings to North Columbia, 17 feet per mile.
3. The upstream, southwest-trending segments, American Hill to North Columbia, 121 feet per mile; and Liberty Hill to Little York Diggings, 120 feet per mile. The gradient of the present Middle Yuba River in the area between Englebright Reservoir to Moore's Flat averages 64 feet per mile.

Lindgren (1911), noting that the northwest-trending portions of the Tertiary channels roughly parallel the present trend of the Sierra Nevada, reasoned that the gradients from these river segments would be little changed by tilting of the mountains. The gradients of the southwest-trending channel segments, however, would have been appreciably increased by the tilting. He thus explained the observed marked changes in gradients of these differently directed channel segments.

The late Cenozoic tilting of the Sierra Nevada has significantly increased the southwest-trending Tertiary channel gradients. It also seems reasonable that the southwestward-directed channel segments trending down the regional slope have had steeper pretilt gradients than the northwestward-directed segments trending perpendicular to the regional slope. The value of 17 feet per mile, which is obtained from the northwest-trending segments, seems to be a minimum gradient for the portion of the channel system studied. The gradient before the tilting of the southwest-trending river segment from Badger Hill to Smartville probably

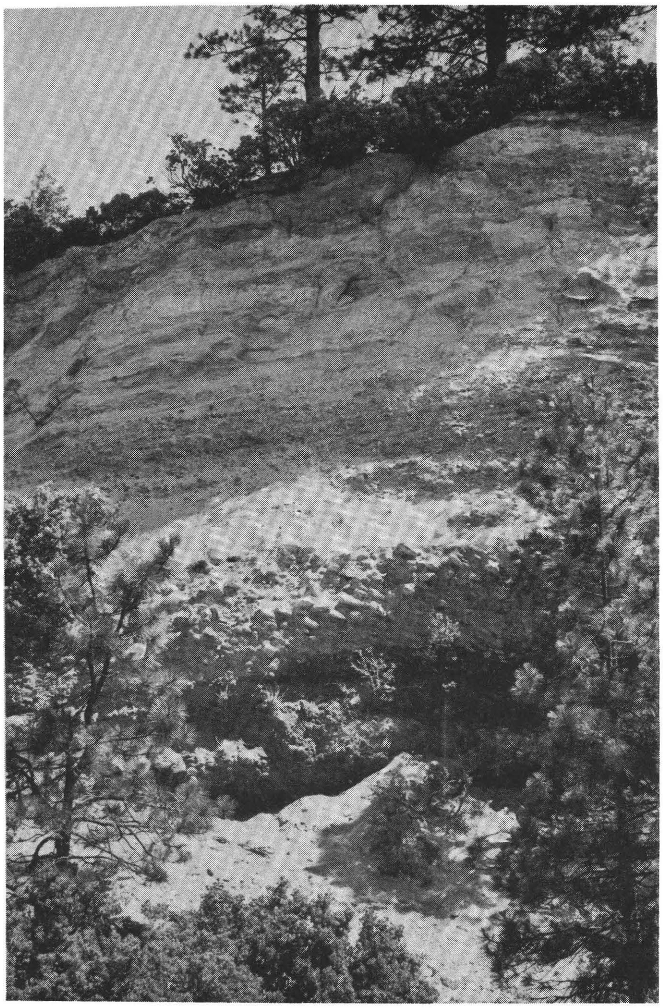


FIGURE 25.—Lower gravel exposed on east side of hydraulic pit at Indiana Hill. Note imbrication in coarse lower gravel indicating current flow right to left (south to north). See figure 2 for location of photograph. View east.

was slightly greater than 17 feet per mile because it was flowing down the regional slope; here a gradient of 20–25 feet per mile would seem reasonable. By comparing this gradient with the present gradient of 79 feet per mile, the effect of tilt after the gravel deposition measured along this stretch of the channel is 54–59 feet per mile. The amount of straight-line tilt measured perpendicular to the mountain axis would be 66–72 feet per mile. If it can be assumed that a similar amount of tilt affected the entire drainage system, then the upstream, southwest-trending portions of the ancestral Yuba River must have had pretilt gradients of 60–65 feet per mile. This gradient is similar to gradients of the present Middle Yuba River in this area.

