BUREAU OF MINES
TECHNICAL PROGRESS REPORT -3

HEAVY METALS PROGRAM

GOLD RESOURCES IN THE TERTIARY GRAVELS OF CALIFORNIA

U.S. DEPARTMENT OF THE INTERIOR

CONTENTS

The Gold Resources in the Tertiary Gravels of California

by

Roland W. Merwin[1/]

INTRODUCTION

This report is one of a series presenting results of investigations conducted by the Bureau of Mines under the Department of the Interior's Heavy Metals Program. The objective of that program is to stimulate domestic gold output which has declined to less than a third of the nation's rapidly increasing consumption.

The role of the Bureau in the Heavy Metals Program is first to determine which domestic resources would, with improved technology, have economic production potential and then to develop the required technology.

In late 1967 resource investigations by the Bureau showed that the Tertiary gravels of California, which had been forced to stop operations in the 1880's because of the damage being caused by discharge of mine waste into streams, represent a potential major gold resource. Further investigation, during the first few months of 1968, confirmed the existence of this vast potential resource and indicated that it might be rejuvenated as a significant contributor to domestic gold production. These initial investigations provided enough data about volume, distribution, and availability of gold bearing gravels to justify a concerted effort by the Bureau to attempt to develop economic mining of these deposits without contaminating the environment as had been done by hydraulic mining. Consideration was given to the direct application or modification of modern surface mining techniques as well as the possibility of selective mining by modern underground methods. It was decided in May 1968 that the Tertiary Gravels represent a suitable subject for a demonstration mining project. The San Juan Ridge area has been chosen as a possible demonstration site. Major sampling and geophysical investigations were underway in June 1968 to develop information as a basis for eventual choice of an appropriate mining system, which would be fully compatible with the maintenance of environmental quality in the area. It is expected that a final decision will be made by the end of FY 69.

Immediate objectives of the Tertiary Channel project will be to provide the mining industry with the results of research and field testing in the techniques of deposit delineation, fragmentation,

1/ Mining Engineer, San Francisco Office of Mineral Resources, San Francisco, California.

ground control, waste disposal, materials handling, environmental control, and beneficiation as they apply to the Tertiary Channel deposits. The ultimate objective, if considered feasible, is to select a technically and economically workable total mining system for field demonstration by the Bureau of Mines.

The following pages present in brief the information which, when supplemented by discussions with industry and local officials and organizations, provided the basis for the Bureau's decision to investigate further the Tertiary gravels.

SUMMARY

Preliminary investigations of gold deposits in the United States that offer a large tonnage potential indicated that the Tertiary gravels of California contain one of the largest known reserves of gold in the United States, and that they are of such grade that a breakthrough in mining and/or metallurgy could stimulate industry to resume working these deposits. The exploitation of these gravels was virtually suspended in 1884 by legal restrictions on hydraulic mining rather than by economic considerations. The cessation of production occurred at the height of hydraulic mining activities that had resulted in the production of about \$500 million at present gold prices, and left unworked more than half of the then known gravels.

This report covers the total known potential of the Tertiary gravels. The U.S. Geological Survey is conducting an investigation of the geology of the gravels and has published the results of its geological and geophysical investigation of the San Juan Ridge deposit, the largest single presently-known deposit in California, (12) 2/. Exploitation of the auriferous gravels in the ancient Tertiary river channels yielded \$507[3/] million from 1,585 million cubic yards, an average of \$0.32 per cubic yard. Hydraulic mining methods were employed almost exclusively. These operations were virtually suspended in 1884 by legal restrictions on the disposal of debris. Attempts to reactivate the exploitation of these deposits by several conventional methods have proved unsuccessful, including expenditure of \$4,650,000 of Federal funds for the construction of debris dams. Remaining reserves of gravel are estimated to total 3 to 4 billion cubic yards with an average grade of \$0.25 per cubic yard. Zones in the lower sections of the gravels are estimated to contain 600 to 800 million cubic yards with an average value of \$1.00 per cubic yard.

