Placer Gold Deposits

John W. Bonneville

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PLACER GOLD DEPOSITS

A THESIS
Presented to
the Faculty of the Department of Geology
University of North Dakota

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science of Geology

by

John William Bonneville

January, 1956
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INTRODUCTION

Mineral deposits formed directly as placers and sediments are of large value, including such as they do, salt, gypsum, potash, sulfur, phosphates, nitrates, and important fractions of the ores of iron, manganese, gold, tin, tungsten, platinum and precious stones; also many common rocks of commercial importance. In this thesis I will cover gold placer deposits. The minerals of placer deposits are derived from the weathering and erosion of land surfaces, either igneous or sedimentary. They are deposited both under air and under water, and mainly by mechanical means.

Mechanical erosion of pre-existing mineral deposits or rocks and their transportation, sorting, and deposition are responsible for the placers of gold. Sands, sandstones, shales, and some clays also belong in this group. During the process of formation the minerals of differing density are more or less sorted out and tend to become segregated in layers. The process is not unlike the artificial process of mechanical concentration where ores are crushed, shaken up, and treated with running water. The process is most effective for minerals which are resistant to abrasion, and to solution, and of such density as to differentiate them from the other minerals of the parent rock.

There are different kinds of placers, which are classified as to their origin such as eluvial, solian, stream, and marine placers. Also there are Old Placers, Fossil Placers, and Reconstructed Placers. All these are discussed in this manuscript. The details covering the mineralogy of placer gold are discussed along with the mining methods and mechanical helps in mining and metallurgy.

The production of placer gold, the uses of gold and the future of gold mining are included in this thesis.
This writer's indebtedness for information derived from printed matter and from personal discussion and advise was of great importance to my thesis. I would like to express my appreciation for advise particularly by Nicholas Kohanowski in preparation of this manuscript.
GOLD PLACERS

Placers, which are in general the more easily discovered and more easily worked deposits, have in the past been the chief source of the world's gold supply. It is estimated that in the first thirty years of the modern era of gold mining, beginning with the discovery of gold in California in 1848, nearly ninety-per-cent of the world's production was obtained from placers. At present the placers of recent geologic age supply a tenth to a fifth of the gold, and the ancient or fossil placers of the Transvaal supply another two-fifths. In the United States about one-fourth of the gold production comes from placers, mainly from California and Alaska.

Placers are detrital or fragmental sediments containing the ore in mechanical fragments, which are derived from the erosion and transportation of solid rock veins or lodes, sometimes called the "Mother lode". During process of transportation and deposition there is more or less sorting, because of the differing densities of the mineral fragments, resulting in the segregation or concentration of the ore minerals in certain layers or channels. Gold, because of its weight tends to work down toward bed-rock, or into scoured or excavated portions of stream channels. In a few cases it is carried in some quantity to the sea and concentrated in beach sands. The processes are not unlike the mechanical concentration of ores by crushing and water sorting. Seldom, however, do the processes go far enough in nature to produce an ore which can be used directly without some further mechanical sorting. Ore minerals concentrated in placers are those which resist abrasion and chemical solution during the processes of weathering and transportation, and which have a density sufficiently high so that they are partially sorted out and concentrated from the accompanying quartz and other minerals. To warrant their recovery, they must
also be of such high intrinsic value that it pays to mine small quantities.

No less than twenty-four percent of the gold produced in the United States comes from placers, and it is probable that the relative amount produced in other parts of the world is similar. The high specific gravity, insolubility, and the general toughness of gold are the factors that control the formation and concentration in placers.

Origin of placers—Rocks at the surface are broken up by erosion and find their way, by the power of gravity, aided by running water, down into the valleys. In the highest valleys only the coarser fragments remain, for the streams carry away the smaller ones. Further down, as the stream current loses its force, some of these smaller ones are deposited and only the still finer material is carried on, until nothing but silt or mud is left. In a gold-bearing region, the veins are broken up and sent on their journey in company with the detritus of the enclosing rocks.

Freeing of gold from associated baser metals—Gold, in deposits not too close to the surface, generally occurs in small quantities in intimate association with metallic sulphides, such as pyrite, galena, arsenopyrite, or mispickel, these sulphides being contained in quartz veins. Near the surface, atmospheric agents attack the veins chemically, and if erosion is slow enough to let these agents exercise their full influence in decomposing, dissolving, carrying away and re-depositing the various constituents, the result is that the surface portion comes to have a different character from the deeper part. The sulphides are broken up and taken into solution; and the metals thus dissolved are either carried quite away or are re-deposited in deeper parts of the vein. But gold is soluble with much greater difficulty than most other metals; hence, when the sulphides which contained it are dissolved, it is left as free gold.
Purification and Chemical Concentration—Where the surface rocks are decomposed, the gold, mixed with the debris produced by erosion, may then be already in a free state. Frequently, however, the sulphides outcrop, or the gold is imperfectly separated from other materials. Then in the gravels exactly the same process goes on as I have described as occurring in the vein outcrop and the baser metals are carried away in solution, and the gold is left behind or is dissolved and re-precipitated. This is one reason why so much of the gold in placers, when examined microscopically, shows unscratched or even crystalline surfaces, indicating chemical deposition. Fragmental pieces of gold may receive fresh coatings from solutions thus originating, or the solutions may deposit gold upon fragments of organic matter or metallic sulphides, for these substances exert a precipitating effect.

It is even probable that gold already deposited in the native state, may be, to a slight extent, re-dissolved and rearranged.

Concentration Mechanically—Particles of native gold in gravels, brought down into the valleys by mechanical action, and freed from other metals and often increased beyond their original size by chemical action, are in the valleys still further mechanically concentrated. Waters shift the gravels so that the heaviest minerals, especially the gold, sink naturally to the bottom; and, where there is not much disturbance by running water, the gold particles seem to be able to work downward through the loose gravel, probably during such movement as the deposit undergoes from percolating waters, or from alternate thawing and freezing.

Pay-streak—The result of the downward shifting of the gold is that
where the valley-deposits of sand, gravel, et cetera, are porous, by far the greater quantity of gold will be found at the very bottom, in the few inches overlying the bed-rock. This is called the pay-streak.

The bed-rock itself, especially if it is a shale or a schist, and so affords cracks for the gold to work itself into, is commonly rich for several inches in depth, and is taken up by miners and worked with the gravels. This fact sometimes leads to the belief that the gold was originally contained in these rocks; but generally the rock a little distance below the surface will be found entirely barren, disproving this supposition.

Where the gravels are not sufficiently porous, the gold cannot work itself down so well, and as a result it may occur scattered throughout the whole deposit, though in this case the gravel is relatively poorer per cubic yard than the pay-streak on the bottom of porous gravels, the amount of gold which is usually concentrated in the pay-streak being distributed throughout the mass.

False Bottom—When there is, in the deposit, an impervious layer such as a clay seam, this will arrest the downward working of the gold, and above it a pay-streak will be formed. A lava bed, or a solid conglomerate, may play the same part. Such an impervious layer is often called the false bottom, from having the appearance of being the base of the gravels. (As illustrated in example) There may be several of these, with intervening gravel beds, one below the other, each overlain by its pay-streak; beneath, the real bottom may also have its pay-streak.
Black and ruby sands in gravel - By the natural process of concentration other heavy minerals are also collected, but, as none of them are as heavy as gold, they are concentrated to a less degree. The magnetite which is present in many rocks is concentrated, and becomes the black sand or magnetic sand of miners; the garnets found in many schists and other metamorphic rocks form the ruby sand. So, when a miner washes a pan of gravel and gets a little black sand, his experience tells him that the chances of gold are small, the exact reason being that the materials in this gravel have not been concentrated. In many regions the auriferous veins are in rocks containing garnet; and the prospector rightly concludes that the presence of ruby sand is a favorable sign. On the other hand, the presence of either of these sands does not necessarily indicate even a small quantity of gold.

