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CIRC. 566

PETERSON AND OTHERS—TERTIARY GOLD-BEARING CHANNEL GRAVEL IN NORTHERN NEVADA COUNTY, CALIF.—U.S.G.S. CIRC. 566

GEOLOGICAL SURVEY CIRCULAR 566

Tertiary Gold-Bearing Channel Gravel in Northern Nevada County, California

12

Tertiary Gold-Bearing Channel Gravel in Northern Nevada County, California

By Donald W. Peterson, Warren E. Yeend
Howard W. Oliver, and Robert E. Mattick

GEOLOGICAL SURVEY CIRCULAR 566

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William T. Pecora, *Director*

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equipment might be used for deeper exploration; they would be slower and more costly to use.

4. Although the present magnetic data are inconclusive, there is some evidence that magnetic concentrates occur in the central parts of at least some of the Tertiary channels, and the magnetic method may provide an economical means of locating the richer deposits.

The resistivity method is not as useful as in many other areas because it is limited by the moderate to locally rugged topography in the hydraulic pits and in dissected volcanic terrain. We did not observe any large IP effects; moreover, the contribution of the clays and limonite-cemented material within the gravels may tend to mask the anomalies that might be caused by the disseminated sulfides.

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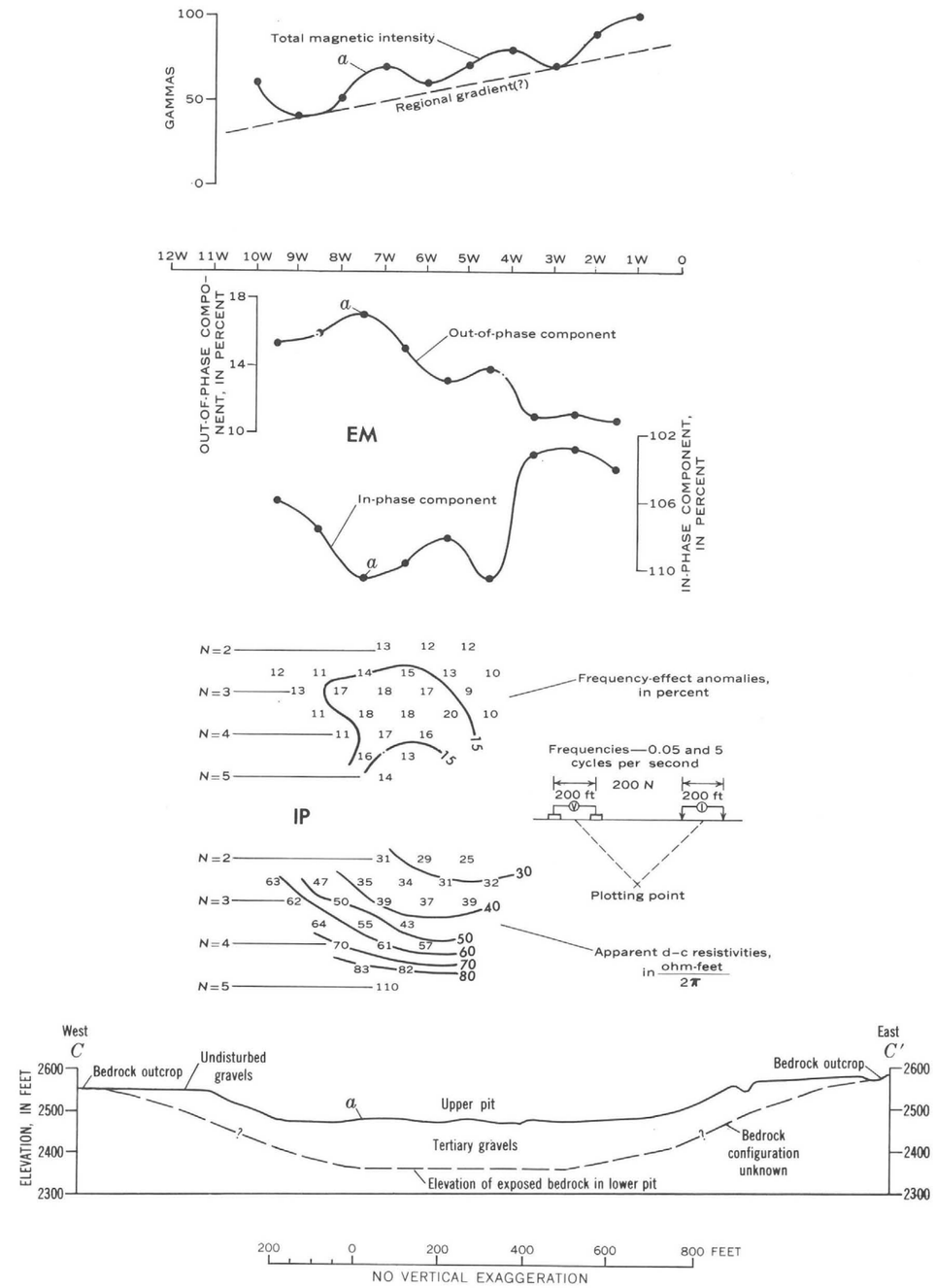


Figure 13.--Magnetic, EM, IP, and geologic data along C—C′ (figs. 2, 5, and 12), Badger Hill diggings. The EM data were obtained using a vertical coplanar loop orientation, a 300-foot loop spacing, and a frequency of 3,600 cycles per second. The location of the peak of the EM anomaly (marked α) is also shown on the magnetic profile and the geologic section.

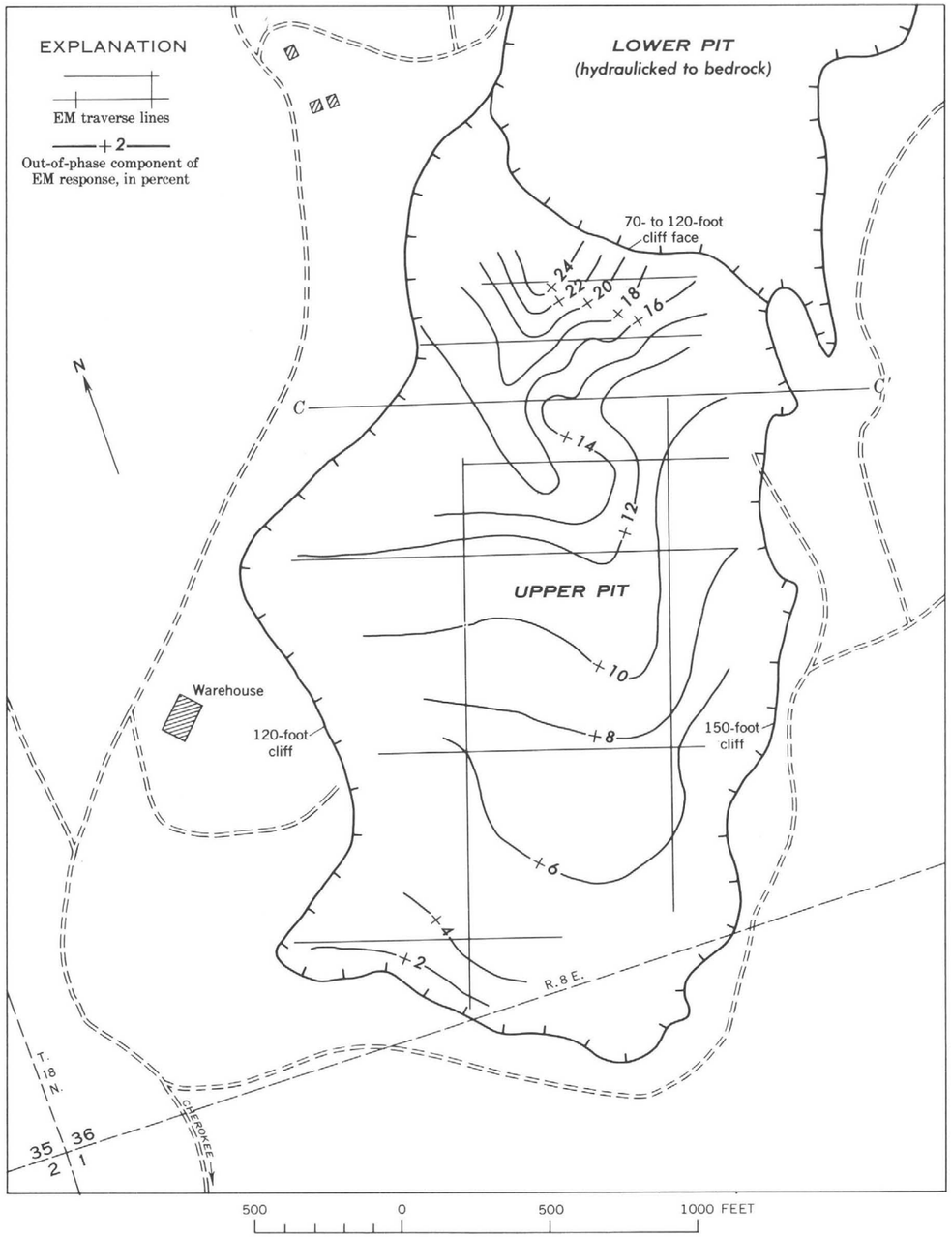


Figure 12.--Electromagnetic survey of Badger Hill diggings (fig. 5). Contour values refer to the out-of-phase component obtained by using a vertical coplanar loop orientation, a 300-foot loop spacing, and a frequency of 3,600 cycles per second. The contours are controlled by stations spaced at 100-foot intervals along the seven transverse and two longitudinal traverses indicated.

Tertiary Gold-Bearing Channel Gravel in Northern Nevada County California

By Donald W. Peterson, Warren E. Yeend, Howard W. Oliver and Robert E. Mattick

Abstract

The remains of a huge Tertiary gravel-filled channel lie in the area between the South and Middle Yuba Rivers in northern Nevada County, Calif. The deposits in this channel were the site of some of the most productive hydraulic gold mines in California between the 1850's and 1884.

The gravel occupies a major channel and parts of several tributaries that in Tertiary time cut into a surface of Paleozoic and Mesozoic igneous and metamorphic rocks. The gravel is partly covered by the remains of an extensive sheet of volcanic rocks, but it crops out along the broad crest of the ridge between the canyons of the South and Middle Yuba Rivers. The lower parts of the gravel deposits generally carry the highest values of placer gold. Traditionally, the richest deposits of all are found in the so-called blue gravel, which, when present, lies just above the bedrock and consists of a very coarse, poorly sorted mixture of cobbles, pebbles, sand, and clay. It is unoxidized, and, at least locally, contains appreciable quantities of secondary sulfide minerals, chiefly pyrite.

Information in drill logs from private sources indicates that a 2-mile stretch of the channel near North Columbia contains over half a million ounces of gold dispersed through about 22 million cubic yards of gravel at a grade averaging about 81 cents per cubic yard. The deposit is buried at depths ranging from 100 to 400 feet.