ACKNOWLEDGEMENTS

Most of the information in this report was compiled from the literature reported in the bibliography. Acknowledgement is made of additional

2/ Underlined number in parentheses refer to the Bibliography at the end of the report.

3/ All production and grade figures in this report are stated on the basis of a gold value of \$35.00 per ounce.

information supplied by Donald W. Peterson and Warren E. Yeend of the U. S. Geological Survey, Thomas Smith of the California Debris Commission, William B. Clark of the California Division of Mines and Geology, and D. H. McCrea of Pacific Gas and Electric Co. Grateful acknowledgement is made to the San Juan Gold Co. for the release of information in its files.

LOCATION

The auriferous gravels covered by this report are those remaining in the beds of the ancient Yuba, American, Mokelumne, Calaveras, and Tuolumne Tertiary River channels, as shown in figure 1. They are located within a belt 40 to 50 miles wide and 150 miles long on the west slope of the Sierra Nevada Mountains at altitudes ranging from 200 to 5,000 feet. The most important deposits are in the Tertiary Yuba River channels. Major quantities are in the Tertiary American River channels and lesser amounts are in the ancient river channels to the south. The locations of the principal deposits in the Tertiary Yuba and American River channels are shown in figure 2.

HISTORY

Shortly after the discovery of gold in California, and while the extremely rich placers in the present rivers and streams were being exploited, it was recognized that the origin of the greater portion of the gold was from ancient Tertiary river channels found along the ridges between the present rivers and from which auriferous gravels had been eroded and re-concentrated in the present rivers and streams. The existence of tremendous quantities of auriferous gravels was evident, but because of their relatively low grade, the depth of gravel, and the lava capping over many of the deposits, they were not workable by the rudimentary methods employed at that time.

This led to development of the hydraulic mining method for the exploitation of these deposits. The first major hydraulic operation began in 1853. In this method large streams of water under heads of from 200 to 500 feet were discharged against banks of gravel by the use of "monitors" or "giants" with nozzle orifices up to 9 inches in diameter. The gravels were washed through long sluice boxes for the recovery of the gold and the debris dumped indiscriminately into the nearest stream or river. Large banks of gravel, up to 600 feet high, were mined by this method.

The large quantities of water under high head that were required necessitated the construction of large dams in the high Sierras and long ditches and flumes to bring the water to the mines. Estimates have been made by many authorities that approximately $100 million was expended in the development of hydraulic mining. Hammond, (8, pp. 123-125) lists 27 major canals with an aggregate length of 2,170 miles.