The relatively steep gradients before the tilt northeastward from the North Columbia and Little York Diggings areas suggest that the river between the two areas flowed parallel to the base of an eastward-retreating highland front. Evidence supporting the presence of such a highland front is manifest in the abrupt change in bedrock slope below the volcanic rocks on Washington Ridge between Little York Diggings and North Columbia (fig. 23). At Central House along Highway 20, the volcanic breccia is about 200 feet thick. One mile west the volcanic breccia has increased in thickness to about 500 feet owing to a lowering of the bedrock surface to the west (fig. 27). A block diagram showing the inferred paleogeography of part of the ancestral Yuba River drainage is shown in figure 28. The river between Little York Diggings and North Columbia probably occupied a broad, fairly flat trough at the foot of a highland and flowed northwest, generally parallel to the dominant structural trend of the metamorphic bedrock.

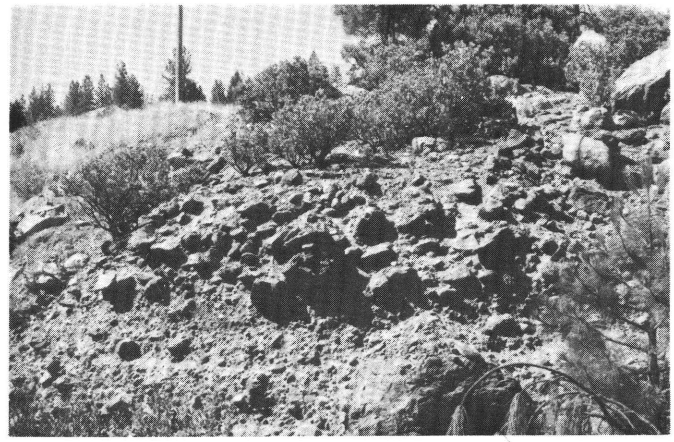


FIGURE 26.—Lower gravel exposed in hydraulic pit at Little York Diggings. Imbrication of cobbles and boulders indicates current flow was from southeast to northwest (left to right). See figure 2 for location. View southwest.

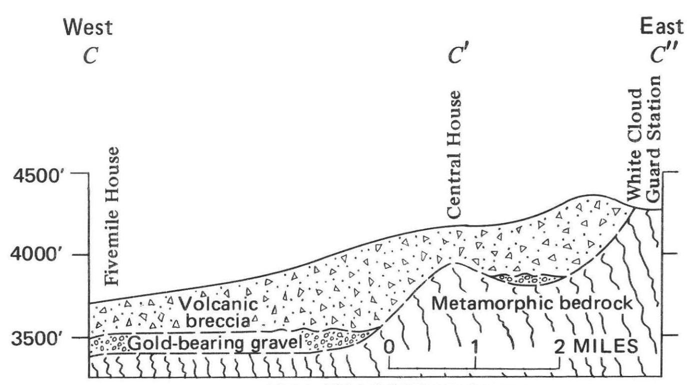


FIGURE 27.—Somewhat generalized cross section along Highway 20 on Washington and Harmony Ridges. The main gravel-filled channel trends northwest, nearly at right angles to this section, and crosses at the base of the bedrock highland front to the east. Line of section shown on plate 1.