Several geophysical methods have been tested for their feasibility in determining the configuration of the buried bedrock surface, in delineating channel gravel buried under volcanic rocks, and in identifying concentrations of heavy minerals within the gravel. Although the data have not yet been completely processed, preliminary conclusions indicate that some methods may be quite useful. A combination of seismic-refraction and gravity methods was used to determine the depth and configuration of the bottom of the channel to an accuracy within 10 percent as checked by the drill holes. Seismic-refraction methods have identified depressions which are in the bedrock surface, below volcanic rocks, and which may be occupied by gravels. Seismic methods, however, cannot actually recognize the presence of low-velocity gravels beneath the higher velocity volcanic rocks. Electromagnetic methods, supplemented in part by induced-polarization methods, show promise of being able to recognize and trace blue gravel buried less than 200 feet deep. A broad vague magnetic anomaly across the channel suggests that more precise magnetic studies might delineate concentrations of magnetic material. The usefulness of resistivity methods appears from this study to be quite restricted because of irregular topography and the variable conductivity of layers within the gravel.

GEOLOGY OF THE CHANNEL GRAVEL

By Donald W. Peterson and Warren E. Yeend

INTRODUCTION

Some of the largest and most productive mines in California operated in the Tertiary gold-bearing gravels between the South and Middle Yuba Rivers, Nevada County, Calif. These mines were in operation from the late 1850's until 1884, when a court decision halted the dumping of debris into streams tributary to the Sacramento and San Joaquin Rivers. Thereafter, small hydraulic mines operated sporadically, and the high-grade deposits just above bedrock were mined locally by underground methods, but production from the gravels never again reached the pre-1884 level.

The region is being studied to learn the extent of possible gold deposits remaining in place and to develop methods for establishing the location and size of gravel deposits that may lie undiscovered beneath younger rocks. This report is preliminary and briefly summarizes the results of current geological and geophysical studies of the gravels in the area shown in figure 1. The work was done as part of the Heavy Metals program of the U.S. Geological Survey.

One particularly attractive area, long recognized as representing a large, only partly exploited block of ground, lies between North Columbia and Badger Hill (Lindgren, 1911, p. 139; MacBoyle, 1919, p. 48, 50, 100; Haley, 1923, p. 118; Averill, 1946, p. 266-267). Drilling records in the files of the property owners

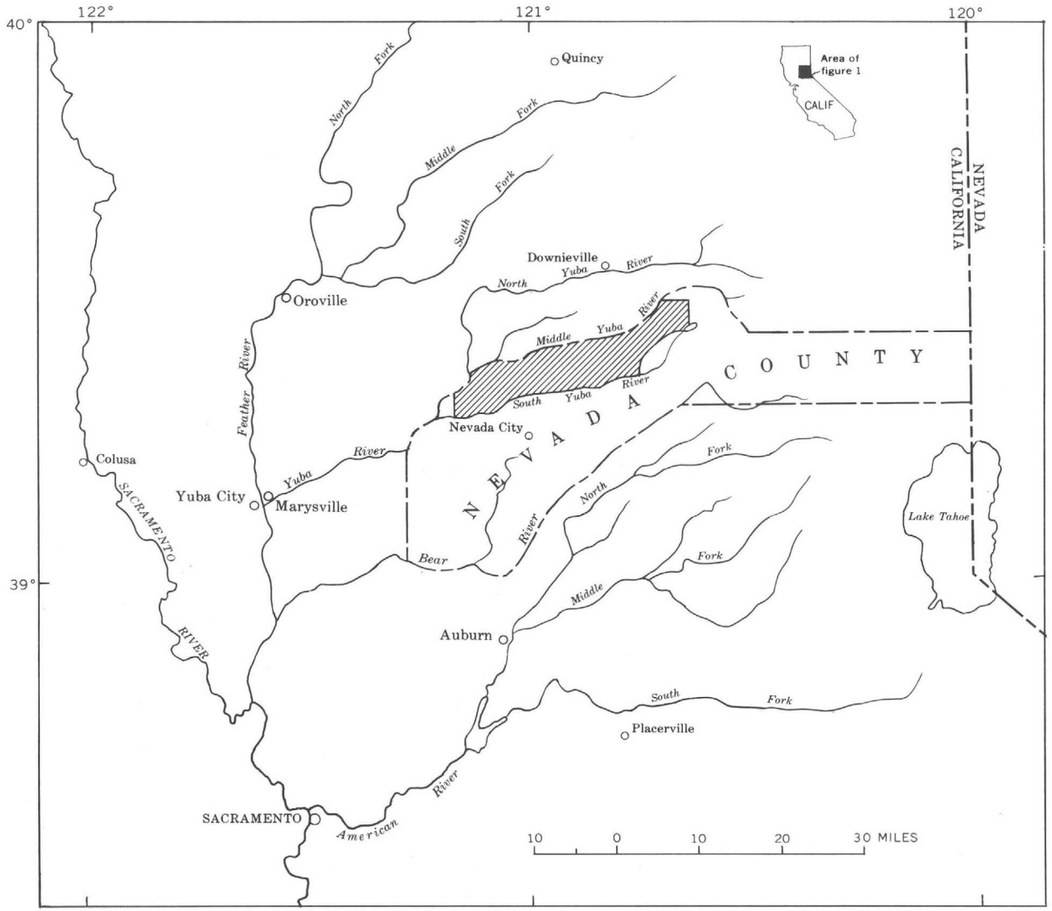


Figure 1.--Index map of part of northern California showing location of report area (shaded).

indicate that a 2-mile stretch of channel within this block contains a placer deposit of over half a million ounces of gold dispersed through about 22 million cubic yards of gravel at a grade that averages about 81 cents per cubic yard. This deposit is buried at depths of from 100 to 400 feet by gravels containing gold values of just a few cents a yard.[1]

Previous Work

The classic geologic studies of the Tertiary gravels of the Sierra Nevada are those by Whitney (1880) and Lindgren (1911); most of the subsequent published reports draw heavily on Lindgren for much of their basic information. The area covered by this report is included in maps by Lindgren and Turner (1895), Lindgren (1900), and Burnett and Jennings (1962). Summaries of local information on the gravels and the mines in Nevada County are given by MacBoyle (1919) and Logan (1941, p. 431-436). General information on the geology of the Tertiary gravels and their exploitation is given by Haley (1923), Averill (1946), and Jenkins (1946). Jarman (1927) reports on the feasibility of resuming hydraulic mining and cites figures on reserves. An excellent brief summary of the Tertiary channels is given by Clark (1965). A summary of the geology of the Sierra Nevada by Bateman and Wahrhaftig (1966) provides a comprehensive discussion of the geologic framework of the Tertiary gravel.

[1] All values cited in this report are based on a price of $35 per ounce for gold.

C-C', located several hundred feet south of the cliff face separating the lower and upper pits (fig. 12). The depth to bedrock along the central part of C-C' is about 110±15 feet based on a projection of the elevation of exposed bedrock in the lower pit.

A significant EM anomaly of about +24 percent occurs at the north end of the upper pit and decreases, widens, and meanders toward the southern end of the pit (fig. 12). The anomaly amounts to 17 percent along C-C' and correlates with a moderate IP anomaly of 18-20 percent in the frequency effect. A slight magnetic anomaly of possibly 20 gammas also occurs at about the same location, although other magnetic variations along the profile tend to obscure the significance of this apparent correlation.

The correlation between the EM and IP anomalies is significant and the EM anomaly in figure 12 may define the trace of the blue gravel. This is potentially an important finding because EM is easily the most portable, rapid, and economical ground-geophysical technique that we have tried. Unfortunately, additional IP data obtained in the diggings show that limonite-cemented gravels also produce frequency effect anomalies of the same order of magnitude.

Seismic tests or drilling would be required to further check on the feasibility of using EM, possibly in conjunction with IP, to trace the blue gravels at depths less than about 200 feet. For depths of over 300 feet, the data at North Columbia (fig. 9) suggest that the geophysical methods used cannot trace the blue gravel. However, the blue gravel would most likely be in the deepest parts of the channel, which apparently can be located by seismic and gravity methods.

LOCATION OF CONCENTRATIONS OF MAGNETIC MINERALS

The application of magnetic methods for locating concentrations of black sand, with which gold is associated in placer deposits, has been used successfully in California, Arizona, Colorado, and Alaska over the last 40 years (Jakosky, 1950, p. 228-230). Jakosky points out that, in some cases, as in Trinity County, Calif., it was possible to outline an old stream bed completely with a ground magnetometer. Joesting (1941, figs. 1-3, 5) documents a rather striking relationship between magnetic anomalies and gold values across four different placer channels in Alaska. He reports, however, that the magnetic method was valuable in preliminary prospecting for only about half of the gold placers in the interior of Alaska. According to Joesting, some of the Alaskan placers contain little or no magnetite, and other channels were incised into a magnetic basement which tends to mask the limited effect, generally less than 100 gammas, of the black sand.

Initial ground magnetic tests are inconclusive. Profiles with 100-foot spacing were obtained across the Tertiary gravels at French Corral, Badger Hill, North Columbia, Malakoff, and the concealed gravels under the volcanic rocks of the San Juan Ridge (figs. 2 and 3). In general, the magnetic profiles are similar to those published for other gold-bearing placer deposits by Joesting (1941) and Jakosky (1950). Small magnetic anomalies occur near the center of the exposed Tertiary gravels at all the above locations and are shown by the symbol M in figure 3. The anomalies range from 20 gammas at Badger Hill (fig. 13) to about 70 gammas at French Corral. At the North Columbia diggings, where the center of the channel is known accurately from drill holes, the anomaly is about 40 gammas along A-A' in the upper pit and is marked "M" on the total intensity profile (fig. 9). This small magnetic high is displaced several hundred feet north of the center of the channel, which coincides with the maximum gold values along profile A-A.

The most significant magnetic anomaly found over the gravels is 0.4 mile east of section A-A' in the lower pit of the North Columbia diggings (marked "M" in fig. 5). Here the depth to bedrock in the central part of the channel is 250-300 feet, about 100 feet less than along A-A' through the upper pit. The anomaly is about 60 gammas and is located directly over the center of the channel.

The bedrock contour map (fig. 6) and the contours of gold values in the North Columbia diggings (fig. 8) provide an unusual opportunity to test the correlation of magnetic anomalies with both of these parameters, but an adequate test should measure magnetic variations at or within 50 feet of the ground surface to an accuracy of ±2 gammas. Such a test might be conducted by helicopter.

Two aeromagnetic profiles at 400 feet above ground level have been made across the Tertiary gravels at North Columbia with fixed-wing aircraft. The data are now in compilation.

