The Placer Gold Mining Game

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Top: Preparing to mine gold-bearing gravel in Sulphur Creek, Klondike District Yukon Canada. Below: a portable sluice retains the gold in the riffles

Overview

Welcome to this interactive computer game in which you get to make the decisions made by real placer miners. When you play the game there are instructions which provide you with various options and tell you what you can and cannot do. To give yourself the best chance at the game you have to understand something about placer gold: how it occurs, how you find out if there is any there at all and how you can recover it. The object of the game, (of course) is to make as much profit as you can. You gain cash by selling the gold that you recover, but everything that you do to find, mine and separate the gold from the gravel cost you either time, money, or both.
As far as possible we have made the game faithful to the real activity, so that you can make the same decisions and be faced with the same challenges that real placer miners encounter. However any real placer miners who have a go will quickly realize that we have had to make some simplifications to make the game workable in an educational context, (such as large claim sizes and a very understanding bank manager!)

The key elements of the game can be summarized as follows:

1. The game is set in the Yukon, the scene of the Gold Rush in 1896 and 1897. There is only a short mining season because of extreme winter temperatures- you only have 100 days a year to find, mine and recover the gold each year. The game last for 5 years during which time you explore and mine your claim. There is insufficient time to mine everything, so you have to know where to explore!
2. There are 6 game scenarios- in some it is easy to make a profit- in others it is more difficult.
3. You have to sample your claim to decide where to mine. You do this by drilling boreholes which samples the buried gravel.You have to interpret the borehole data in terms of abundance and gold size to decide what equipment to buy and what type of processing plant you need to optimize recovery.
4. The gold-bearing gravels are buried beneath permafrost. You have to strip the vegetation from the ground and let in thaw in summer before you can mine it.
5. You have to decide whether to buy new (expensive) machines- or second hand ones. Second hand machines are more likely to break down and cost you time. The less time you mine- the less gold you can get!
6. You have to plan where to put your waste to minimize the amount of gravel you move around. The more you use your machines and the older they get the more likely they are to fail.
7. When you recover gold you can sell it- or keep it. The gold price changes just as in real life-so you can take a chance on it improving- but it may not.
8. If your bank balance is in the ‘red’ you will be charged interest.
9. And finally: just as in real life it is possible to do everything right and be unlucky- or be clueless and strike it rich…..

Good Luck!
Rob Chapman and Matt Bindoff, March 2010

Background to the Game 'Gold Miner'

The following booklet tells you about placer gold and highlights principles which are important when playing the game

1. Introduction

Gold has been regarded as a valuable material from the time of the earliest human civilizations. The colour, lustre and total resistance to tarnishing suggested that it was a manifestation of the Sun on earth, and its rarity afforded its ownership only by those of high social status. The reasons for gold's attractiveness also made its collection possible. Gold does not form chemical compounds readily with other elements, (hence it does not tarnish, in the same way as metals such as copper, iron and lead) and when it occurs naturally it does so as a metal, usually alloyed with a small amount of silver. When gold – bearing mineralization is weathered, the gold particles are released and transported by the normal processes of erosion, whereas the minerals containing other metals are chemically degraded in the oxygen–rich atmosphere. Furthermore, unlike other minerals, gold is malleable, so upon transport it is not crushed into smaller fragments rather it is deformed into increasingly flatter flakes. The high density of gold means that it settles to the bottom of sediments in rivers, often accumulating in cracks at the river bed. This high density results in inertia within the sediment load and consequently the concentration of gold in a river can increase during erosion of the surrounding gold bearing rocks, as the lighter minerals are preferentially removed as river sediment. Gold occurring in this way is called 'placer gold'. In places where a river has swept away all the overlying gravel, gold nuggets may be seen in these bedrock cracks, which is probably how man first came to collect sufficient gold for the manufacture of artefacts.

At some point in history the relationship between gold in rivers and a source in the local rocks became established and thereafter the search for 'in situ' gold increasingly became the focus of gold exploration. However, placer gold remains important, both because it informs exploration for in situ gold and because it forms a resource in its own right. When Jason and the Argonauts searched for the 'Golden Fleece' they were involved in a tradition of placer gold mining that continues to this day and is an important component of the economy of many areas worldwide.