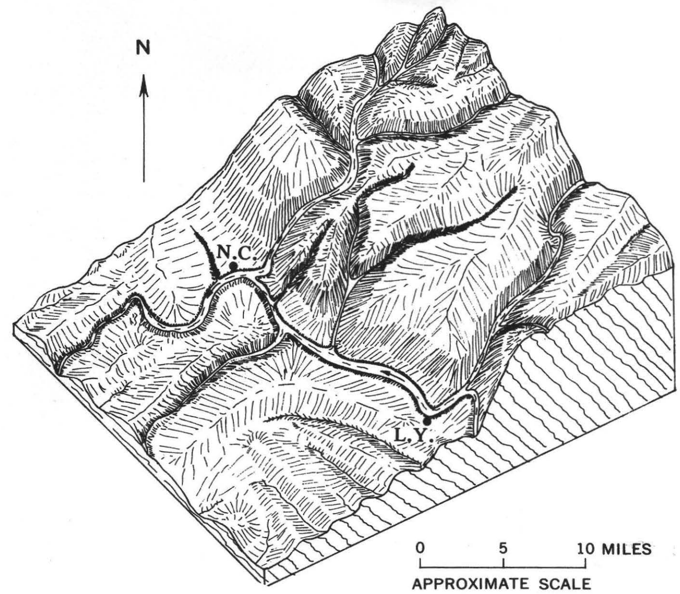


FIGURE 28.—Generalized block diagram of inferred paleogeography of part of the ancestral Yuba River drainage. Vertical scale is partially exaggerated. N.C.=North Carolina; L.Y.= Little York Diggings.

The anomalous reverse gradients near Badger Hill Diggings and Gold Run are probably a result of tilting of the Sierra Nevada. Because the channel trends northeast in these two locations, the more downstream segments of the channel experienced greater uplift.

DRAINAGE AREA AND LENGTH OF THE ANCESTRAL YUBA RIVER

Although the gradient and width of the ancestral Yuba channel can be determined with a reasonable degree of certainty, the original length or drainage area of the old river system cannot be directly measured. Because little remains of the river deposits above the 4,000-foot level, attempting to tie together widely scattered gravel outcrops into an accurate drainage reconstruction is practically impossible. By comparing modern river systems, it was hoped that an approximation of the unknown parameters of length and drainage area could be determined. A comparison of gradient, valley width, and drainage area might show a relation such that, given a particular gradient, a drainage size could be predicted within somewhat limited values.

A modern analogue of the ancestral Yuba River would be located in a warm, wet climate with moderate relief. Southern Mexico fits these conditions, but the lack of detailed topographic maps precludes making adequate comparisons. The southeastern part of the United States approximates the right climate, but the characteristic relief conditions are lacking. The river systems selected for study are those of western Washington, Oregon, and northern California, because both the topographic conditions and the wet climate are analogous. The elements lacking are warm temperature and semitropical vegetation. U.S. Geological Survey stream-gaging stations were used as points of measurement above which the size of drainage basin was determined. River gradients and width of valley fill were determined at the gaging stations, and only those portions of rivers that occupied a valley 500 or more feet wide were selected for study. Restricting the study to these valleys best simulated an aggrading river system like the one that deposited the gravel in the ancestral Yuba River valley. The following rivers were used in this study:

Northern California		*Oregon*		*Washington*	
Klamath	Sacramento	Deschutes	Hoh	Toutle	Snoqualmie
Eel	Trinity	Umpqua	Humptulips	Cowlitz	Skagit
Mad	American	Santiam	Satsop	Nisqually	Nooksack
Pit	Feather	Willamette	Wynouchee	Puyallup	Naches
			Lewis	Duwamish	

The study included about 65 different measurement localities and showed a great variability both within and between the different river systems. Particularly evident was the great variation in the width of valley fill for the rivers with similar slope and drainage size.

Logarithmic plots of channel gradient versus drainage area and channel gradient versus valley-fill width, shown in figures 29 and 30, show the broad limit possible for any given channel gradient rather than specific values of drainage area and channel width. For example, using the determined value for pretilt gradient of the ancestral Yuba River of 20–25 feet per mile, the plots show that the largest area likely for the drainage basin would be 1,800–2,500 square miles. Lindgren (1911)