CONCLUSIONS

Although many of our data are still being processed, particularly from the gravity and airborne studies, the following positive conclusions can now be made:

1. By using shallow seismic refraction in conjunction with gravity methods, the configuration of the bedrock beneath the exposed Tertiary gravels has been determined to an accuracy of within 10 percent.
2. Bedrock depressions that are under several hundred feet of volcanics, and that may be occupied by channel gravels, can be recognized by seismic refraction. Application of the method may be made difficult by high surface relief, and the problems of laying geophone cables along shot lines through chaparral and timber can be severe.
3. The slingram EM method, possibly used in conjunction with IP, offers some promise of being able to trace the blue gravel where it is not more than 200 feet deep. Other EM and IP methods and

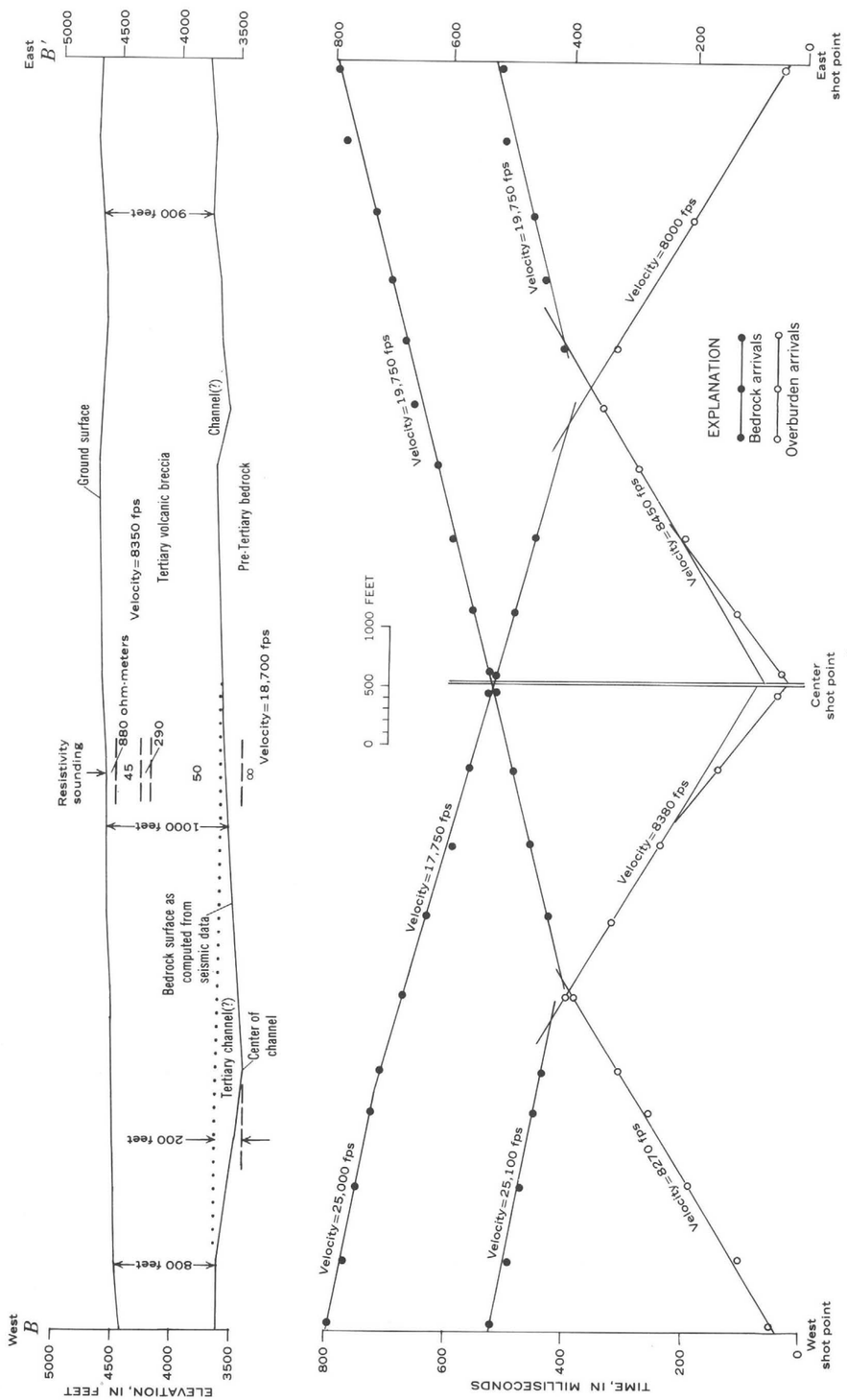


Figure 11.--Geologic section, resistivity data, and seismic traveltimes along B—B' (fig. 2). The buried Tertiary channel postulated from the seismic data apparently crosses this section at an angle of about 45° (see fig. 3). The depth to bedrock computed from the resistivity sounding is 1,120 feet, about 12 percent larger than the 1,000 feet interpreted at that point from the seismic data.

Acknowledgments

The interest and cooperation of property owners throughout the area are gratefully acknowledged. The San Juan Gold Co., D. R. Schiffner, Harold Helland, M. J. Meredith, the Coughlan brothers, Herbert Jeffries, C. R. Echlin, and E. J. Colley have granted access to their lands and operations and have offered valuable suggestions and information. Special thanks are extended to the San Juan Gold Co. for permission to examine and use information in their files. The California State Division of Beaches and Parks, the California State Division of Forestry, and the U.S. Forest Service have aided this study by their interest and cooperation.

GENERAL GEOLOGY

The geologic map (fig. 2) shows the distribution of the gravel and adjacent rocks in a strip from 2 to 6 miles wide extending from French Corral on the west to Bowman Lake on the east, a distance of about 30 miles. The channels were cut into a bedrock surface of metamorphic and igneous rocks of Paleozoic and Mesozoic age. The winding main channel descends from east to west and ranges from 1,000 to 7,000 feet in width and from a few tens to nearly 500 feet in depth. The tributary channels are smaller. Few exposed stretches of gravel remain entirely undisturbed by mining, but some of the partly mined deposits still contain large amounts of unexploited material.

After deposition of the gravel, the area was extensively blanketed by volcanic breccia. Although there has been some erosion, this breccia still covers the gravel over much of the area, and in the eastern part of the area, glacial deposits partly conceal the older rocks.

Bedrock

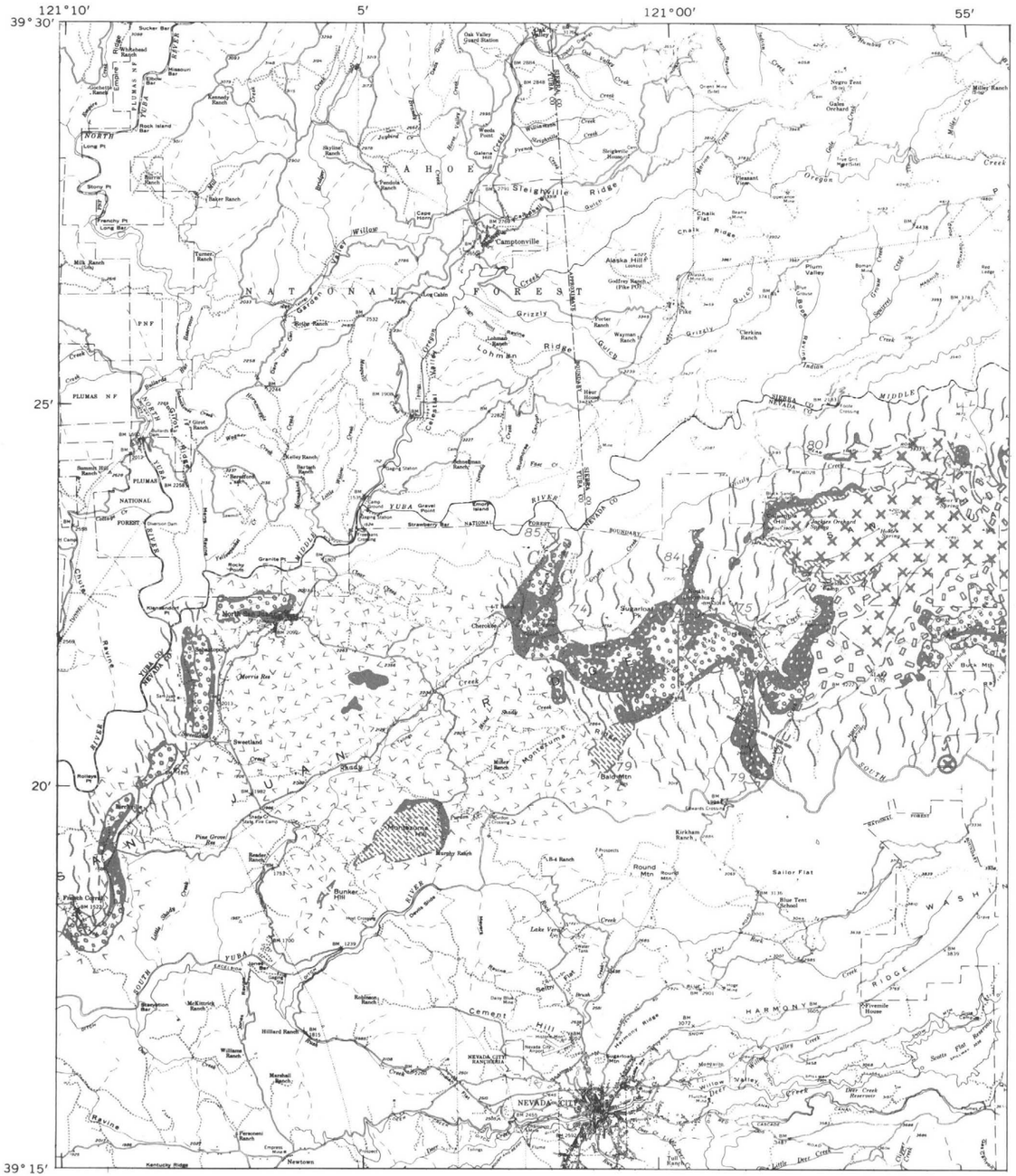
Steeply dipping metasedimentary and metavolcanic rocks constitute the bulk of the exposed bedrock. In the western part of the area, these rocks are part of the late Paleozoic Calaveras Formation (Lindgren, 1900; Ferguson and Gannett, 1932). In the eastern part they consist of the Silurian(?) Shoo Fly Formation (Clark and others, 1962, p. B16, B17). Siliceous slate, quartzite, phyllite, and greenstone crop out in belts striking north-northwest and dipping northeast. Serpentine, gabbro, diorite, granodiorite, and quartz veins locally intrude the metamorphic rocks. Large bodies of Mesozoic granitic rocks intrude the metamorphic rocks at the east and west ends of the mapped area. Mesozoic metavolcanic rocks possessing a structural attitude similar to that of the older Calaveras Formation crop out between French Corral and Birchville.

The steep dips, multiple intrusions, and metamorphism indicate a complex structural history for the pre-Tertiary rocks. At the east end of San Juan Ridge the north-striking Melones fault zone cuts the metamorphic rocks and brings serpentine into contact with them. The volcanic rocks capping the ridge, however, are not offset by the fault (fig. 2).

Auriferous Gravel

Gravel deposited by a major river system crops out on the divide between the Middle and South Yuba Rivers and is perched 500 to 1,000 feet above the present major streams. Although large sections of the old river channel have been removed by erosion, the path of the ancient river can be reconstructed with reasonable certainty. Its path as determined in the present study (fig. 3) is in general similar to the path portrayed by Lindgren (1900, 1911) and Lindgren and Turner (1895). The geologic map (fig. 2) shows the boundaries of the preserved gravel and the outline of the hydraulic pits. Paleocurrent indicators such as crossbeds and imbricated pebbles show that drainage was from east to west.

