

GEOLOGY OF PLACER DEPOSITS

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GEOLOGY OF PLACER DEPOSITS

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ABSTRACT

The exploration of placers is a problem involving nearly all phases of the science of geology, especially physiography and stream sedimentation, neither of which has been given sufficient consideration in connection with the economic problems concerned. The use of aerial photography is a great aid in the study of placers, both ancient and modern. The use of geophysics, when applied as a part of a geologic program of exploration, can materially assist in guiding drilling operations and underground prospecting, with the result that the cost of expensive development work can be greatly reduced and hastened to an earlier completion.

Placers are classified according to the way they are formed: residual, eluvial, stream, glacial-stream, bajada, eolian, and beach. Since the ordinary stream placer is by far the most important, various phases of stream study are discussed in this paper. A need for further scientific study and the development of systematic working criteria is apparent.

The depleted placers of California consist largely of Recent and Pleistocene stream gravels and uncovered or buried, but easily accessible, Tertiary channels, while the large reserves lie in more remote positions. These are exemplified by hidden buried bench gravels not connected with the surface nor with channels already worked, and by the lower untouched channels that lie on true bedrock beneath the 'false bedrock' of the dredged areas along the western foot of the Sierra Nevada. Some Pleistocene gravels still lie in pockets beneath the waters of the larger rivers where faults have caused down-dropping of the stream bed. Benches still lie in isolated regions such as the Klamath Mountains. The desert affords several types of deposits: stream placers buried by alluvial fans, re-worked older placers, gravels interbedded with lavas, and the more recent bajada placers. Marine placers of Cretaceous, Eocene, Pleistocene, and Recent periods exist in the state, which may in places be worth investigating.

The largest of all these possible reserves in California probably lies in the remaining buried Tertiary stream channels of the Sierra Nevada.

INTRODUCTION

The gold-bearing gravel deposits or *placers* of California that still remain untouched lie, for the most part, in more obscure positions than the depleted gravels which formerly produced vast wealth for the state. The depleted gravels, which were once readily

accessible but are now nearly mined out, fall into three principal classes:

Depleted Placers

1. Recent and Quaternary stream gravels.
2. Uncovered channels of Tertiary age.
3. Buried Tertiary channels, easily located.

About one billion dollars worth of gold came from these three sources, the first having produced twice as much as the other two put together.

The placers which still remain to be sought out and worked, offer a challenge to the ingenuity of the exploration geologist. The problems involve the following types of deposits:

Placer Reserves

1. Deep gravel deposits lying immediately beneath several large rivers, such as the Feather and Klamath.
2. Isolated high benches such as those found in the Klamath Mountains.
3. Ancient gravels that lie beneath 'false bedrock' (interbedded volcanic layers) of the dredging areas along the western foot of the Sierra Nevada.
4. Gold-bearing gravels occurring in the 'shore' deposits of the lone (Eocene) formation, and the Chico (Cretaceous) formation.
5. Buried Tertiary channels and associated benches located in the known gold-bearing districts of the state.
6. Buried Tertiary channels and associated benches in the lava-covered district between the Sierra Nevada and the Klamath Mountains.
7. Bajada placers, or desert alluvial fan deposits, where gold is derived directly from the original mineralized bedrock source.
8. Desert placers, where the gold is reconcentrated from more ancient gold-bearing streams.
9. Buried desert stream placers.

The scope of these problems indicates the great need of an understanding of the geological principles involved. In no kind of mining is geology more applicable than in the exploitation of these more obscure placer deposits.

Significance of Improved Exploration Methods

A widespread geologic study of the ancient Tertiary gold-bearing stream channels of the Sierra Nevada, the gravel deposits of which are found to a

large extent buried beneath a mantle of volcanic materials, was concluded by the United States Geological Survey over half a century ago. Lindgren's "Tertiary Gravels" summed up, in a splendid manner, in 1911, these various geologic studies. His data were drawn from his own careful observations, from those of his associates, H.W. Turner, F.L. Ransome, and J.S. Diller, and from such early sources as J.D. Whitney, W.H. Storms, and Ross E. Browne.

Lindgren's Colfax folio, published in 1900, was the last great detailed field study of this kind in the Sierra Nevada. By no means, however, is this folio confined to the subject of stream channels, for it deals with every phase of the geology of the quadrangle. Everything of importance which it was possible to accommodate on a map of the small scale used—two miles to the inch—was recorded. At the time this field work was done, the best equipment and finest techniques of the day were employed, and very little escaped Lindgren's keen observation, each feature being scrutinized and shrewdly interpreted by his masterful mind.

Since then, however, considerable advance has been made in exploration techniques; other and different points of vantage are now available; and a greater degree of refinement of study is therefore in order. Furthermore, mining itself has many advantages today over the earlier methods.

I. Aerial Photography

From the air, regional photographs are systematically taken by qualified aerial photographers. The pictures are then examined under the stereoscope, or used in constructing topographic maps which show the most amazing completeness of detail. Many surface features never before realized are thus simply unfolded before the eye. Geologic truths in great numbers are revealed, and many important problems solve themselves. Used as a base for location of field observations and surface mapping, these aerial photographs are unexcelled. They are undoubtedly the greatest practical aid which has yet reached the hands of the geologist; besides they give secrecy, speed, and low-cost surveying to the program of modern exploration.

II. Geophysical Surveying

Added to this regional view from the air is the greater insight into the very interior of the earth itself afforded by several types of geophysical instruments, now well-tried and standardized. Peculiar characters of rock structure and composition are not only revealed but measured with precision by skillful engineers. Since the proper interpretation of all results thus obtained requires sound geologic reasoning, it is important that a better and more detailed background of geology should be drawn, and this is made more effective by aerial photography.

III. Physiography

The subject of physiographic geology or *geomorphology* has in recent years made notable progress in developing sound, scientific principles concerning the history and origin of the present surface configuration of the earth. Since these principles are directly applicable to the more ancient earth surfaces of the Sierra Nevada, over which flowed the Tertiary streams now extinct, *Tertiary physiography* is the key to the ancient channel problem.

IV. Study of Desert Processes

Study of the geologic processes at work in the desert has led to a better understanding of the desert placers, which offer a practically virgin field for exploration, holding a potential wealth not yet known.

V. Stream Sedimentation

Furthermore, the study of sedimentation has now reached a refined stage of development. There are today available various methods of technique which may be extensively applied to stream deposition. This sort of research includes the critical study of texture and structure of strata, as well as the microscopic examination of their mineral grains. It should yield a wealth of practical information concerning the processes involved in the accumulation of gravels, in the nature and direction of stream flow, in knowledge of what to expect as regards the concentration of gold and other heavy minerals, and in the correlation of channels of the same period or of the same system.

The more obvious criteria of stream sedimentation have long been used by the experienced miner, who, by examining the gold particles under the simple hand lens, infers whether they were robbed from earlier channels or whether they came directly from a vein. Also he uses the 'shingling' of gravels to tell him the direction of stream flow. These and a few other working criteria now used by the miner, however, have not all undergone a thorough scientific test, and at present there is a wide difference of opinion as to their interpretation.

The advances in technique and sound geologic interpretation should, therefore, be made to serve as wide practical aids in channel exploration, and much more definite and conclusive results should be gained now than were possible years ago.

Usefulness of Contouring an Ancient Surface

The most elucidating method of tracing in detail and showing graphically the position and course of an ancient stream valley is by preparing a contour map of the old drainage surface. The contours may be superimposed over a base map which should also show the present surface topography and areal distribution of the geologic formations, as well as any mine workings, drill holes, etc.

With the old-surface contours superimposed on the present surface contours, an accurate estimate may be made of the thickness, extent, and yardage of the

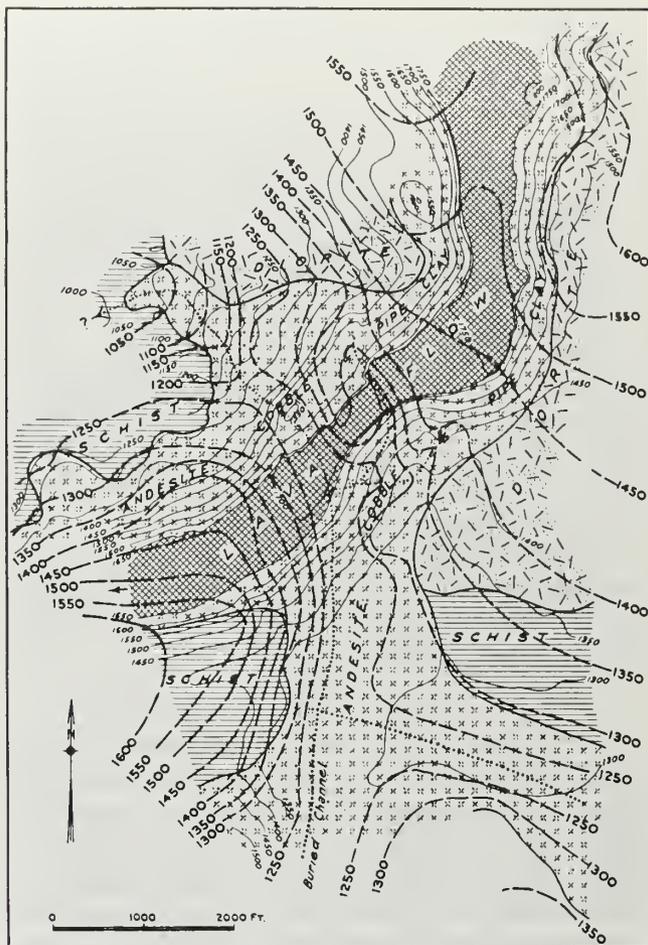
intervening channel-filled area. The points which are to be used in preparing an old-surface contour map should be secured through careful study of geologic and physiographic conditions, and obtained during the surface and underground survey. Drill-hole data and the essential results of geophysical observations should also be represented on this map. Careful enough study should be made so that the points used represent only one period of erosion.

If the geologic work is done prior to a contemplated geophysical survey and drilling program, much time and money may be saved in the location and number of points of observation, as well as in the number of drill holes needed. An approximate old-surface contour map may generally be constructed as a preliminary step by a skillful geologist, though he is limited only to surface data. This map should locate the general trend of the ancient valley to which later detailed work should be confined, thus eliminating much unnecessary and more costly work in adjoining areas unlikely to be productive. The most accurate elevations are those taken on bedrock where it is in direct contact with the older gravels, or with the pipe-clay and other volcanic materials of the oldest period of the area. Thus geological investigation should limit the extent of the geophysical work, which in turn defines the area to be drilled and later to be explored by underground methods.

Provinces of the Ancient Channels in California

The so-called 'buried channels' occur for the most part in the northern Sierra Nevada, where, during the Tertiary period, millions of years ago, volcanic outbursts with their mud-flows, covered the then existing network of stream courses. Thus entrapped and preserved, this old surface of the earth, probably Eocene in age, with all its forest-covered hills, beautiful valleys, and winding streams laden with gold, became completely hidden. Not until the area was lifted by mountain-making forces did the later rivers cut their canyons through the heavy mantle and expose whatever was beneath it. But even then, further volcanic mud-flows, cobble-washes, and new streams of lavas, filled and refilled the valleys formed. Finally, modern canyon-cutting trenched the whole area deeply, leaving remnants of flat-topped ridges between.

Though no volcanic mantle ever covered the ancient streams of the Klamath Mountains, the region was uplifted in late Tertiary and Quaternary times, and the rivers were therefore entrenched. As a result, benches of gravel were left at various elevations



Example of a geologic map showing the earlier prevolcanic topography in contrast with the present topography. Old-surface contours (dashed lines) are drawn over present-surface contours (fine, full lines). A major early Tertiary valley is thus reconstructed, and the general position of its buried stream channel is indicated, lying beneath volcanic materials of two later geologic periods, i.e., (1) Miocene cobble and pipe-clay (mud-flows and lake beds), (2) Pliocene lava flow which followed a canyon cut in the andesitic materials. The older channel cut in bedrock is gold-bearing. Its course was controlled by bedrock, for it followed the contact between hard diorite and softer schist. The gradient of the lava flow is not as steep where it is directed south as where it turns towards the west. This is explained by the westward tilting of the Sierra Nevada.

along the sides of the canyons. Faulting also played an important role in the history of the uplift, trapping gold-bearing gravels which date back to the Eocene. The whole subject of the surface features of the region, past and present, represents a series of very interesting problems not yet entirely solved.

In the Mojave Desert, Tertiary gold-bearing streams may have once flowed south from the region which is now the Sierra Nevada; but during the Pleistocene epoch their deposits became so broken and disrupted by faulting, and so extensively covered by later desert wash, that now there remains little to be recognized or traced.

The problem of the 'dry placer' is one of considerable importance, and when more is learned about it, an immense potential gold wealth may be discovered which has not yet been glimpsed. It is quite possible, however, to find and develop a sufficient underground water supply in many places for dredging operations. The finding of such water supplies may also be greatly assisted through the use of geological knowledge and geophysical surveying.

In the Peninsular Ranges of San Diego County, some placers have been mined. In the Poway (Eocene) marine conglomerate is found the Ballena placer, known as early as 1893.

Economic Significance of the Tertiary Gravels

The economic significance of the buried channel and the importance of its exploration should not be slighted, for it represents a vast future source of gold wealth for California. The revival of the channel-mining industry is made still more interesting by an understanding of the detailed geologic features, the possibilities they suggest for certain of these buried stream courses, and the realization of the vast extent of the region yet to be explored.

Since an estimate of the potential wealth of the desert placers depends upon further exploration and mining of them, it is not yet possible to evaluate their place in this study.

History of Development

The discovery of the Tertiary channels followed shortly after the discovery of gold in the present stream courses. In places, remnants of Tertiary channels were found lying exposed high up on 'flats,' stripped of their volcanic covering by Pleistocene erosion. Starting from these flats, the miners followed the uncovered channel to the point where it was covered by the lava capping, the top of which formed another kind of 'flat.' Water was nearly always encountered, which led to the construction of long and expensive drainage tunnels. To place these tunnels at the proper elevation to serve their best purpose was the most serious problem, for the old-timers did not have the powerful pumps which we use today.

The ideas developed concerning the courses and positions of the ancient channels were many and varied. Misconceptions of Tertiary physiography led many persons astray, and millions of dollars were spent in vain. In spite of the millions gained, the losses were so great as to stamp this form of mining as hazardous in the extreme.

It is most instructive to follow carefully the recorded history of mining in a given district and to consider its relation to the geologic condition of that area. The two are so closely related as to provide a guide to the probable history which might be expected to be found in another area if the geology were known, or *vice versa*; the recorded history reflects what geologic conditions may be expected.

The geologic history and structure of the buried channels are so complex that the best of engineers have been baffled by them. Fragmentary benches and segments of rich gravel deposits which still rest in positions completely hidden from the surface, or even from the underground passages which enter into the lower main channels afford alluring possibilities to the geologist and geophysicist as well as to the prospector. A three-dimensional surface, complex and irregular in the extreme, is the problem to be faced.

The key to the solution is geology, aided by aerial photography, followed by geophysical surveying, and finally by directed prospecting through means of the drill, shaft, incline, or tunnel. To be effective, all these methods should be coordinated into one unified exploration program.