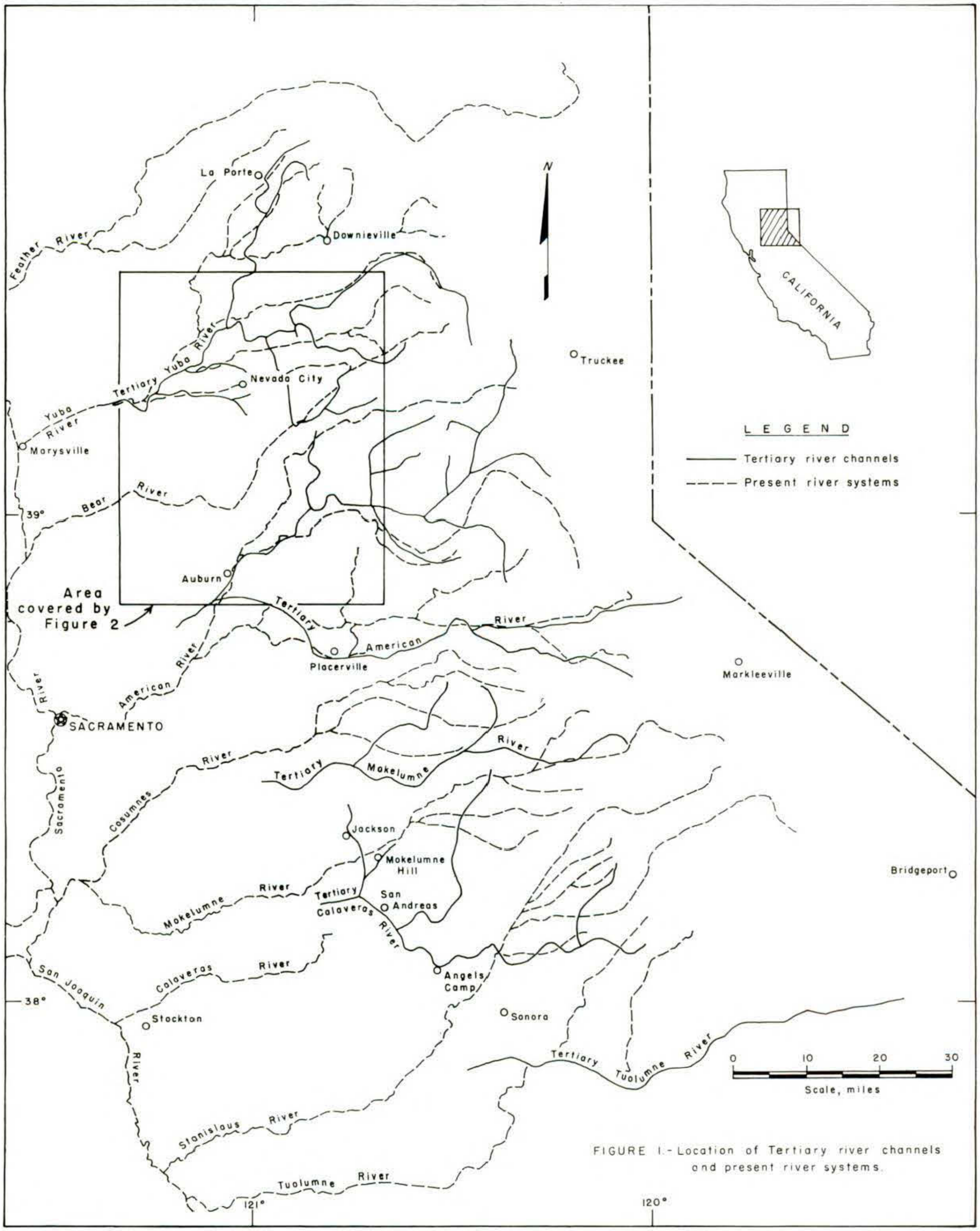

FIGURE 1.- Location of Tertiary river channels and present river systems.

Other authorities state that the total length of all the ditches, large and small, was nearly 5,000 miles. In 1880 at the height of activity, the U. S. Army Corp. of Engineers reported that 46 million cubic yards of gravel was mined and that 710,000 acre feet of water was used.

The immense amount of debris from the hydraulic operations was carried downstream into the Sacramento and San Joaquin Rivers, causing great damage to agriculture and navigation. A long series of legal disputes culminated in 1884, when the Federal District Court issued an injunction permanently restraining the hydraulic miners from discharging any debris into the Sacramento and San Joaquin Rivers and their tributaries. This was the famous Sawyer decision, and while it did not prohibit hydraulic mining as such, it did have the practical effect of causing an abrupt cessation of mining because there was no economic method for the storage or disposal of debris.

In an effort to alleviate the situation, The California Debris Commission was established in 1893. This is a Federal agency under the supervision of the Corps of Engineers. The Debris Commission was authorized to issue permits for hydraulic mining, regulate operations, and assist in the storage of mining debris. The lack of success in reactivating hydraulic mining is shown by the fact that up to 1967 only 32 million cubic yards was mined under permit as compared to an estimated 1.5 billion cubic yards mined prior to the Sawyer decision.