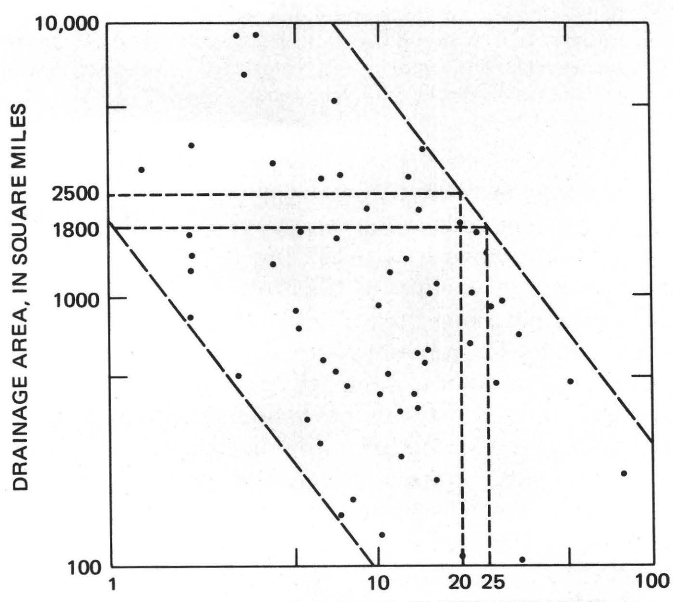


FIGURE 29.—Relation between channel gradient and drainage area for selected localities on rivers in the Pacific States.

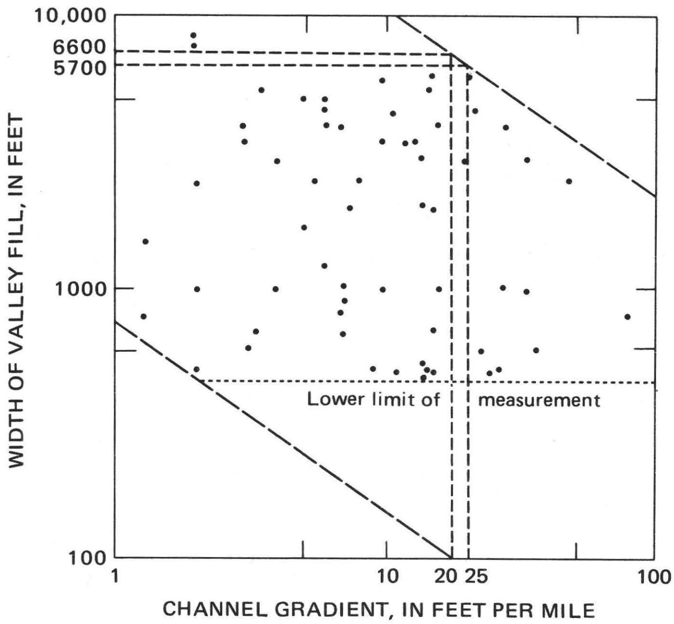


FIGURE 30.—Relation between channel gradient and width of valley fill for selected localities along aggrading rivers in the Pacific States.

estimated a minimum drainage basin for the ancestral Yuba of approximately 1,000 square miles. Using the same 20–25 feet per mile gradient and applying it to the plot of valley-fill width versus channel gradient (fig. 30), the valley-fill widths would likely range from about 500 feet to as much as 6,600 feet. This width corresponds well with the variation of valley-fill widths observed for the ancestral Yuba River. If the drainage area is assumed to be 2,000 square miles (above the area studied) and is applied to the diagram by Leopold, Wolman, and Miller (1964, p. 144) of drainage area versus channel length for major rivers of the world (fig. 31), the maximum length attained by the ancestral

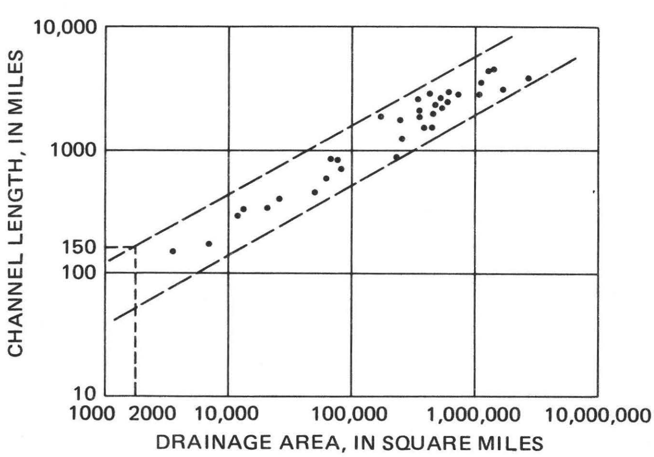


FIGURE 31.—Relation of channel length to drainage area for various rivers of the world (after Leopold and others, 1964).