CLASSIFICATION OF PLACERS

Outline of Classification

A systematic geological study of placers calls for an orderly classification dividing them into *genetic types*, which indicate how they were first formed. The following classification is based upon the fundamental conditions of deposition:

Fundamental Classification of Placers

- A. Residual placers or 'seam diggings.'
- B. Eluvial or 'hillside' placers, representing transitional 'creep' from residual deposits to stream gravels.
- C. Bajada placers, a name applied to a certain peculiar type of 'desert' or 'dry' placer.
- D. Stream placers (*alluvial deposits*), sorted and resorted, simple and coalescing.
- E. Glacial-stream placers, gravel deposits transitional from moraines, for the most part valueless.
- F. Eolian placers, or local concentrations caused by the removal of lighter materials by the wind.
- G. Marine or 'beach' placers.

Of these seven types, the ordinary stream placer is by far the most important. All types are, however, more or less interrelated and intergradational; they are all subject to deformation or burial, and they may be formed during any geological period.

Most of these various types of placer deposits are well known in Alaska. B.N. Webber proposed the name, "Bajada placer" for peculiar desert, or so-called 'dry' placers, which he carefully analyzed (*American Institute of Mining and Metallurgical Engineers Technical Publication 488, 1935*). The concentration of gold by the agency of wind in Western Australia has been described by T.A. Rickard and Herbert C. Hoover (*American Institute of Mining and Metallurgical Engineers Transactions, vol. 28, 1898, pp. 490-537; 758-765*).

General Statement

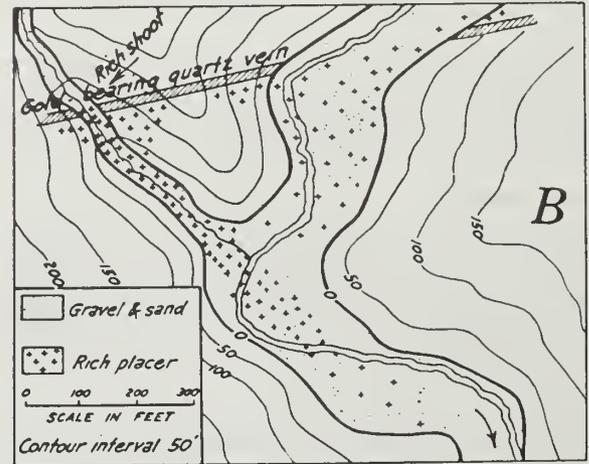
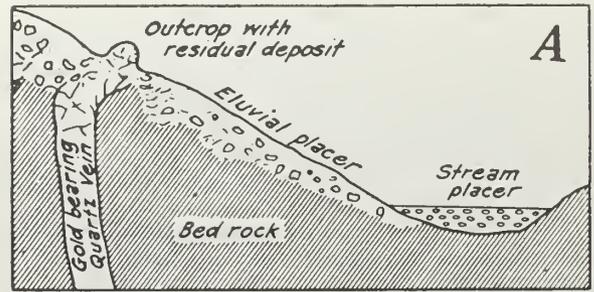
In valuating a placer, one of the first considerations should be the determination of how it was formed. It is recommended, therefore, that the exploration engineer should classify genetically each gravel deposit to be prospected. This calls for an understanding of the historical geology of the region and of the processes which have been responsible for the formation of the deposit, as well as how it came to be preserved or modified from its original form. The actual sampling of a deposit is carried on in a much more intelligent and satisfactory manner when a clear understanding of the geologic set-up has been acquired.

CHARACTERISTICS OF THE PRINCIPAL TYPES OF PLACERS

Residual Placers

In order that gold may become released from its original source in bedrock, the encasing material must be broken down. This is most effectively done by long-continued surface weathering. Disintegration is accomplished by persistent and powerful geologic agents, which effect the mechanical breaking-down of the rock and the chemical decay of the minerals.

The surface portion of a gold-bearing orebody will become enriched during this process of rock disintegration, because some of the softer and more soluble parts of the rock are carried away by erosion, leaving the remaining portion of higher tenor. The name *residual placer* is applied to this type of deposit. After the residual portion is mined away by comparatively inexpensive methods, the harder mineralized rock is encountered, and the mining methods must be changed to accommodate another type of deposit, i.e., the lode.



- A. Diagrammatic cross-section showing the transitional stages in the development of placer deposits: First, the quartz vein; second, disintegration at the outcrop to form a residual placer; third, formation of eluvial placer by 'creep' of residual material down the hill slope; fourth, deposition of water-worked material as alluvium, forming on auriferous gravel deposit, or stream placer.
- B. Sketch map showing the development of rich placers broken-down directly from the disintegration of a gold-bearing vein. (After Lindgren, "Mineral Deposits.")

The so-called 'seam diggings' are in weathered, gold-bearing quartz stringers, occurring along fracture zones of disintegrated schists.

Eluvial Placers

After gold is released from its original bedrock encasement through agents of rock decay and weathering, the whole weathered mass may 'creep' down the hillside (in some regions partly because of frost heaving) and may finally be washed down rivulets into gulleys. Lindgren in *Mineral Deposits* (p. 213), stated:

When the outcrops of gold-bearing veins are decampased a gradual concentration of the gold follows, either directly over the primary deposits or on the gentle slopes immediately below. The vein when located on a hillside bends

over and disintegration breaks up the rocks and the quartz, the latter as a rule yielding much more slowly than the rocks: the less resistant minerals weather into limonite, kaolin, and soluble salts. The volume is greatly reduced with accompanying gold concentration. The auriferous sulphides yield native gold, hydroxide of iron, and soluble salts. Some solution and redeposition of gold doubtless take place whenever the solutions contain free chlorine. The final result is a loose ferruginous detritus, easily washed and containing easily recovered gold. This gold consists of grains of rough and irregular form and has a fineness but slightly greater than that of the gold in the primary vein.

On its way down the hillside, gold is sometimes concentrated in sufficient value to warrant mining. Such deposits are classified as *eluvial placers*. They are transitional between residual and stream, or *alluvial*, deposits.

There have been a number of residual and eluvial gold deposits mined in both the Sierra Nevada and Klamath Mountains; for example the 'seam diggings' of Georgia Slides, Eldorado County, and Scott Bar, Siskiyou County.

Stream Placers

By far the most important type of placer is the ordinary alluvial gravel or stream placer. So far, it has been the source of most of the placer gold mined; but now its supply is nearing depletion, save for values remaining in those ancient channels which lie deeply buried beneath a cover of lava or rock debris.

Deposits by streams include those of both present and ancient times, whether they form well-defined channels or are left merely as benches. Stream placers consist of sands and gravels sorted by the action of running water. If they have undergone two or more periods of erosion, and have been re-sorted, the result will in all probability be a comparatively high degree of concentration of the heavier mineral grains.

Quoting from J.B. Mertie (U.S. Geological Survey Bulletin 739):

All bench placers, when first laid down, were stream placers similar to those of the present stream valleys. In the course of time the stream gravels, if not reworked by later erosion, may be left as terraces or benches on the sides of the valley, if the local base-level is lowered and the stream continues to cut down its channel. Such deposits constitute the so-called bench gravels. On the other hand, if the regional or local base-level is raised, the original placer may be deeply buried and a second or later placer deposit may be laid down above it... If the local base-level remains practically stationary for a very long period, a condition seldom realized, ancient and recent placers may form a perfectly continuous deposit in a long valley, for the deposition of a gold placer is known to occur at that point in a valley where the stream action

changes from erosion to alluviation, and such deposits are therefore formed progressively upstream.

Where several parallel and contiguous streams that are forming placers emerge from their valleys upon an open plain, perhaps into some wide valley floor, a continuous or coalescing placer may be formed along the front of the hills. If the streams empty into some lake or estuary, a delta placer, genetically the same but perhaps different in some minor respects, may be formed. Manifestly such compound placers may be formed by either present or ancient streams and may be elevated or buried in the same way as simple stream placers.

In order to understand thoroughly the subject of stream placers, streams themselves must be studied in regard to their habit, history, and character. The effects of existing and changing climates, the relation to surrounding geologic conditions, and the effect of movements of the earth must also be considered.

Glacial-stream Placers

It is a frequent fallacy of the placer miner to attribute the deposition of gold-bearing gravels to the action of glaciers. Contrary to such a belief, glaciers do not concentrate minerals; the streams issuing from melting ice, however, may be effective enough in sorting debris to cause placers to be formed under certain especially favorable conditions. In California, glaciers occurred throughout the high Sierra during the Pleistocene, but in Tertiary times they were wholly lacking. The Pleistocene streams cut through the earlier channels, robbing them of much of their gold.

Blackwelder has said (28th Report of the State Mineralogist, p. 309-10):

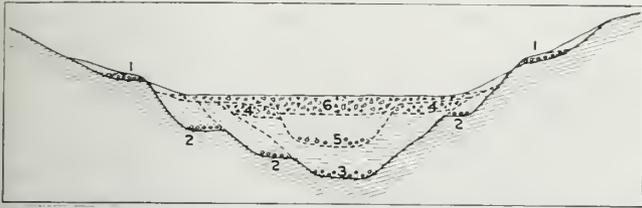
Since it is the habit of a glacier to scrape off loose debris and soil but not to sort it at all, ice is wholly ineffective as an agency of concentration for metals. Gold derived from the outcrops of small veins is thus mixed with large masses of barren earth. Attempts to mine gold in glacial moraines, where bits of rich but widely scattered float have been found, are for that reason foredoomed to failure.

If a glacier advances down a valley which already contains gold-bearing river gravel, it is apt to gouge out the entire mass, mix it with much other debris and deposit it later as useless till. Under some circumstances, however, it merely slides over the gravel and buries it with till without disturbing it.

On the other hand, the streams born of glaciers or slowly consuming their moraines have the power to winnow the particles of rock and mineral matter according to size and heaviness. Such streams may form gold placer deposits in the well-known way by churning the load they carry and allowing the heavy minerals to sink to the bedrock. Placers may therefore be found in the deposits of glacial rivers if there are gold veins exposed in the glaciated area upstream. Nearly all the gravel which has been dredged for gold along the foothills of the Sierra Nevada was deposited

by rivers derived in part from glaciers along the crest of the range, but most of the gold was probably picked up in the lower courses of such rivers. Since glacial rivers choke themselves and build up their channels progressively, their deposits are likely to be thicker and not so well concentrated as those of the more normal graded rivers which are not associated with glaciers.

A few gold-bearing deposits in re-worked glacial till may be found along the eastern front of the Sierra Nevada, as, for example, in the region just north of Mono Lake.



Cross-section of a gold-bearing desert stream valley (Manhattan, Nevada), showing the results of several periods of stream deposition from the oldest (1) to the youngest (6). (After Ferguson, *United States Geological Survey, Bull. 723.*)

Bajada Placers

A bajada is a confluent alluvial fan along the base of a mountain range. B.N. Webber described the *bajada type* of placer deposit as follows:

Bajada is the Spanish term for slope and is used locally in the Southwest to indicate the lower slope of a mountain range, the portion consisting of rock debris and standing at a much lower angle than the rock slope of the range proper...

The total production of gold from bajada placers in the southwestern United States is necessarily small, probably not over ten million dollars....

Most of all bajada placer gravels are Quaternary and the larger part are Recent...

The genesis of a bajada placer is basically similar to that of a stream placer except as it is conditioned by the climate and topography of the arid region in which the placer occurs....

Erosion, transportation and deposition in a region of extreme aridity present some phenomena not encountered in more humid areas. Practically all the work of running water is strongly conditioned by aridity....

Rock-floored canyons through which rock fragments are moved by infrequent torrential floods should constitute excellent pebble mills for the further reduction of the material, but the amount of attrition accomplished seems to be slight, as fragments, large or small, on the bajada slope are decidedly angular and show little effect of attrition.... Probably a small percentage of the gold is freed during this phase of the movement of gravel. The gradient of these intermont drainage channels is too high to permit lodgment of the finer gravel. When a small amount of gravel is temporarily lodged in one of these channels, the deposit displays most of the characteristics of stream gravel.

As debris reaches the bajada slope a rapid diminution in volume of water due to seepage and an extreme decrease in the grade of channel causes deposition of debris, and either (1) an alluvial fan or (2) a gravel-mantled pediment may be formed. If detritus is supplied to a bajada slope much faster than it can be removed, an alluvial fan is the result... If rock debris is supplied to the bajada slope in considerable volume but not in excess of the quantity capable of transference to the center of the basin by the existing agencies, a gravel-mantle pediment results....

The bulk of the gold that has been released from its matrix on the journey from lode outcrop to bajada slope is deposited on the bajada slope close to the mountain range. The gold is dropped along the contact of the basin fill and bedrock; this is referred to hereafter as the lag line and is coincident with the line of contact of bajada gravels lying at a low angle and the rock slopes of the range standing at a high angle....

The heaviest deposition of gold is on bedrock at the lag line, and since the lag line is moving in the direction of the crest of the range, values on bedrock may be distributed over a large area of which the longest dimension is parallel to the foot of the range. Because bulk concentration does not operate as in a river channel, and a certain percentage of the gold is still locked in fragments of matrix, to be partly released by further disintegration on the bajada slope, there is a strong tendency for less gold to reach bedrock and for more to remain erratically distributed throughout the detritus than in the case of stream gravels.

Eolian Placers

Bajada placers usually show enrichment on the surface due to removal of lighter material by wind and sheet floods. This is true of some of the dry placers of California, though no commercial eolian gold deposits such as those mined in Australia are known in this state.

Wind action, however, is responsible for the removal of large amounts of fine detritus in the desert. The process involved has been called *deflation*. It is quite likely that it will be found to play an important part in the surface concentration of desert placers.

Spurr described "auriferous sand dunes" in the Nevada desert seven miles south of Silver Peak, 18 miles from the California boundary line, in his *Ore deposits of the Silver Peak quadrangle* (U.S. Geological Survey Professional Paper 55).

Beach Placers

Concentrations of heavy minerals occur in various places along the Pacific Coast as a result of the action of shore currents and waves, which tend to sort and distribute the materials broken down from the sea cliffs or washed into the sea by streams. The

heavy minerals consist for the most part of magnetite, chromite, ilmenite, monazite, and zircon, with occasional fine particles of gold and platinum. Beach placers are of two kinds, (a) present beaches and (b) ancient beaches. An elevated coast line is often found overlaid with terrace gravels which were deposited at a time when the coastline was depressed. The beach placers of economic importance are those that have been reconcentrated over and over again.

Excellent descriptions of the geologic processes involved may be found in reports on beach placers of Nome, Alaska, and of the coast of Oregon and California. In discussing the origin of the gold in the Oregon beach placers, J.T. Pardee says (U.S. Geological Survey, Circular 8):

Some of the miners believe that the gold of the beaches comes up out of the sea, an idea suggested by the fact that after a storm a formerly barren stretch may be found to be gold-bearing. This notion is true so far as the immediate source of some of the gold is concerned. Materials composing the foreshore ore carried out in the offshore zone at one time and returned to the beach at another. In the process of shift up or down the coast may occur.... Soundings of the Coast and Geodetic Survey show black sand to occur in the offshore zone at the present time. Gold and other minerals are doubtless present also.... For the beaches that border retreating shores, however, the most of the gold and other minerals come directly from the rocks that are being eroded by the waves.