The regulations of the California Debris Commission required that all debris be confined behind approved dams. Private interests constructed many small local dams and two major structures, the Bullards Bar and Combie dams. The two major dams are shown in figure 2. The yardage mined and stored behind these private dams amounted to 29 million cubic yards. The Bullards Bar dam was by far the largest structure, but the available storage capacity was only partly utilized, and the reservoir has since been nearly filled with natural stream debris.

In the 1930's, after a series of Federal and State hearings, it was concluded that large scale hydraulic mining could be resumed if public funds were alloted for the construction of debris dams, with the costs to be reimbursed by the payment of storage fees. Federal funds were alloted, and the Corps of Engineers constructed two large dams, Englebright and North Fork, which are shown on figure 2. The total cost of these two dams was $4,650,000 and they provided storage capacity for 140 million cubic yards of debris. The California Debris Commission obtained guarantees from mine owners that they had much more than the necessary yardage of gravel required to amortize the investment, and issued permits for these operations. However, as of 1967 only 3 million cubic yards had been mined under this program and there is no present activity.

The primary cause for the failure of this effort was the lack of sufficient water for the operations. Upon the cessation of activities in 1884 the existing canal systems were either abandoned or sold to

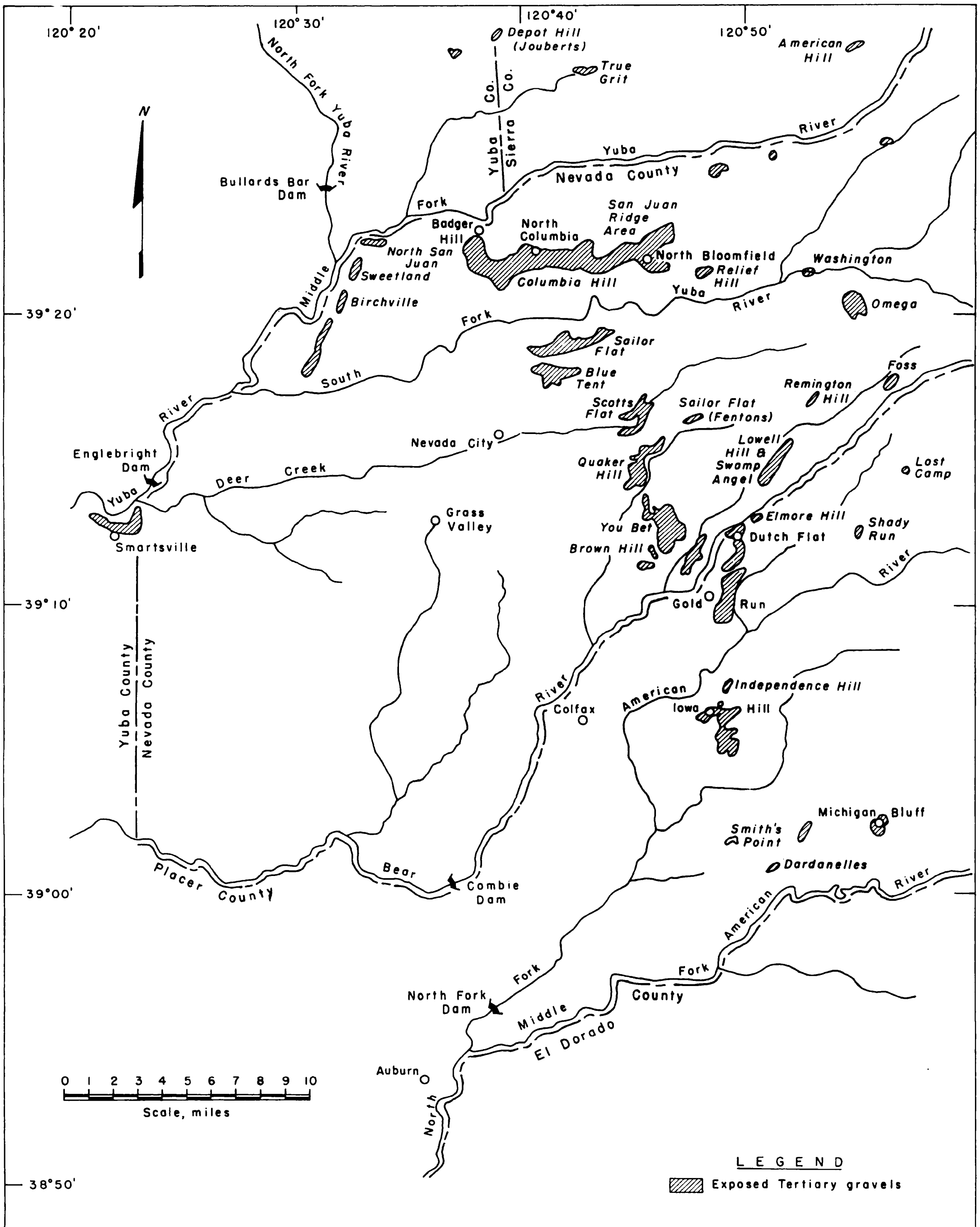

FIGURE 2.-Location of major deposits of exposed Tertiary gravels.

irrigation districts and power companies, and water rights for hydraulic mining were lost by non-usage. It is the general rule in California that an established right to utilize water is lost after non-usage for 5 years.

Secondary reasons for the plan's failure were the capital expenditures required to rehabilitate the mines, the cost of water if purchased from established users, general non-availability of water at the elevations required for hydraulic mining due to multiple use in a series of power plants prior to the water reaching the mining areas, and pollution problems that would be created in the streams between the mines and the storage dams. The cooperative assistance provided by the Federal government probably would have been successful if offered in 1884 or shortly thereafter, but the passage of time created unsolvable problems.