2. Gold mining, what is placer gold, how important is it economically?

Most of the gold produced today is from very large underground mines where gold-bearing rocks have been identified in sufficient quantity. During the last 100 years most of the gold in the western world has been mined in South Africa from the enormous Witwatersrand deposit which stretches several hundred kilometres through the Orange Free State and the Transvaal. Recovering gold from these ores requires a huge infrastructure, and the amount of investment to start a new mine is usually only possible when large multi national companies are involved. In contrast, the exploitation of gold from placer deposits is relatively straightforward. The gold is either at or very near to the earths surface and deep mining is not necessary. The gold has been liberated from the original host rock already, and therefore no expensive machinery is required to crush ore.

The gold has already been concentrated within sediments and is of a sufficiently large size that very simple techniques may be used to isolate it from the river gravel. The large multinational companies that mine in situ gold rarely concern themselves with placer gold, however it is a valuable resource to very small companies and individual workers. In some parts of the workers unskilled 'artisan' miners make their living from panning the gravels by hand. Elsewhere, in places such as Canada, small mechanised operations exploit the large placer deposits of the Yukon Territory and British Columbia.

Typical view of a placer mine in the Klondike district, Yukon Territory, northern Canada. The excavators, ('back hoe's') remove the old stream bed and feed the processing plant which utilises a trommel, (cylindrical rotrating screen) and a sluice to recover the gold. Cobbles too big to pass through the trammel screen are transported by conveyor to a tip, (right) and the sluice tailings flow into a settling lagoon, (off picture, bottom right).

3. Formation of gold placers

In situ gold deposits may be formed in a variety of geological environments, and geologists who work in this field require much background knowledge in areas such as ore geology, fluid chemistry and structural geology, (geological maps, cross sections and the effects of folding and faulting of rocks). The process by which placer deposits form is much easier to understand, because it is a consequence of erosional processes that occur everywhere. The requirements for a placer deposit to form are:

1. Gold mineralization in the surrounding area in which the particle size of the gold is sufficiently large to be concentrated by fluvial action.
2. Active erosion of the mineralization
3. A river system capable of preferentially transporting the less dense material.

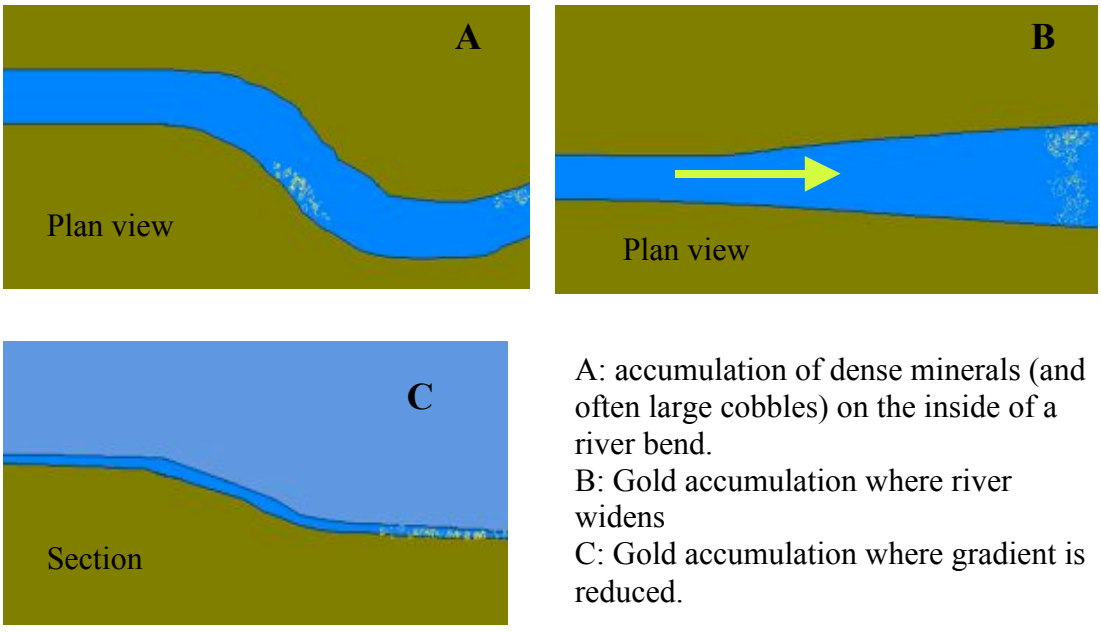
Most of the economically important placers exploited today represent a concentration of the gold from the original source into a small volume of river gravels. Very simply, the gold remains behind because of its very high specific gravity and resistance to movement in water. The larger the particle size of the gold, the more resistant to movement it is. Rivers sort sediments according to particle size- beaches at the sides of rivers tend to be formed by pebbles of a similar size- but they also sort according to the density of the material. Just as large cobbles are not present in all the river sediment, heavy minerals too are preferentially deposited in parts of the sediment load. Understanding where these spots are likely to be is the skill of the placer miners- and may make the difference between a successful placer mine and a failure. There are a few general principles which need to be understood to help us find the gold-rich gravel- (known as 'pay dirt!).