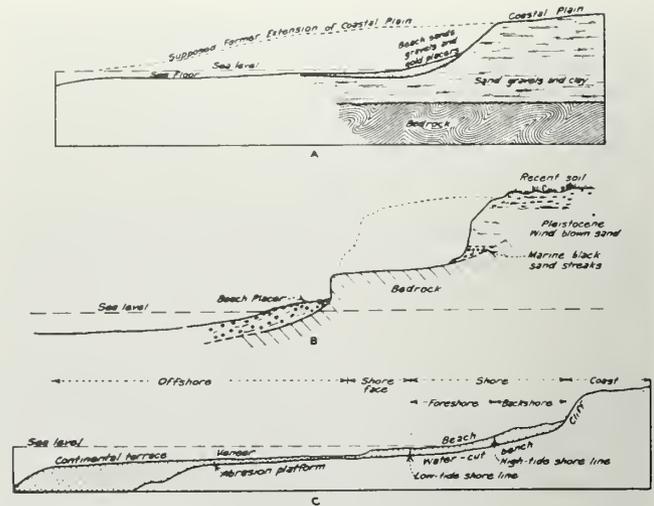
The economic possibilities of mining the black sands of the California coast for their gold content have long been discussed.

Gold-bearing gravels of marine origin occur in the Chico (Upper Cretaceous) sediments of northern California. That they are marine in origin and not fluvial is shown by their content of abundant fossil sea-shells, as well as by the character of their strata. They were formerly wrongly classed as "the gravel-filled channel of a Mesozoic river." Gold-bearing gravels have also been reported from marine sediments of the Lower Cretaceous of northern California.

Since the gravels of the Eocene rivers of the Sierra Nevada were richly gold-bearing, it is to be expected that some of the gold reached the sea. The sedimentary deposits of this Eocene sea are known as the Lone formation. They occur along the western foot of the Sierra Nevada.

Lindgren says:

At the mouth of the rivers which descended from the Tertiary Sierra Nevada extensive delta deposits were accumulated, and it is thus difficult in many places to draw any exact line between the lone formation and the river gravels proper. The gravels in the formation are



- A. Diagrammatic cross-section illustrating the formation of beach placers in Alaska. (After Collier and Hess, United States Geological Survey, Bull. 328.)
- B. Cross-section of a typical beach placer (Oregon). (After Pardee, United States Geological Survey, Circular 8.)
- C. Diagrammatic cross-section of a coast, showing shore zones in an advanced stage of development. (After Johnson, see Pardee, United States Geological Survey, Circular 8, 1934.)

locally auriferous, though generally poor, because spread over large areas.

The deposits contain quartz gravels and finely divided quartz grains; they are closely connected with the oldest river-channel deposits; they occur along the extreme western foot of the Sierra Nevada. Therefore the lone sediments

...indicate delta deposits formed at the mouths of many westward-flowing streams. Marine fossils in the upper part of the lone formation show that they accumulated on the shores of an Eocene sea.

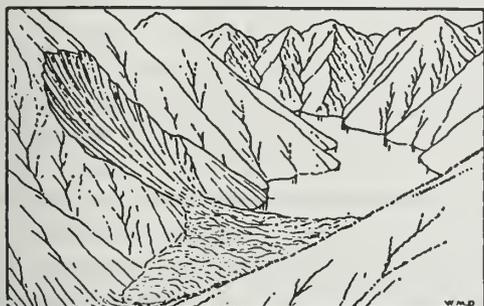
The processes involved in the distribution and concentration of gold in the marine strata of both the Cretaceous and Eocene formations have never been carefully studied. If these marine and delta placer deposits have any particular economic significance, it certainly has not been adequately demonstrated.

PRESERVATION OF PLACERS

Placers are preserved if something keeps them from being eroded away. Since streams are continually changing their positions, fragments of their deposits are often left isolated. In cutting a deeper channel, a stream leaves 'benches' or 'terraces' at different intervals along its valley sides; but erosion tends to destroy them, unless they are protected in some way.

Burial is the most effective way in which a placer may be preserved. The name 'buried channel' has often been restricted to streams covered deeply by lavas, mud-flows, ash-falls, etc., all of which were very common during the Tertiary period in the Sierra Nevada. There are, however, other means by which burial may be effected.

1. By covering with landslide material. (An example occurs in Canyon Creek, Trinity County.)
2. By covering with gravel, caused by the faulting-down of a part of the river system. (Examples are believed to occur along the Klamath, Trinity, and some of the larger rivers of the Sierra Nevada.)



Ideal sketch showing how a landslide may dam up a mountain valley to form a lake. Silt, sand, and gravels deposited in and on the edge of this lake will cover the stream gravels in its bottom. (After Davis, *State Mineralogist's Report XXIX*.)

3. By covering with lake deposits. (Many of the buried Tertiary channels were covered first by lake sediments called 'pipe-clay', before lava or mudflows poured over them.)
4. By covering with gravels when the stream is choked. (Examples are common along stream systems.)
5. By covering with gravel when the stream course is lowered below the general base-level of erosion. (Examples of this case are found along the western foot of the Sierra Nevada.)
6. By covering of the bedrock surface of down-faulted blocks, *graben*, by sediments of various sorts. (Many examples, especially in the Great Basin and Mojave Desert regions.)

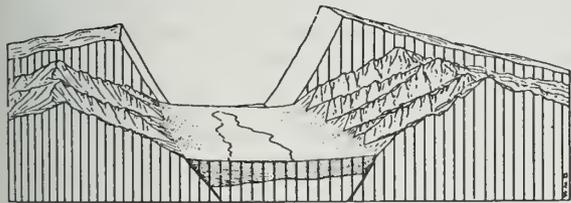


Diagram showing a down-dropped fault block (*graben*) between two uplifted fault blocks. Erosion covers the one with materials derived from the others. Streams cut in bedrock prior to faulting may thus be buried under the alluvium of the *graben*. (After Davis, *State Mineralogist's Report XXIX*.)

7. By covering of older stream courses with alluvial fan material, as conditions favorable to stream existence fail. (Many examples in the Great Basin and Mojave Desert regions.)
8. By covering with glacial till. (Examples may be looked for in the glaciated areas of the Sierra Nevada.)
9. By covering of beach placers with marine sediments as the fluctuating coast is submerged, but later elevated. (Such as the present elevated beach placers which are in places covered with other marine sediments.)
10. By covering of one geologic formation with another, through the processes of earth deformation and thrust faulting. (In a geologically active region such as California, examples of this case might very well be found.)
11. By submergence of river canyons to great depth beneath the ocean. (Off the coast of California many submarine channels have been discovered and mapped by the U.S. Coast and Geodetic Survey.)

To find gold-bearing stream channels, buried and preserved in such a manner that they may be profitably mined, is the challenge to the exploration geologist.

MODIFICATION OF PLACER DEPOSITS

Placer deposits may be greatly modified in form and structure by earth deformation. The gravel content may also become firmly cemented by interstitial deposition of mineral matter, such as by lime and iron carbonate, or silica, through the action of infiltrating solutions. The older the placer, the more apt it is to have been modified in these ways from its original form and attitude.

The regional tilt of the Sierra Nevada has increased the gradient of the Tertiary channels (where they lie in the direction of the tilt) from 20 or 30 feet to the mile to twice, three times, or even several times that amount. Locally, tilting has been even greater. In places where the ancient channels lie in opposite direction to the tilt the original gradient may have been reversed. Often steep tilting is accompanied by local faulting of a few feet to several hundred feet. Generally the down-throw is on the east side of the fault plane. In form, this is a replica of the action which took place and still is taking place along the eastern escarpment of the Sierra Nevada. Such displacements and changes in channel-gradient as well as in actual position of the channel, are important factors which greatly influence mining procedure. They should be understood so far as surface data will permit, before actual mining is started in a given area.

In the Mojave Desert and Great Basin region, faulting and tilting have been extremely active, greatly affecting streams antedating late Tertiary and

early Quaternary periods.

The flow of ground water through stream gravels, the former channels of which have been blocked, cut off, tilted, or folded by earth movements, is a factor of considerable consequence when it comes to mining such placers.

GOLD IN PLACERS

Original Source of Gold

The particles of gold found in placers originally came from veins and other mineralized zones in bedrock, from which they were released through surface weathering and disintegration of the rock matrix. Though the original source may not in every case have been a deposit which could today be mined at a profit, the richer placers usually indicate a comparatively rich source. A long period of deep weathering, resulting in separation and release of large quantities of gold from the bedrock, followed by a more active period of erosion, generally due to uplift, is an ideal condition for gold to be swept into stream channels and there to be concentrated into rich placers. Still richer deposits may be formed through reconcentration from older gold-bearing gravels.

These are the most important geologic conditions which have been found to exist in the various gold belts of the world, and particularly in the Sierra Nevada of California.

For the most part, the original source of gold is not far from the place where it was first deposited after being carried by running water. This is certainly true in both the Sierra Nevada and Klamath Mountains. The streams, flowing through regions of metamorphic and intrusive igneous rocks threaded throughout by gold-bearing veins, were found by early miners to contain auriferous gravels. But the more recent streams which have had only barren lavas to pass over, as in the volcanic covered area between the Sierra and Klamath regions, have proved to be barren.

To quote Lindgren (*Mineral Deposits*) again:

The great majority of gold placers have been derived from the weathering and disintegration of auriferous veins, lodes, shear zones, or more irregular replacement deposits.... In many regions the rocks contain abundant joints, seams, or small veins in which the gold has been deposited with quartz.... It is often stated that gold is distributed as fine particles in schists and massive rocks and that placer gold in certain districts is derived from this source. Most of these statements are not supported by evidence, though it is not denied that gold may in rare instances be distributed in this manner.

Release of Gold from Bedrock

Without some widespread process of release from the quartz veins and rocks – vaults in which the metal was originally firmly held – gold particles could not have escaped to be transported as such by running water. Therefore, extensive rock weathering and decay over a long period of time is a primary factor of extreme importance. It has permitted the original source to contribute gold particles, large and small, to placer accumulations. The same geologic processes which form residual and eluvial or 'hillside' concentrations of commercial merit operate in the general release of gold from bedrock.

The factors of prime importance in weathering are *solution*, changes of *temperature*, depth of *water-table* and therefore depth of *oxidation*, action of *rain*, effect of *gravity*, growth of *vegetation*, nature and *composition of material* acted upon, and degree of *topographic relief*. Rock weathering, especially *complete* disintegration down to the water-table, rather than *deep* disintegration, is often more favored by tropical climates. This, however, is only one factor, and large areas of deep secular weathering are found in the north, in such places as Alaska, where placers are abundant.

The processes which take place in the separation of gold from bedrock are described in detail by A.H. Brooks, who says, in his article on the gold placers of the Seward Peninsula (U.S. Geological Survey Bulletin 328, pp. 125-127):

The breaking down of the rock and the accompanying chemical changes of the constituent materials set free the gold, one of the relatively indestructible minerals, and this becomes intermingled with the other insoluble material. Clay dominates in the residual mass, but if the parent rock contained quartz, this, too, usually remains, being probably the most refractory of all the common minerals toward purely chemical agencies. Mineralized vein quartz very commonly carries easily decomposed minerals, such as pyrites, and is therefore readily broken up, allowing the insoluble ingredients of the ore body, such as gold, to be set free. This process is hastened by purely physical agencies, such as frost and changes of temperature, which break up the insoluble rock constituents....

As a rule, the changes in a rock mass brought about by weathering result in a very material reduction in its bulk. The loss of material by weathering among siliceous crystalline rocks, according to Merrill, amounts to more than 50 per cent, and in the purer forms of limestone it may reach as high as 99 per cent. Pumpelly [*American Journal of Science* 3rd Series, vol. 17, p. 1361] has estimated that in the limestone areas of the Ozark Mountains the residual material represents only from 2 to 9 per cent of the original rock mass. Such reductions in volume necessarily result in

more or less concentration of any insoluble material that may have been disseminated in the parent rock. This concentration will be materially greater in the case of substances of high specific gravity, such as gold, than in that of the lighter minerals, for the former will have a constant tendency to settle to the bottom of the loose material. On declivities gravity will accelerate the process and help to sort the material, producing in some places a rough stratification. This is a secular process and will proceed as long as the rocks continue to disintegrate...

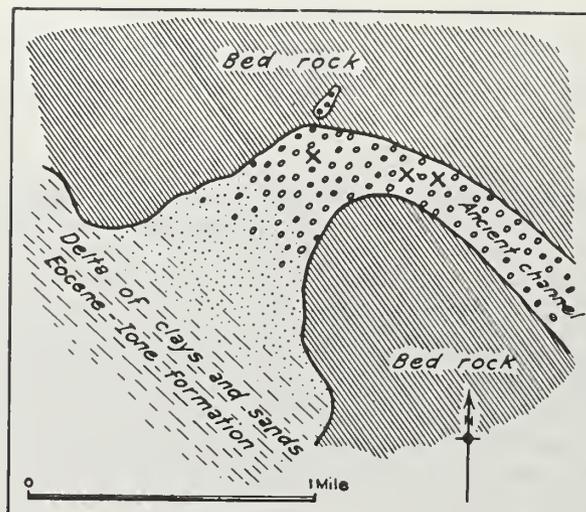
It is evident that the effectiveness of all these agencies is proportional to the length of time in which they are operative. A land mass must remain stable relative to sea level for a long period of time to permit the accumulation of any considerable amount of residual material. Uplifts bring about renewed activities of the water-courses, and the residual mantle is quickly removed by erosion. It is evident that the conditions that are most favorable to the accumulation of residual material are those in which the land mass is at or near base-level when erosion is reduced to a minimum.

It seems that topographic and climatic conditions which existed during the Eocene period in the Sierra Nevada were very favorable for the release of gold. Rejuvenated drainage at the close of the period swept the immense quantities of gold, freed from the enclosing hard matrix, into the early Tertiary stream channels; and these, soon after, became buried and preserved by lake sediments, masses of gravel, cobble-wash, volcanic ash, breccia, and lava flows.

Associated Minerals

Mineral grains that are very heavy and resistant to mechanical and chemical destruction accompany the gold in placers. The so-called 'black sands,' generally made up principally of magnetite, are well known to the miner. A long list of the minerals found in sluice-box concentrates is recorded by the United States Bureau of Mines (Information Circular 6786). Besides magnetite, there are found titanium minerals (ilmenite and rutile), garnet, zircon, hematite, chromite, olivine, epidote, pyrite, monazite, limonite, platinum, osmiridium, cinnabar, tungsten minerals (wolframite and scheelite), cassiterite, corundum, diamonds, galena, as well as quicksilver, amalgam, metallic copper, bird-shot, bullets, hobnails, penknives, watches, and nails.

Buried deeply in the gravels of the modern Feather River was once found (and someone thought it was an ancient fossil) the remains of a mule's hind leg with hoof and iron shoe nailed to it. What may be found in some of the placers of today may not, therefore, be representative of what was deposited by the more ancient streams.



Sketch map of an early Tertiary channel and its delta in the Eocene (lone) sea. The crosses indicate where the gold has been mined in the channel—on a bend in the stream, and at the point where a tributary entered. Finely divided gold particles occur interbedded in lenses of quartz pebbles and sand lying above clay layers ('false bedrock').