Concurrent with hydraulic mining, and continuing after its cessation, long lengths of Tertiary channels were mined by underground or drift mining methods. This consisted of drifting along the bottom of the channels, or along higher grade sections in the upper parts of the channels, and removing the high-grade gravels. Generally, an 8-foot vertical section of payable gravel was mined and washed.

Due to the incompetent nature of the ground, timbering was required leading to a high-cost operation. Therefore, drift mining was employed only where hydraulic mining could not be used because of great depth of gravel, but principally where lava capping covered the channels, and then only for high-grade deposits.

With the exhaustion of the known and more accessible gravels this method of extraction declined and was not revived to any great extent during the gold boom for the 1930's. It does not appear likely, under current labor costs, that this method of mining will be revived.

The total extent of drift mining is not known, although many miles of channel were drifted upon. However, the yardage of gravel mined was estimated at 30 million cubic yards by Gilbert, (8, p. 48). This figure is insignificant when compared to the total yardage mined by hydraulic methods.

The use of bucketline dredges for mining the Tertiary gravel deposits was considered by several operators, but did not appear to be practical, principally because of topographic conditions, excessive depths of gravel for dredge operations, and the lava capping overlying many of the known deposits.

DESCRIPTION OF THE DEPOSITS

The geology of the Tertiary river systems and the deposition of the auriferous gravels were described in detail by Lindgren (11). This report still is the most authorative publication on the geology of this type of occurrence.

The ancient channels are the remnants of the river systems of Tertiary age. The rivers flowed westerly and southwesterly from the then existing crest of the Sierra Nevada Mountains, with grades much steeper and flows much greater than the present Quarternary rivers, and moved tremendous quantities of material of pre-Tertiary age. Conditions were such that the river systems were choked with detritus that constitute the present Tertiary gravels. After leaving the granites of the Sierra Nevada, the rivers cut through great thicknesses of sedimentary and metamorphic rocks, and these formations were the source of the auriferous gravels in the Tertiary channels. The gold was derived not only from veins in place in these formations but from concentrations in pre-Tertiary drainage systems. The net result was the concentration in the Tertiary river channels of very large amounts of auriferous gravels.