4. Placer gold and 'Pay Streaks'

Gold accumulates in sediment where the energy of the flow changes from high energy to low energy. This occurs in several places within a small river:

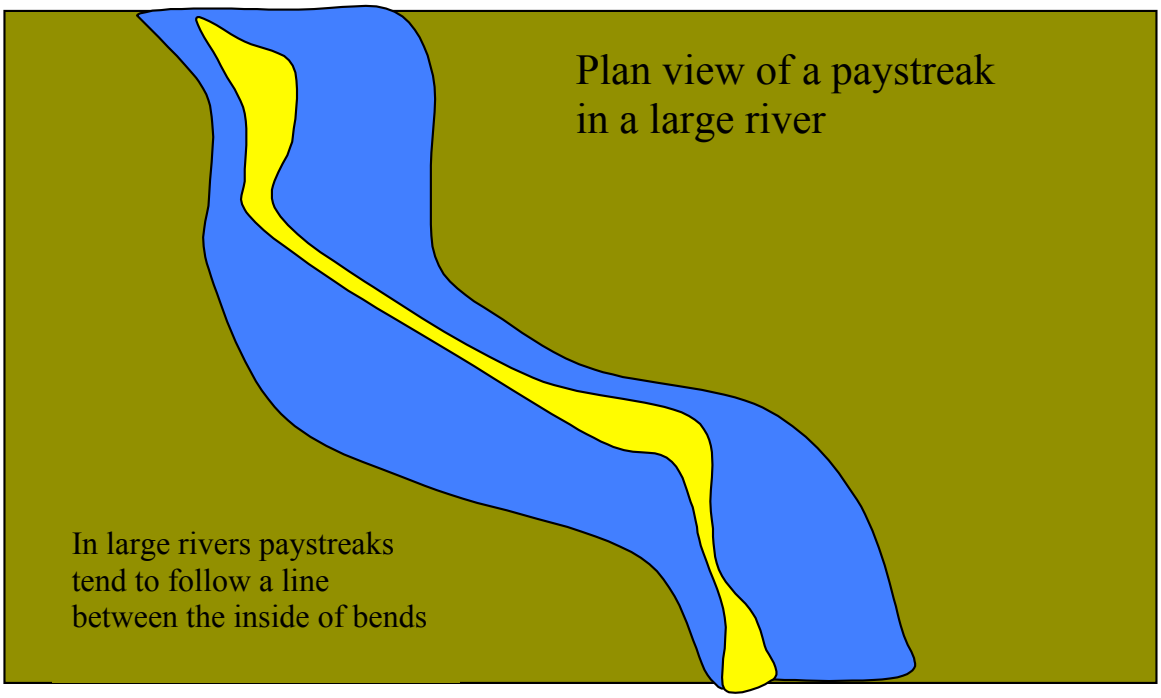
1. On the inside of bends
2. When the gradient changes from steep to shallow
3. When the river widens, so that the water speed is reduced.

Where gold accumulates in rivers



A: accumulation of dense minerals (and often large cobbles) on the inside of a river bend.
B: Gold accumulation where river widens
C: Gold accumulation where gradient is reduced.

In larger rivers the effect of these factors is usually less pronounced, and the flow is more predictable. In these cases miners look for 'pay streaks' (areas of gold rich gravel) which arise from the more regular nature of the flow. Typical shapes and positions of pay streaks are shown in the diagram below. The largest placer mines exploit these pay streaks and mine gravels selectively.