The major channel of the ancestral Yuba River can be traced, with minor interruptions, from the town of French Corral in the western part of the map area to Orleans Flat in the northeastern part of the area (fig. 2). Between North San Juan and the Badger Hill diggings, a distance of approximately 4 miles, the old river channel has been completely eroded by the Middle Yuba River. Large hydraulic pits occupy the channel from the Badger Hill diggings to North Columbia. The greatest volume of gravel lies near North Columbia, and this deposit is probably the largest in the Sierra Nevada (Lindgren, 1911, p. 139). In this area the gravel deposit reaches a width of 7,000 feet and a thickness of nearly 500 feet. Lindgren (1911, p. 139) estimated that 25 million cubic yards of gravel were removed and that 165 million cubic yards remained in the North Columbia area. Despite the extensive hydraulic mining, bedrock was not reached. A major tributary entering from the south and a minor tributary flowing from the north presumably helped produce the large gravel deposit. Eastward, the main channel is buried beneath volcanic breccia and colluvium for part of the distance between the diggings at North Columbia and those at Malakoff. A part of the channel is also buried beneath colluvium at the Malakoff diggings, where hydraulicking has resulted in a colorful, awe-inspiring hole in the ground that is now a State park. The gravel here, which reaches the extreme thickness of 500 feet, is probably the result of the confluence of several rivers. Because of the extensive colluvial cover in the Malakoff area, it has not been possible to map the major channel and its tributaries in detail. Information from underground drift mines, such as the Derbec and Union Blue, indicates that the major channel extends northeastward from the Malakoff diggings, underneath colluvium and volcanic breccia, and finally emerges at Woolsey Flat (Lindgren, 1911, p. 140–141). Approximately 3 miles of the channel is concealed beneath San Juan Ridge. A tributary of undetermined size, draining from the north and covered by volcanic rocks, and a minor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Lake Vera
Kirkham Ranch
Sugarloaf
Cherokee
Morris Ridge
Sweetland
Newtown
Kentucky Ridge
Blue Tent School
Fivemile House
Little Deer Creek
Deer Creek Reservoir
Round Mtn
Bald Mtn
Buck Mtn
Negro Tent (Bldg.)
Gates Orchard
Milley Ranch
Oak Valley Guard Station
Willow Spring
Graniteville Road
Chalk Ridge
Pleasant View
Oregon
Plum Valley
Clerkins Ranch
Godfrey Ranch (Pike PO)
Wayman Ranch
Forter Ranch
Lohman Ranch
Grizzly
Lohman Ridge
Willow Creek
Cape Horn
Pendola Ranch
Skylark Ranch
Baker Ranch
Milk Ranch
Tunney Ranch
Rodgers Ranch
Long Cabin
Sleighville Ridge
Oak Valley
Sucker Bar
Whitehead Ranch
Kennedy Ranch
Rock Island Bar
Long Pt
Storey Pt
Ranchy Pt
Long Bar
Summit Hill Ranch
Bear Creek Ranch
Greek Ranch
Bear Creek
Bear Ridge
Middle Yuba River
South Yuba River
Sierra Nevada Co
Nevada Co
Yuba Co
Sierra Co
Plumas Co
Plumas N F
North Yuba River
Pine Grove Res
Bender Ranch
Hillard Ranch
Marshall Ranch
Williams Ranch
McKinnon Ranch
Kohlmann Ranch
Dairy Stock Bridge
Lake Vera
Harmony Ridge
Harmony Valley
Scotts Flat
Little Deer Creek
Deer Creek Reservoir
Ravine
Pilot Hill
Pilot Hill Ranch
Pine Grove Res
Morris Ridge
Sugarloaf
Cherokee
Buck Mtn
Round Mtn
Bald Mtn
Bunker Hill
Sailor Flat
Cement Hill
NEVADA CITY
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Scotts Flat
Little Deer Creek
Deer Creek Reservoir
Fivemile House
Blue Tent School
Kirkham Ranch
Lake Vera

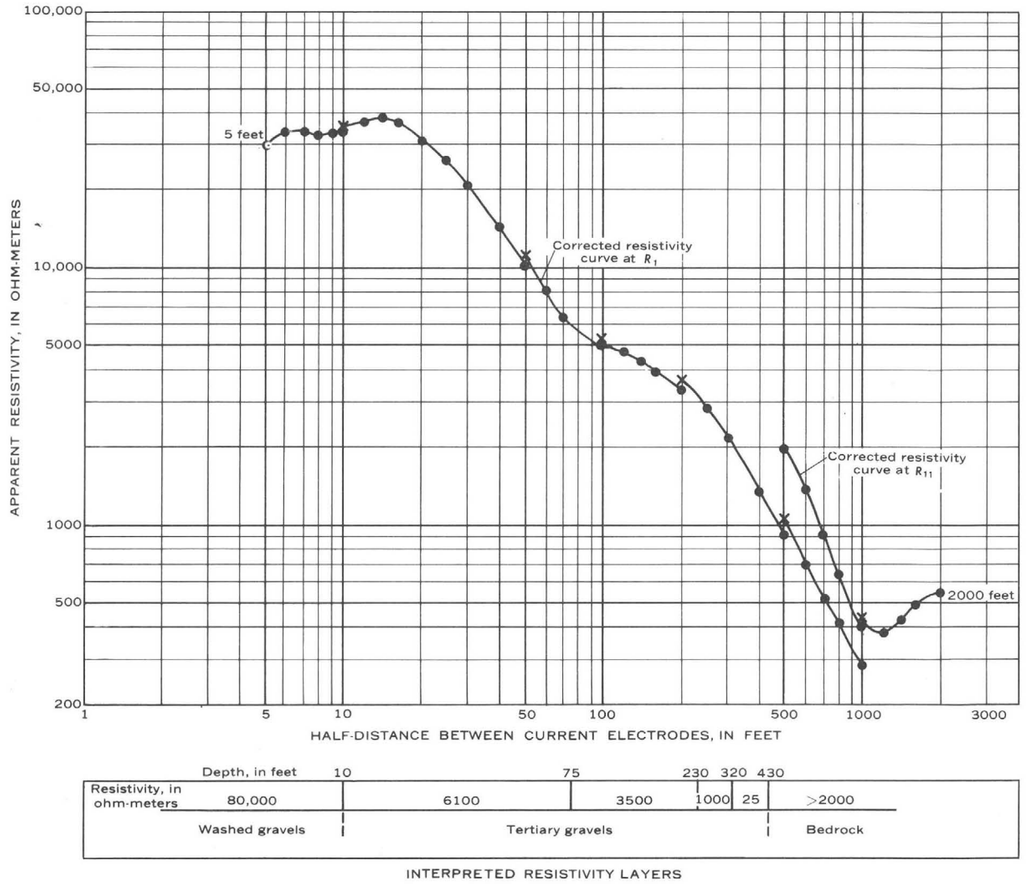


Figure 10.--Resistivity soundings at R_1 and R_{11} (geologic section, fig. 9) made with Schlumberger arrays (Keller and Frischknecht, 1966, p. 95) expanded parallel to profile A—A'. The six-layer interpretation using the auxiliary point method (Zohdy, 1965) is constrained to fit the depth to bedrock determined by drilling.

in most of our work. The EM data illustrated in figure 9 were obtained using a 200-foot loop spacing. They indicate that there are no electrical conductors within about 150 feet of the surface over the deep part of the channel, a conclusion which is consistent with the resistivity sounding (fig. 10). EM anomalies do appear as the bedrock surface begins to rise toward both the north and south ends of the profile, which indicates that some conductor has come within about 150 feet of the surface (zero for the out-of-phase component is off by about 5 percent). Previous study of electrical effects over buried channels in the search for uranium (Black and others, 1962) indicates that some of these anomalies probably represent elongate clay lenses in the stream gravel. Perhaps the 25-ohm-m layer (blue gravel?) discovered by the resistivity sounding does not pinch out toward the side of the channel but continues to overlie the bedrock at least intermittently where it comes to within 150 feet of the surface.

Induced-Polarization Method

Tests of the induced-polarization (IP) method were made in the diggings at French Corral, Badger Hill, North Columbia, and Malakoff (fig. 2). Rough terrain severely restricted the depth of exploration in most of the diggings by limiting the electrode separation. Thus IP profiles were essentially limited to looking for clays, disseminated sulfides, and other anomalous materials within about 200 feet of the ground surface. Indications of bedrock configurations were obtained at both the Malakoff and Badger Hill diggings. The evidence at Badger Hill is illustrated in figure 13, which shows contours of apparent direct-current resistivities bending upward to the west on the west flank of the hydraulicked channel. Although the exact bedrock configuration is unknown in this area, this pattern is similar to the general form of the bedrock surface as depicted in the geologic section (fig. 13).

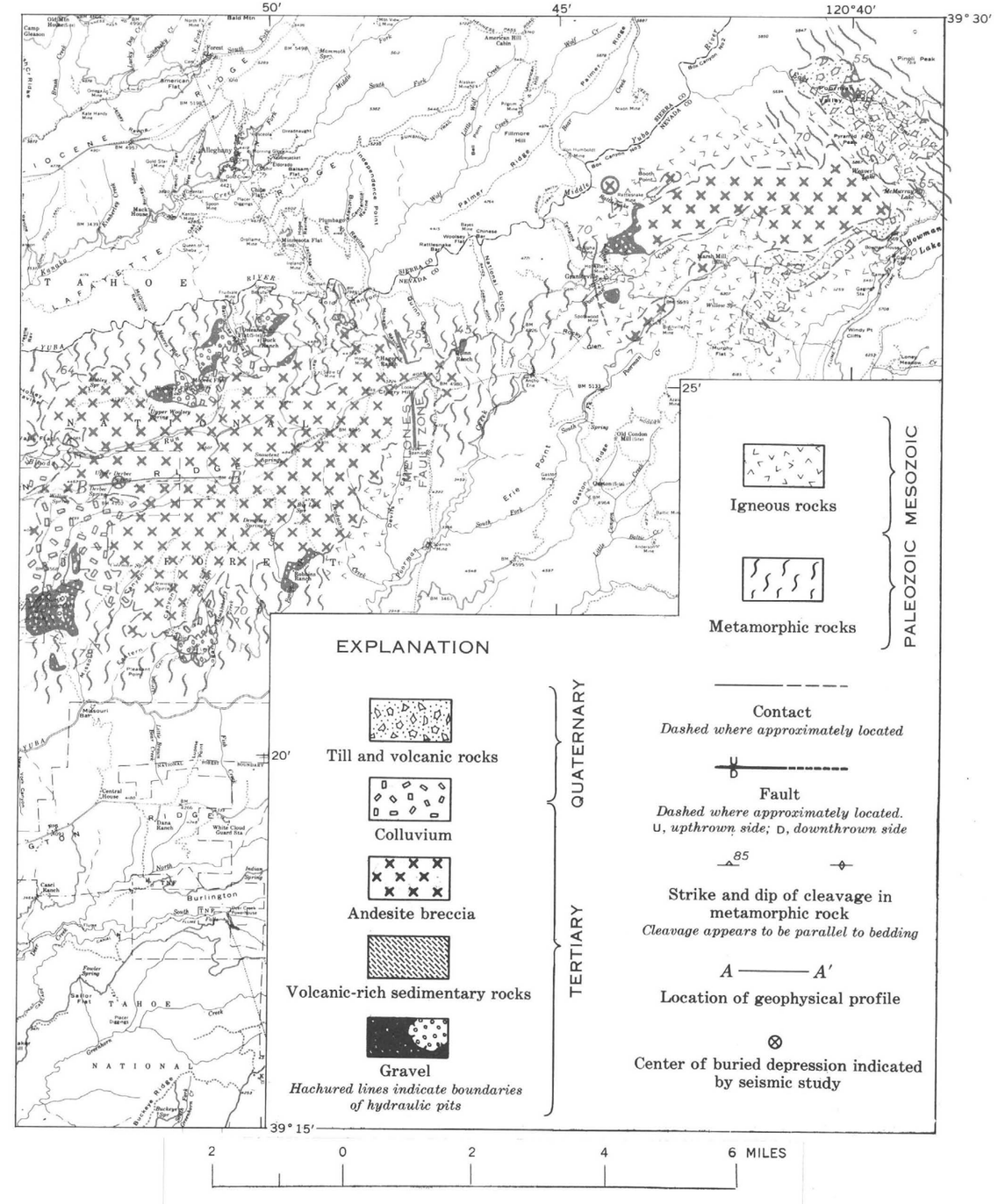


Figure 2.--Continued.