Effects of glacial action - Frozen water, is a powerful erosive agent. It fills crevices in rocks and by its expansion in freezing rends them apart; it accumulates in masses on the steep hillsides, in mountains as glaciers; it moves down into the valleys as valley glaciers; and or, finally, piling up over mountains over valleys, forming a great ice cap, or continental glacier. The slowly flowing ice grinds away the rock on its bottom and sides, and carries along on its surface what slides down on it from cliffs above. So in glacier regions there is generally a much greater abundance of surface debris than in unglaciated ones. It may be therefore, that glaciers are often effective in breaking up auriferous rocks; but the cases where profitable placers are due entirely to glacial action are probably few. This remark is made because it is a favorite theory with miners that the gold was brought down by glaciers. Placers often occur in districts which do not have any glaciers.
Quartz Creek, Alaska
This cross section of the stream shows the gold-bearing gravels on its sides and bottom. The gold is being mined 2 or 3 feet below the surface on what the miners call the bedrock, which is a dense, blue clay. This clay is a lens of fines interbedded in the sands and gravels. This blue clay afforded a floor upon which the gold was concentrated. This is called a "false bottom". The real bedrock at this point has not been reached. When it is reached, a new pay-streak will probably be found.

Scale - 1" = 100'
and never had any. It is true that many regions now bare of glaciers were formerly covered with them, such as the great glaciated areas of Canada and North Eastern United States; but in each place we must find the characteristic mark of glacial deposits; unstratified drift or till, ice scratches, gouges, glacial topography, etc., before we can allow this factor to even become possible in any theory of placer formation.

Besides the ground-up unstratified drift which is the product of the glacial mill, streams derived from the melting of the glaciers, coming from their surface and below, work over, rearrange and deposit the drift in more or less stratified form. Such action tends to classify the minerals present, but the process is generally incomplete as compared with that accomplished by streams in valleys. Hence, even stratified glacial deposits are not very favorable for placers.

Nevertheless, ordinary streams may take up material supplied by glacial action and by classifying it so as to shake the gold down to the bottom, produce good placers. In some cases, even, the material ground out of auriferous rocks by glaciers, and worked over by glacial streams, may be rich enough in concentrated gold to be valuable.

The following two examples show two forms of glacier-caused deposits; the first being a angular-gouged out area in metamorphic schist, filled with auriferous gravels and sands containing gold as found in Alaska. The second example shows an area which has been folded and then covered by a large glacier which gouged out irregularities in the metamorphic rocks; upon retreat of this glacier these irregular depressions were filled with glacial gravels containing gold.
Basin containing auriferous glacial gravels.

Otago, New Zealand

cross section

Irregular depressions filled with auriferous glacial gravels.

Otago, New Zealand

Folded beds (sedimentary)
Geologic Agga—Placers or gravel deposits serve chiefly as a source of native gold and may contain a little silver. These gravels are derived chiefly from quartz veins of Mesozoic age in the Pacific coast region, and to a less extent from pre-Cambrian veins of the Appalachian region and the Black Hills of South Dakota. Some are also derived from veins in Tertiary lavas, but these usually contain the metal in such a finely divided condition that it does not easily accumulate in stream channels. Large quantities of placer gold are obtained from Alaska and California especially.

Placer Types—

1. Eluvial Deposits—Gold placers may be formed by rapid erosion of hard rock, but such placers are not often rich and highly concentrated. In the great placer regions the concentration has generally been preceded by an epoch of deep secular decay of the surface. It has been supposed by many that this deep rock decay is peculiar to the tropics, but this is not correct. The process has been active in the southern Appalachian States, in California and in Alaska, as well as countries like Guianas and Madagascar. When the outcrops of gold-bearing veins are decomposed 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 downhill 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 action takes place and ferrous sulfate is common. This is the solvent for the gold. Also found is MnO₂, which is the catalyst for this reaction. 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. Stellar has applied to such residual concentrations, which may be worked like ordinary placers, the term eluvial gold deposits.

2. Dry or Eolian Deposits—Deposits concentrated by eolian agencies can be formed only in dry countries where long sub-aerial decay has paved the way for the work of the dust storms; from the decomposed and crumbled outcrops of the lodes the winds blow away the lighter sands, leaving a mass of coarser detritus which contains the gold. Such wind-born placers have been noted by geologists near the croppings of the West Australian gold fields. No examples of this kind have been found, as yet, in the Cordilleran States of America.

3. Stream Deposits—

a. Gulch Placers—Gulch placers are formed in the highest narrow valleys, or gulches, of a river system. They usually head in hills or mountains, and the material in their bottoms, though rudely stratified, is coarse and shows only slightly the effects of wear and transportation. In the extreme upper portion of the gulch, where it heads in the bedrock, gravel is often wanting, but the amount of it increases as the gulch gains depth. The gulches are generally more or less V-shaped in outline; hence the width of the deposit is slight. The gold, being near its place of origin, is comparatively coarse. The relative richness of various gulches, even neighboring ones, varies greatly, according to the richness of the rocks through which they cut.
b. **Broad Valley Placers**—The upper valleys or gulches unite further down to form larger and broader valleys. Here the stream flows in a level plain of gravelly materials, which stretches back to the valley sides. As the stream wears away one bank and builds up another, it changes its position, and so, at one time it runs along one side of its valley, and at another time the opposite side. In this lateral swinging it works over, classifies and smooths the gravels of its floodplain. In auriferous regions these gravels become placers.

The valley gravels are in far greater quantity than the gulch gravels; and, since with increasing distance from the head of the stream the gradient of the stream usually decreases, permitting increased deposition, their thickness is comparatively great. On account of the more complete work of the swinging rivers, the gold content is apt to be more uniform than in the gulch placers; and since not only the rich but the barren gulches have contributed their material, this content is apt to be considerably less than the rich but limited gulch placers. Although valley placers attain often to a considerable depth, the statements made above concerning the working downward of the gold in gulch placers, by reason of its gravity, seem to apply here also. Naturally, in broad valley placers the gold is generally of finer size than in the gulches. A typical valley placer is shown in the following example.

c. **Beach Placers**—When a river, rising in a gold-bearing region, reaches the sea with a slow current, it carries only fine mud or silt, and the finest possible particles of gold. These gold flakes almost float on the water; they are largely taken into solution by the sea water, whence it comes that this water contains gold to the amount of about eleven milligrams to the ton. Part is probably deposited with the settling mud,
Diagramatic cross section of typical BEACH PLACERS at Nome, Alaska.

Cross section of the Rye River valley, Oregon, showing typical bench placer and valley placer.
but the amount is very small and of no direct commercial importance.

But where the rivers discharge into the ocean with a strong current, they carry coarse rock fragments and gold particles of considerable size which are deposited on the sea shore. The waves and currents work this material sidewise till it forms beaches extending along the coast. The surf, continually moving that portion of the material which comes within its reach, often effects a concentration, the gold being accumulated and much of the lighter material swept away. Shore ice, especially in northern regions, may also be sometimes an important agency in working over the material. Thus beach placers are formed.

Sometimes the shore waves undercut a gravel bank containing gold, and then concentrate the material in the same way as before. This kind of beach placer differs from that mentioned above, in that the rivers do not directly contribute the gold to the beach; yet they do it indirectly, for the gravels undercut by the waves have generally been brought to this position by rivers—that is, they are broad valley gravels, or they are old sea-shore gravels brought down by former streams, and raised high and dry by an uplift of the crust.