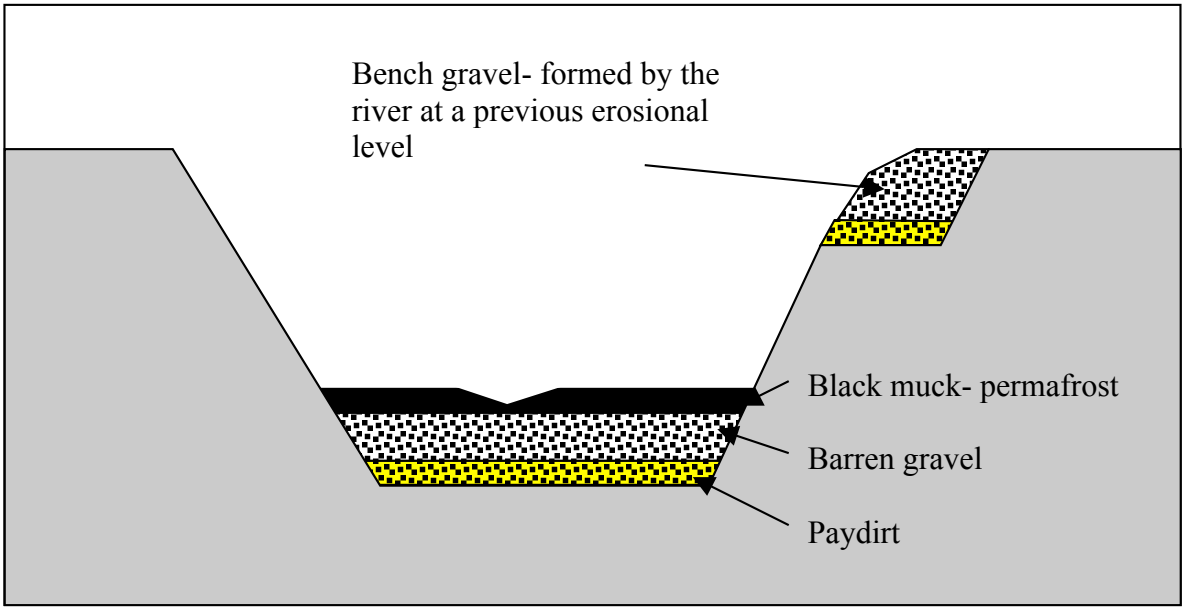


Identifying the position of gold in plan view of a river is only part of the task. The high specific gravity of gold causes it to accumulate at the base of the sediment load. This the concentration of gold in gravel within a paystreak will vary hugely with depth, reaching a maximum at the point where the gold can penetrate no further. This is at the base of the sediment, which is usually 'bedrock' . However gold can penetrate into cracks in the bedrock and miners usually tear out the top metre of bedrock to ensure they have all the gold. Miners do not try and recover gold form all the gravel in a paystreak area, because the upper gravels usually contain no gold at all. The amount of gold increases roughly exponentially with depth so that the miner has to decide when to start processing the gravel to recover gold. Processing is expensive to the trade off is between getting as much gold as possible versus the cost of processing low grade ore. (The 'grade' is a measure of concentration usually in terms of grams per ton).

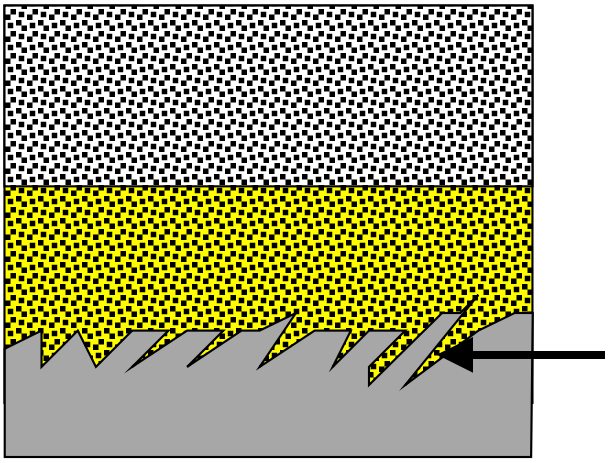
5. Mining gold placers

This 'placer mining game' is based on the placer gold deposits of northern Canada, in the Yukon. Here the mining is complicated slightly by the presence of a layer of permafrost overlying the old gold bearing gravels, (see diagram below). The permafrost is a fine black 'loess' which accumulated in the valleys by wind action before the last Ice Age.

Ice formations within black muck overlying gravels in upper Sulphur Creek, Klondike District.. Yukon Geological Survey geologist Bill LeBarge is enjoying a 10,000 year old popsicle.



Section of typical valley in the Klondike District. Some of the best areas are in old channels now many metres above the present river bed.



Detailed section through gravels and bedrock below the black muck. Gold is present to some extent in all the gravel, but the concentration is subeconomic in the upper layers. The miner must decide at what point to process the gravel. That decision determines the position of the 'overburden' and 'paydirt', but in reality the change in gold grade with depth is gradual. Gold penetrates cracks in the bedrock to a depth of about 0.5m. Where the bedrock is soft and easily excavated miners usually scrape off the top metre for processing.