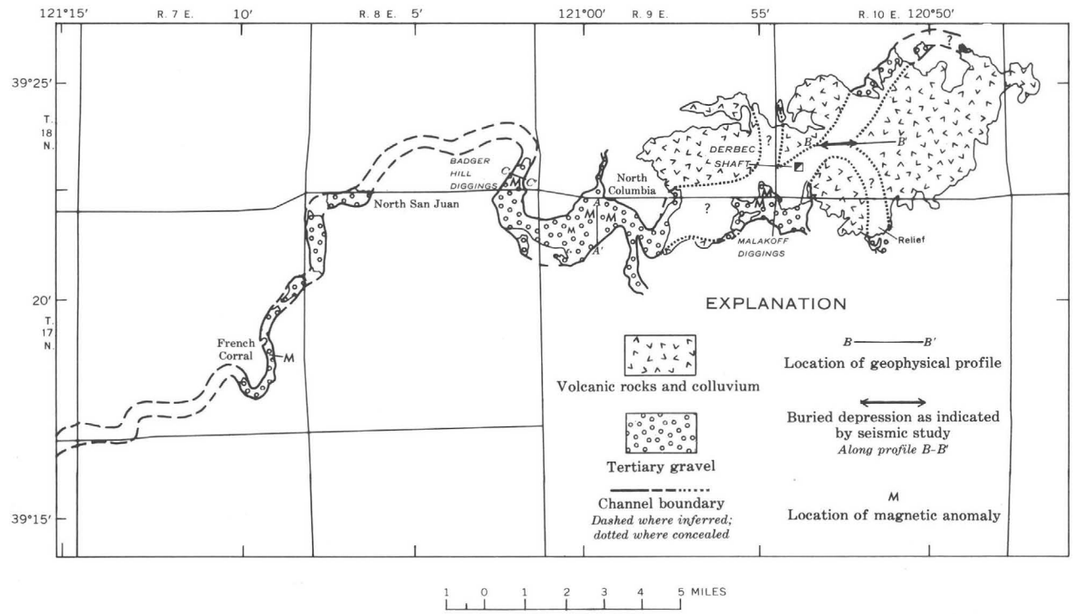


Figure 3.--Reconstruction of the path followed by the Tertiary Yuba River and its tributaries. Inferred boundaries show areas where the gravel has been removed by erosion. Concealed boundaries indicate probable position of gravel where it is buried by younger rocks.

tributary coming from the southeast probably joined the major channel at Malakoff. Another large channel appears beneath the volcanic cover on a small spur above the South Yuba River at Relief and must join the major drainage somewhere beneath the volcanic cover of San Juan Ridge. Small remnants of the major channel are preserved on bedrock spurs above the Middle Yuba River at Orleans Flat and Moores Flat. The channel probably continues northeastward from Orleans Flat, but it has been eroded by the Middle Yuba River. We have not yet studied the extension of the channel on the north side of the Middle Yuba River.

Most of the exposed parts of the channel have been modified by mining activities, so that its original configuration cannot be seen. At the few localities where gravel is undisturbed, the channel is expressed as a low topographic ridge—a topographic reversal of what originally must have been a linear depression. The ridge can be explained by the high resistance of the gravel to erosion relative to the surrounding bedrock. The gravel has high porosity and permeability, so that rainwater tends to percolate into the gravel instead of carrying it away in surface runoff. Figure 4 is a diagrammatic cross section of the channel and its gravel fill.

The gravel-bedrock contact is well exposed along the channel from French Corral to North San Juan and again at the Badger Hill diggings. No bedrock is exposed along the channel floor between Badger Hill and Woolsey Flat, a distance of about 11 miles. The bedrock floor of the Malakoff pit was exposed during the days of hydraulic mining (MacGinitie, 1941, fig. 1), but the pit has subsequently been partly filled with fine sand, silt, and clay from successive mudflows from the steep surrounding cliffs. Where exposed, the bedrock surface beneath the channel shows characteristic river scour, polish, fluting, and grooving. Some sections of the channel possess a narrow, steep-walled gut within the major broad channel (fig. 4). Generally, this gut is 30–50 feet across and 20–40 feet deep. It is thought to have contained many of the high-grade deposits. Quartz veins in the bedrock stand as low ridges in a few places along the exhumed channel floor. Such obstructions along the river bed would act as giant riffles and were probably important concentrators of coarse gold.

The gradient of the channel has been determined where the floor is sufficiently exposed to establish its elevation. Between French Corral and North San Juan the gradient is 67 feet per mile. The reconstructed gradient along the eroded stretch between North San Juan and the Badger Hill diggings is 61 feet per mile. Lindgren (1911, pl. 10) gives gradients of 65 and 80 feet per mile, respectively, for these two segments of the channel. Drill holes in the hydraulic pit near North

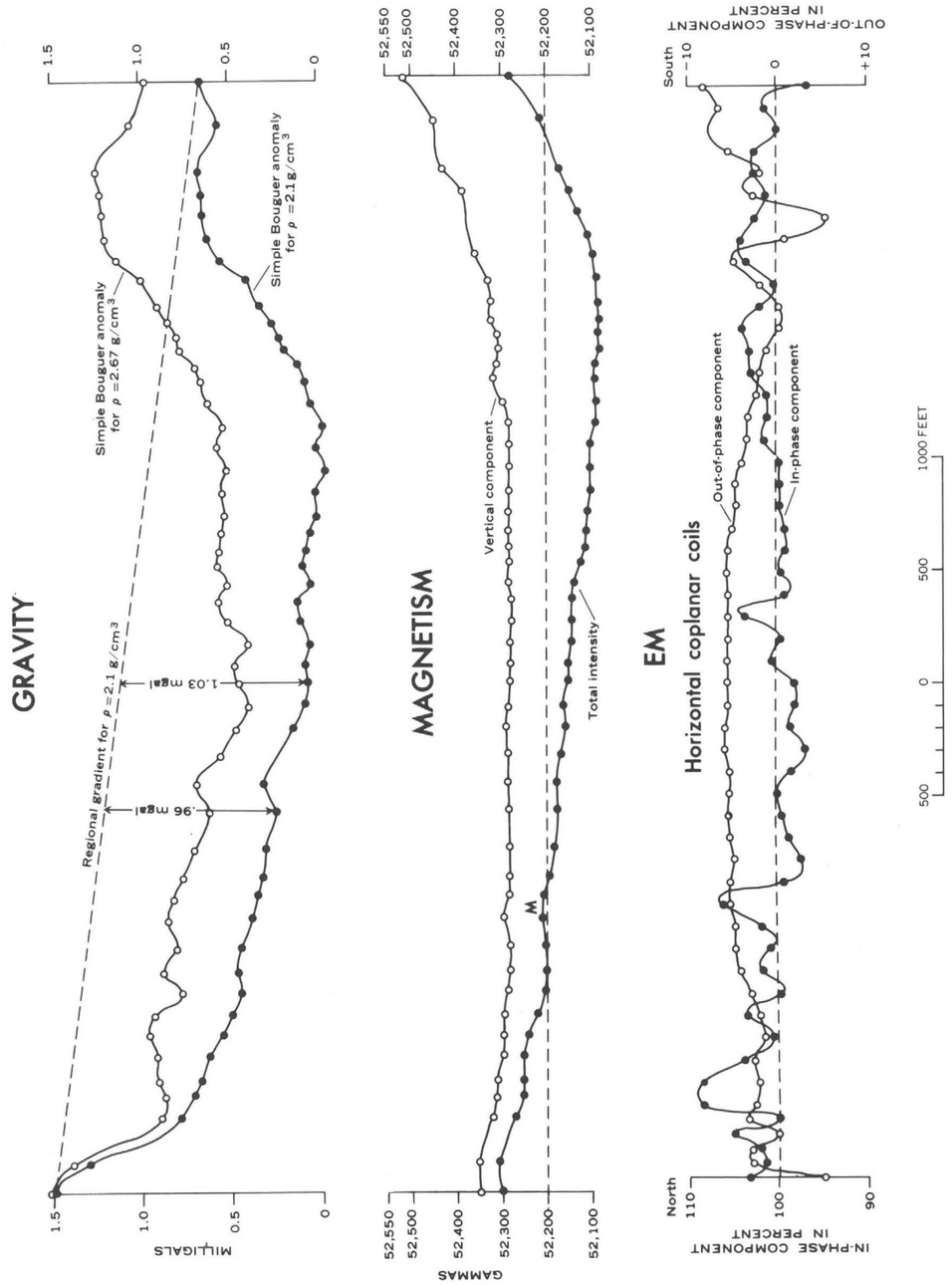
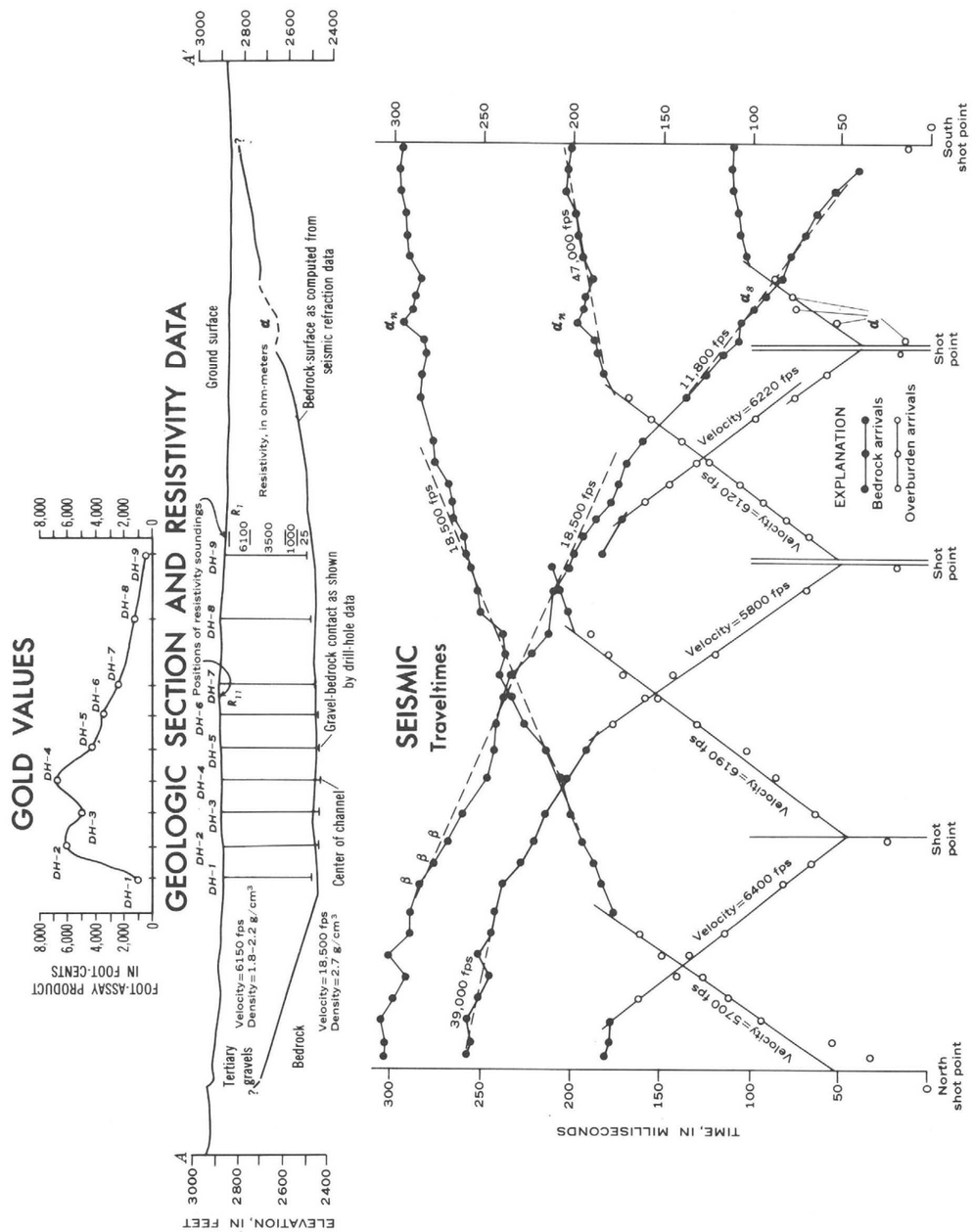


Figure 9.--Seismic, resistivity, gravity, magnetic, and electromagnetic data and the interpreted geologic section along A—A′ (figs. 2 and 5). The average error in the computed depths to bedrock at the nine drill-hole locations is 4.6 percent with a maximum error of 8.6 percent or 28 feet at the southernmost drill hole. The amount of gold in each drill hole is shown as a graph of the foot-assay product. This graph is a profile through a—a′ of figure 8.