Beach placers, like bar placers, are almost invariably, from their nature, shallow and hence short-lived. They are confined to a narrow strip along the beach, for, even when the gold has been derived from auriferous gravels forming the shore, these older gravels will be relatively much poorer, and either will not pay for working at all, or must be worked on a larger scale at a much smaller profit per ton. That portion of the gravel seaward from the surf-beaten zone will not have undergone the concentrating action of the surf, and will also ordinarily contain a very much smaller proportion of gold. A typical beach placer is shown in previous example.
d. Bar Placers- When a stream runs through auriferous gravels and by undercutting its banks brings down and works over large quantities of these gravels, the gold undergoes a further concentration in the stream current. At places where the current slackens to the right point, the heavy gold and the coarse pebbles are deposited; further on, the fine gold and the smaller pebbles and sand. On such a river colors of gold may be found everywhere in panning, but the richest spot is where the most and the heaviest gold has been deposited, on bars. The following example shows the spots along such a stream where the gold will best accumulate. Bars are always the first point attached by the prospector in a new country. They are often very rich, but are quickly worked out.

e. Bench Placers- A river valley often shows along its sides shelves, terraces or benches, part of the old river bottom when the stream was at a higher level, in which bottom it has cut itself a newer and deeper channel. If the rock region is gold-bearing, and especially if there is gold on the bars and in the valley gravels of the present streams, then gold may be also looked for in the gravels lying on these high benches. A typical bench placer is illustrated in the previous diagram.

4. Marine Placers- These placers are similar to, and sometimes called Beach placers; the description of this type placer is similar to that given for beach placers.

5. Old Placers- Sometimes the earth's surface is disturbed by crustal movement. In some cases the movement may be a general elevation or depression, while in other cases a gentle tilting is produced, so that one portion of a given region is relatively more elevated or depressed than another. Again, the disturbance may be quite irregular, producing a warping of the crust. After such movements the rivers
Diagram of an ideal river, showing the accumulation of bars. Dark brown areas are probable spots for gold deposition. Direction of stream is indicated.

(After J.E. Spurr)
the rivers change their velocity and often their direction, adjusting themselves to the new slopes of the surface.

A certain river may be running rapidly down a steeply sloping country; and, on account of its strong current, it is steadily cutting its bed deeper into the rock. A gentle crustal movement occurs, and the lower portion of the river experiences more uplift than the upper. The gradient is changed; the current becomes sluggish; the stream ceases to cut into the rock, and most of the detritus which is brought down is not carried out to sea as formerly, but is smoothed out by the stream along the valley. Thus the valley becomes more and more deeply covered with gravels and hence more and more shallow, and it may end by being entirely filled up.

On the other hand, take a region of sluggish streams which have filled up their valleys with gravels, and think of the region being slightly tilted so that the streams begin to run rapidly. If the tilt is in the direction of the old streams, the new ones will have much of the former direction, but, if it is in other directions, the new rivers may flow at right angles to the old, or even in the opposite direction, for a country whose rivers have filled up their valleys will be nearly flat and will permit the streams to change their beds easily. In any case, new channels are cut. When this is accomplished, the old river gravels will be left between the new valleys, and, in proportion as the latter are deeply cut, the former becomes relatively high above them. These old gravels may have been placers, and, when thus left on or under the hills above the present valleys, they may be called old placers. A generalized diagram of an old placer is shown in the following diagram.
This is a generalized cross section of an old placer, which has been overlain by a volcanic flow, with common terminology.
6. **Fossil Placers**—The old placers proper are usually of Tertiary age; they are plainly river deposits belonging to an age just preceding the present, and, save, for thin lava beds or barren gravel deposits, they are not covered by younger beds. But placer gravels may be of any age. They may be hardened in rocks and be folded and faulted so as to lose all evidence of their original relation to any stream. They may be deeply buried by the accumulation of later beds; and, when again exposed by erosion, they may outcrop either in the mountains or in the valleys. But they will often still retain the gold that was in them originally, and may be profitable for mining; or, when they are attacked by erosion, the gold will accumulate in stream bottoms to form a new generation of placers.

The number of instances where fossil placers permit of productive mining is not so large as might be expected; but it is probable that, in many cases not yet recognized, modern placers derive their gold from old conglomerates which are of this nature. Solid rocks must contain many times more gold than loose gravels to be equally profitable.

7. **Re-concentrated Placers**—Any one of the classes of placers above mentioned may have derived its material wholly or partly from older placers. Thus the gold may have to pass through several successive concentrations, at different times, before it can render a placer profitable. A gulch placer may represent the re-concentrated remains of a bench placer, and a bar placer may be a re-concentration of the gulch placer. Similarly a fossil placer may be attacked by erosion and its gold concentrated anew. Numerous other combinations have commonly occurred.
Here an ideal sketch shows the development of various types of placers in Calif.
Production of Placer Gold- In 1940 placer gold production reached thirty million dollars. The main producing states in this country are California, Alaska; the main producers, with Colorado, Idaho, Montana, Nevada, and Oregon producing fairly large quantities; and Alabama, Arizona, Georgia, New Mexico, North Carolina, South Carolina, South Dakota, Utah, Washington and Wyoming produce some placer gold. About twenty to twenty-five percent of the total gold production of this country comes from placers.

Areas besides the United States which are large producers of placer gold are: Alaska-Yukon territory, which includes the Klondike Fields which are mostly deposits of auriferous gravels, and cover an area of two-hundred square miles; Seward Peninsula—this area is largely made up of beach sands and gravels; Victoria—this area is made up of buried placers, lava caps, etc.; Russia—mainly in the areas of the Lena River, Siberia, and made up of gold gravels, some of the largest in the world; South Africa—mainly in Transvaal, auriferous conglomerates overlain by volcanics.
Physical Properties of Gold—The color of gold is gold-yellow, becoming a lighter yellow if silver is present. The luster of gold is metallic. Its hardness is 2.5 to 3 and its specific gravity is 19.6 to 19.3 (19.33 if pure). Gold has no cleavage and is very malleable and ductile. Gold is insoluble in most acids. Gold crystallizes in the isometric system.

The principal gold mineral is native or metallic gold. This occurs in nature in small scales, crystals, and irregular masses, and also in microscopic particles mechanically mixed with pyrite and other sulphides. Chemically gold is very inactive and combines with but few elements. A small part of the world's supply is obtained from the gold-silver tellurides, such as calaverite (AuTe₂), Au 39.5%, Te 57.4%, Ag 3.1%; sylvanite; krennerite; and petzite. Gold is also found in chalcopyrite, arsenopyrite, stibnite, sphalerite, pyrrhotite and may occur in primary, secondary enrichment, or oxidized zones.

Gold ores were deposited in a number of different geologic periods, notably the pre-Cambrian, Cambrian, Cretaceous and Tertiary.

The associated minerals found with gold in placer deposits vary considerably. Placers may contain a number of heavy minerals, which settle out with the gold in the sluice boxes. These include magnetite, ilmenite, (black sand), garnet, zircon, monazite, cassiterite, and platinum; pyrite and marcasite may also form in the gravels.

Size of Placer Gold—Gold occurs in placers in the form of nuggets, flakes or dust-like-grains. The nuggets represent the largest pieces and the finding of some very large ones has been reported from time to time in different parts of the world. Two large nuggets are recorded from Victoria: one the "Welcome Stranger", weighing 2280 ounces; and the
other the "Welcome Nugget", weighing 2166 ounces. Most of the placer gold obtained is in small grains and commonly may be very fine. Lindgren states that a piece of gold worth one cent is without trouble divisible into two-thousand parts, each of which can be readily recognized in a pan.

Tenor of Gold Ore—Like that of all products having a varying market value, the price of gold influences the tenor of the ore that can be mined economically. Placer gold is purer than the average gold ore, and may be nine-hundred and fifty fine (1000 fine = 100% pure) or even higher. This will be discussed further in the section on mining methods.
Placer Mining—Deposits which are not "in place" and which are detrital or the result of deposition by erosional agencies are mined by special methods. Alluvial or placer deposits may contain gold, tin, platinum, metals of the platinum group, and rare earths. Practically all these substances are characterized by specific gravities higher than those of the accompanying alluvial material, and as a consequence admit of convenient separation by washing in sluices, undercurrents, and upon tables, or by the more primitive methods of pan and rocker.