Miners often find bones of the large animals which lived on the cold plains- mammoths, bison, sabre toothed tigers and short faced bears.

6. Who owns the gold?

During the nineteenth century there were several 'gold rushes' following the discovery of placer gold in areas of the new world and Australasia which had recently become accessible. Thousands of people flocked to these areas in search of their fortunes so a system was needed to give the right to mine in specific areas. The land was divided up into regular plots each of which was known as a 'claim'. Prospective miners had to register their claims and mark them on the ground using a claim post. This system is still in use today. The size of each claim is 500ft along the river and 500ft either side of this. Claims can be bought and sold, and miners keep their claims as long as they actively work on them. If claims lapse they can be acquired by others.

7. Placer mining in the Klondike

Most valleys are very wide and shallow. Despite being so far north the area has not been glaciated, and the sediments accumulated over the last several million years have not been 'scraped off'. The old, gold bearing gravels formed many thousands of years ago are below the permafrost or 'black muck' as the miners call it. In order to reach the gold- rich gravels, the black muck must be removed. Digging frozen ground is virtually impossible, so the first stage in mining is stripping the vegetation and allowing the muck to thaw during the summer. This operation must take place one year before removal of the muck and mining the gravel. Miners do not want the expense of thawing and removing the muck only to find that the gravel below is not 'pay dirt'. They must try and find the position of the pay streak within the gravel buried beneath the permafrost before they start mining. They do this by test drilling, and this process is described in the next section.

Claim posts in the Klondike may be made either from felled trees, or from stakes buried to 0.5m below ground. Each post must show specific information about the claim

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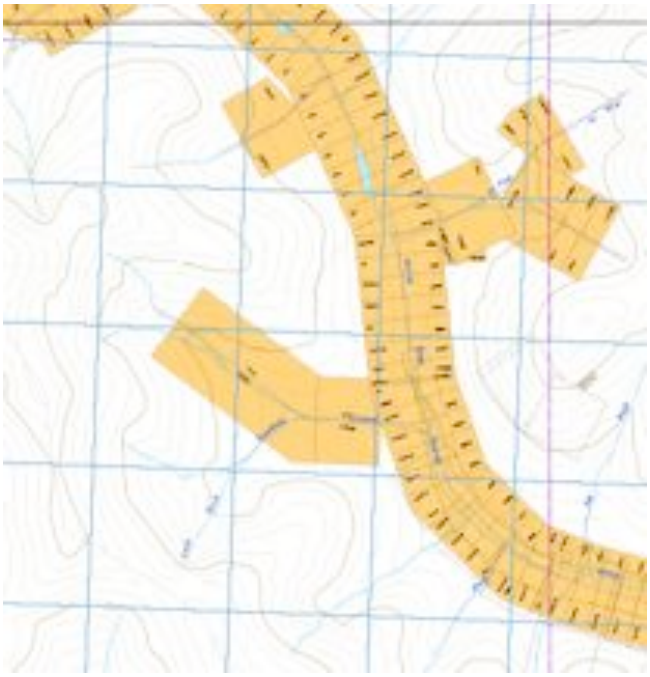


Map of part of the Klondike on the Yukon Geological Survey website, showing individual claims.

Maps show which claims are active and which have lapsed. At the time of writing (Sept 2009) very few claims are available as a consequence of the high gold price.

Mining is carried out using an assortment of machines such as bulldozers, (to move loose sediment around) 'back hoes' (large diggers/excavators) and sometimes smaller utility vehicles that have a number of applications, ('JCB' type diggers).

Tools of the trade.

Bulldozers are classified according to how much material they can shift at a time- this is a 'D11' (11 tonnes). Machines such as this can move entire hillsides in a day.

Smaller mines tend to use versatile general purpose diggers such as this for a variety of tasks. This machine can act as a small bulldozer but may also transport material to various parts of the site. This site is in upper Eldorado Creek, Klondike District

Most mines use 'back hoes' to excavate material. In this picture two are working in tandem in a large cut in lower Dominion Creek, Klondike District