Yuba above the area of this study was about 150 miles. This means that the drainage divide and headwaters of the ancestral Yuba River were, most likely, no farther east than western Nevada. This study uncovered no rock types in the river deposits that could not have been derived from the Sierra Nevada. But Bateman and Wahrhaftig (1966, p. 139) and Durrell (1966, p. 187) list rock types within Tertiary gravel of the Sierras that could have come only from Nevada.

RECENT MINING

Three different areas along the ancestral Yuba River have been sites of gold mining within the years 1967–70. Small operations have been carried on near French Corral and near Birchville along the lower stretches of the channel and in Spring Creek near North Columbia.

Approximately 1 mile northeast of French Corral, a two-man operation was carried on for several years, processing lower gravel within an old hydraulic pit (fig. 32). A large bulldozer was used to break up the gravel and to move it within reach of a bucket dragline. The gravel was washed through a ¾-inch trommel, and gold was collected in both hungarian riffles and a rotating bowl. Electric power supplied by a portable generator was used to run the concentrator. The plant capacity of 900 cubic yards of gravel per day was seldom achieved because of constant equipment breakdown. "Clean up" once a week produced values ranging from $7 to $0.70 per cubic yard that was taken from blue gravel 20–70 feet above bedrock. The marginal operation barely paid expenses, it was continued with the hope of reaching richer gravel with depth. A limited water supply restricted the length of time that the plant could operate. Costs became excessive near bed-

FIGURE 32.—A small gold-mining operation located in hydraulic pit of the ancestral Yuba River 1 mile northeast of French Corral. Blue gravel is exposed in a hole in the foreground where the water table was intersected. Note darker colored, wet ground.

rock because large boulders were encountered that could not be effectively removed from the undrained circular pit and gold values did not increase substantially. The mining company, Sierra Mining and Exploration, of French Corral, Calif., ceased operation in 1968.

A similar operation was carried on for several years 1–2 miles "upstream" on the ancestral Yuba River near the vicinity of Birchville. Blue gravel along the side of an old hydraulic pit yielded values similar to those obtained in the operation near French Corral. Mr. Herbert Jeffries, owner of the operation at Birchville, claimed that the blue gravel yielded a table concentrate of 10 pounds of sulfides per cubic yard of gravel. It was believed that a substantial amount of gold was "tied-up" in the sulfides (see section on "Secondary Sulfides"). The operation ceased when Mr. Jeffries was severly injured in a nonmining accident in 1968.

The Dulo Mining Corp., Grass Valley, Calif., recently (1969–70) set up a concentrating plant along the ancestral Yuba River on Spring Creek (fig. 33), approximately 1–2 miles southeast of North Columbia at a position just upstream from the confluence of the two major branches of the ancestral Yuba River where the tributary is narrow. The operation is similar to those previously described, except that the equipment is somewhat larger and can handle a greater volume of gravel. An "air-flow" table is used to separate the gold from the heavy black sand concentrate. Lower gravel approximately 80 feet above bedrock is being mined. The operation is in its incipient stages, and gold values have not yet been determined.