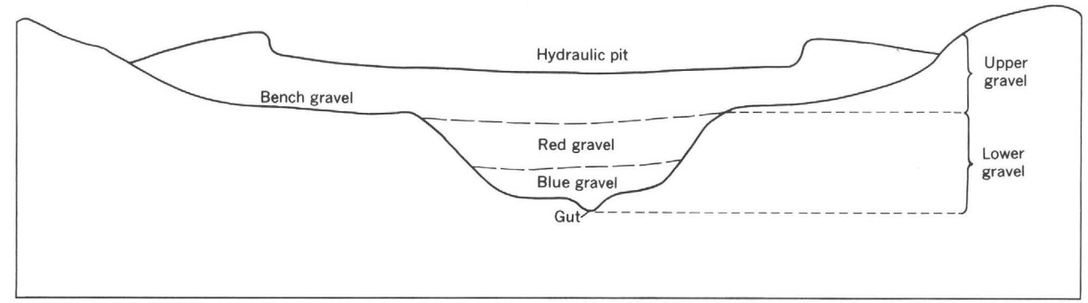


Figure 4.--Diagrammatic section across an idealized Tertiary channel. The deeper part of the channel is occupied by lower gravel, which is coarse and poorly sorted. The lower gravel can be divided into two parts: (1) blue gravel, which is below the water table, has a characteristic bluish color, and carries secondary sulfides, (2) red gravel, which has been oxidized, is stained red or brown by iron oxides, and generally lacks sulfides. It is not known if blue gravel everywhere occupies the base of the channel. The upper gravel, bench gravel, or white gravel is considerably less coarse and better sorted and contains many beds of clay- and sand-sized material. Not all channels have a gut but, where present, the gut may contain rich gold deposits.

Columbia indicate a gradient of 66 feet per mile along 2 miles of the channel. The gradient of the Tertiary channel is probably a function of both the original river gradient and the subsequent tilting of the Sierran block. Apparent gradients could be significantly affected by any vertical displacements along faults. In the area covered by figure 2, however, only one fault offsetting the channel has been recognized. This northwest-trending fault cuts the tributary channel south of North Columbia near Spring Creek. The northeast block is displaced upward, and if the channel gradient is similar to that determined for the North Columbia area, the throw of the fault may be as much as 150 feet.

Although the channel gravel was mapped as a single unit, it is far from uniform in texture and composition. The lower 100 to 150 feet of gravel is coarser than the upper part and is compositionally less mature. This lower gravel is exposed only at Badger Hill, Birchville, French Corral, and northeast of Edwards Crossing on the Spring Creek tributary. Size analyses of the lower gravel give the following averages, based on the Wentworth size classes: cobble and boulder (> 64 mm), 13 percent; pebble (64 to 4 mm), 56 percent; granule and sand (4 to 1/16 mm), 28 percent; and silt and clay (< 1/16 mm), 3 percent. Pebble counts of the 16- to 32-mm-size fraction give: bluish-black siliceous slate, 52 percent; undetermined weathered rocks, 31 percent; milky quartz, 12 percent; and other constituents, 5 percent.

Two separate units can be recognized within the lower gravel—blue gravel and red gravel. The gravel within 50 feet of bedrock is commonly water saturated. This gravel is unoxidized and has a bluish-gray color that is especially conspicuous when wet; it has been called the blue gravel, blue lead, or blue clay. The color is due to the high content of bluish-gray slate derived from the Paleozoic metamorphic rocks. The blue gravel contrasts markedly in color with overlying oxidized gravel, sometimes called red gravel, but the two units are similar in sorting characteristics and lithology of their components. As Lindgren (1911, p. 76) points out, the blue gravel seems to be a zone lying below the water table and is associated with reducing conditions, rather than being a lithologic unit distinct in composition from the overlying oxidized gravel. Secondary sulfides, chiefly pyrite, coat the pebbles and are disseminated through the matrix of the blue gravel in several localities. Gravel-concentrating plants operating near French Corral and Birchville are producing gold from undisturbed blue gravel along the main channel.

The light-colored, compositionally more mature upper gravel overlies the lower gravel. This white gravel or bench gravel is well exposed in most of the hydraulicked cliff faces and constitutes the bulk of the deposit in most areas. The term "bench gravel" comes from its frequent occurrence on bedrock benches bordering the deeper channel trough. Size analyses of the upper gravel at numerous localities give the following averages: cobble and boulder, 1 percent; pebble, 41 percent; granule and sand, 53 percent; and silt and clay, 5 percent. Pebble counts of the 16- to 32-mm-size fraction are: white quartz, 52 percent; siliceous slate, 40 percent; quartzite, 7 percent; and other constituents, 1 percent. Clay beds are common in the upper part of the gravel. The chief differences between the upper and lower gravels are that the upper gravel contains: (1) fewer clastic fragments of cobble and boulder size, (2) sand and clay beds, and (3) abundant milky-white quartz pebbles. Large fragments of silicified wood are common in the upper gravel, whereas wood fragments in the lower, water-saturated gravel are carbonized.

Leaf imprints (as yet unidentified) have been collected from clay beds in the pit near North Columbia. MacGinitie (1941) studied leaf flora at Chalk Bluffs,

about 11 miles south of North Columbia, at a stratigraphic position similar to that of the channel, and he dated the flora as early middle Eocene.

When one studies or visits this area, it does not take him long to gain an appreciation for the magnitude of the gravel deposits and a feeling for the enormous physical size of the river system responsible for their development. Maximum relief on the early Tertiary surface was at least 1,000 feet, but local relief was generally 200 feet or less. A much different stream regimen, with a correspondingly larger drainage basin, must be postulated for the Tertiary rivers than currently exists for the present Yuba River. This leads to speculation that the headwaters of the ancient river system may have been far east of the present crest of the Sierra Nevada, possibly as far east as Nevada.

Volcanic Rocks

Fragmental volcanic rocks overlie and are locally gradational with the auriferous gravels. Two separate volcanic units have been mapped (fig. 2). The lower unit is composed of volcanic-rich sedimentary rocks, including claystone, siltstone, sandstone, and conglomerate; it crops out in two locations. In the vicinity of Columbia Hill it is overlain by volcanic breccia and is about 120 feet thick along the Graniteville Road below Columbia Hill Lookout. In the southwest corner of the map area, weakly cemented volcanic gravel as much as 400 feet thick forms a cap on Montezuma Hill and Bunker Hill. Clasts are composed predominantly of andesite with minor amounts of nonvolcanic rocks similar to those found in the underlying gravel. Clasts are rounded, the matrix is moderately well sorted, and cut-and-fill structure and crossbedding are common, all of which suggest an alluvial origin for this material.

The upper volcanic unit is an andesite breccia that caps much of San Juan Ridge (fig. 2). The breccia is poorly sorted and fragments are angular; some blocks are as much as 6 feet in diameter, but more 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. The unit resembles the late Tertiary Mehrten Formation described from other areas in the Sierra Nevada (Piper and others, 1939; Curtis, 1954), but correlation has not yet been established. This unit is at least 500 feet thick over much of San Juan Ridge and probably is locally thicker over the Tertiary river channels. Zones containing rounded, apparently waterworn cobbles and boulders are intercalated in the breccia at several localities. These zones are good aquifers and springs are common, particularly along the Relief Hill Road above the old town of Relief. The surface of the volcanic breccia is generally flat and slopes gently to the west.

The age of similar andesitic material in other parts of the Sierra Nevada has been determined to be late Tertiary (Piper and others, 1939; Dalrymple, 1964). The volcanic rocks were originally much more widespread and probably constituted a nearly continuous sheet over this part of the range. Parts of the Tertiary river system have been exposed only after subsequent erosion of the volcanic rocks.

Colluvium

A mantle of landslide debris, here termed "Colluvium," is composed largely of fragments of andesite breccia and borders some of the steep slopes capped by breccia. The colluvium has an irregular, hummocky, and sometimes blocky surface, indicating little modification since its development. The colluvium 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 a mile from the volcanic cliffs.

Curiously, the colluvium is almost restricted to those places, such as Relief, Moores Flat, Woolsey Flat, Malakoff, Lake City, and Bloody Run Creek, where the early Tertiary river channels extend beneath the thick volcanic cover. This interesting relationship can perhaps be explained by the fact that the upper part of the gravel is rich in clay. Slope failure could be expected under conditions of a thick, relatively porous, water-saturated volcanic layer overlying weak clays; therefore, the presence of colluvium might be a useful indicator to otherwise unsuspected gravel throughout the Sierra Nevada.

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.

TERTIARY CHANNEL NEAR NORTH COLUMBIA

Gravel in the Tertiary channel from North Columbia to Badger Hill has been partly removed by hydraulic mining, but a large amount of gravel remains in place. No records indicate that any appreciable underground mining has exploited the higher grade gravel in the lower part of the channel in this vicinity; consequently, the area is an attractive one for investigation. Figure 5 is a geologic map showing the extent of both undisturbed and partly removed gravel in the area from North Columbia to Badger Hill.

An extensive drilling program was conducted near North Columbia during the late 1930's, and the property owners have kindly made the drill records available. These records indicate that 59 holes totaling more than 20,000 feet were drilled; the location of the holes is shown in figure 5. Two categories of information from the drill holes are of particular interest: (1) the shape and configuration of the bottom of the channel, and (2) the distribution and amount of gold in the gravel.

"α_0" (fig. 9) is inconsistent with a near-surface explanation for the late bedrock arrivals. On the other hand, if the late arrivals α_n and α_s are caused by a local depression in the bedrock, as shown by the dashed curve in the bedrock surface, the delayed α_n arrival recorded from the north shot point should theoretically be displaced a distance of 180 tan (19°-12°) or about 20 feet south of the bedrock depression; similarly, the delayed α_s arrival recorded from the south shot point should be displaced 180 tan (19°+12°) or about 110 feet to the north of the depression and 130 feet or about 1 geophone spacing north of α_n. As the maximum delay times α_n and α_0 are not displaced relative to each other within the limits of these data, the interpreted bedrock depression "α" should be considered as questionable pending more detailed data. An alternate interpretation of the seismic anomaly is a low-velocity (<6,150 fps) lens located within the lower part of the Tertiary gravels at "α".