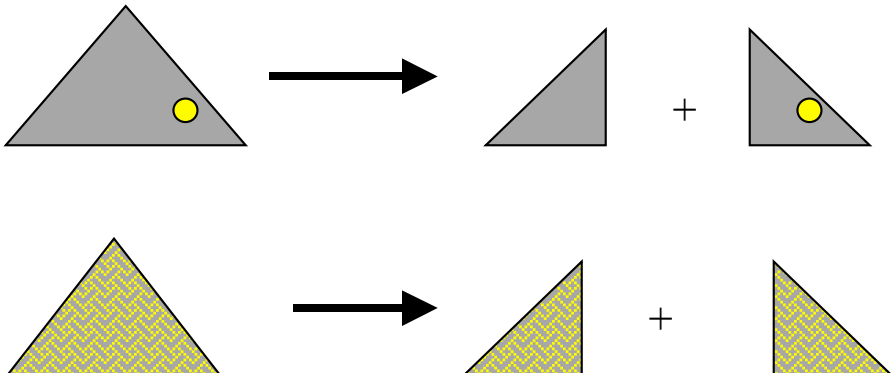
Once the muck has been removed the miner must decide how much of the gravel to process. This decision is made on the basis of the drilling results, (see next section).

8. Exploration

The success or failure of a mining venture may depend on the amount, quality and interpretation of information from drilling. Drilling produces a core of material about 15cm in diameter. The miner pans the core and gains information about the concentration of gold and how it varies with depth. The problem with this approach is that the results are not always reliable. This is particularly the case where the gold is very coarse in the

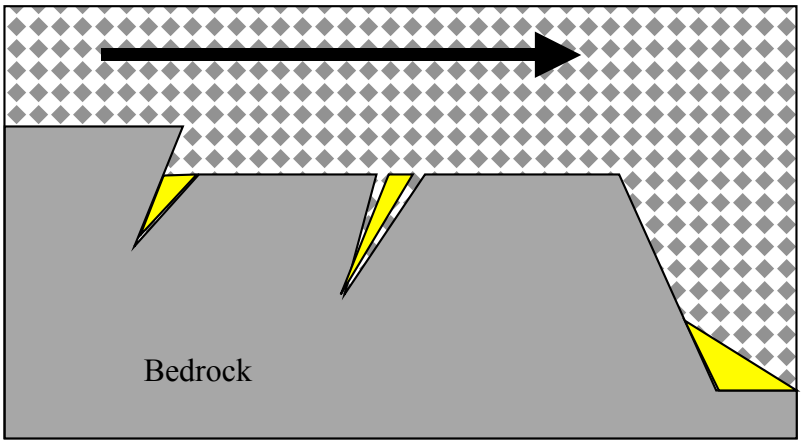
form of nuggets. The problem of accurately sampling material where there are a few large gold particles is called the 'nugget effect' and is illustrated below

The nugget effect



In the first example a single 20 g gold nugget is contained within 1 tonne of gravel. When the gravel is sampled to give two equal amounts one half contains no gold and the other 40g per tonne. Both analyses are unrepresentative of the original ore. In the second example 20g of fine gold occurs as fine dust throughout the 1 tonne of ore. When sampled, both sub samples also contain 20g per tonne. In areas of coarse gold drill cores may not be particularly indicative of the true potential of the placer.

In addition to the nugget effect there may be high variation in the gold concentration over a very short distance. Certain bedrock configurations are conducive to gold accumulation, (see fig below)



Gold accumulates in bedrock imperfections, particularly on the downstream side of obstacles.

The concentration of gold at these points is often over 100 times greater than elsewhere

In large river valleys it is unfeasible (and unprofitable to mine all the gravels. Buried paystreaks are identified by drilling, using a mobile all terrain drilling rig as shown left.

If the drill finds one of these an atypical high value would result- conversely if a flat bedrock surface is intersected the gold concentration may be lower than that present overall. To some extent this problem may be remedied by taking duplicate or triplicate samples – this provides some information on the likely variation in gold grade, but there is a limit to the number of drill holes a miner can make, (because of the time required). The only way to find out the actual value is to mine and recover all the gold to work out the true grade. Thus the best way to evaluate what to mine next is to use the results of previous mining in conjunction with drilling results. Miners try and combine all the information they have to predict the best areas for exploitation in future years.

9. Mining the gravel

Placer mining is basically an exercise in moving large amounts of gravel around. A D11 bulldozer, (which can move 11 tons at once) can create a small hill in an afternoon. However these powerful machines use a lot of fuel, and the more they are used the more likely they are to break down. Successful placer miners plan where they are going to put waste material so they don't have to move it more than once,

In large mines, bulldozers move the thawed permafrost and upper layers of gravel. The pit dug into the gold bearing gravel s called the 'cut' and is usually about 100m in length. The depth at which gravel is processed rather than dumped is decided by the results of the drill tests. Gravel is mined from the cut by a back hoe, together with the top 1 m of bedrock. All this material passes to the processing stage.