The methods used in practice are grouped under four heads: Placer mining, hydraulic mining, dredging, and drift mining. The selection of a method presupposes a determination of the controlling features of the deposit. These are: the superficial extent or area; the thickness of the deposit; thickness of overburden; thickness of pay gravel; the surface topography and the significant surface features; the slope of the bedrock; its general surface; its physical nature, whether hard or soft, fissured or seamed, rough or irregular; the nature of the gravel, whether fine, medium, or coarse; whether free or compact; whether clayey or sandy; whether large boulders are present or conspicuously absent; whether cemented; the distribution of the mineral; whether uniform, concentrated on or in crevices in bedrock or at intermediate points; the fineness or subdivision of the mineral; the disposal of the waste; the separation, whether by sluice, washing plant, or jig; the methods available for excavation and transportation; the water supply available and the necessary features required for its development; ground-water level is important; transportation, climatic and economic features; taxes and laws. The most important characteristics of any deposit are quantity, value, and the distribution of value. Shaft sinking and boring are necessary steps to determine these. The determination of the pay streak is important,
since operations can sometimes be concentrated and the complete working of the deposit avoided. The distribution of the gold is best studied by comparing sections of the pits or boreholes.

The subdivision of the gold is of importance in determining the details of the washing appliances. Finely divided gold is more difficult to separate than coarse, and the presence of nuggets necessitates the examination and picking of coarse or oversize material.

**Gold Content per Acre—**In most placer operations the unit taken is the gold content per cubic yard, and the value of the ground is often expressed in cents per cubic yard. The acre is the usual unit of area. The average thickness of the placer deposit and its area will give volume. Placer ground exceeding 50 cents per cubic yard may be often worked at considerable profit. Dredging ground may have a value of 5 to 50 cents per cubic yard.

**Manual Methods—**Manual methods of placer operation are restricted to pioneer conditions, small rich deposits, thin scattered deposits, and remote places without roads or convenient access, or where it is impracticable to obtain machinery or to develop water supplies for hydraulic mining. There are two fundamental methods of hand operation, shoveling into sluice boxes and ground sluicing. For the application of the first a water supply is obtained by damming a stream and conducting water by flume or pipe to the area to be worked. A sluice box is constructed in a bedrock cut at the lower end of the deposit; a strip 12 to 15 feet in width is worked along the axis of the gravel bed, the sluice box being extended as the excavation advances upgrade. The gravel is shoveled into the box and is disintegrated by the water as it flows over the riffles.
Sluice Types—The sluices are a washing or separating device. Before satisfactory separation can be accomplished the gravel must be disintegrated. Disintegration is practically effected in excavation and completed in the sluice. The length of the sluice is the important dimension controlling disintegration. Gravels that are easily loosened require a relatively short sluice, while gravels that are compact or contain much clay must pass through a long sluice before all the fine material is broken up and mixed with the water. At the dump box, or receiving end of the sluice, a punched plate screen or grizzly is often placed to receive the gravel. This separates the large stones and coarse gravel, leaving only the fine material to pass through the sluice. The width of the sluice ranges from ten inches to six feet and the depth from one up to three or four feet. Riffles are placed in the bottom either transversely or longitudinally. Many different kinds of riffles have been devised by the placer miner. Usually the available material determines the selection. Round wooden poles, poles protected by iron strips, wooden blocks, cobblestones, steel rails, metal grids, and Hungarian riffles are some of the kinds used in sluice boxes where the ordinary run of coarse and fine gravel must be handled. For fine sand and gravel, smaller riffles or carpet, blanket, burlap and coco matting protected by expanded metal or riffles are used. The form of the riffle and the spacing should be such as to permit large stones to slide or roll along the bottom of the sluice. Riffles are subjected to intense wear, and the surface receiving the wear should be protected by steel strips wherever possible. The following illustration shows a number of types of riffles and timber and steel boxes. The treatment of fine material containing fine gold is best effected by shallow wide sluices set on comparatively steep grades. Coarse material requires a deep, narrow sluice.
**Riffle Types**

- Pole Riffle (lengthwise)
- Hungarian Riffle (angle iron)
- Pole Riffle (transverse)
- All Steel Riffle
- Cobblestone Riffle
- Oroville-Hungarian Riffle (angle iron over wood)
The grades range from 2 to 12.5 %. The smaller grades are a cut the lower limit and are suitable for light sands and fine gravel. The commonest grade is 4.16 %, or 6 in. per 12 feet section.

The length of the sluice will depend upon topographic conditions and upon the nature of the gravel. Short sluices do not give much opportunity for the gold to be caught. With small sluices (12 to 1½ in. wide) and with coarse to medium gold, from 36 to 72 feet may be all that is necessary. With compact gravel and the other conditions the same, from 200 to 300 feet may be necessary. One authority states that the sluices should not be less than 240 feet long.

Hydraulic Mining—Water under a pressure of from 50 to 650 feet is used in this method for excavating and washing gravel to make sluices, in which it is disintegrated and transported to waste, the gold and heavy minerals being caught by the riffles. A water supply at a suitable elevation above the deposit is developed and the water is carried by ditch, flume, or pipe to the pressure box or penstock supplying the pipe system of the pit or hydraulic mine. Reservoirs may supply sufficient water for continuous operation, but some hydraulic mines start when water is available and close when water supply becomes insufficient. For best results, bedrock should be of sluice grade, not less than 1.5 % and preferably 4.5 % or more. The following illustration shows a typical bed-rock cut and sluice procedure.

In hydraulic mining a large pressure-nozzle called a hydraulic gun is used. A double joint enables it to be swung in a horizontal plane over the complete circle, and it may be elevated or depressed in a vertical plane. Nozzle sizes range from 2 to 8 inches in diameter. The supply inlet is 2½ times the nozzle diameter. Its weight ranges from 300 to
This is a sectional view of a hydraulic mining procedure. This typical sketch is a common scene in the southwestern U.S.
A counterbalance gives better control and the larger sizes are equipped with a deflecting nozzle that enables the pipeman to move the nozzle with but little effort.

The hydraulic mining sluice serves a triple purpose: It completes disintegration, it transports the water and gravel to the dump, and it catches the gold and heavy minerals in its riffles. Two general types of riffles are in use, one arranged longitudinally in short sections and the other transversely. Transverse Hungarian riffles facilitate disintegration, and longitudinal riffles help transportation; both are efficient mineral savers. Wooden blocks with spacers are used for transverse riffles; and poles, often shod with steel plates or bars, are used for longitudinal riffles. Wooden sluice boxes are used in many instances. In more modern installations they are of abrasion-resisting steel, and riffles are angle iron or steel rails, made up into short sections that can be handled in cleanups. Transverse steel riffles are given a slight upward cant against the stream flow and are spaced 2 or 3 inches apart; longitudinal riffles are given the same spacing. Cobblestone riffles are nearly obsolete.

Distribution of Gold in Sluices—Particle size of the gold, rather than the length of the sluice, determines the distribution of the gold in the sluice. Cleanups are made at frequent intervals in the upper sections of a sluice; the lower sections may be cleaned only once a season. Drones are sometimes placed in the sluice line to increase disintegration, and at such points undercurrents with 8 to 10 grades are placed to catch fine gold.

The quantity of water required in hydraulic mining varies between wide limits. With favorable bedrock and sluice grades of 4 to 4.5%, maximum duty is obtained and ranges from 3.5 to 7 cu. yd. per inch
This photo shows the hydraulic giants at work washing the placer gravels down into the sluises in the forground--at North Bloomfield, California.

A washed-out placer in Bloomfield, Calif.
per 24 hr. Under more adverse conditions duties of from 1 to 2.5 cu. yd. per miner's inch are not uncommon. Ordinarily water is supplied under natural head, but there are a very few instances where power pumps have been successfully used.

Hydraulic mining costs vary widely and greatly influenced by local conditions. At one extreme may be placed the California costs of the old days, where under especially favorable conditions gravel yielding 2 to 3 cents per cubic yard is said to have been profitably worked.

Opposition to hydraulic mining debris and stream pollution closed down hydraulic mining in California in 1884. Comparatively recently, debris-restraining dams have made possible some hydraulic mining; but since 1933 the development of this kind of mining has been slow, despite the increased price of gold, because of fear of legal entanglement. However, hydraulic methods of mining are used in many placer regions for mining gold, tin, Platinum, and other minerals.