The presence of quantities of magnetite associated with extremely fine gold particles, makes a difficult metallurgical problem. To the geophysicist, however, the presence of any minerals having a strong effect on the magnetometer is a godsend to effective exploration.

The determination of heavy minerals and their approximate relative percentages has been extensively used in subsurface correlation of sedimentary beds in the oil fields. The same method of research could well be applied to the tracing of channels. Though it has not yet been given consideration in California, this interesting field is open for study with a well-developed technique available.

The source of the minerals deposited and associated with the gold particles lies in the rocks over which the stream has flowed. The source of chromite, platinum, and diamonds is generally attributed to belts of serpentine and related ultrabasic igneous rocks, while garnet, ilmenite and magnetite might come from metamorphic rocks, and monazite, zircon, cassiterite, wolframite, and scheelite would probably have their source in granite pegmatites.

The processes of transportation and deposition of gold in a stream are aptly stated by Mr. Brooks (p. 128):

The transporting power of a stream is dependent on its velocity, which is a variant determined by the gradient, volume and load. When a stream is overloaded with sediment, the excess is dropped. When it is underloaded, it erodes. When equilibrium has been established, neither erosion nor deposition takes place. Gradient, volume and load usually vary in the same stream so that deposition may be going on in one part of its valley and erosion in another. When a stream is eroding, the material within reach of its activity is constantly moved in a downstream direction. All movements of this kind are accomplished by more or less sorting and make for the concentration of the heavier particles.

Deposition takes place in a stream when the velocity is decreased, either by the periodic changes in volume or by a change of gradient. Where there is a change of grade, resulting in diminished velocity, the gold is laid down with the other sediments. It must be remembered, however, that placer gold may find lodgment in inequalities of the bedrock surface where no considerable deposition of detrital matter has taken place, though extensive placers are, as a rule, not formed because of irregularities in the bed-rock surface alone. The concentration of gold in river bars is analogous to its deposition in stream beds, for it is dropped where the velocity of the current is checked by the formation of eddies, due to the inequalities of the river floor.

A further study of this subject is made herein in connection with the more detailed analysis of stream action.

When the bed of a stream is the actual rock floor of the valley, it is called 'bedrock' in the true sense of the word. Later in its history the stream may flow on an aggraded bed of gravel or other sediment. If the stream gravels become covered with volcanic or other materials, the stream is obliged to flow over this new cover, called 'false bedrock.' Gold particles are normally deposited on or near the bed of the stream, which is called 'bedrock' or 'false bedrock' according to whether the bed is the true hard rock floor of the valley or whether it is a superficial layer of clay, volcanic tuff, or some such impervious material overlying previously deposited gravel. It is readily surmised, therefore, that there may be two or more tiers of gold-bearing stream channels, but the upper ones do not necessarily lie directly above the older and lower channels, and may not follow the direction of their courses at all. If the stream cuts clear down to the true bedrock, remnants of the older channels will lie at relatively higher positions instead of at lower horizons. In some cases, where gravel is deposited

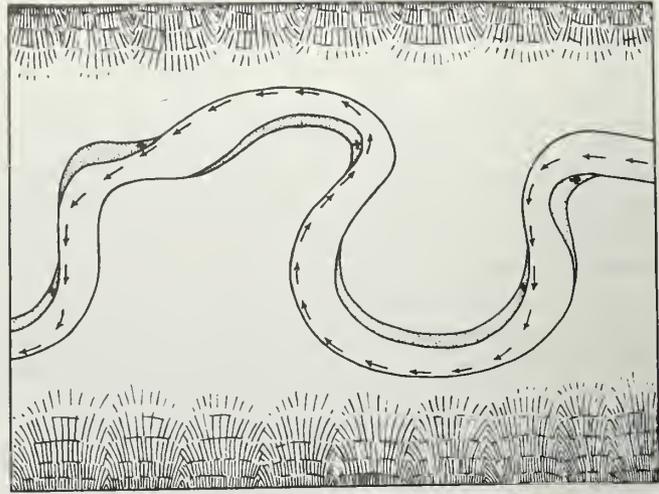


Diagram to illustrate the course of a river, indicating where gold particles are most likely to become concentrated. (After Spurr, U.S.G.S., 18th An. Rept. 1898.)

deeply on bedrock, forming a new aggraded bed, rejuvenation of the stream will stir up the entire mass of gravels, including the gold-bearing layer deposited on top, and the final result will be that most of the gold particles will reach a position very near true bedrock. The complexity of the history of these processes is apparent; so also are the difficulties of the engineer who attempts to do a fair job of sampling.

In excavating for the Boulder Dam a sawed plank of lumber was found 60 feet deep, "lying under gravel on the edge of the inner gorge, a place that it could not have reached in any imaginable way except by burial during some comparatively recent flood." This case and many others show that the depth of burial by recent rivers does not necessarily mean that a great period of time has elapsed for the accumulation of the deposit. During high water, the whole mass may be stirred up and even boulders floated in the soapy mixture of heavy rock debris and water. This action gives the gold particles a chance to work their way toward the bottom of the mass.

For thousands of years particles of gold of various sizes, from nuggets to flour gold, were dropped and lodged in the riffles of bedrock along the natural river-slucies of the Sierra Nevada. Flattened particles are most easily carried: sometimes, suspended by air-films, tiny scales even float on the surface of the water. Extremely fine grains of gold were swept by torrents through the canyons and out

into the Great Valley. In the present dredging grounds where they are found, they have been easily caught in false bedrock, which consists of clayey layers of volcanic tuff.

The very high specific gravity of gold, six or seven times that of quartz, with the ratio increasing to nine times under water, is the primary factor which causes this heavy resistant metal eventually to work its way to a point where it may sink no farther. Once it is caught on bedrock, the stream has great difficulty in picking it up again.

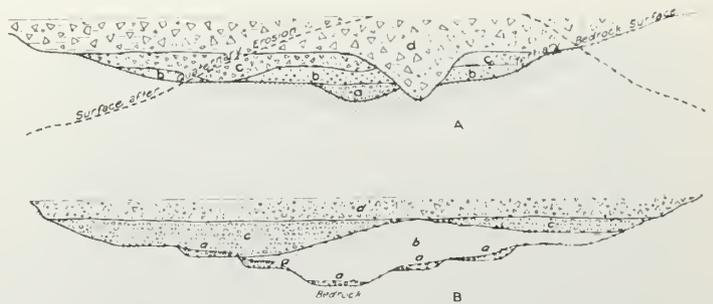
When a stream leaves its mountain canyon and enters a more level country or a still body of water, the materials carried by that stream are deposited in the form of a fan or delta. At the apex of this fan or delta fine gold may be deposited, and may never reach bedrock. It may be deposited on top of clayey, 'false bedrock' layers. The stirring action found to occur in rugged mountainous canyons during times of floods, which permits gold to reach bedrock, does not take place in the delta.

By an odd paradox [stated Dr. Lindgren], gold is at the same time the easiest and most difficult mineral to recover. It is divisible to a high degree and owing to its insolubility the finest particles are preserved. A piece of gold worth one cent is without trouble divisible into 2000 parts, and one of these minute particles can readily be recognized in a pan.

Although gold is very malleable, and may be hammered into different shapes by stones hitting it as they tumble along in the stream, different particles are not welded together to form larger nuggets, as some people are prone to believe. Lindgren has shown that the largest masses of gold have come from lodes, not placers. Particles of gold may be broken down, however, from another piece. The more rounded or flattened nuggets have probably gone through more knocking about than the rougher pieces. These showing the original crystalline forms have probably not traveled far in the 'free' state.

It is also found that the more ancient placers, and those which have undergone many reconcentrations, contain gold of a higher degree of fineness than those whose source is near by, or in which the gold has not been deposited for such a long period of time. This may be due to the removal of alloyed silver by the dissolving action of surface waters.

The solution and reprecipitation of gold in the gravels is shown to be exceedingly rare or non-existent, commercially. On the other hand, in some of the Tertiary channels, thin crusts of pyrite or marcasite are found deposited on the surface of the gold particles themselves.



- A. Diagrammatic cross-section showing the four principal epochs of Tertiary gravel deposition in the Sierra Nevada. The deep gravels a represent Eocene; b to d are successively younger and probably represent Miocene stages for the most part. The rhyolite period is represented by c and the andesite by d.
- B. Diagram showing deposits in the Deep Blue lead, Placerville. The alder channel and benches of the inter-rhyolitic epoch are represented by a; rhyolite tuff, b; andesite cobble, c; andesite tuff-breccia, d. (Lindgren, U.S.G.S., P.P. 73.)



Diagram showing the place of greatest erosion on the bend of a river.

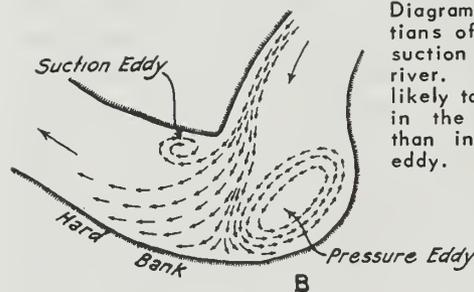


Diagram to show positions of pressure and suction eddies in a river. Gold is more likely to be deposited in the suction eddy than in the pressure eddy.

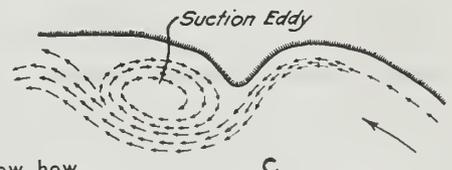
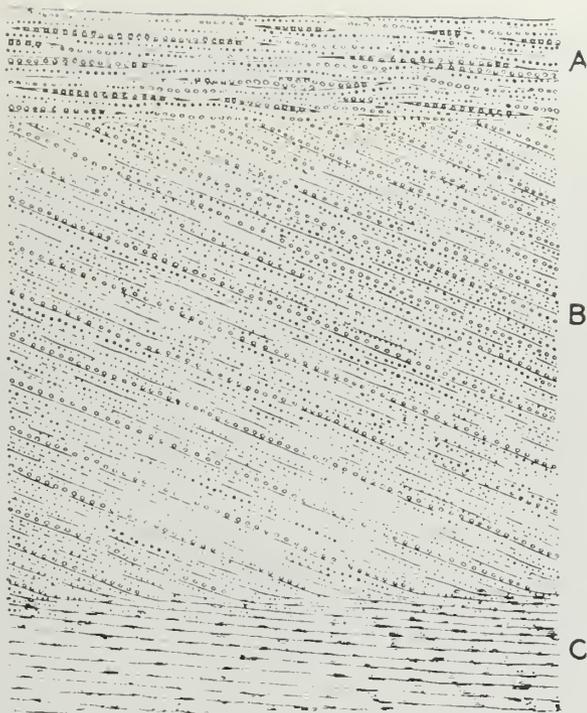


Diagram to show how a suction eddy is formed in a river. (After Thomas and Watt, see Ries and Watson, Eng. Geol.)



Ideal vertical section of a delta, showing the typical succession of strata: (A) tapset, (B) foreset, and (C) bottomset, beds. (After Gilbert, U.S.G.S., 5th An. Rept., 1883.)

Factors of Concentration

A placer worthy of mining is like any other commercial mineral deposit in that it is a special case of concentration due to several combining natural processes which were all in favor of the accumulation of the one desired mineral. Source, release, transportation, deposition, reconcentration, and retention of the gold have already been discussed. Three extremely important factors are: (1) Structural control of the stream pattern, so that the streams run along the course of the zones of mineralization; (2) Decay and disintegration at the surface of the mineralized rocks prior to erosion; (3) A change in the cycle of erosion, causing rejuvenated flow of streams and the rapid washing of the released gold into stream channels.

Accumulation of gold in an important placer deposit is rarely a mere coincidence; it is rather the fortuitous concurrence of several favorable factors. In regions where nature has bestowed the advantages of extensive mineralization, rapid rock decay, and well-developed stream patterns, a relatively large amount of gold placer may be formed. But even in this ideal case, the favorableness of these several important factors must be assumed.

The general considerations which favor the accumulation of gold in special locations have been frequently

discussed. Physically, the phenomenon is simple; in such locations where the gold has been deposited, the transporting power of the stream has become insufficient to carry away the particles of gold that have settled. The richness of the deposit will therefore depend not only upon the completeness of this loss of transporting power, and on the ability of the bedrock to hold the deposited gold at this point, but also, most importantly, on the general relationship of the gold sources to the stream. The early miners untiringly sought the 'ledge' or 'mother lode' which furnished certain rich placers. However, with the presence of mineralized zones as a source of the gold, the richness of a placer is perhaps due more to the efficiency of the stream as a concentrating device than to its uncovering rich lode deposits.

The ability of a stream to transport materials is essentially dependent upon the velocity of the water and the area and specific gravity of the particles of material being carried. The transporting power of water varies approximately as the sixth power of the velocity. This means that even small velocity changes have an enormous effect upon transporting power, ranging rather abruptly from velocities which can not transport an appreciable amount of gold to those which easily transport much of the gold that may enter the stream or be released from the gravels therein. The velocity of water is a complex relationship of grade, shape, and size of the channel, quantity of water, and other factors. A grade ranging from 30 to approximately 100 ft. per mile will favor the deposition of gold. With appropriate conditions of flow, these limits may be somewhat increased or reduced without serious handicap. When considering the grades of the ancient channels, however, one must remember that faulting and regional tilt often have considerably modified the original grade.

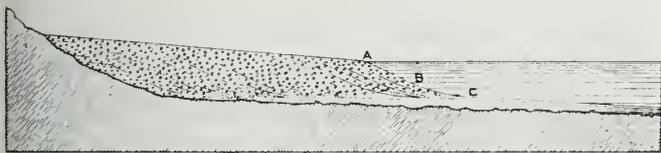
For the richest accumulations, the erosional conditions must be well balanced, so as to provide a long period of concentration. Slight uplifts tend to rework and further enrich placer deposits, as do increased volumes of water, inasmuch as both of these factors tend to increase the velocity. Local variations in the shape of the channels are of most interest, however, because they are immediately responsible for specific deposits of placer gold. When a stream canyon widens out, deepens, turns, or joins another watercourse, certain zones of concentration will be formed where the water velocities have been somewhat reduced and where eddy currents occur. These reductions in velocity immediately allow gold and heavy mineral particles to separate from the mass of gravel that is being carried and rolled down the canyon. Gold has a specific gravity of approximately six times that of the gravel, but under water this ratio becomes about nine times. This large gravity difference permits the gold quickly to work its way to bedrock and into any crevices therein. Here it remains, requiring excessive erosion to remove it to new locations.

In order that a major deposition of gold may occur, there must be an abundance of source material which contains more or less gold and which may be more or less easily eroded. A decayed formation of low-grade material could easily furnish more gold than a hard, higher-grade deposit. The decomposed material also supplies more gravel for balanced conditions of stream transportation, providing

that overloading or choking is minimized by uplifts or increasing water volumes. Plainly, a stream running along a vein system will have a greater opportunity to accumulate gold than one merely crossing it. Bedrock-controlled streams, therefore, provide a maximum contact with source material.