Other more subtle examples of late arrivals more likely caused by local relief in the bedrock surface are marked "β." Although not considered in the first-order analysis, they occur at the correct surface location for critical rays generated at the south shot point and emerging at an angle of 19° from the center of the channel as shown by the drill-hole data.

Gravity Method

Regional gravity data were obtained in the area of figure 2, and six detailed profiles were made across the Tertiary gravels at North Columbia, Malakoff, and San Juan Ridge. Simple Bouguer anomalies along one of the profiles at North Columbia (A–A', fig. 5) are shown in figure 9, one curve for an assumed bedrock density of 2.67 g/cm^3 (grams per cubic centimeter) and the other for a gravel density of 2.1 g/cm^3. The 2.1 g/cm^3 reduction density is based on actual measurements of the blue gravel at Birchville (fig. 2) which average 3,500 pounds per cubic yard (Herbert Jeffries, oral commun., 1967). However, bucket-size samples of the bench gravel at North Columbia yield densities in the range 1.4–1.8 g/cm^3 for dry samples and 1.8–2.2 g/cm^3 for wet samples. The porosity of the bench gravels is evidently about 40 percent.

The gravity low of about 1 milligal, which is presently uncorrected for terrain, corresponds to the thick part of the channel fill and qualitatively demonstrates the potential usefulness of the method. Quantitative refinements and extensions to the north and south of the bedrock surface as interpreted from the seismic data along A–A' should be possible after terrain corrections are completed.

Magnetic Method

Inasmuch as slates, phyllites, and quartzites of the Calaveras Formation are generally nonmagnetic, as shown by 17 east-west high-level aeromagnetic profiles with a north-south spacing of about 5 miles across the central Sierra Nevada (Isidore Zietz, written commun., 1967), the magnetic method was not expected to be of much help in determining bedrock configuration. However, a north-south ground magnetic profile crossing the North Columbia pit along A–A' and extending half a mile into bedrock on both ends shows a broad magnetic low of several hundred gammas associated with the Tertiary channel. The central part of the anomaly is illustrated in figure 9. The form of the anomaly, with the magnetic minimum displaced to the south of the deepest part of the channel, is qualitatively consistent with a homogeneous basement magnetized in a direction parallel to the earth's magnetic field. However, a rather high basement susceptibility of about 10^{-3} cgs (centimeter-gram-seconds system) would be required to explain the anomaly if caused entirely by the basement configuration. Results from the detailed airborne survey, when available, should help resolve this apparent problem.

Resistivity Method

Tests of the resistivity method for determining depths to bedrock were somewhat disappointing in the North Columbia area. However, at the Malakoff diggings where bedrock is shallower and the terrain more favorable, it does seem likely that the depth to bedrock was obtained at three places across the pit. At North Columbia five soundings were tried and a 1,300- by 700-foot area of the lower pit was mapped. The data from and the interpretation of two of the soundings are shown in figure 10 and the interpreted resistivity layers within the Tertiary gravels are plotted in the geologic section A–A' (fig. 9).

With the exception of the sounding at R_{11} illustrated in figure 10, the current electrodes could not be expanded far enough to pick up the effect of basement rocks because of the hydraulicked cliffs and deep gullies within the pits. Moreover, soundings expanded across the Tertiary channel, such as in figure 10, may have dip effects from the rising basement rocks to the north and south. These problems preclude the use of resistivity for determining bedrock configurations in this area, although the method may be useful for tracing layers within the gravels. Possibly the four Tertiary layers with sharply decreasing resistivities of 6,100, 3,500, 1,000, and 25 ohm-m (ohm-meters) (figs. 9 and 10) correspond in some way to the bench, red, and blue gravels (fig. 4).

Electromagnetic Method

EM has some advantages over resistivity at North Columbia because it is not affected by the highly resistive washed gravels (fig. 10). However, the method is able to "see" only as deep as about one-half to three-quarters of the loop spacing, which was 300 feet

be revealed; and IP and magnetic methods were tested in order to determine whether they could detect disseminated sulfides or concentrations of magnetite, respectively, that might be associated with placer gold deposits.

Acknowledgments

The geophysical tests were under the overall direction of H. W. Oliver. Investigators responsible for the fieldwork and the interpretation of data for the respective methods are as follow: R. E. Mattick, seismic; D. B. Jackson, resistivity; Peter Popenoe, EM; D. B. Hoover, IP; S. L. Robbins, gravity and ground magnetic; F. C. Frischknecht, airborne; and E. D. Seals, surveying. Field parties included Cletus Wotorson from Liberia, J. H. Seo from South Korea, and C. E. Shipp, J. R. Matis, D. R. Shoenthaler, R. N. Babcock, J. T. Page, Jr., C. L. Tippens, Arthur Conradi, Jr., and A. W. Savage, III. Herbert Jeffries kindly provided magazine storage at North Columbia for explosives. We are particularly grateful to Clyde Newlin and Eric Leffingwell for expediting approval by the California Division of Beaches and Parks to carry out tests in the Malakoff Diggins State Historic Park.

INSTRUMENTATION AND FIELD PROCEDURES

The seismic tests were made with a 7000-B recording unit built by Houston Technical Laboratories. This unit recorded the output of 12 vertical seismometers on photographic paper. The seismometer spacing ranged from about 100 feet (fig. 9) to 650 feet (fig. 11), and energy was propagated from dynamite charges of 50 to 200 pounds buried at depths of 5 to 15 feet. Ground elevations of the seismometer stations and shot points were surveyed and staked to the nearest 0.1 of a foot and used in conjunction with the gravity survey.

Gravity, magnetic, and EM data were obtained at every seismometer stake as well as along extensions of the seismic lines. LaCoste and Romberg meter G62 was used for the gravity survey, and three-frequency slingram equipment built by the U.S. Geological Survey was employed for the EM measurements. The vertical magnetic measurements shown in figure 9 were obtained using two Sharp flux-gate magnetometers in tandem with a Barringer precession magnetometer which provided the total-intensity data. The Sharp magnetometers were placed on leveled planetables and the Barringer sensor set on a wooden staff to insure the greatest possible accuracies of the respective instruments. Aeromagnetic surveys were made with the U.S. Geological Survey's flux-gate equipment mounted in the tail of a Convair CV-240.

Standard direct-current equipment built by the U.S. Geological Survey was used for the resistivity measurements. Commercial instrumentation manufactured by Burr-Brown Corporation was used for the IP survey.

DETERMINATION OF BEDROCK CONFIGURATION

Seismic Method

The drill-hole data furnished by the property owners provided an excellent opportunity to test methods of finding depths to bedrock. Two seismic refraction profiles were shot in the North Columbia diggings—one along A–A' in the upper pit and the other along the line of drill holes located about 0.4 mile east of A–A' in the lower pit (fig. 5). The seismic results, as well as resistivity, gravity, magnetic, EM, and drill-hole data obtained along profile A–A' are shown in figure 9.

The total length of the seismic profile within A–A' is about 4,200 feet, and the average geophone spacing, although variable, was about 100 feet. Weathering spreads have been shot in the vicinity of each of the five shot points and elevation corrections made to the unreduced traveltimes shown in figure 9 for a near-surface velocity of about 1,000 fps (feet per second).

Except at the northern end of the profile where bedrock arrivals were recorded in only one direction, depths to bedrock were computed at each geophone by the time-depth method (Hawkins, 1961). Although the drill-hole data were available prior to the seismic tests, no referral to specific drill-hole depths was made until completion of the computed seismic cross section. Disregarding the thin weathering layer (about 20–25 feet thick), the average veolocity of the layer of sand, clays, and gravel which overlies the bedrock surface is about 6,150 fps. In contrast, the average velocity of the bedrock, as computed by the method of Willmore and Bancroft (1960), is about 18,500 fps. This simple two-layer case, together with the large velocity contrast between the bedrock and overlying material, suggests that seismic-refraction methods should yield accurate bedrock depths. In this case, a comparison of the depths to bedrock computed from the seismic data and the depths found in drilling shows that the average error in the seismic depth data is 4.6 percent. This agreement along one profile is very close but should be considered as possibly fortuitous until all the test data have been analyzed.

Most of the scattering in bedrock arrivals about straight-line segments shown on the time-distance curves (fig. 9) can be explained by ground surface relief or better interpreted as resulting from near-surface lateral changes rather than from relief on the bedrock surface. One possible exception is the late arrivals marked "α_n" and "α_s" near the south end of the profile. These arrivals were recorded in an area where the ground surface is nearly flat and where a detailed weathering spread indicated no velocity anomalies within the upper 30 feet of gravels; moreover, the scatter of the overburden arrivals marked

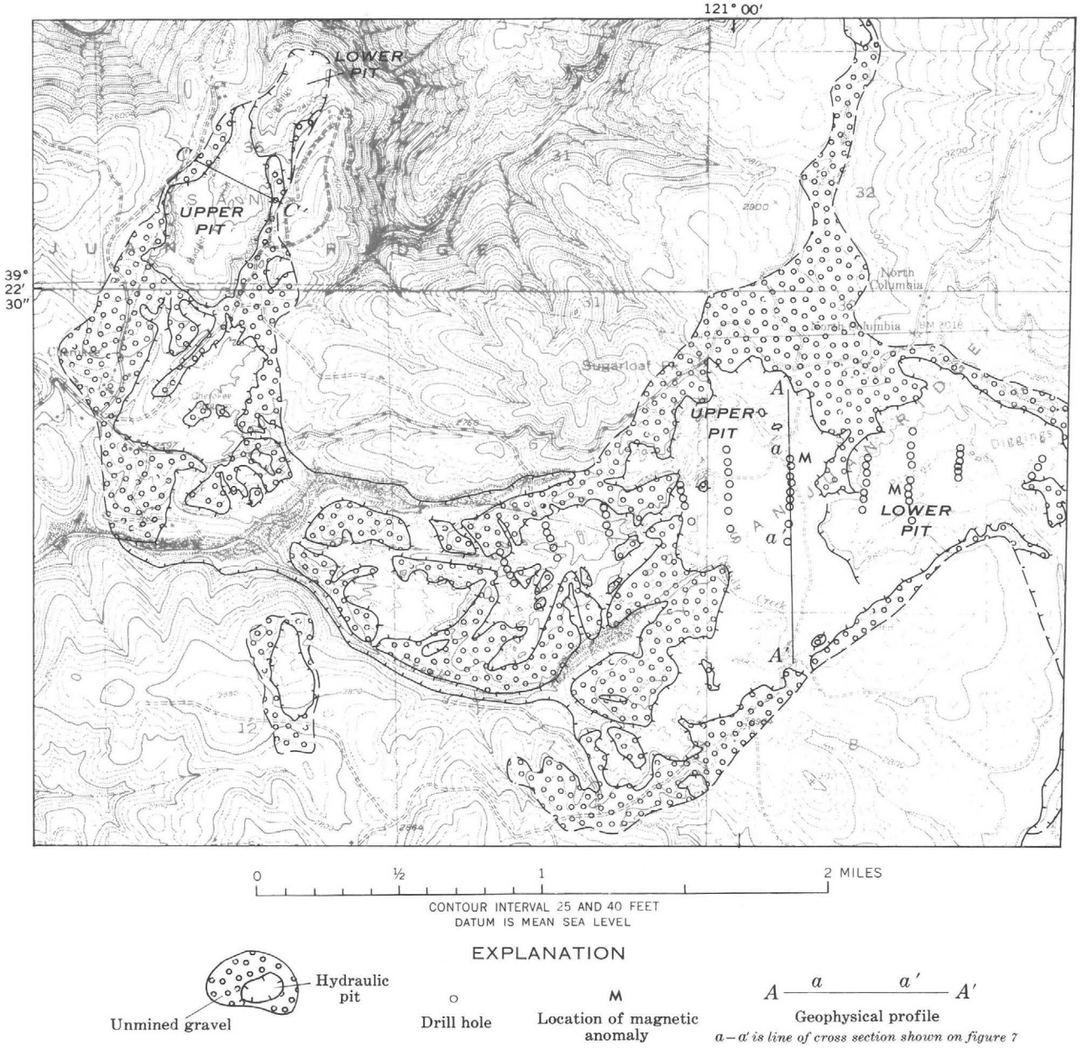


Figure 5.--Detailed geologic map showing location of hydraulic pits and drill holes in the Tertiary gravel in the vicinity of North Columbia and Badger Hill. Unmined gravel remains in place in most of the hydraulic pits, and only in the lower pit of the Badger Hill diggings has bedrock been exposed by hydraulicking.