Dredging—Dredging and other similar backfilling methods are applicable to alluvial deposits that are of the basin, lake-bed, delta, terrace, and river-bed types. Dredging of alluvials had its inception in New Zealand about 1882; it was introduced into the U.S. at Bannock, Montana in 1897. Larger and deeper digging dredges have been designed until at present the deepest dredging operations are 124 to 135 feet below pond level; with a bank above pond level, a deposit some 100 to 200 feet thick can be mined by this method.

Two types of dredges have been used in mining, the continuous or connected-bucket dredge and the suction dredge. The latter has never been successfully used in gold mining and is now probably no longer used in tin mining, where it found some application. Several different
(compare the two row-boats in these photos)

These two pictures show the progress of development in the gold dredge. The upper photo is a typical 1909 modal used by the Yuba Co. on the stream placers of west-central California. The lower photo is the new Yuba #2I a giant in comparison not only in size, but in production, of course, as well.
Designs of the continuous-bucket dredge are in use. The stacker design is predominant, the flume design being a feature of smaller dredges used in Alaska and a few other alluvial districts. In the simplest type, and buckets discharge into a flume or sluice that projects over the stern of the barge and discharges its tailings into the pond; another modification employs a revolving screen to receive the bucket discharge. The oversize is dropped into a chute at the stern and the undersize is discharged into sluices on either side of the screen; tailings being discharged by tail sluices beyond the end of the barge. A third type discharges its screen oversize upon a belt conveyor that extends out beyond the end of the barge and builds up a low pile. The flume is a metal sluice with longitudinal or transverse steel riffles. Dredges of this type are of 1.5 to 3 cu. ft. bucket capacity and are used for shallow digging, 4 to 29 ft below pond level. Many such dredges have been used in Alaska.

Dredges—The gold dredge is a self-contained electrically operated digging, washing, and disposal unit, operating in a pond and digging below water as well as on a bank of moderate height above water. It backfills its pit as it advances the cut. Its machinery is mounted on a shallow-draft hull. The digging element is a chain of manganese-steel buckets carried by a ladder. The ladder at its lowest digging position is usually at an angle of 45 degrees and when raised to its highest position is usually at a small angle below the horizontal. The bucket speed of the chain is 20 to 35 per minute, when at average speeds. The buckets discharge into a hopper and chute and thence to a revolving screen and shaker, and system of riffles where the gold is retained. This is illustrated in the following diagram.
Cross section of typical gold dredge hopper housing showing save-all tables and grizzly at discharge hopper of gold dredge. (Yuba dredging company)
One of the huge Yuba Co. gold dredges capable of processing 10,000 cu. yds. per day.

This dredge is working a small river in southern California. It cost the Yuba Co. $1,000,000.
Gold dredges are rated according to bucket size, and their proportions, power, and other design features depend upon this as well as depth of digging, kind of gravel, digging conditions in general, and climatic conditions in which they are to be operated. Dredge design is standardized as far as possible, but the important features of the dredge are in accordance with its particular work. Bucket sizes are $1\frac{1}{2}$ to $2\frac{1}{2}$ cu. feet on the smallest and $3, 5, 6, 7\frac{1}{2}, 9, 10, 13\frac{1}{2}, 15$ and 18 cu. feet on the larger dredges. Buckets are bowl-shaped and are made with replaceable lips held by two bolts. They are joined by massive bucket pins of alloy steel. Bucket eyes are bushed to allow wear replacement.

Depth of digging, which is a controlling feature, ranges from 4 to 124 feet below pond level. Ladder length is dependent upon digging depth and maximum ladder angle. The deepest digging on record is by a 12 cu. feet dredge described by P. C. Payne, which recovered ore from 120 to 135 feet below water line. The ladder length of this dredge is 195 feet. Yuba 20, a California dredge, has a digging depth of 124 feet at a ladder angle of 45 degrees and a ladder length of 216 feet. The cost of a dredge is closely related to bucket size and digging depth and whether wooden or steel hulls are used. A dredge of the Yuba 20 type (18 cu. ft.) represents a prewar cost of about $1,000,000.

Dredge capacity depends upon the kind of material dug. Loose free gravel gives maximum capacity, and compact cemented gravel, imbedded in stiff clays with large boulders in excess, gives lowest rates. Bucket speeds, which ordinarily range from 20 to 30 buckets per minute, is another factor. A-c power is almost always installed.

Dredging costs vary with the size of the dredge, depth of digging, compactness of gravel, proportion of boulders, efficiency of the dredge crew, power cost, repair and replacement costs, and climatic conditions. For smaller dredges in California costs range from 6 to 8 cents per cubic
The essential parts of an open-connected bucket dredge.
The never ending digging mechanism of the gold dredge—"the bucket line."

These ungainly but efficient gargantuans are an engineering triumph of strong steel hull, cables, and an endless line of steel buckets powered by huge electric motors. These machines can scoop the gold-containing gravels from the bed-rock 124' below water level with ease. The large buckets of this dredge can scoop up 18 cubic feet each.
yard; larger dredges operate at about 3 to 5 cents per cubic yard. For deep digging, lowest costs are at 100 feet in depth and for deeper digging the cost gradually rises.

A water supply of 1000 gallon per minute or more is required to maintain pond level in dredging. Total pond inflow is also dependent upon the yardage dredged per day, the porosity of formations enclosing the pond, and sometimes upon the necessity of diluting the slimes that accumulate in the pond. The dredge draws its supply for washing from the pond and all this return to the pond except the relatively small amount retained on the oversize material. Pond level is maintained by weirs and ditches, and pumping may be necessary.

The gold dredge has been highly developed as a machine, and modern design must more than fulfill the tasks imposed upon them. C.M. Romanowitz is of the opinion that in the dredge of the future electronic devices will be applied to give better control in overcoming variations in digging conditions, to utilize electric power more completely, and to operate safety controls when the bucket line strikes submerged objects such as boulders and logs. Such devices will be particularly applicable to deep-digging dredges.

Dry Placering—In deserts, where there is insufficient water for sluicing, alluvials are worked by a combination of portable screening units and dry washers, which effect concentration by transverse riffles set upon steeply inclined trays and winnowing by air currents supplied by bellows or fans. The final partially concentrated product is cleaned up by panning in water. Operations of this kind are on a very small scale and power is used only for screen and washers. The material treated in the air separators must be bone-dry.
Dredges like Yuba # 2I operate around the clock and around the calendar except Christmas and July 4.

Last year Yuba dredge # 2I, alone scooped up more than four million cubic yards of gravel from which was extracted 26,608 fine ounces of gold, plus other metals, with a gross value of just under a million dollars, and a total mining profit of nearly a half a million dollars.
Science and especially designed machinery like this has taken the color and adventure out of gold prospecting. Today gold extraction is an engineering slide rule, planned enterprise as dull in comparison with the forty-niner as the statistical tables of the geologist and assays of the mining engineer. Little is left to chance. Testing of areas considered workable now, or in the future, enables an almost uncanny prediction of how much gold can be recovered.
Drift Mining—Underground methods applied to alluvial deposits are included under the term "drift mining." As such methods are more expensive than surface operations, the deposits must be richer. Usually drift mining is attempted only when the pay channel is concentrated and too deep to be mined by open-pit methods. Gravel grades are about $4 per cubic yard and upward. Thickness ranges from 4 to 12 feet or more; width is from 20 to 200 feet or more; depth below the surface may be 30 to 200 feet or more and the length may be up to a mile or more. Much water is usually present, and in Alaska frozen gravel may sometimes be encountered.

Where an adit is possible, it is driven on a drainage grade, \( \frac{1}{2} \) to \( \frac{3}{4} \) percent on the shortest practical course to get beneath the deepest part of the channel. Where a shaft is used, it likewise is placed so as to command the lowest part of the channel. Where the channel grade is flat the shaft may be sunk in the mid-portion of the channel length. Surface conditions are a factor in selecting shaft sites. Predraining of the channel by boreholes and deep-well pumps facilitates shaft and other development work. The shaft bottom is sumped and is the drainage focus of the mine.