A further and very important factor is the ability of bedrock to hold the deposited gold in spite of the scouring action of the stream at higher water stages. A smooth, hard bedrock is a very poor one for placer accumulations. Bedrock formations which are decomposed or possess cracks and crevices are good, and those of a clayey or of a schistose nature are excellent in their ability to retain particles of gold.

Gold tends to resist most stream transportation. Coarser gold will migrate downstream an amazingly short distance from its apparent source throughout a long erosion period. The fine gold, which the stream can transport, is dropped rather completely within a restricted area at the mouth of the stream canyon.



Ideal cross-section of a delta, showing (A) topset, (B) foreset, and (C) bottomset, beds. (After Gilbert, U.S.G.S. 5th An. Rept. 1883.)

AGE OF PLACERS

Significance

The geologic age of a placer deposit is often a factor of primary economic interest. In the Sierra Nevada, the oldest system of Tertiary channels has proved to be the richest, for it was formed prior to the extensive volcanic activity which resulted in the covering of the mineralized bedrock surfaces as well as the valleys in which gold-bearing streams flowed. These streams, which cut directly through the mineralized zones, had an ideal opportunity to tap the primary gold resources of the region, while those which flowed only over a barren volcanic cover remained themselves barren of gold. In the region of the buried channels of the Sierra Nevada, many stream deposits of different periods are now found intermingled. To decipher their history and relative age is an essential part of the exploration geologist's work, in his search for the channels of greatest possible economic consequence.

Various criteria are used in determining the relative age of stream deposits, but the most positive evidence is structural relationship. For example, the cutting channel is younger than the channel which it cuts.

The deepest channel is not necessarily the oldest nor yet the youngest. In the case of the modern canyons of the Sierra—the youngest are the deepest; yet along the western foot of the range the present streams flow over older channels buried beneath. Where a canyon is filled with detritus or with lava, the newer stream flows on top of the deposit and is therefore higher than the old stream-bed beneath, while still more ancient stream terraces or benches may lie at higher and varying elevations on either side of the canyon. Some benches, representing former streams, may have even been left prior to a lava flow covering the deepest channel, while other benches may have been left later.

It is apparent, therefore, that the subjects of historical sequence and relative age are matters of detailed geologic and physiographic study which deserve more than mere superficial examination. They cannot be classified by dogmatic rules.

Paleontologic Criteria

In order to assign definite geologic periods to the deposits of ancient streams, their age should be related in some way to the well-established epochs of regional geologic history. Fossils, diagnostic in determination of geologic periods, if found in the stream deposits, are of inestimable value in this regard.

In the Sierra Nevada, parts of fossil plants consisting of leaves, logs, etc., have been extensively collected and determined by paleobotanists. Also, some vertebrate bones have been sent from the old drift mines to the Smithsonian Institution and elsewhere for scientific study.

Geologic periods the world over have been established largely on their marine fauna rather than their continental flora or fauna. For instance, marine beds of the Ione formation contain fossil sea-shells definitely assigned by paleontologists to the Eocene, or earliest Tertiary period. The fossils found in the sediments filling the Tertiary valleys of the Sierra are not, however, marine, but are of ancient lands and lakes. Correlation of geologic age by means of these land plants and land animals brings in complications that have not yet permitted the two bases of criteria,

marine and nonmarine, to be perfectly coordinated. Besides, most of the fossil leaves occur in tuffaceous lake beds that overlie the gold-bearing quartz-gravel deposits, and therefore do not give much direct evidence as to the age of the latter. Fossil wood, so common in the most ancient of the gold-bearing gravels is not as yet determinable nor diagnostic. In most cases it represents unstudied tropical forms which have been placed in the Eocene by paleobotanists because of the known climate of that period. The older gravel containing this fossil wood has previously been referred to the Cretaceous. In the Smartsville quadrangle, for example, a deposit containing petrified logs of probable Eocene age is described by Lindgren as follows:

The high, isolated area of well-washed gravel 3 miles north-northwest of Montezuma Hill is noteworthy; it is so much higher than the adjacent gravel channel of North San Juan that it must be assumed to belong to an earlier period; very likely it is of Cretaceous age.

It is a fact, however, that no fossils indicating a Cretaceous age have yet been found in these older gravels. Wherever definite marine Cretaceous beds do occur on the western foot of the Sierra Nevada the oldest stream channels of the vicinity are found to cut the Mesozoic sediments, showing a profound difference in age between the two.

R.W. Chaney has summarized the results of paleobotanical study of the fossil plants found in the Sierra Nevada as follows:

The tuffs and shales in which fossil plants occur interbedded in the Auriferous Gravels range in age from lowermost Eocene to upper Miocene. During this time there was a climatic trend from subtropical to temperate conditions, which resulted in the elimination of palms and other large-leaved species and the incoming of types of plants similar, in general, to those now living in North America. The Miocene flora indicating a temperate climate, includes genera no longer living in western America, although they occur in eastern America and eastern Asia. The evidences of difference in living conditions in the Eocene and the Miocene make it possible readily to differentiate between the older and the younger floras of the Auriferous Gravels.

Most of the fossil vertebrate bones described from the drift mines of the Sierra Nevada have been collected and sent in to paleontologists by persons who did not record their definite location, so that the exact geologic formations in which the fossils were embedded are unknown.

The paleontologist who works with vertebrate remains is not always apt to apply the same age to beds as that which has been assigned them by the paleobotanist; generally the former assigns a younger age. Many of the well-established Sierran Tertiary as

well as later beds containing vertebrate bones were once given the blanket designation of Pleistocene.

Physiographic Criteria

Age correlation has sometimes been done purely on physiographic evidence. F.E. Matthes assigns Eocene, Miocene, Pliocene, and Quaternary times of uplifts to the various old surfaces found in the Yosemite region, tying in the Miocene surface correlation with geologic features of a fossil leaf locality occurring in the Tuolumne Table Mountain region. The fact that old surfaces have been resurrected during the Pleistocene has only recently [1934] been given consideration.

Quaternary erosion resulting in the uncovering of Tertiary volcanic ash and the resurrection of early Tertiary surfaces, formerly cut into pre-Cretaceous bedrock along the western flank of the Sierra Nevada, is a widespread geologic process which has heretofore not received the recognition it deserves. The process involves features of vast economic concern. One key locality for this study is in the region of Table Mountain, Tuolumne and Calaveras counties, California, where a very resistant late Tertiary latite flow has served the purpose of preserving not only fragments of earlier and less resistant geologic bodies consisting of volcanic materials, mud-flows, lake beds, and stream gravels of different ages, but also the underlying bed-rock surfaces of earlier Tertiary age. These ancient surfaces, the topography of which appears to have been controlled by bedrock structure, may be found in various stages of resurrection. In this area, the gold-bearing gravels were mined in ancient channels that ran in directions opposite or at an angle to the Table Mountain Channel; the latter apparently never contained any appreciable amount of gold-bearing gravel, contrary to the common belief. Though unmantled and dissected through Pleistocene and Recent epochs fragments of upland peneplained bedrock and in places gravel-covered surfaces are actually early Tertiary land forms, which have been brought to light after having been buried throughout later Tertiary volcanic epochs

Lithologic Criteria

The nature and composition of the material filling the ancient channels and valleys also indicate to what geologic period a deposit may belong. Gold-bearing gravels, composed purely of sand and quartz-pebbles, or of the bedrock complex, indicate that the channel is of the pre-volcanic period possibly Eocene in age. Most of the rhyolites were apparently formed during the latter part of this period and in the Oligocene. The most abundant of the volcanic rocks are composed of andesites, which seem to be largely of late Miocene or early Pliocene age. During the late Pliocene and early Pleistocene there were many basalt flows. Tuolumne Table Mountain is composed of latite, probably of late Pliocene age.

In the Recent epoch much pumice has been expelled from craters and blown over various parts of the Sierra Nevada.

Streams may always be considered younger than the rocks from which their gravel has been derived, though mudflows may receive their materials from active volcanoes. There is here an opportunity for a petrographic study of both volcanic rocks and the materials of the sediments. Special detailed analysis of stream correlation might be performed by means of the method known as "heavy mineral separation," previously mentioned as widely employed in petroleum geology.

LIFE HISTORY AND HABIT OF STREAMS

Need for Scientific Background

Exploration of placers and various ancient stream channels requires an understanding of the habits and life history of streams in general. This includes, on the one hand, processes of erosion and deposition, and on the other, physiographic history. Each is important; the first, more directly, while the second has to do with regional features, knowledge of which is essential to the exploration geologist. The fundamental science of streams was outlined in 1877 in a simple yet splendid manner by G.K. Gilbert in his masterpiece on the Henry Mountains, Utah.

Such natural processes as those related to streams are so universal that a study of them in one part of the world may be applied to conditions found in another. Similarly, an understanding of the ancient Tertiary streams of the Sierra may be gained by applying the knowledge of processes found in operation today where conditions and environments would appear similar.

In a province, such as the Sierra Nevada, where the development of the drainage system has been repeatedly interrupted by earth movements or by burial as a result of volcanic mud washes and lava flows, the history of the stream of any one chronological horizon is a separate entity, and may be entirely different in form and pattern from either earlier or subsequent systems. This fact, together with the complexity of any one system presents a problem much involved.

The need for a scientific background in the study of streams is therefore apparent. The more pertinent features of this study, together with its terminology, are outlined here.

Stream Erosion

Stream or *fluvial* erosion is complex. It may be divided into the several processes, *hydraulic action*, *abrasion*, *solution*, and *transportation*. A brief statement of the essential factors which control erosion is

quoted from an authoritative textbook* as follows:

The capacity of a stream to erode, depends on its volume and velocity. The velocity in turn depends on (1) the slope down which the stream is flowing, (2) volume of water, (3) the shape of its channel, and (4) weight and volume of its load.

The rate of descent of the bed of a stream is the *stream gradient*. It is ordinarily expressed as so many feet per mile. The gradient changes from place to place along the course of the stream. Velocity increases rapidly with increase of gradient. Thus mountain streams with high gradients erode their valleys much more quickly than lowland streams of comparable size with low gradients. It follows that streams wear high gradients down to low ones by continued erosion, and that as the gradients are worn down the rate of erosion must decrease.

The volume of water is a variable factor in all streams, largely because of fluctuations in rainfall. Velocity and rate of erosion in any stream are therefore always changing. As a rule, these changes are too slight to be readily noticeable, but in some regions they are great enough to cause streams to dry up at certain seasons, and to rise in floods at others. In other regions, fluctuations are less extreme. Every spring the lower Mississippi has a normal rise in water level of 15 to 20 feet. The Nile normally rises 24 feet and the Ganges 32 feet. The erosive effect of such floods is considered below.

The shape of the stream channel as seen in cross-section also influences velocity. Since friction between water and channel slows a stream down, velocity is greatest in channels with the smallest area in proportion to volume of water. Deep, narrow channels therefore give greater stream velocity than broad, shallow ones.

A stream continues to acquire a load until it is carrying the greatest possible amount permitted by the gradient, volume of water, and kind of material available.

The "laws of erosive power" concern both transportation and abrasive power of the stream. If all the fragments of rocks had the same specific gravity, then the following definite action would take place.

If the velocity of a stream be doubled, the diameters of rock fragments it can move are increased 4 times. In other words, *the maximum diameter of the individual rock fragments a stream can move varies as the square of the velocity...* Calculations have shown that doubling the velocity of a stream increases its abrasive power at least 4 times, and under certain conditions as much as 64 times. In other words, *abrasive power varies between the square and the sixth power of the velocity.*

These laws not only explain the vastly greater erosion accomplished by swift streams than by slow ones under normal conditions, but they show clearly why exceptional floods; greatly increasing velocity by increasing volume, have such tremendous destructive power. The volume of

*Longwell, Knopf, and Flint, A Textbook of Geology, Part I, Physical Geology: John Wiley & Sons, 1932, pp. 42-44.

the Colorado River measured at Yuma, Arizona, during a flood in 1921, was 155 times its normal volume. Again, when the St. Francis dam near Los Angeles gave way in 1928 and flooded the valley below, huge blocks of concrete weighing up to 10,000 tons each, were moved by the escaping water. In India, during the Gahna flood of 1895, which lasted just four hours, the water picked up and transported such quantities of gravel that through the first 13 miles of its course the stream made a continuous gravel deposit from 50 to 234 feet thick.

Preparation of Material Removed by Erosion

As previously described, the materials which are removed and washed into the streams are first prepared through *weathering* processes. Particles are loosened from the outcrop by surface disintegration, consisting largely of oxidation, hydration, and solution.

Since climatic environments were different in the past than they are now, the subject of ancient climates is an important problem in its relation to the development of ancient stream channels. The study of fossils imbedded in the deposits gives the most important clue to the nature of ancient climates. The condition and composition of the sediments themselves give another.

Transportation

The subject of river engineering brought forth at an early date much definite information as regards the carrying power of streams. The following statement is quoted from David Stevenson: (*Principles... of canal and river engineering*, p. 361).

The following are results deduced from experiments... on the size of detrital particles which streams flowing with different velocities are said to be capable of carrying:

- 3 in. per sec.—0.170 mile per hour, will just begin to work on fine clay.
- 6 in. per sec.—0.340 mile per hour, will lift fine sand.
- 8 in. per sec.—0.4545 mile per hour, will lift sand as coarse as linseed.
- 10 in. per sec.—0.5 mile per hour, will lift gravel the size of peas.
- 12 in. per sec.—0.6819 mile per hour, will sweep along gravel the size of beans.
- 24 in. per sec.—1.3638 miles per hour, will roll along rounded pebbles 1 inch in diameter.
- 3 ft. per sec.—2.045 miles per hour, will sweep along slippery angular stones the size of a hen's egg.

The following table is quoted from F.C. Gilbert (*Engineering Journal*, 1932, p. 4) maximum diameters of boulders which can be moved in sluices at certain velocities:

Diameter (inches)	Velocity (feet per second)
2	3.3
4	5.3
6	6.2
8	7.4
10	8.4
12	9.1
16	10.8
20	11.9
24	13.0
30	13.7

Transportation is done by the carrying of materials in *solution*, through *suspension*, and by the process of *saltation*. The materials thus carried are deposited by *precipitation* from solution, *sedimentation* from suspension, and *grounding* after 'leaping' along by that process called 'saltation.'

It has been shown by G.K. Gilbert, who carried on extensive laboratory experiments with running water, that the materials borne in suspension are easily enough sampled and their quantity measured; but the "bed load" is much less accessible. The load is carried forward by sliding or rolling along a smooth channel bed, as well as by saltation, which takes place when the bed is uneven and causes the particle to move irregularly in a series of jumps.

Gilbert calls the transportation of the bed load *hydraulic traction* in contrast to *hydraulic suspension*. His summary of "Modes of transportation, collective movement" is expressed as follows:

When the conditions are such that the bed load is small, the bed is malded into hills called dunes, which travel downstream. Their mode of advance is like that of eolian dunes, the current eroding their upstream faces and depositing the eroded material on the downstream faces. With any progressive change of conditions tending to increase the load, the dunes eventually disappear and the debris surface becomes smooth. The smooth phase is in turn succeeded by a second rhythmic phase, in which a system of hills travels upstream. These are called antidunes; and their movement is accomplished by erosion on the downstream face. Both rhythms of debris movement are initiated by rhythms of water movement.