Configuration of the Channel

The drill holes range in depth from 100 to 484 feet. They outline a channel bottom broadly concave in cross section that descends westward with a gradient of about 66 feet per mile. A contour map showing the topography of the bottom of the channel is shown in figure 6. A typical vertical cross section across the channel along one line of drill holes is shown in figure 7. This section is part of one of the profiles that was examined in detail by geophysical methods.

Grade and Distribution of Gold

The drilling records indicate that the highest gold concentration is near the bottom of the deepest part of the channel. Values in the upper part of the gravel deposit vary from a fraction of a cent to a few cents per cubic yard, but in the lower part of the deposit the grade increases to several tens of cents per cubic yard and locally attains several dollars per yard. The richest grade indicated in the records is an interval of 42 feet in one hole, which assayed $9.21 per cubic yard.

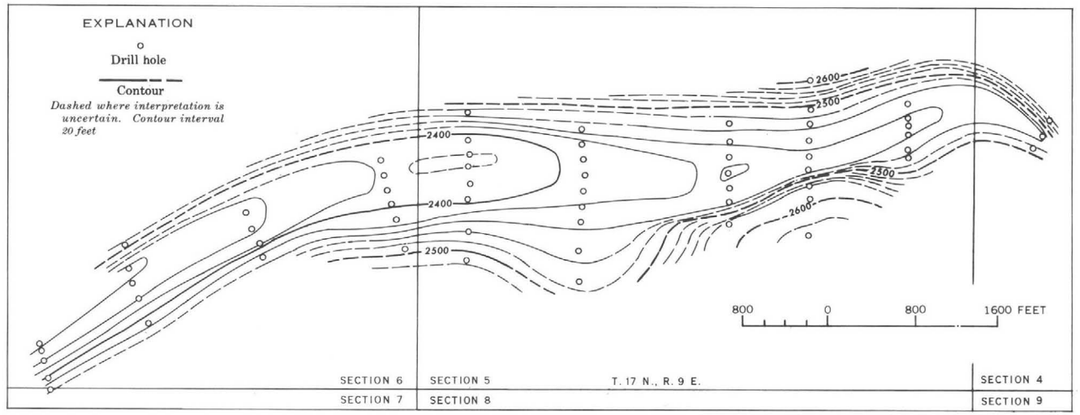


Figure 6.--Contour map of bedrock surface at base of gravel in North Columbia hydraulic pit. Contours based on drill-hole data.

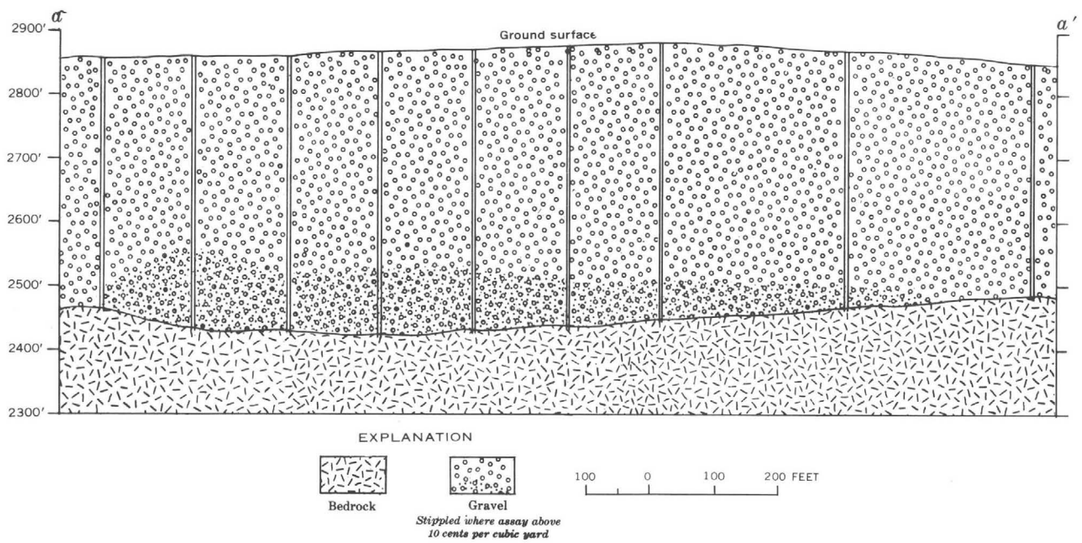


Figure 7.--Cross section of channel near North Columbia as indicated by one line of drill holes. Line of section a—a' is shown in figure 5.

Calculations made from the drill records indicate the total amount of gravel and the value of its gold content. The ground was divided into rectangles, each with a drill hole at the center. The volume of gravel underlying each rectangle was determined, and from the assay values given for specific intervals in each hole, a figure was obtained for the value of the gold under each rectangle.

The summation of these numbers indicates that the entire block of drilled ground consists of a total of 145.2 million cubic yards of gravel containing about 570,000 ounces of gold, or about $19.9 million in gold. The average grade of the total block is 13.7 cents per cubic yard, but this includes much material that assays at only 1 or 2 cents per cubic yard or less. Therefore further calculations have been made, arbitrarily assigning a cutoff grade of 10 cents per cubic yard. About 21.8 million cubic yards of gravel, containing values richer than this cutoff grade, has a total gold content of about 506,000 ounces, or about $17.7 million in gold, at an average grade of 81.2 cents per cubic yard. This higher grade gravel is buried at depths ranging from 100 to 400 feet, and a representative cross section

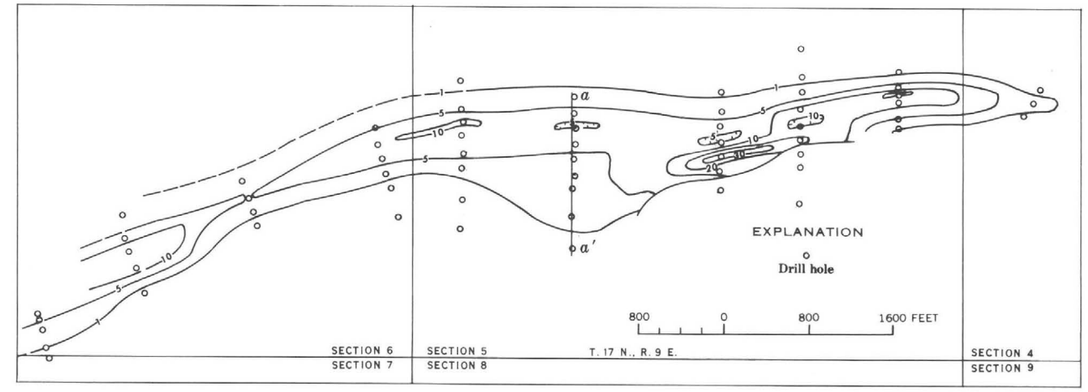


Figure 8.--Contour map of the foot-assay product as indicated by drilling information. Contour figures are in thousands of foot-cents.

of its distribution is shown in figure 7. Figure 5 shows that over half the length of the channel in the North Columbia-Badger Hill area is not included in the block of drilled ground. It is reasonable to speculate that the potential total volume of the deposit and the gold content are considerably greater than the above figures.

The foot-assay product[2/] has been determined for each drill hole that contains gold values exceeding the cutoff, and a map giving contours of foot-assay products is shown as figure 8. A comparison of figures 6 and 8 shows that each peak locality of the foot-assay product lies in the trough of the channel and that the maximum foot-assay product of any cross section generally coincides with the lowest part of the trough. The three major peaks of the foot-assay product along the central and eastern stretches of the channel lie at or just downstream from a bend in the channel. Considerable variation occurs lengthwise along the channel, and values drop abruptly toward the sides. These observations are based on drill records that have not been confirmed by additional tests. Inasmuch as reliable sampling of placer deposits is notoriously difficult, these records must be interpreted with care.

In view of the waste-disposal problems, water costs, and land values, it is unlikely that hydraulic methods can again be employed on a large scale to recover gold in this area. Furthermore, the grade is too low to permit conventional underground mining methods. The challenge of a large target, however, may stimulate the imagination and ingenuity of gold seekers to devise a low-cost mining method that will permit recovery of the gold in this and other deposits in the Tertiary channels of the Sierra Nevada.

[2/] The foot-assay product is the number obtained by multiplying the length in feet of each segment of the drill hole by the assay value of that segment in cents per cubic yard. The total foot-assay product for each hole is obtained by adding together the products of the segments. The foot-assay product is an expression of the total quantity of mineral in the block but does not necessarily express the grade. Ten feet of 10-cent gravel has the same foot-assay product as 1 foot of $1.00 gravel.

GEOPHYSICAL INVESTIGATIONS OF THE CHANNEL GRAVEL

By Howard W. Oliver and Robert E. Mattick

INTRODUCTION

A series of tests have been conducted in parts of the Tertiary channels in northern Nevada County, Calif. (fig. 2), to determine the feasibility of using geophysical methods to (1) determine the configuration of the bedrock surface beneath the exposed gravels, (2) find and trace Tertiary channels where they are covered by volcanic breccia, (3) locate structures, such as transverse ridges, faults, and lithologic boundaries in the bedrock, that might have served as natural traps for gold concentrates, and (4) determine the distribution within the gravels of other relatively heavy minerals such as magnetite and pyrite that are known to be associated with concentrations of gold in this area (Lindgren, 1911, p. 73-74). Initial tests of seismic, gravity, ground magnetic, resistivity, ground electromagnetic (EM), and induced-polarization (IP) methods were made during July to mid-August 1967. In addition, tests of three airborne methods—magnetic, EM, and radiation—were carried out in October 1967. The compilation of all these data is incomplete but several important preliminary results are reported herein.

The geophysical methods employed were selected in an attempt to obtain as varied and detailed information as possible on the gravel deposits. Seismic refraction supplemented by gravity and resistivity techniques was used to find out if bedrock configuration could be determined and if gravel deposits could be traced under a cover of volcanic rocks; resistivity methods, EM and IP, based on a suspected variation in the water and (or) clay content and hence on the electrical properties of the blue, red, and bench gravels, were used to see whether structures in the gravels and the distribution of the gold-rich blue gravel could