Volcanic activity throughout the Tertiary age strongly influenced the course of the rivers and in some cases created intervolcanic channels containing auriferous gravels. Near the end of the Tertiary age, the activity increased to the extent that lava flows covered the entire area filling the Tertiary river channels, covering the accumulated gravels, and bringing to a close the whole system of Tertiary drainage.

Subsequent uplift of the Sierra Nevada range during the Quarternary age created a new drainage system constituting the present river pattern on the west slope of the mountains. These rivers, in general, paralleled the old Tertiary rivers because the greater depth of the lavas filling the Tertiary channels was more resistant to the cutting action of the new rivers than the lesser lava depths over the old Tertiary ridges. The new rivers, however, cut much deeper than the older rivers, leaving long lengths of the Tertiary channels perched on the ridges between the present river canyons.

Where partially or completely dissected by the present river systems, the ancient gravels were removed by erosion and re-concentrated in the present rivers, providing the main source of the gold in the Quaternary gravels from which the earliest gold production in California was obtained.

Along other sections of the Tertiary channels only the lava capping was removed, exposing the gravels for exploitation by hydraulic mining. Many extensions of these exposed channels under the lava flows were mined by underground methods (drift mining) where the values were sufficiently high to warrant the higher costs. Other long lengths of the Tertiary river channels remain undeveloped. The thick cover of lava, faulting, and the lack of details of the Tertiary river drainage hamper their evaluation.

Where exposed, and there traced by underground workings, the gravels range from a few feet to as much as 600 feet thick, with widths that in some cases range up to 2 miles at the confluence of old river channels.

Continuous lengths of channels have been traced for distances in excess of 10 miles with interpolated lengths of over 30 miles. Hammond (8, p. 114) estimated the aggregate length of the ancient channels at 400 miles in 1888. It is believed that this length could be extended appreciably by geological investigation.

The physical composition of the gravels is extremely variable, both regionally and locally. The gravels range from large boulders several feet in diameter with coarse sand, through small pebbles with fine sand, to volcanic breccia, tuffs, and clays. In most areas the gravels are porous; in some sections they are tightly cemented or closely interbedded with layers of clay.

DISTRIBUTION OF THE GOLD IN THE GRAVELS

The bulk of the gold in the gravels is fine although large nuggets are sometimes found. In general, the gold is concentrated near the bedrock of the channels, but important deposits may occur in benches along the sides of the channels. The upper gravels contain less gold than the lower gravels, but it would be unusual to encounter completely barren gravels, regardless of their depth. Locally, the richest occurrences are in the form of "pay streaks," usually near the bottom of the channels, but some times higher in the beds. These pay streaks often wander from side to side of the old channel, the distribution being controlled by the stream conditions at the time of final deposition.

Lindgren (11, p. 71) stated that the greatest part of the gold is ordinarily contained in the gravel within 3 feet of the bedrock. He also reported that the hydraulic mining of deep banks of gravel varying from 50 to 300 feet in height yielded from $0.17 to $0.68 per cubic yard. The top gravels ranged from $0.03 to $0.17 per cubic yard and the drifting ground on bedrock, from $0.85 to $25.50 per cubic yard, or more. Authenticated data on the distribution of gold is almost non-existent in the records of old operations. However, Hammond (8, p. 113) noted that in 1876-77 one major hydraulic operator segregated the upper and lower gravels in one section of his pit. From the upper gravels, which ranged from a few feet to over 200 feet in depth, he mined 1,592,000 cubic yards with a yield of 6.4 cents per cubic yard. From the lower gravels, which averaged 65 feet in depth he mined 702,000 cubic yards with a yield of 55.6 cents per cubic yard. Hammond reported (8, p. 114) that, in general, from one-fifth to one-half of the total gold in a channel is contained in the lower 4 to 8 feet of the gravel.