In showing how complicated a stream's action may be, Gilbert states:

The flow of a stream is a complex process, involving interactions which have thus far baffled mechanical analysis. Stream traction is not only a function of stream flow

but itself adds a complication. Some realization of the complexity may be achieved by considering briefly certain of the conditions which modify the capacity of a stream to transport debris along its bed. Width is a factor; a broad channel carries more than a narrow one. Velocity is a factor; the quantity of debris carried varies greatly for small changes in the velocity along the bed. Bed velocity is affected by slope and also by depth, increasing with each factor; and depth is affected by discharge and also by slope. If there is diversity of velocity from place to place over the bed, more debris is carried than if the average velocity everywhere prevails, and the greater the diversity the greater the carrying power of the stream. Size of transported particles is a factor, a greater weight of fine debris being carried than of coarse. The density of debris is a factor, a low specific gravity being favorable. The shapes of particles affect traction, but the nature of this influence is not well understood. An important factor is found in form of channel, efficiency being affected by turns and curvature and also by the relation of depth to width. The friction between current and banks is a factor and therefore likewise the nature of the banks. So, too, is the viscosity of the water, a property varying with temperature and also with impurities, whether dissolved or suspended.

Gilbert classifies streams according to their transportational characters:

The classification of streams here given has no other purpose than to afford a terminology convenient to the subject of debris transportation.

When the debris supplied to a stream is less than its capacity the stream erodes its bed, and if the condition is other than temporary the current reaches bedrock. The dragging of the load over the rock wears, or abrades, or corrades it. When the supply of debris equals or exceeds the capacity of the stream bedrock is not reached by the current, but the stream bed is constituted wholly of debris. Some streams with beds of debris have channel walls of rock, which rigidly limit their width and otherwise restrain their development. Most streams with beds of debris have one or both banks of previously deposited debris or alluvium, and these streams are able to shift courses by eroding their banks. The several conditions thus outlined will be indicated by speaking of streams as *corrading*, or *rock-walled*, or *alluvial*. In strictness, these terms apply to local phases of stream habit rather than to entire streams. Most rivers and many creeks are *corrading* streams in parts of their courses and alluvial in other parts.

Whenever and wherever a stream's capacity is overtaxed by the supply of debris brought from points above a deposit is made, building up the bed. If the supply is less than the capacity, and if the bed is of debris, erosion results. Through these processes streams adjust their profiles to their supplies of debris. The process of adjustment is called gradation; a stream which builds up its bed is said to aggrade and one which reduces it is said to de-grade.

An alluvial stream is usually an aggrading stream also; and when that is the case it is bordered by an alluvial plain called a flood plain, over which the water spreads in time of flood.

If the general slope descended by an alluvial stream is relatively steep, its course is relatively direct and the bends to right and left are of small angular amount. If the general slope is relatively gentle, the stream winds in an intricate manner; part of its course may be in directions opposite to the general course, and some of its curves may swing through 180° or more. This distinction is embodied in the terms *direct alluvial* stream and *meandering* stream. The particular magnitude of general slope by which the two classes are separated is greater for small streams than for large. Because fineness is one of the conditions determining the general slope of an alluvial plain, and because the gentler slopes go with the finer alluvium, it is true in the main that meandering streams are associated with fine alluvium.

Commenting on the curvature of a channel, which greatly complicates the transportation and deposition of debris by a stream, Gilbert says:

In a straight channel the current is swifter near the middle than near the sides and is swifter above mid-depth than below. On arriving at a bend the whole stream resists change of course, but the resistance is more effective for the swifter parts of the stream than for the slower. The upper central part is deflected least and projects itself against the outer bank. In so doing it displaces the slow-flowing water previously near the bank, and that water descends obliquely. The descending water displaces in turn the slow-flowing lower water, which is crowded toward the inner bank, while the water previously near that bank moves toward the middle as an upper layer. One general result is a twisting movement, the upper parts of the current tending toward the outer bank and the lower toward the inner. Another result is that the swiftest current is no longer medial, but is near the outer or concave bank. Connected with these two is a gradation of velocities across the bottom, the greater velocities being near the outer bank. The bed velocities near the outer bank are not only much greater than those near the inner bank but they are greater than any bed velocities in a relatively straight part of the stream. They have therefore greater capacity for traction, and by increasing the tractional lead they erode until an equilibrium is attained. On the other hand, the currents which, crossing the bed obliquely, approach the inner bend are slackening currents, and they deposit what they can no longer carry.

It results that the cross section on a curve is asymmetric, the greatest depth being near the outer bank. As the winding stream changes the direction of its curvature from one side to the other, the twisting system of current filaments is reversed, and with it the system of depth, but the process of change includes a phase with more equable distribution of velocities, and this phase produces a shoal separating the two deeps. The shoal does not cross the channel in a direction at right angles to its sides but is somewhat oblique in position, tending to run from the inner bank of one curve to the inner bank of the other. In meandering streams it is usually narrow and is appropriately called a bar. In direct alluvial streams, where bends are apt to be separated by long, nearly straight reaches, it is usually broad and may for a distance occupy the entire width of the channel.

Deposition

The nature of stream or fluvial deposits and their detailed structure and texture are described in various textbooks, but not with sufficient detail to explain all the types of complicated features found in gravel deposits, especially complex deposits such as those of a mountainous region like the Sierra Nevada.

The constructive process of fluvial deposition goes forward side by side with fluvial erosion. This is a result of the complexity and variability of the stream currents, which constantly drop some rock fragments to the bottom while they pick up others. When a stream is actively eroding its bed at a certain point, it is merely picking up and carrying away more rock material than it is depositing there, and when it is actively depositing the reverse is going on. Therefore whereas fluvial erosion and deposition are processes physically opposed to each other, they can be separated in practice only by recognizing the preponderance of one over the other.

The arrangement of materials deposited in a delta, however, is well known, and gives a picture which is more or less duplicated whenever the current of a stream is checked by a body of standing water and the materials transported are permitted to drop. The term *foreset beds* is applied to the deposition on the frontal slope of the growing embankment. *Bottomset beds* are of finer grain and are formed by the particles carried out beyond the slope and deposited in deeper water. *Topset beds* are composed of the materials laid down and spread out on top of the other materials by the fluctuating stream.

The material deposited by a stream is called alluvium and makes up *fan*, *floodplain*, and *delta* deposits. The term *fanglomerate* is used for the gravel materials of alluvial fans.

An alluvial fan is built up at the point of abrupt change in gradient of a loaded stream. A floodplain is a series of coalescing alluvial flats along a valley. A delta is the final deposit by a stream, unloaded as it enters a still body of water.

Overflow of a stream onto its floodplain will cause *natural levees* to be built up as low ridges bordering the channel. Lateral swinging of a stream causes cutting on the outer sides of the curves and deposition on the inside, which results in the widening of the valley. A meandering stream may develop to the point of straightening itself in places by the cutting off and silting up of the meanders, forming *oxbow* lakes as a result. A stream which forms a complex interlocking network on its floodplain typifies *anastomotic* drainage. An overloaded stream on a low gradient, becoming choked, and constantly obliged to cut new channels, develops an intricate network on a floodplain; the process is termed *braiding*.

If the stream is rejuvenated and therefore cuts deeper, floodplain *terraces* or *benches* are formed.

The benches may, however, be cut and left in the bedrock and covered with only a film of gravel on the surface.

Streams composed entirely of thick mud, called *mudflows*, are akin to landslides.

Another normal though infrequently operative process in arid regions is the *mudflow*. It occurs only where fine rock material becomes water-soaked on steep slopes after heavy rains, and moves downward on a slippery mass. . . . It advances in waves, stopping when it becomes too viscous to flow and doming the water behind it until it liquefies and again proceeds like an advancing flow of lava. Mudflows can carry boulders many feet in diameter. Observers have seen these great rocks bobbing 'like corks in a surf.' Successive mudflows play a part in the building of fans. (Longwell, Knopf, and Flint, pp-78.)

The transporting power of mudflows, their various peculiarities, and the resultant unsorted deposits have many characteristics much like those of glacial deposits and have frequently deceived engineers.

The distinguishing characters of glacial deposits are clearly summarized by Eliot Blackwelder, who has made a special study of them:

The deposits left by glaciers should be distinguished from those made by streams, lakes and other agencies.

The ice tongue of a glacier leaves only one type of deposit called *till*. It is wholly unstratified and its components are quite unsorted—a jumbled orderless mass of clay, sand, and boulders. Blocks three to five feet in diameter are common and those 25 feet or more are not rare. In general, the size of such boulders depends upon the spacing of the joint-crocks in the rocks of the mountain sides. Usually till is on earthy mass well sprinkled with stones and boulders but in some cases the boulders predominate. This is particularly true of the deposits of small glaciers which have done little more than sweep the coarse talus from the valley slopes. The stones in till may be of any shape from well-rounded to angular but many have the corners and edges rounded. It is usual to find some that have been bevelled by being rasped along the bottom of the glacier. Hard rocks may thus be well polished. Such stones, like the bedrock, are covered with scratches which are easily recognized.

It is often difficult to identify till, especially if it has been much decayed or eroded or is poorly exposed. It may then be confused with other bouldery deposits which are unstratified. From volcanic mudflow deposits, such as abound in the Miocene beds on the Sierra Nevada flanks, till may often be distinguished by its containing large quantities of nonvolcanic rocks. Even this criterion fails where glaciers occupied volcanic mountains such as Mts. Shasta and Rainier. Ordinary mudflow deposits are seldom so thick as glacial moraines and are generally interbedded with typical stream gravel and sand, as in the alluvial fans of the arid regions. Unless the surface topography is still preserved or unless one finds plenty of scratched stones, it may be almost impossible to distinguish till

from landslide dumps. In many cases no one type of evidence can be relied on, but one must study all the facts and weigh the importance of each.

The rivers which issue from glaciers deposit coarse gravel, then fine gravel, and finally sand as the current weakens near the edge of the mountains. These three grades of detritus are more or less interbedded, because variations in the river's power occur from time to time at a given place. Like river deposits in general, those of glacial streams are distinctly stratified, though usually cross-bedded. They are fairly well sorted into separate layers of sand and gravel of various sizes. The pebbles are normally well rounded and very rarely either faceted or scratched. Angular stones are rare. Although small boulders are carried by ice cakes and become stranded in the glacial river gravel, large boulders are generally absent.

To distinguish the deposits of a glacial from a non-glacial river is difficult and often impossible, unless one can trace the gravel terraces into actual connection with a glacial moraine or can work out in detail the physiographic history of the district.

The deposits made in glacial lakes are rather distinctive. On the bottom of the lake, clay and silt are laid down very evenly in thin sheets which are commonly banded as seen later in cross-section. This is due to the fact that the layer deposited in winter is finer and darker in color than the one laid down during the summer melting season. Unlike most lake deposits the glacial lake clays commonly contain scattered pebbles and even small boulders which have been dropped from cakes of ice floating over the lake. These laminated clays may be associated with beds of peat or chalky diatomaceous earth formed by organisms that inhabited the clearer parts of the lake. Streams entering the lake form advancing deltas composed of gravel and sand in which the stratification is characteristic of deltas in general. In quantity the delta deposits often exceed the other lake deposits greatly, for the glacial rivers carry large quantities of coarse detritus all of which lodges in the deltas rather than upon the floor of the lake.

Other deposits that may be formed in glacial valleys, such as landslides, talus, and alluvial fans, need not be described specifically. They are local and generally well known.

The deepening of canyons and the deposition of gravels by outwash streams which issue from the snouts of glaciers form a very important chapter in the robbing and destruction of earlier gold-bearing gravels. Much of the material carried by Pleistocene glacial outwash streams of the Sierra Nevada was dumped at the foot of the western slope of the range at the point where the major rivers enter the Great Valley. The extensive gold-dredging ground of California to a large extent owes its existence to these streams.

So far as the processes involved in stream action are concerned, much can be gained by the detailed study of ancient glacial stream channels found throughout the world, especially in its northern belt.

The mere definition of some of the terms used in stream physiography gives a direct insight into the science.

Cycle of Erosion includes the series of changes from the *initial* cutting of a surface to the final reduction of a region to a *baselevel*. The surface of a region reduced to fairly low relief, but still undulating, is called a *peneplain* (also spelled *peneplane*). It is a significant fact that the Sierra region in early Tertiary time was approaching the peneplain stage of erosion, when the area was covered with lava to form a more nearly plain-like surface, and later uplifted. The uplift caused deep dissection by streams.

Stages of stream development, from gulleys to completely worn-down plains, consist of *youth*, *maturity*, and *old age*, with continuous transitional stages between. The early stages represent very rapid growth, which slows down gradually until at old age the changes may be extremely slow.

The *genesis* or origin of the stream takes into consideration the initial surface over which the stream first flowed. Several terms are used by geologists in relation to this subject. *Consequent* streams are those whose positions were determined by the initial slopes of the land surface. *Subsequent* streams are those which are established by growing headward along belts of weak rocks.

Where the underlying structures of the rocks have affected the direction of the stream and its valley, the stream is said to have *structural control*. The terms *fault*, *joint*, *strike*, *anticlinal*, *synclinal*, and *monoclinical* are prefixed to the word 'valley'; thus, *fault-valley*, *strike-valley*, etc. It is especially significant that the richest gold-bearing channels have structural control—the streams originally ran on and along mineralized zones in bedrock.

Streams may start their courses over one sort of geological formation, but as time progresses they may cut through it and be *let down* on a lower and entirely different type of structure; such streams are said to be *superimposed* (or simply *superposed*) on the underlying rock structure. When a certain stream *pattern*, originally developed because of previous topographic or structural conditions, is retained even after those conditions are removed, the stream is said to have *inherited* its peculiar features from much earlier periods of its life.

Streams may be *intermittent* or *permanent*. Depression of topography along a coast may cause the sea to invade the valleys, and the streams are *drowned*. Uprise along the coast may leave *hanging valleys*. Tributaries to a main stream which has been much faster-cutting may also be left 'hanging'; as, for example in Yosemite Valley where the side streams reach the Merced River by way of beautiful waterfalls.

The *longitudinal profile* of a stream is taken from its source to its mouth, while its *gradient* represents

its inclination at some particular part of its course. Tributaries are said to be *accordant* when they enter at about the same level as their main stream. A stream is said to be *at grade* when rate of degradation and rate of aggradation are about equal.

A stream which is able to maintain its course, even when a segment of the earth is gradually raised athwart that course, is called an *antecedent* stream. If, however, the uprise of the mountain causes the flow of the streams to be accelerated down its slope so that they cut deeper gorges, they are said to be *rejuvenated*. Even stream *meanders*, developed on a plain, may be *entrenched* or *incised* deeply, to form a winding canyon by elevation of the plain.