From the shaft or adit a main drift is extended the length of the claim or pay streak. The drift is 5 by 7 feet or 6 by 6 feet and timbered with sets from 4 to 5 feet on centers. Lagging is placed on top and sides. Where the gravel is free, forepoling is necessary. At intervals of 100 feet or more, crosscuts are extended from the main drift and the width of the pay streak is determined. Mining begins at the end of the main drift. The working faces are at right angles to the drift or across the pay streak. The first working face is obtained by driving crosscuts on either side of the main drift to edges of pay streak.
Plan view of a placer which is being mined out by typical DRIFT MINING methods.
Metallurgy or Treatment of Gold Ore—The method of extracting gold from its ores is different from that of removing silver, unless the two metals occur together. If the gold occurs as native gold or free milling ore, a common method of extraction is to crush it in stamp mills until the particles are small enough to be washed through a fine screen, from which they flow over a plate coated with mercury. This crushing and so forth is not usually necessary in placer gold particles. The gold unites, or amalgamates with the mercury, and the waste rock passes on. This waste rock may also be treated to recover the small amount of gold that it still contains. From time to time, the amalgam of gold and mercury is scraped off the plate, the two metals are separated, and the mercury can be used over again.

Some ores are of a grade so low, or are so complex, containing copper, lead, and other minerals, that they are treated by different methods. Two different methods are used; they are cyanidation and smelting.

Cyanidation methods are specially suited for the treated of low grade ores. If necessary, the ore is first roasted to drive off the tellurium or sulfur. It is then crushed very fine and treated with a cyanide solution that dissolves the gold. The solution is then passed through zinc dust to precipitate the gold which is then melted and cast into bars.

Smelting is employed for complex ores, the gold follows the copper or lead and is recovered from them during their refining. Gold and silver are finally separated or parted by electrolytic methods.

Industrial Uses of Gold—Gold is brilliant, malleable, ductile, almost unalterable and more dense than all the common metals except platinum; but it has one defect (besides its rarity) and that is it is not hard enough and therefore wears easily. Gold is chiefly used for coinage,
ornaments, and ornamented utensils. Its value for the use in the arts depends on its brightness, freedom from tarnish, and its malleability and ductility, which permit it to be easily worked. As pure 24-carat gold is too soft for use, it is alloyed with copper to gain hardness. The price of gold today is at a stable thirty-five dollars an ounce.

Placer Gold Reserves—Lindgren has pointed out that the gold reserves of the United States are large, but that it is difficult to estimate them with any degree of exactness. A rough estimate is possible in placers which now exist and are found in California and Alaska. They are estimated to contain perhaps one-billion dollars of gold in reserve and the output from this source will probably decrease for sometime. As to the future, the engineer-geologists teams, together with dredge designers and builders are busy contemplating all possibilities of even greater mining depths now out of reach of the ravencous dredge bucket brigades.
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IRON-CEMENTED DRIFT
in
LOGAN COUNTY, NORTH DAKOTA

A Paper
Presented to
the Faculty of the Department of Geology
University of North Dakota

Geology 500

by
John William Bonneville
January, 1961
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Plate 1. Map showing the regional glacial geology of the south central part of North Dakota.

(after Lemke and Colton, 1958)
ILLUSTRATIONS

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IRON-CEMENTED DRIFT

in

LOGAN COUNTY, NORTH DAKOTA

by

John W. Bonneville

ABSTRACT

In south-central Logan County, North Dakota, west of the Burnstad or Altamont Moraine is exposed a well indurated-limonite-goethite cemented glacial drift. The writer believes the origin of the cementing material to be similar to that of most bog-iron ores, and that this cement accumulated during a pre-Wisconsin interglacial age.

The glacial drift directly overlying the iron-cemented drift has previously been assigned to the Tazewell (?) sub-age; however, the writer believes it to be Iowan in age. If this is proven to be true, by C14 datings now in progress, the iron-cemented drift is pre-Wisconsin in age, the first such deposit reported from this part of North Dakota.

A possible sequence of events is offered to explain the entire Pleistocene history of the outcrop area.

INTRODUCTION

GENERAL—A number of interesting deposits of iron-cemented glacial drift were found by the writer while mapping the surficial geology of southern Logan County, North Dakota. (see plate I) An interpretation as to the origin and geologic significance of this deposit was thought important in the overall regional glacial history of the area because (1.) similar deposits have not been reported from the region thus far, (2.) the significant occurrence of C14 datable material underlying one outcrop, and (3.) a pre-Wisconsin age for the deposit is suggested by correlating the overlying drift with type Iowan drift in Iowa.
Plate II. Sketch map showing glacial geology and outcrop locations of iron-cemented drift in central Logan County, North Dakota.

EXPLANATION:
- Burnstad End Moraine (Flint's A-1; Lemke and Colton's Post Tz(?)-Pre Two Creeks).
- Ground moraine, low relief.
- Bedrock topography, high relief, well-integrated drainage, drift patchy.
- Outwash-meltwater channels empty into Missouri River.
- Outcrop locations of iron-cemented drift.
LOCATION, TOPOGRAPHY, AND PHYSIOGRAPHY—The iron-cemented glacial drift was found in seven outcrops in three different locations in T. 134, N., R. 71 W., and T. 72 W. (see plate II) All exposures of this drift were found in areas of bedrock topography, with a local relief of up to 150 feet. The topography is largely due to the headward erosion of the tributary streams of Beaver Creek (see map) cutting into the thick weakly-consolidated Cretaceous Fox Hills sandstones which underlie the entire area. In most places only thin patches of glacial till, gravel, or boulders remain on the divides eroded from bedrock. At the present time, the well-indurated iron-cemented drift forms resistant caps on bedrock highs. This topography, including the integrated drainage, is much older than the topography one or two miles to the east in the Beaver Lake area. In that area the poorly developed drainage, thick drift, young glacial features, and the well developed Burnstad end moraine, show that a more recent ice advance covered this area. (Flint's A-1 advance, Lemke and Colton's Post-Tazewell (?)—pre-Two Creeks drift), (see plate I).

FIELD AND LABORATORY WORK—A thorough field examination of Logan County revealed a total of seven outcrops showing the iron-cemented drifts. Tracing of this drift under younger drift in two localities was possible, but drill holes in adjacent areas of thicker drift were not available for additional study.

Lithologic descriptions and stratigraphic relations were noted in the field, and 100 lbs. of samples from the outcrops were brought back to the laboratory for examination. Twelve
thin sections were made from different samples for a microscopic study of the sediment. Stannous chloride was used to dissolve the limonite-goethite cement from the drift for residue analysis.

STRATIGRAPHY AND DETAILED DESCRIPTION OF THE IRON-CEMENTED DRIFT

MACRO DESCRIPTION—The iron-cemented drift is a clastic sediment, (probably glacial outwash), with a heavy chemically or biochemically precipitated limonite-goethite (Fe₂O₃·nH₂O) cement. It is massive to weakly stratified as most glacial gravels are, and it has numerous molds of the more soluble pebbles which have been completely leached out of the cementing material. The molds, which probably were carbonate grains, have not been filled with cementing material, but there is evidence of some early surficial replacement of the carbonate before more extensive leaching removed them. The texture is rudaceous to arenaceous with most beds being conglomeratic. The sorting is usually poor. The entire deposit has been impregnated with precipitated limonite-goethite which has cemented the glacial gravels. Laboratory tests using stannous chloride and HCl showed cementing material constituted an average of 40% by volume, and 55% by weight of the total sample. The permeability and porosity are moderate to high, and the mineral composition is extremely variable. Hand samples show various altered and decomposed metamorphic and igneous rock fragments, cherts, quartz, sands, vein quartz and Cretaceous Fox Hills bedrock.
pebbles. All carbonates, or calcareous shales such as the Pierre shale have been completely leached out leaving the hollow molds. Laboratory tests for manganese and phosphorus were positive, and are suggestive of bog ore deposition of the cementing material. The origin of this deposit will be discussed in detail later in this paper; briefly it involves deposition of the glacial drift in local depressions, solution of iron from surrounding drift and bedrock by surface and ground waters, precipitation of the iron in the swampy depressions as bog-ore. Then drainage of the depressions and leaching of the carbonates from the iron-cemented drift occurred. Using Pettijohn's (1957, p. 255) classification, this deposit could be termed a reddish-brown ferrigenous polymictic orthoconglomerate.