GEOLOGIC HISTORY

The foothills region of the Sierra Nevada was part of a north-trending highland that experienced deep and pervasive erosion during the Cretaceous and earliest Tertiary (Bateman and Wahrhaftig, 1966, p. 126–127). The great amounts of sediment eroded from this highland accumulated in the Pacific geosyncline to the west. A layer of rock possibly as much as 17 miles thick was removed from the area we now call the Sierra Nevada, and the great batholith forming the core of the mountains was unroofed and exposed (Bateman and Wahrhaftig, 1966, p. 127–128). For the highland to persist throughout the Cretaceous and early Tertiary, the area probably was more or less continually uplifted. Perhaps the earliest coarse gravels of the ancestral Yuba River reflect a particularly vigorous pulse of uplift. Most of the erosion had already taken place by the time the ancestral Yuba River was carving its channel. The final position of that drainage system can be reconstructed, but the older drainage patterns may never be known. The final drainage system was established prior to the middle Eocene and perhaps as early as the Paleocene. In its early history, the system probably was characterized by narrow, high-gradient high-energy streams and rivers flowing in deep, narrow steep-walled canyons much as the modern rivers that drain the Sierras. These rivers possessed sufficient energy to transport 10-foot boulders a minimum distance of 8 miles.

FIGURE 33.—Mining the lower gravel of the ancestral Yuba River along Spring Creek.

During the long period of degradation, local gold-bearing rocks were being eroded, physically broken down, and transported by the rivers. The gold was released from the host rocks mainly by mechanical breakdown but partly by chemical breakdown. As the rivers were primarily downcutting throughout their early history, no great thickness of fill accumulated in the valleys. Perhaps as much as 50–100 feet of coarse, poorly sorted gravel in the bottom of the channel was continually subjected to scour, mixing, and eventual transport along the drainage system. The free detrital gold in this "lower gravel" increased in concentration as more and more gold was added to the rivers while less and less was removed. The gold, as the heaviest mineral in the gravel, would resist most lateral transport and increase in concentration, particularly in the lowest parts of the gravel. Because coarse, chemically unweathered rock debris was constantly supplied to the river throughout its extent, this lower gravel was kept in a state of immaturity both compositionally and texturally. Most of the material was eventually flushed into the sea to the west, but the gold, particularly the coarse gold, remained behind in the river channels.

In summary, the lower gravel was deposited in an area of high relief in which physical weathering predominated although the climate probably was favorable for active chemical weathering. Semitropical vegetation, large trees in particular, was carried into the rivers and buried with the gravel. The rivers continued to downcut, predominantly during times of flooding and vigorous runoff, and the 50- to 100-foot-thick veneer of coarse gravel flooring the river valley would be moved downvalley only to be replaced by new material from upstream.

As downcutting proceeded, the river systems became integrated and through headward erosion extended their basins and tributaries eastward. By middle or late Eocene time, the steep slopes of the earlier landscape had given way to gentle slopes. Relief was subdued and chemical weathering was the dominant process in the breakdown of the rocks. Thick soils developed on the land surface, and all but the most resistant rocks and minerals were broken down to their constituent elements and either carried away in solution or recombined into stable clay minerals. The river gradients became less steep as dissection lowered the drainage basin until the final phase of river aggradation began. Subangular to subrounded milky-white quartz pebbles and euhedral and subhedral zircon grains deposited in the rivers during this period imply that the material eroded was not transported for a great distance. Local sources continued to supply the detritus as before, but because of the intensity of the weathering, only the most resistant minerals survived the journey to the rivers. The valley fill increased in thickness as the rivers continued to aggrade, and extensive flood plains were formed. The rivers, perhaps 150 miles in length, may have been draining areas as far away as western Nevada. Plant leaves were occasionally trapped, and their impressions were preserved in the clays deposited on the flood plain. MacGinitie (1941, p. 78) characterizes the climate as probably similar to the present climate in the lower slopes of the Sierra Madre in the State of Vera Cruz, Mexico—a frostless subtropical climate with heavy rainfall in the warm season and a well-marked dry season. The average annual temperature at the low altitudes may have been 65°F, the annual rainfall at low altitudes, 60 inches.