Rejuvenation may be effected in other ways than mountain-making. Change of climate may make a decided change in stream cutting. Stream *piracy* is another important cause. This consists of the *capture* of

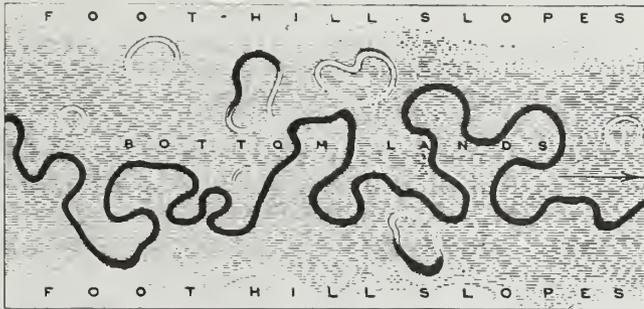


Diagram to show a meandering stream with oxbow loops. Such a stream develops in a valley worn down in base-level and not subject to extensive floods.

one stream by another. The second lies at a lower elevation; its head cuts back until the first is tapped, or *beheaded*. Then the water from the first stream, from that point upward, is caused to flow into the capturing stream. In this manner the flow in the first is accelerated often to such an extent that a new gorge may be formed. Whole stream systems may thus be *readjusted* and repeatedly go through new life cycles. Piracy and stream adjustment were apparently very active in the Sierra Nevada during Tertiary time; this process partly accounts for many of the deep accumulations there of Tertiary gravel.

The *pattern* of an individual stream, or of the whole or any part of its system, develops in its own peculiar way because of certain controlling geological, topographical, and climatic features. The pattern, therefore, is a character significant enough to bear special study and to support many new descriptive terms. It is now best studied by means of aerial photographs, though detailed topographic and geologic maps once presented the only bases of accurate expression.

Many clues as to the geologic structure and history of the underlying region are gained by the study of stream pattern, from either an intensive or regional point of view. In the northern Sierra Nevada, the stream pattern developed prior to volcanic activity was structurally controlled by bedrock; but during the later period of volcanism it suffered change by that widespread activity. The major streams subsequent to volcanism followed the slope of the lava-covered, tilted, and uplifted fault-block range.

An instructive outline of the subject of stream pattern is given by Emile Zernitz who describes and illustrates by many actual examples such patterns as follows: *dendritic*, *trellis*, *rectangular*, *annular*, *radial*, and *parallel*. He states that:

The patterns which streams form are determined by inequalities of surface slope and inequalities of rock resistance. This being true, it is evident that drainage patterns may reflect original slope and original structure or may reflect the successive episodes by which the surface has been modified — including uplift, depression, tilting, warping, folding, faulting, and jointing, as well as deposition by the sea, glaciers, volcanoes, winds, and rivers. A single drainage pattern may be the result of several of these factors. (*Journal of Geology*, vol. 10, p. 498).

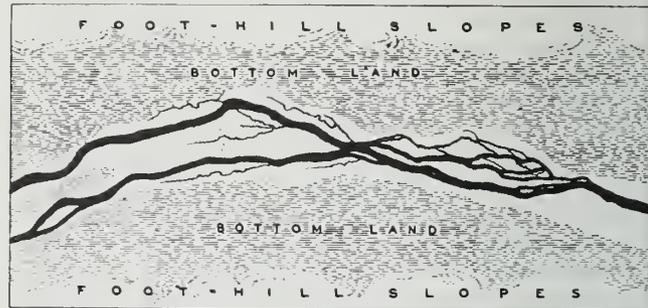
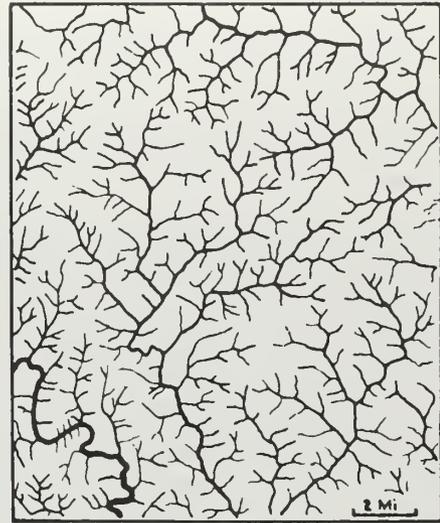
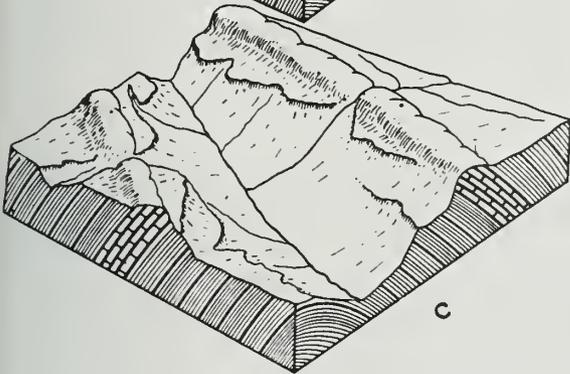
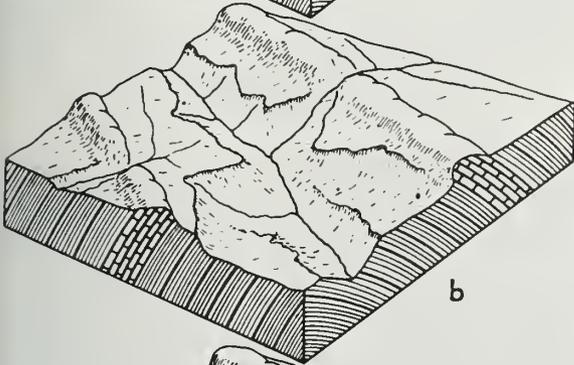
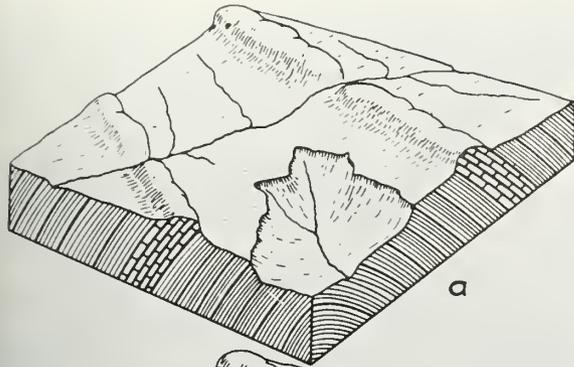
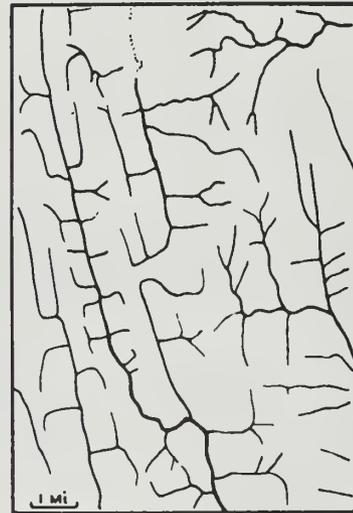


Diagram to show a subdividing or *anastomosing* stream in a valley subject to floods.

The fact that lakes fill depressions, basins, and valleys along stream courses, and that their deposits are intimately associated with those of streams, makes their study interrelated with that of stream channels. The so-called 'pipe-clay' deposits, which nearly always immediately overlie the gold-bearing gravels, represent beds of silt and finely divided volcanic ash, which have settled in lakes and formed a series of thin layers. They often contain impressions of leaves, showing the character of the forests that grew in that early period. This feature indicates that before the volcanic flows came to cover them up, the stream valleys had been transformed into lakes, into which the volcanic ash settled.



A. An example of *dendritic drainage pattern*, which develops where the underlying rocks lie in a horizontal position and offer uniform resistance to erosion.



B. An example of *trellis drainage pattern*, which develops in folded rocks differing in degrees of resistance to erosion. The stream courses are therefore *structurally controlled*.

Diagrams to illustrate three successive stages in *stream piracy*. The stream cutting back at the lower elevation heads and captures the stream flowing at a higher level.

In general, a lake is not as long-lived as a stream. Streams tend to destroy lakes, either by gradually filling their basins with detritus or by cutting down their outlets to a point where their basins may be drained. Sometimes, however, lakes persist long enough so that the area whose drainage they receive is worn down to a *local and temporary baselevel*. Lakes are formed in a number of ways: by landslides across stream courses; by lava flows which dam up the drainage; by the down-faulting of segments of the earth which are then filled with water; by glacial action, either by scooping out rock basins or by damming with till; by peculiar action of rivers themselves, such as silting off oxbow loops in a meandering course. An excellent paper, now out of print, was written by the late Dr. W.M. Davis. It not only discusses the present natural lakes of California, but the origin of lakes in general. (*California Journal of Mines and Geology*, vol. 29, pp. 175-236).

Desert Processes

In the desert, the processes of erosion and of stream action differ very much from those in more humid areas. Only quite recently have the geologic processes in the desert been given much consideration; so also has much serious thought only lately turned toward the possible development of desert placers on a larger scale than mere 'dry washing'. The fact that adequate supplies of water may usually

be derived from underground sources in the desert, and the fact that these sources may be found through geological investigation and geophysical surveying, are gradually being accepted.

The most significant results of recent desert-process studies are summarized by Blackwelder as he describes the five distinct types of desert plains:

1. Pediments (including those only thinly veneered with alluvial fans), which represent the desert slope, cut in bedrock, in contrast to the built-up thick alluvial fans or bajadas.

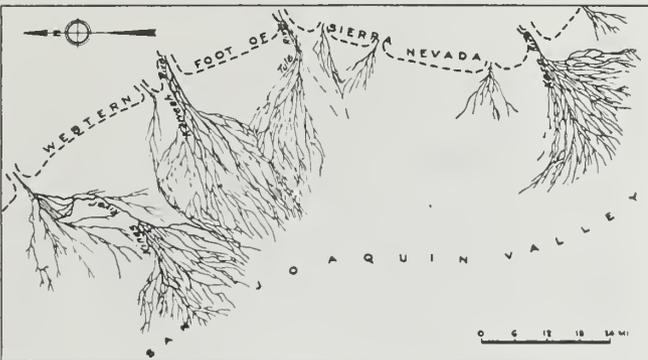
Pediments are essentially compound graded floodplains excavated by ephemeral streams... the pediment, not the bajada, is the normal and inevitable form developed in the arid regions under stable conditions.

2. Bajadas (compound alluvial fans), which are built up largely as a result of disturbed or interrupted development of graded slopes. The upward movement of a fault block causes renewed erosional activity, and thick gravel deposits are formed by the consequent torrents and mudflows when they are released from their canyons and enter a region of lesser gradient.

3. Dried-up lake bottoms of the desert, or playas, whose conditions indicate that once more permanent lakes filled the flats and were fed by streams that are now nonexistent.

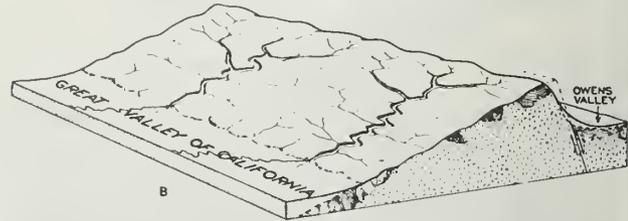
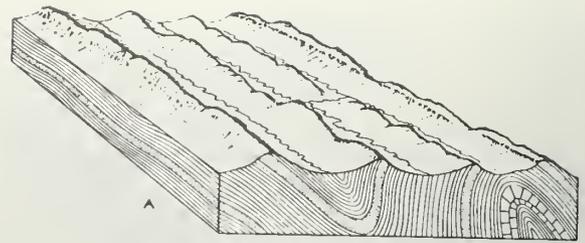
4. Dip slopes, which are broad planes developed on a denuded, hard, flat-lying or gently tilted rock layer.

5. River floodplains, which are abnormal desert features, but which were apparently more widespread at an earlier time, when precipitation in a given region was much greater than it is today.



Map of the southeastern margin of the San Joaquin Valley showing fans built by streams which disappear after leaving their mountain canyons. The coalescing alluvial fans form in this manner an extensive bajada.

These earlier plains and stream courses have been covered by the bajadas of today, so that the older channels have become buried in the true sense of the word. Some of them may represent a large potential placer reserve, but they have not yet been well investigated.



A. Block diagram illustrating Cretaceous Sierra Nevada topography. The upturn edges of bedrock controlled the drainage pattern, which was later inherited by streams of the early Eocene period.

B. Block diagram to show the tilting of the Sierra Nevada and its effect on stream cutting. Erosion, prior to the tilting, planed down the surface and exposed the granite, leaving only occasional fragments of the intruded metamorphic rock bodies as roof pendants. The streams, at the point where they leave their mountain canyons and enter the Great Valley, form alluvial fans.

Need for Establishment of Working Criteria

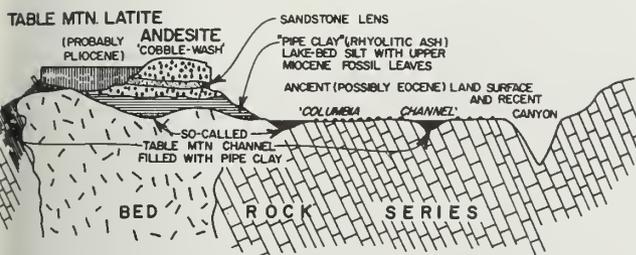
From the study of the complicated life history and habit of streams and the processes involved in their development, a series of working criteria should be developed by the exploration geologist for interpreting the conditions found in the deposits of all streams, including those of Tertiary age in the Sierra Nevada.

GEOLOGIC CONDITIONS IN THE GOLD PROVINCES OF CALIFORNIA

In the Sierra Nevada and Klamath Mountains of California gold-bearing quartz veins are generally found in metamorphic rocks not more than a few miles, at the most, from intrusive bodies of granitic rocks. The age of the metamorphics, which are made up of slates, schists, limestones, and meta-igneous bodies, is earlier than Cretaceous, namely pre-Paleozoic, Paleozoic, Triassic, and Jurassic. The time of intrusion of the granitic masses was late Jurassic.

The quartz veins were formed shortly after the igneous intrusion, during the last stages of the Jurassic. It would seem that the metamorphic rock masses were uplifted and intruded by molten magmas which then cooled and contracted, causing the surrounding and over-lying roof-rocks to crack along many planes of weakness and to form thousands of fissures. Into these openings the residual gaseous solutions, released from the crystallizing granites and composed largely of silica, were injected. These,

after solidifying, were crushed again, and solutions containing gold entered the complex mineralized zones, enriching especially the cross-fractures where openings were most abundant.



1. An early Tertiary surface, developed on bedrock over which flowed the old river system of the Columbia basin.
2. This surface, including its rich gold-bearing gravels, was later covered with lake sediments ('pipe-clay') consisting of fine silty volcanic ash.
3. Andesite 'cobble-wash' then covered the entire country.
4. A canyon was cut in this andesite mudflow.
5. A basic lava (latite) flowed down this canyon as a molten stream.
6. After this lava cooled and hardened, it became the bed of another river which deposited some gold-bearing gravels on its surface, washed in from the surrounding eroded region.
7. Continued erosion during the Pleistocene resulted in the washing away of the less resistant volcanic materials, leaving the very resistant latite standing as Table Mountain. Furthermore, the earlier pre-volcanic bedrock surface was uncovered, or resurrected, exposing the gold-bearing gravels originally deposited in the Columbia channel system.
8. Quaternary erosion has cut canyons of great depth, far below the level of the former Tertiary surfaces.

The gold-bearing veins thus formed deep beneath the surface of the earth, had then to be brought to the light of day by the erosion and removal of the covering layer of rocks, nearly two miles in depth. This gigantic work was accomplished during the Cretaceous period, and as a result thousands of layers of shales, sandstones, and conglomerates several miles in stratigraphic thickness were laid down in an adjoining marine basin. Some of these beds—especially the last ones to be deposited—are gold-bearing, showing that the last part of the Cretaceous erosion finally reached the hidden veins.