HYDROLOGY

The hydrology of the Tertiary gravel deposits has never been investigated. Records of the old drift mine operations indicate that conditions may vary greatly. In general, the sides and bottoms of the ancient channels consist of impermeable formations while the gravels themselves are porous except for cemented sections and bedded layers of clay. The lava cappings may be either permeable or impermeable. The channels act as conduits for surface waters that have percolated downward, and underground flows may be considerable in some instances. If channels have been cleanly dissected by the present river drainage and are unobstructed, the water flows will be largely confined to the lower few feet of the gravels. However, faulting, tilting, and volcanic damming may create deeper pools of water, quiescent at depth, with flows at upper elevations.

PAST PRODUCTION FROM THE TERTIARY GRAVELS

Accurate figures are not available for the amount of gold produced from the Tertiary gravels because production figures from the various mines were not compiled during the period of greatest production from 1853 to 1884. Lindgren (11, p. 81) estimated that output totaled \$507 million virtually all produced before hydraulic mining ceased. Lindgren considered his estimate to be conservative.

The cubic yardage from which this production was obtained was the subject of two investigations, first by Turner (13) and later by Gilbert (6). Turner made his estimate on the basis of water usage and Gilbert checked the major portions of the region covered by Turner with actual volumetric determinations of gravels mined, increasing Turner's estimate by 51 percent. This latter work by the U.S. Geological Survey is considered to be a rather accurate estimate and amounted to a total of 1,585 million cubic yards in the region covered by both himself and Lindgren.

Using the production estimated by Lindgren, and the yardage estimated by Gilbert, it appears that the yield amounted to \$0.32 per cubic yard mined.

RESERVE ESTIMATES

All estimates have indicated that considerably greater yardages of gravel remain than were mined. The maximum estimate was 7 billion cubic yards. In view of the fact that all major operations ceased at the height of activity, this general assumption would appear to be valid.

Turner (13) estimated reserves of 1.5 billion cubic yards remaining in an area where he estimated that 858 million tons had been mined. His report was made shortly after the cessation of hydraulic mining. Using his estimates, the remaining reserves amounted to 176 percent of the yardage already mined.

It would appear reasonable to apply this factor to the more factual estimate of Gilbert of the U. S. Geological Survey (6, p. 43) which stated that the total mined by hydraulic and drifting operations amounted to 1,585 million cubic yards. This would give an indicated present reserve in the region under consideration of 2.8 billion cubic

Figure 1. Hydraulic Mining Operations in Malakoff Diggings Pit. (Circa 1880)