10. Recovering the gold

High gold grades are obviously very beneficial to the miner, but a good 'recovery' of the gold is required to maximise profits. Machines separate the gold from the gravel by utilising the high specific gravity (s.g) of gold, a property also exploited in the simple gold recovery technique of panning. When particles of gold and gravel of equivalent size and shape are suspended in water, they settle at different rates because of their different specific gravities. In air, gold (s.g. 18) is about six and a half times a dense as most other rock forming minerals, (e.g. quartz, s.g. 2.7) However in water that difference increases to about 10, because the s.g. of water must be taken into account ((18-1)/(2.7-1)). Settling rates are also influenced by the mass of the particle. Large lumps of rock will have a similar settling velocity as much smaller pieces of denser gold. Thus machines which utilise the high s.g. of gold to recover it first remove the larger cobbles and pebbles. This process is called 'screening'. In simple operations only one screening stage is employed, but more sophisticated processing may use two, to ensure that gold recovery is not adversely affected by the presence of larger pebbles.

All the key elements of mining are illustrated in this photograph of a large mine on the lower Indian River, Yukon. Key to activities:

1. *Removal of forest and thawing*
2. *stripping black muck to use in final restoration*
3. *Stripping overburden*
4. *Mining paydirt*
5. *processing plant discharging into settling pond*
6. *Restored area*

When the particle size of gold is over 1mm and the shape of the gold is round, little problems are encountered in separation. However as the gold particle size becomes finer than 0.5mm, they become increasingly difficult to recover. If a simple processing circuit is used for fine gold, much is lost to the waste, (tailings) so a carefully designed system must be used to ensure that the maximum amount is recovered. Another problem facing miners who have fine gold is that if the gold is far-travelled it may be flat, and this exaggerated shape can hinder recovery. You can do a simple experiment with two pieces of A4 paper to illustrate this- if one is rolled into a ball and the other left as a sheet, the rate of falling through air is far slower for the paper sheet, even though both objects are the same mass. Fine flaky gold is particularly difficult to recover efficiently and good recoveries can only be obtained using a carefully designed and expensive recovery system. When starting a new mine it is important to know about the nature of the gold because this will inform the choice of processing plant. If the gold is coarse, (> 1mm) and chunky a simple cheap processing plant will suffice. But if the gold is fine and flaky, multiple screening is required before the separation.stage. This information is available from the drilling carried out in the exploration phase.

11. Machines which recover gold.

In northern Canada gold is recovered from the gravels almost exclusively using a device called a sluice. A sluice is an artificial channel into which the gold –bearing gravel is flushed. There is sufficient water flow to wash away all the largest pebbles remaining after screening, and the gold settles to the base of the flow, where it is trapped behind slats known as 'riffles' . The technology is exactly that used several thousand years ago in the Middle East , where short cropped animal fleeces were pinned to the bottom of the

Examples of placer gold morphology.

Gold close to the original source of ten inherits many feature of the original gold particle- e.g shape, surface texture.

On transport in a river, the gold becomes beaten and flattened. Gold of this shape is much more difficult to recover by gravity separation than the chunky particles shown above.

water race. The fibres trapped the heavy gold which was subsequently recovered either by washing, or burning the fleece.

The trommel is a cylinder with various hole sizes punched into the plate. The material which passes through the holes is collected in the trough, and then passes to a sluice.

The photographs below show extremes of sluice box operation. The first shows a short sluice, overfed with water. The flow is turbulent, and under these conditions only coarse gold will settle out. The second sluice exhibits an ordered even flow, which allows even fine gold to become trapped in the sluice bed.

A comparison of sluice operation.

The sluice left is running very fast and the flow is turbulent. Only coarse gold will be collected here. The rig below is optimised for fine gold. There are two stages of screening and the feed rate flow is adjusted to give laminar flow along the sluices.

Gold is not the only material caught by the sluice. Other minerals are present which have a high s.g relative to most rocks, but which are not as heavy as gold. These minerals are usually a mixture of iron oxides, (haematite and magnetite) sometimes with ilmenite, (iron titaniuim oxide) or cassiterite, (tin oxide). If present in large amounts these 'black sands' can impact severely on gold recovery because they inhibit the settling of the gold grains, particularly if these are flaky. In areas where black sand is abundant, the sluice must be cleaned more regularly, because gold cannot penetrate the beds of black sand which accumulate behind the riffles.

The contents of the sluice are emptied periodically in an operation called 'clean up'. Here the gold is separated from the black sands. In small operations this is often done by hand panning, but other small machines are available, (although not all work very well!).