Gold-bearing rocks continued to be eroded and broken down, but little of the gold was preserved in the gravels and sands deposited during this aggradational phase of the river's history. The lack of gold in these rocks poses a puzzling and unsolved problem. Judged by the amount of vein quartz in the gravels, tremendous amounts of potentially gold-rich rocks were eroded. It is not known whether the gold lagged behind in the regolith and was not transported in any major quantity, or was broken down physically to a small size and transported into the bordering oceans, or was carried off in solution. Further exploration of sedimentary rocks of equivalent age in the Central Valley, along with laboratory experiments on physical and chemical breakdown of gold, will aid in solving this problem.

These conditions of low relief, intense chemical weathering, aggrading rivers with wide flood plains and a subtropical climate continued to the end of the Eocene, after which volcanic activity began.

At the beginning of the Oligocene Epoch, volcanoes erupted, probably to the east near the drainage heads. Rhyolitic tuffs were deposited over much of the area extending to the bordering ocean on the west. These tuffs have been preserved most commonly in the river valleys along the flood plains where they were quickly covered by younger volcanic rocks. River gradients were increased, perhaps by renewed uplift, and volcanic cobble gravel was deposited within the older river valleys. A few of the older prevolcanic channels were filled with the volcanic detritus, and a thin blanket of volcanic clastic rocks covered parts of the old land surface. Channels of new drainage patterns formed, occasionally cutting across and eroding the older gold-bearing gravel, reworking the older alluvial deposits and becoming enriched in gold.

The climate probably was very similar to that of the middle Eocene. Fossil flora from volcanic rocks of this age imply a climate intermediate between temperate and tropical (Potbury, 1937). Volcanic eruptions, together with alluvial erosion and deposition, continued throughout the Oligocene to Pliocene.

Widespread volcanic mudflows covered most of the landscape during the Miocene and Pliocene. These predominantly andesitic flows probably were derived from the slopes of volcanoes located near the present crest of the Sierras. Detritus repeatedly flowed down the regional slope toward the west and extended out into the Central Valley. The flows were initially confined to the unfilled major river valleys that had been formed in the Eocene. As these became filled, the mudflows spread out and covered all but the highest hills of the surrounding land surface. Between successive mudflows incipient river systems were born and waterworn boulders and cobbles of andesite were deposited in restricted channels. These short-lived rivers were constantly being destroyed by subsequent mudflows. Soil zones between successive mudflows, though rarely preserved, record periods of diminished volcanic activity. A rhyolitic tuff was deposited over the southern parts of the area in the Pliocene.

Probably in late Pliocene time, as volcanic activity subsided, the Sierran block was uplifted and tilted toward the west (Christensen, 1966). The present drainage pattern was developed on the volcanic mudflow surface, and streams have subsequently cut through the volcanic rocks, the Paleocene and Eocene gold-bearing gravel, and several thousand feet into bedrock. The Sierran block must have been tilted west of the present foothill–Central Valley boundary, for the ancestral Yuba River has steep tilt-produced gradients several miles west of the foothill front (the last appearance of the gravel before it disappears beneath the present land surface). Associated with the tilting, small-scale faulting produced displacements of the prevolcanic gravel and overlying volcanic rocks. During and following the uplift, initiated in late Pliocene time, most of the volcanic cover was eroded and vast areas of the prevolcanic land surface exhumed. It is because of this exhumation of the early Tertiary surface that major portions of the prevolcanic gold-bearing gravel is exposed today. The modern rivers cut through the old gravel deposits and isolate them on the interstream divides. Long stretches of the prevolcanic gravel were eroded in places where the modern rivers followed the earlier river courses; the reworked gold became part of the present river deposits, and much of it has been subsequently mined.

Although Pleistocene glaciers were not present in the area of study, the associated wet cool climate probably promoted extensive mass wasting and the reduction of the volcanic deposits capping ridges. Colluvial deposits continued to accumulate at the base of the oversteepened volcanic cliffs. However, the greatest recent change of the land surface was produced by man. One cannot help but be overwhelmed by the enormous effect of hydraulic mining on the landscape. Hydraulic mining, by disrupting the natural geologic processes, locally changed the foothills landscape as well as the present stream and river systems. Although this happened decades ago, the effects are still vividly apparent in the foothills and the Central Valley, and in San Francisco Bay.

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