That part of the geologic history, however, which was most important so far as the making of rich placer deposits is concerned, was the Eocene period. The deep erosion which took place during the Cretaceous had worn the surface down to such an extent that the metamorphic rocks with their mineralized zones had been reached, so that the streams of the Eocene ran along and through them.

Structural control of the drainage, fully developed during the Cretaceous, was thus inherited by the

Eocene streams. Ridges and valleys followed the north-south trending beds of hard and soft rock. The subtropical climate of the early Eocene together with other conditions particularly favorable to rock disintegration, such as a more prolonged time of stability in the earth's crust, made it possible for the gold in the surface rocks to be released from its matrix.

Then came the inception of the Tertiary Sierran uplift, which rejuvenated stream flow, causing the released gold in the disintegrated veins to be washed into the river channels, resulting in very rich concentrations. The streams were loaded with fine quartz sand and pebbles, together with clays derived from the decomposed feldspathic parts of the rocks. The finer particles were washed to the sea, and as a result the Eocene (Ione formation) today contains large deposits of commercial clay interbedded with quartz sands.

The westward tilting and resulting acceleration of stream flow interrupted the north-south drainage system inherited from the Cretaceous period. The readjustment of the streams resulted in their general direction of flow being finally changed from north and south trends to a westerly course, somewhat as it is today. The longest of these known streams even headed far to the east into what is now Nevada.

Hardly had the Eocene come to a close when much rhyolite ash, thrown into the air from volcanoes, settled over the region. By Oligocene time, rhyolite ash had covered much of the northern Sierra Nevada, damming rivers and forming lakes, the bottom sediments of which are now represented by thinly layered pipe-clay immediately overlying the richer gold-bearing gravel. The newly developed rivers, flowing directly down the western-tilted slope of the Sierra, over a volcanic cover, as consequent drainage, were repeatedly interrupted by continued ejections of lava and a further tilting of the region. Not until the late Pliocene or early Pleistocene did the constant outpouring of lava cease. Then, by a series of violent earth movements, the Sierra Nevada broke away from the region to the east along huge fault-scarps, which are formed at the foot of the present steep eastern slope, where displacements are now measured in thousands of feet. Within the Sierran slope, smaller adjustment faults also broke the continuity of the older buried Tertiary stream grades. Some of the ancient streams, the courses of which headed farther to the east, were virtually 'chopped' into many pieces; some were elevated and others depressed, and many were warped to various peculiar positions. Undoubtedly there are some segments of these old channels which now lie deeply buried beneath great thickness of alluvium in down-dropped fault-blocks east of the Sierran escarpment.

In the Great Basin and the Mojave Desert region of California and Nevada are remnants of Tertiary stream deposits, interbedded with or lying beneath

lavas, all of which have suffered much by faulting and warping.

In these regions, however, the most important period of placer formation was in the early Pleistocene, rather than in the Tertiary. Two types of lode gold supplied the source. One type was formed in much the same manner as the Sierra Nevada lodes. The other consisted of mineralized zones in rhyolite of early and middle Tertiary time. In the Pleistocene there were normal streams flowing through the desert, fed by melting glaciers of the higher mountains. Placers that were formed by these Pleistocene streams have since been largely covered by desert alluvial fans. Some have been elevated and are cut by more recent streams, when present in this arid region, so that recent concentrations from older river gravels provide one source for the desert dry placer.

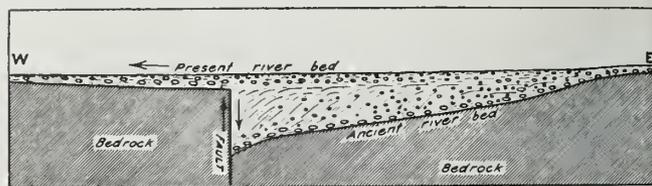
In the Klamath Mountains, though the early geologic history was much like that of the Sierra Nevada, there were no lavas to fill the valleys in which the stream gravels were deposited. Uplifts, accompanied by renewed stream-cutting, caused terraces to be left on the valley sides, where the rich gravels have given up their gold to hydraulic mining. Some of the finer gold particles were washed by the rivers to the sea and have formed deposits known as beach placers along the northern shore of California.

Down-faulting of various degrees of magnitude in places caused accumulations of gravels to form, especially on the down-throw sides of faults. A number of such faults are located in both the Sierra Nevada and Klamath Mountains, and may hold a reserve of gold not yet entirely recovered. In the Sierra most of these minor displacements show that the east side of the fault-plane has been dropped down, so that where faults cross westward flowing rivers, accumulations of gravels have taken place in pockets thus formed, east of the fault-plane and upstream.

The whole Pleistocene period was one of great events for California. The eastern side of the Sierra Nevada was raised to very lofty heights. The westward-flowing streams, as a consequence, were so greatly accelerated that they cut deep and rugged canyons. The uprise, accompanied by faulting, caused such violent earthquakes that enormous masses of rock were shaken from the mountain sides, in many places to form local lakes which were later to be drained and destroyed by active erosion. Glaciers developed in the higher mountains and crept down the canyons, carving them wider and leaving them U-shaped in form. Their melting supplied much water to the streams. Some local volcanic cones were built up here and there near or over the fault planes.

The Tertiary stream gravels, which had long been buried deeply beneath lavas, were exposed by the

Pleistocene canyon-cutting rivers. From the dissected portions of the old channels, gold was removed and washed into the newer streams, which concentrated it on their bedrock riffles. The remaining portions of the Tertiary deposits were left with their stubs exposed high up on the intervening ridges. In places, erosion merely stripped the covering of volcanic tuffs, sands and gravels from the bedrock, leaving the channel with its rich gold deposits laid practically bare for the lucky early miner to win. Some of the finer particles of gold were swept clear out to the Great Valley where they were dropped on the edge of the plain. These areas are now the dredge grounds.



Ideal cross-section of a river in the Sierra Nevada, the bed of which has suffered down-faulting on the upstream side, causing gravels, sand, and silt to accumulate in the pocket thus formed.

The general western tilt of the Sierra Nevada has been found to continue along the same slope (about two degrees) far beneath the alluvium and sediments of the Great Valley. Areas dredged for gold values in the gravels thrown down by the great canyon-cutting rivers of the range lie along the extreme western margin of the foothills near the place where bedrock passes beneath the alluvium, and aligned in a direction $N.20^{\circ} W$. The gravels dredged do not lie directly on bedrock but on tuffaceous clay layers, spread out above the detritus-covered down-warped Sierran surface. Beneath the 'false-bedrock' and cut in the true bedrock surface is a stream pattern with gold-bearing gravel filled channels, now reached only in one or two places. This buried channel system undoubtedly holds in reserve a great wealth for future improved exploration and development. Excessive underground water is always encountered in these mines which are located beneath the level of the alluvial plain.

The great differences between the geology of the Coast Ranges and that of the Sierra and Klamath regions are fundamental in that the western area served frequently as a basin for deposition during the Tertiary and Cretaceous, while the latter represented land areas throughout that time. The Coast Ranges together with the Great Valley now contain enormous accumulations of marine Tertiary and Cretaceous

sediments while the Sierra Nevada and Klamath Mountains are not so covered. Cretaceous and Tertiary streams coursing down the mountain flanks brought gravel, sands, and clays into a marginal sea.

The very fact that streams are conveyors of materials, in contrast to the basins of deposition toward which they flow, accounts for the very different geologic conditions on the two sides of the Great Valley. Certain geologic time divisions of the Cretaceous and Tertiary of the Coast Ranges are represented by strata measured in many thousands of feet, while in the Sierra mere films of Tertiary gravels, or deposits of no greater thickness than a few hundred feet, trapped by volcanic coverings, represent some of these same later periods. Particles of gold, recurrently washed from the mineralized rocks of the mountain range were dropped by reason of their high specific gravity, and retained in the bedrock riffles of both the ancient and modern streams, while the lighter detritus was carried to the broad sea basins to form strata covering hundreds of square miles.

CONCLUSION

The depletion of the more accessible and more easily discovered gold placers, followed by losses due to poorly directed exploration, calls for a more effective technique to bring further success to placer mining. The technique is available; the next thing to do is to apply it.

First, there is aerial photography which may speedily and accurately give a wealth of valuable information as regards geology, and in addition, the finest sort of a map showing surface features in greatest detail.

Second, there is geophysical surveying which, when coordinated with geology, may greatly aid underground prospecting in making new discoveries and in reducing its cost by more intelligently directing its course of action.

Third, physiographic geology, advanced to a more systematic science than ever before, may be used in unravelling the history of the ancient streams and their corresponding topography. Contouring the pre-lava surface is found to be an excellent method of showing graphically this ancient topography, and especially the old valleys in which lay the early gold-bearing streams.

Fourth, a better understanding of desert processes in general and desert placers in particular should help to develop a gold reserve which has so far not received the attention it deserves.

Fifth, the technique recently developed in the examination of stratified sediments, their structure, texture, mineral-grain composition, etc., may be aptly

applied to placers, to aid in tracing out their origin and the courses of the older drainage systems now extinct.

In taking stock of the possible reserves of placer gold in California, several sources would seem worth investigating. All of these require detailed exploration prior to any attempt at mining. For the most part, these reserves are buried or concealed in such a way that they have either been overlooked or considered too remote or too much of a speculation for a mining venture. Such factors as involved water-rights, litigation, difficulty in gaining title, laws unfavorably affecting hydraulic mining, lack of sufficient capital, and many other stumbling blocks now prevent good placer ground from being worked.

The possible reserves discussed in this report may be summarized as follows:

Pleistocene and Recent Placers.

1. Deep river gravel deposits, over which the present larger rivers are now flowing. Recent and Pleistocene faulting caused gravel to be accumulated on the down-throw side of faults, while the rivers have continued to flow over the gravels without washing them completely out.
2. Pleistocene stream placers, buried beneath alluvial fans of the Great Basin and Mojave Desert.
3. Recent ephemeral stream deposits and alluvial fans or 'bajada placers' of the Great Basin and Mojave Desert regions.
4. Marine or beach placers along the coast, for the most part located in northern California.
5. Isolated high terraces or bench gravels, such as those which occur in the Klamath Mountains.

Tertiary Stream Placers

6. Gold-bearing channels cut in bedrock which lie beneath the false bedrock layers of the dredged areas along the western foot of the Sierra Nevada.
7. Buried Tertiary channels and associated covered benches located in the well-known gold-bearing districts of the state. Large areas still lie buried and unexplored in some of the older mining districts.
8. Buried Tertiary channels and benches in the lava-covered district which lies between the Sierra Nevada and Klamath Mountains. Most of this area is probably too deeply covered to be reached by mining, but the southern marginal area may have some possibilities.
9. Tertiary channels of the Great Basin and Mojave Desert areas, interbedded with volcanic rocks or lying beneath them.
10. Tertiary marine placers. Finely divided gold particles in the lone formation at the point where the corresponding Eocene streams entered the lone sea.

Cretaceous Marine Placers.

11. Cretaceous marine placers, largely in the Chico conglomerate (Upper Cretaceous) beds of northern California. The Lower Cretaceous beds are also reported to contain some gold-bearing layers.

Largest Reserve.

The largest of these possible reserves probably lie in the remaining buried Tertiary stream placers of the northern Sierra Nevada.

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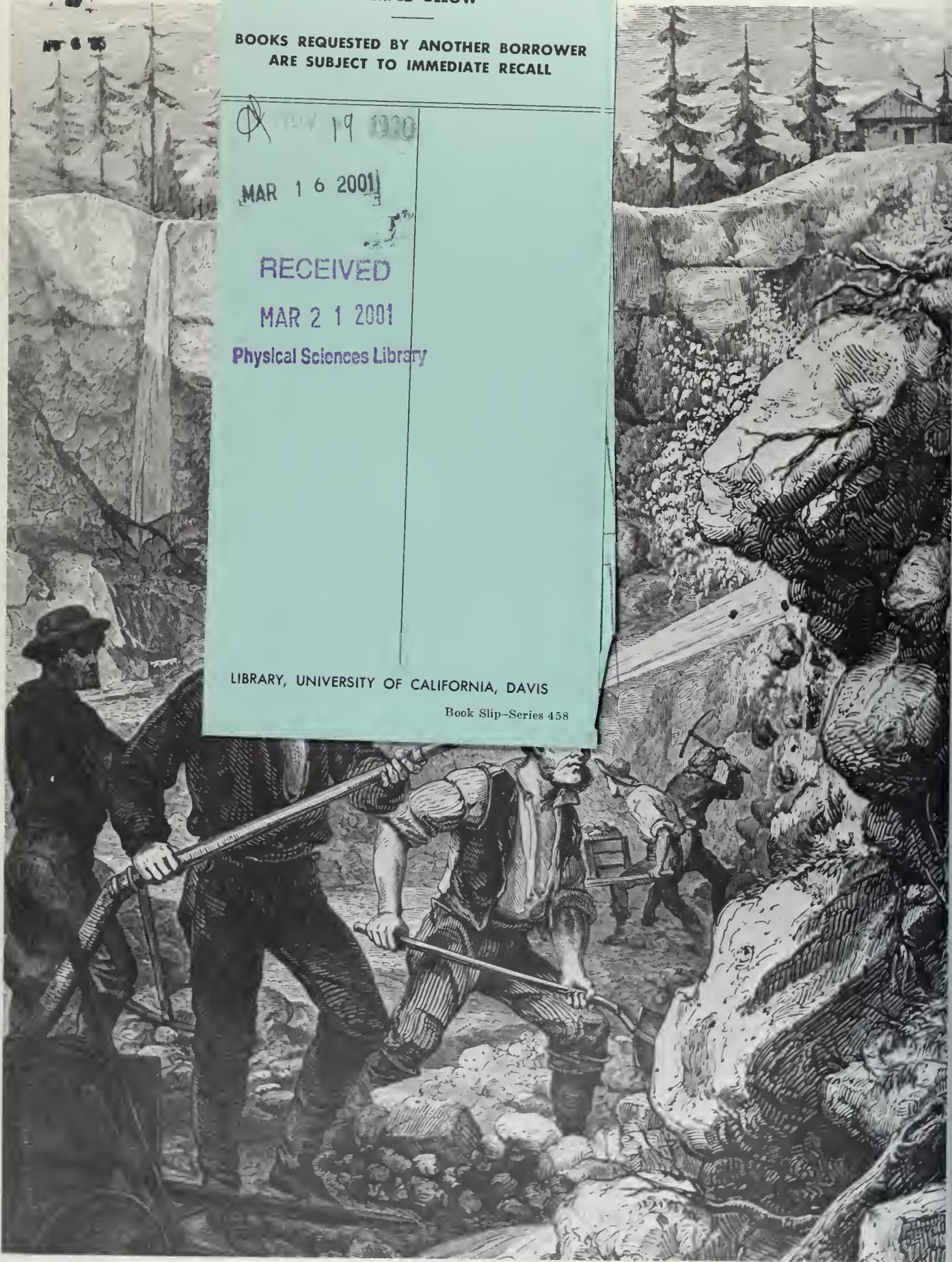
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