A typical outcrop is shown in the photo on plate III.

MICRO DESCRIPTION-Micro-photographs taken from four typical thin sections made from samples of iron-cemented drift are shown in plates IV and V. The thin sections made from the deposit in Logan County, North Dakota, were very similar to those described by Moore (1910, p. 531-2) in his studies of bog-ores in Ontario. Moore found in his examination of thin sections that the limonite was in the form of an opaque, reddish-brown mass, which was heterogeneous and had no distinguishing features beyond a porous condition. The limonite mass contained numerous angular to rounded fragments of quartz, feldspars and rock fragments. No definite axes orientation of fragments scattered throughout the limonite groundmass were noted.

Angular silt-sized grains of quartz similar to those
Plate III. Photo of iron-cemented drift outcrop area in eastern edge of NE² Sec. 23, T.13½N., R.72W., Logan County, North Dakota. Pick is 22 inches long.
mentioned by Moore, were observed "floating" in the limonite-
geothite cement, and are common in the thin sections from Logan
County; these are probably due to sheet wash or aeolian action
blowing silt into the open bog during iron deposition.

STRATIGRAPHIC POSITION AND TOPOGRAPHIC EXPRESSION

The series of stratigraphic sections shown on plate VI
show the relationships of the iron-cemented drift to the over-
lying and underlying sediments in the outcrop areas. Plate VII
shows a composite section of the entire county.

The iron-cemented drift forms a thin resistant cap on
bedrock highs where post-glacial erosion has dissected the area.
In one locality (see plate VI) the deposit is underlain by
0-3' of gray to black peaty silt, this contact is a sharp one.
(see plate VI and plate VIII) This silt has numerous carbonized
plant remains which were collected and sent to the U.S. Geological
Survey in Washington, D.C., for C14 dating. If this material
is within datable range, it will help decipher the glacial
history of the area.

The most important outcrop area is that of fig. 4, plate
VI, where Cretaceous Fox Hills bedrock is directly overlain by
the iron-cemented drift, which is in turn overlain by a gray
to light brown unleached till. The contact is sharp with no
loess, soil zone, or lag of pebbles at the contact. No other
till contacts of other ages in the area have distinctive
separating deposits either.
Plate IV. Microphotographs of thin sections of iron-cemented drift.

Fig. 1. (Top) Ordinary light, X55, silt-sized grains of quartz, chert, and rare feldspars "floating" in a groundmass of limonite. The uniform size and scattering of the grains is probably due to sheet wash or wind deposition of silt into the marsh while bog ore was forming. The black area is limonite-goethite cement.

Fig. 2. (Below) Ordinary light, X55, silt, sand, and pebblesized grains and rock fragments cemented by limonite. Large grain at left is an igneous rock fragment; the three grains in the middle and right side of the photo are chert grains. The light areas at the bottom and top right are voids. The spherical objects are bubbles, and the black area is limonite cement.
AGE OF THE IRON-CEMENTED DRIFT

The age of the entire drift sheet west of the end moraine complex known as the Altamont or Max Moraine in this area, has long been in controversy. This drift sheet is herein called the Napoleon drift in Logan County. Todd (1914), referred to it as Nebraskan or Kansan in age; Leonard (1916, p. 532), tentatively referred to the boulders lying on bedrock as Kansan(?) south of the Missouri River, but the drift just west of the Altamont Moraine looked younger to him, and the color of the tills looked more like those of Early Wisconsin. Leverett (1917, p. 114), suggested an Illinoian or Iowan age; and Alden (1932, p. 86), after studying the type Iowan in Iowa, concluded that the drift west of the Altamont in North Dakota was not older than Iowan or possibly Illinoian.

The most important reference is that of Flint (1955, p. 78), where he states that in South Dakota this drift is Iowan with some possible Tazewell drift also, based on tracing around the west side of the James Lobe from the type area in northeastern Iowa.

Continued tracing on aerial photos from the South Dakota border north through McIntosh County into Logan County (only 24 miles) shows the same drift. Lemke and Colton (1958, p. 47), assigned a Tazewell (?) age to the drift, but this assignment is not supported by field evidence in the writer's opinion. In the field, lithologic and topographic expression of the drift in Logan County, and that described from the type Iowan
Plate V. Microphotographs of thin sections of iron-cemented drift.

Fig. 1. (Top) Ordinary light, X55. Micaceous metamorphic rock fragment at top of photo with numerous rock fragments and quartz grains at the right. All are cemented together by limonite-goethite (black area). The light areas at the far left are voids.

Fig. 2. (Bottom) Ordinary light, X55. Large chert fragment in the upper right, and the many angular quartz and chert grains to the left and lower right have been cemented together by limonite-goethite (black area). The light area in the upper left corner is a void.
are very similar. On the foregoing criteria, the writer believes the Napoleon drift in Logan County is very probably Iowan in age, with some patches of pre-Napoleon drift found in a few locations underlying it. The iron-cemented drift is such a deposit. The C14 dating now in progress from the previously mentioned peaty silt bed, and another sample taken from peat in the Napoleon drift itself in northern Logan County should help prove or disprove this. If the Napoleon drift is proved to be Iowan in age, the underlying iron-cemented drift would then be pre-Iowan or pre-Wisconsin in age. The deposition of the iron and the leaching of the carbonate pebbles, then, probably took place during the Sangamon or an earlier inter-glacial age.

POSSIBLE ORIGINS OF IRON-CEMENTED DEPOSITS

GENERAL-The major part of the iron-cementing material in the deposits studied was limonite-goethite. These minerals in sedimentary rocks are most characteristic of bog iron-ores. Bog ore is composed principally of an earthy mixture of yellow to dark-brown ferric hydroxides, mainly geothite.

Lake and bog iron ores have been described from Ontario, Quebec, Sweden, Siberia, the eastern United States, and in Washington, but are especially abundant in glaciated northern regions of North America, Europe and Asia. In these areas percolating waters dissolve iron from the glacial drift with the aid of organic and carbonic acids. The iron is carried in solution as soluble carbonate, sulphate, or combined with organic acids. The iron may then be precipitated chemically or
biologically in marshes, peat bogs or other shallow surface depressions (Hurlbut, 1941, p. 206 and Harder, 1919, p. 52). Chemical precipitation takes place either by removal of the solvents by reaction by other materials in solution, or by oxidation. It is generally agreed that plants and bacteria are the chief agents in producing the chemical action in the formation of bog iron. "Iron bacteria" feed on the organic acids which have helped dissolve the iron, this forces the iron to be precipitated in the form of limonite. In other cases the bacteria or algae extract iron for their life processes and sheath formation. The limonite collects as a thin film on the surface of the water and then sinks or is collected on objects along the shore. When it becomes oxidized near the surface, insoluble limonite results (Moore, 1910, p. 532, and Gruner-1922, p. 457).

FORMS OF BOG ORE DEPOSITS-The common form of bog ore deposits found are horizontally tabular bodies a few feet thick, and red, brown or yellow in color. They are described either as soft or hard-bedded masses, concretions, or as a cement in gravels and sands which the iron-rich solutions have impregnated. The deposits studied by the writer thought to be such a porous gravel which has been impregnated by iron-rich waters, with subsequent biochemical precipitation of the limonite-goethite as a cementing material.

IRON SOURCE-The source of the iron which was deposited must have either been derived from the existing glacial drift, or the bedrock, and most probably from both due to the scarcity of drift. It is the present writer's belief that some of the iron came from
Plate VI. Sketches showing stratigraphic sections and field relationships of the iron-cemented drift in Logan County, North Dakota.
the existing drift, but most of it came from the Cretaceous Fox Hills sandstone which contains many iron-bearing minerals, and is in many places hydrostatically higher than the local depressions in which the iron-cemented drift was formed. This provided ground waters an opportunity to remove iron from the Cretaceous sands, and to carry it to depressions at lower elevations where it was precipitated as bog ore.