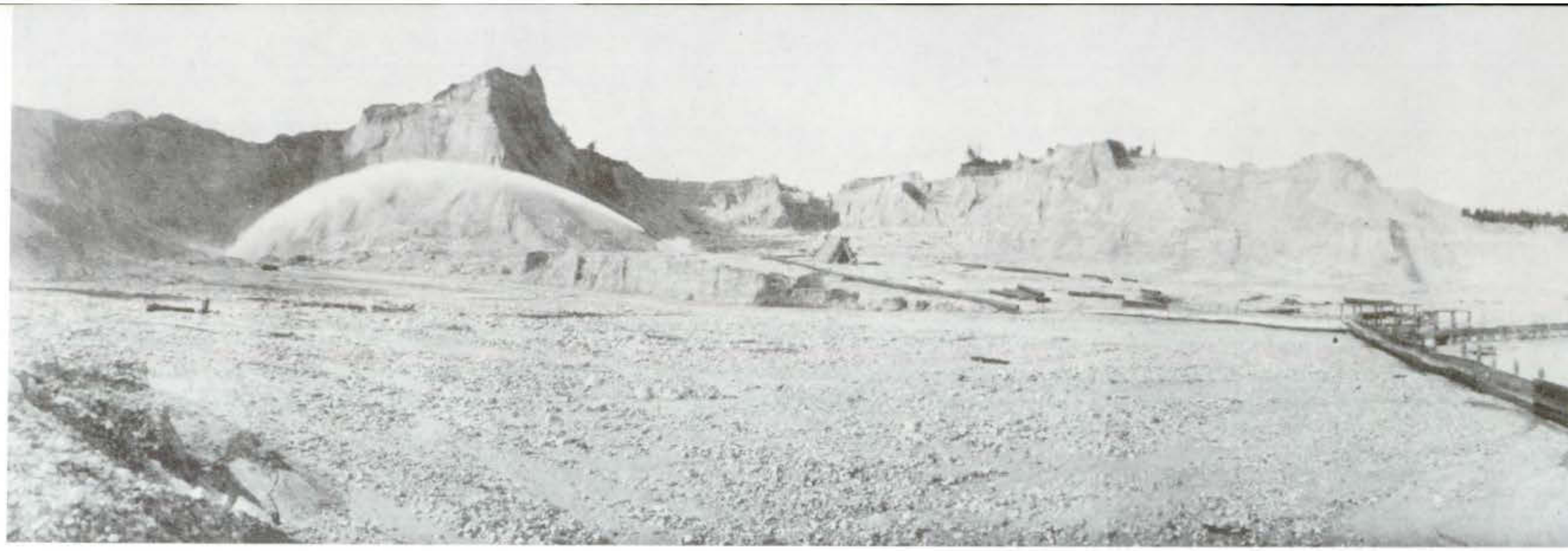

Figure 2. Hydraulic Mining of Surface Gravel in North Columbia Pit. (Circa 1880)

Figure 3. General View of North Columbia Pit Showing Extent of Surface Gravel Removed (Circa 1880)

yards. Assuming the yield of $0.32 per cubic yard (developed in the section on Past Production) this would amount to a total reserve of $893 million. Haley (7, p.5) estimated resources of auriferous gravels, principally Tertiary in the area being reviewed by this report, at 7 billion cubic yards, of which he stated that about 4 billion cubic yards would yield $0.25 per cubic yard. This included not only ground that would be mined by hydraulic methods but channels beneath lava flows and suitable for drift mining.

The State of California Hydraulic Mining Commission submitted a report to the Legislature of 1927 on the feasibility of resuming hydraulic mining in California by construction of debris dams downstream from the best known Tertiary gravel deposits. In this report, Jarman (9, p.75) stated that a preliminary estimate of easily worked gravels amounted to 712 million cubic yards and (in table 2) estimated the average yield for the first 200 million cubic yards to be worked would be $0.195 per cubic yard. No attempt was made to define the total yardage available in the Tertiary channels or to include the deeper gravels or those gravels capped by volcanic flows, because the objective of the report was only to delineate enough gravel to justify the construction of specific debris dams.

In 1937, as a prerequisite to the construction of the Englebright and North Fork debris dams by the Federal government, 12 private operators furnished guarantees to the effect that they were prepared to initiate the hydraulic mining of 781 million cubic yards of gravel tributary to these dams and that the average yield would be $0.27 per cubic yard. The California Debris Commission reviewed these figures and reduced them to 379 million cubic yards averaging $0.21 per cubic yard.

The largest single presently-known deposit of Tertiary gravel is located in the San Juan Ridge area of Nevada County. According to Jarman (9, p. 103) it contains approximately 800 million cubic yards in a channel 9 miles long and from 0.5 to 1.25 miles wide, with depth of gravel up to 300 feet. The entire deposit appears to average about $0.17 cubic yard. This deposit is being investigated by the U. S. Geological Survey and the U. S. Bureau of Mines.

From the information presently available it is estimated that the quantity of auriferous Tertiary gravels, including the deeper gravels and the virgin deposits capped by lava flows and not presently delineated, will total 3 to 4 billion cubic yards with an average grade of $0.25 per cubic yard. This represents a gold potential of from $750 million to $1 billion. The total yardage and the grade both could be higher.

Because of the nature of the deposits, a conservative assumption is made that 80 percent of the gold is contained in 20 percent of the gravels in the lower part of the channels. Based on the estimates in the preceding paragraph, this would provide target zones for exploitation containing 600 to 800 million cubic yards of material with an average value of $1.00 per cubic yard.

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