12. Environmental protection

The large scale of placer operations impacts on the local environment. Placer mining activity is regulated both during and after active mining.

River gravels contain varying amounts of very fine sand and clays. The process of mining and sluicing generates a lot of very muddy water, which if allowed to enter the main river would quickly eradicate all aquatic life. Consequently miners have to build settling ponds on their property to ensure that the quality of the water leaving the claim is the same as that entering it. Water quality is checked periodically by environmental officers who have the power to close operations if they do not fulfil this criterion.

A large placer operation on lower Dominion Creek, Klondike District. Mined out areas are used to accept fresh tailings and to act as settling ponds. A methodical approach to mining is required to successfully mine these low- grade high volume placers.

Narrow valleys utilise mined out areas downstream as settling ponds

Settling ponds are simply enclosed areas in which fine sediment can settle from suspension. It is often necessary to have two or more settling ponds is gravels contain a lot of clay, or a lot of black muck has been eroded. The construction of settling ponds is a fairly straightforward task, but their position has to be such that the sluice tailings enter directly into the top pond. This means that planning the location of the plant is important, and this is often a trade off against the cost of transport of pay dirt from the cut.

In the past, once a mine was finished it was simply abandoned. Now, placer miners have a duty to remediate their property, i.e. to restore it to a state which can support an ecosystem. This involves returning the site to one where revegetation is possible by ensuring that the black muck, (stripped off in the first phase of mining) is returned to the surface. In addition the course of the river must be stabilized to prevent future erosion of the soft unconsolidated material left by mining. If the river banks are not armoured by boulders, the large influx of sediments into the river is highly detrimental to aquatic life.

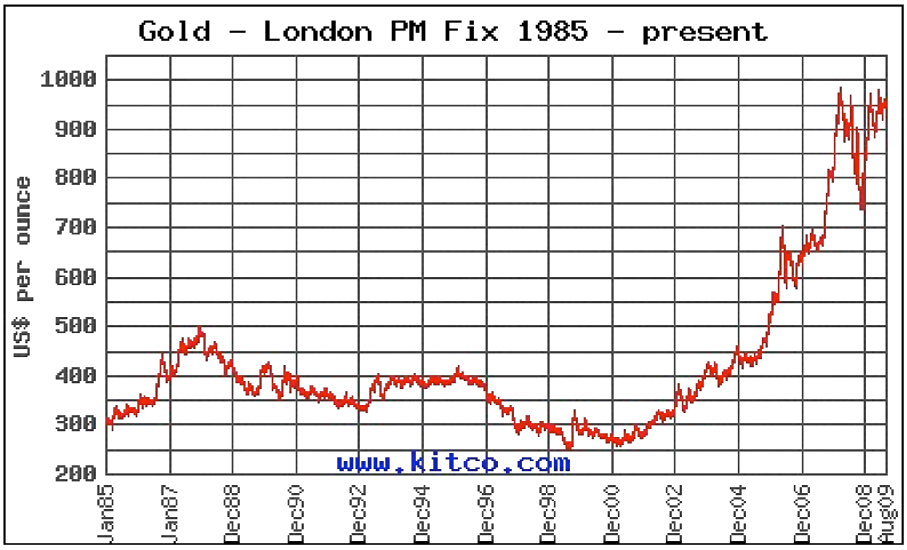
Selling the gold

Placer miners sell their gold to a local government agent. Gold from different areas contains different amounts of silver, and so all ‘raw’ gold not worth the same. When a miner submits gold for sale he or she receives 75% of the gold price for the raw gold

mass submitted. The silver content of the gold is then determined and the miner receives the balance, (less commission) at a later date.

13. How much is gold worth?

The gold price is determined by the world financial markets and is influenced by many factors. In general the more uncertain the international political situation the higher the gold price. The plot below shows that the gold price has varied by about a factor of 3 over the last 10 years. At the time of writing it is relatively high, which has stimulated all forms of gold exploration and gold mining activity. One problem facing gold miners is that it is difficult to predict the price of gold later in the year. In some cases a fall in the gold price can result in serious financial problems for the miner.



14. Further information

Very detailed information about placer mining may be found at the websites of the Yukon and British Columbia Geological Surveys:

www.**geology**.gov.yk.ca/

www.em.gov.**bc**.ca/**geology**/

15. And Finally……

Keeping gold safe in the Yukon…..

Where mines are situated in remote localities security is not an issue. Here are some 'storage solutions' for rather large amounts of gold…

Acknowledgements

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