OTHER OCCURRENCES OF IRON-CEMENTED DRIFT IN
NORTH AND SOUTH DAKOTA

Leonard (1916), studied the occurrences of older (pre-Wisconsin?) drift west of the Altamont Moraine in North Dakota. He noted that in most areas the drift was represented almost entirely by gravel and boulders resting directly on bedrock. These gravels and boulders were especially noticeable on the tops of divides and on upland areas which they helped protect from erosion. One particularly significant deposit Leonard (p. 526-527), mentions is a boulder bed on the Missouri River near the mouth of Tobacco Garden Creek in McKinzie County, North Dakota. This glacial deposit is composed of boulders and ferruginous gravel which fills the interstices between the coarser material. The entire deposit is cemented into a firm indurated mass. It is very ferruginous and brown colored from the limonite which forms the cementing material, and in many places the boulders are firmly held by the iron-cement and sand which serve as a matrix in which the boulders are embedded. When they weather out, their shape is preserved in
The prominent Altamont Moraine is Flint's A-1 (first Mankato).

Youngest drift in the area is Flint's B-1 Streeter Moraine (second Mankato).

Napoleon drift sheet
Tz(?)
Iowan(?)

Iron-cemented drift
Peaty clay silt

Fox Hills ss.

Plate VII. Composite section showing the stratigraphic relations of all the Pleistocene deposits found in the central part of Logan County, North Dakota.
the matrix. Leonard thought that if there ever were any finer materials in this deposit, they have been carried away leaving only the gravel and boulders which were cemented by the iron of the "surface waters". He thought this boulder bed was kansas(?) in age, but had no substantial proof of this age assignment.

Leonard's description of this deposit is very similar to those which the author found in Logan County, North Dakota. Both deposits are west of the outermost, or Altamont, moraine, are similar in lithology and in having a heavy, firm limonite cement, and both are basal glacial drift deposits overlying bedrock. Probable age assignment of the iron-cemented drift of Logan County is discussed later in this paper.

Paulson (1952, p. 29), mentions a possible pre-Wisconsin drift found in drill holes under known Wisconsin-age tills in southern Stutsman County near Streeter, North Dakota. These test holes showed gravel and gravelly till overlying Cretaceous shales. These gravels were up to 91 feet thick, but were discontinuous from one hole to the next. Tan and white clays are common throughout the deposits, with some patches of red oxidized material. Most of the pebbles in the gravels were igneous and metamorphic rather than shales and carbonates which are common in Wisconsin drifts. One test well showed carbonized wood fragments suggesting a possible soil zone on top of older drift. More drill holes in the area and better sampling methods may prove or disprove this, and may also uncover deposits similar to those cropping out in Logan County.

Flint (1955, p. 30), states that pre-Wisconsin (Illinolian)
Plate VIII. Photograph of outcrop of iron-cemented drift underlain by peaty clay-silt. The sharp contact can be seen on the photo. This photo was taken facing east at the western edge of the NW¼ Sec. 24, T.134N., R.72W., in Logan County, North Dakota. (See Plate II for location)

In these outcrops the iron-cemented drift forms resistant caps on the erosional divides.
has been recognized in only a few places west of the Mississippi River. These locations are in southeastern Iowa and southeastern Minnesota. A probable Illinoian drift near Chamberlain, South Dakota, and a till of unknown age underlying Loveland loess in Moody County, are the only other possible pre-Wisconsin deposits known in South Dakota.

In regions outside South Dakota, Flint goes on to state that tills have been differentiated on a basis of weathering. Wisconsin tills are little altered, while pre-Wisconsin tills are considerably altered. Conversion of a till to a gumbotill therefore indicates the till is pre-Wisconsin. On page 31, Flint states that accumulations of red iron oxide have been found characteristically developed in soil profiles formed during the Sangamon and other interglacial ages. In accordance with this general relationship, a till altered to a reddish soil in South Dakota is considered pre-Sangamon in age with a high degree of probability.

Whether this can be used as a valid criteria to determine or even suggest a pre-Wisconsin age is at least questionable. The writer has seen reddish altered soils and outwash deposits of late Wisconsin age stained completely red with iron oxides. The age determination of the iron-cemented drift in Logan County, North Dakota, is not based on Flint's above mentioned theory, even though it is believed that this drift is pre-Wisconsin in age.

INFERENCES AND CONCLUSIONS

GENERAL - The similarities in mineralogy, topography, and possible
origin between the iron-cemented drift in Logan County and bog ore deposits reported throughout glaciated areas of North America and other parts of the world lead this writer to believe that the limonite-goethite cementing material was of the same origin. Thin sections of bog ore and the iron-cemented drift show similar relationships also.

The significance of such a deposit located stratigraphically below a till of Iowan (?) age (depending on C\(^{14}\) results), is important in the interpretation of the Pleistocene geology of North Dakota.

Tracing of the Napoleon (Iowan ?), drift of Logan County to type Iowan in Iowa, together with stratigraphic, lithologic, and topographic close similarities to type Iowan are strong evidence that the age proposal of Iowan is correct. The two C\(^{14}\) dates from this drift should help in solving the problem.

If the age of the Napoleon drift is Iowan, the iron-cemented drift under it is pre-Wisconsin, and proves North Dakota was glaciated in pre-Wisconsin time.

The possible sequence of events in the formation of the iron-cemented drift deposits in Logan County is shown and described on plate IX.
STAGE

Fig. 1. Meltwaters fill depressions far ahead of the advancing ice, forming swampy areas. The fines carried by the meltwater together with plant debris such as mosses are deposited contemporaneously in the depressions—this is the peaty clay found at present. Thin non-peaty clays and silts were deposited over the peaty clays in some areas when the ice advanced.

Fig. 2. The ice overrode the area of swampy bogs, and may have either deposited outwash gravels as it advanced by bottom scraping of the ice, or by normal meltwater deposition either during advance or retreat.

Fig. 3. The next changes in environment were: retreat of the ice and a return of local swampy conditions, and a high water table. Iron was dissolved from the drift and the Fox Hills sandstone at higher elevations, and was carried to the bogs where it was precipitated as bog ore (limonite and goethite). Precipitation was probably accomplished both chemically and biochemically.

The period of bog ore deposition was during an interglacial age, also during which the bogs were probably drained due to headward erosion of streams with lower base levels. This initiated downward moving ground waters and the ultimate complete leaching of carbonate materials in the iron-cemented glacial gravels, leaving molds of these pebbles in the cemented drift. These voids are not filled with iron-cement which shows the leaching occurred after cementation ceased due to draining of the bogs.

Fig. 4. A later readvance of the ice (Iowan(?)) left a thin deposit of drift over the leached iron-cemented drift patches.

Fig. 5. Subsequent erosion since the Iowan(?) until the present time, about 35-40,000 years, has left only the more resistant indurated iron-cemented drift capping the Cretaceous Fox Hills bedrock, with only remnants of thin easily eroded Iowan(?) drift overlying it. In this dissected area. Parts of the region immediately to the north have not been eroded as extensively, and still have the Iowan(?) drift covering bedrock in most places. No drill holes are yet available to prove the existence of additional iron-cemented drift deposits under the younger drift.
REFERENCES

(*)Those indicated are referred to in the text.


Emmons, S.F., 1913, Ore Deposits: The Institute, New York, p. 694, 695.


Plate IX. Possible sequence of events.
(see opposite page explanation)

Fig. 1. vegetation
peaty clay in local depressions
meltwater

Fig. 2. ice

Fig. 3. ice

Fig. 4. Iowan(?) drift deposit over leached iron-cemented drift

Fig. 5. resistant iron-cemented drift caps eroded bedrock highs, some remnants of Iowan(?) drift

bog ore being deposited in swampy depressions, and later draining of the bogs and leaching of carbonates

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