GOLD MINERALISATION MODELS AND THEIR USE IN THE PROCESSING OF GOLD ORES

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ABSTRACT

Gold occurs in association with a variety of minerals in rocks of different geological ages. Many years of efforts by exploration geologists have culminated in the development of mineralisation models for epithermal gold deposits. The models can be used by metallurgists in the prediction of extraction processes for epithermal gold ores. The use of the models can be extended to other gold deposits found in different geological environments. This paper examines gold mineralisation models for some of the major primary gold deposits in Precambrian, Palaeozoic and Mesozoic terrains and the probable extraction processes for treating these gold deposits described as 'gold only' deposits.

INTRODUCTION

Gold occurs in all rock types of geological ages. Examination of gold deposits of different geological ages shows a general increase in silver value of native gold and increase in base metal values in gold ores from Archaean to Cenozoic deposits. Recent mineralisation models developed by exploration geologists for epithermal gold deposits can be extended to gold deposits of other geological ages. The models can be used also by metallurgists to predict and design extraction processes for gold deposits found in the Archaean through to Cenozoic terrain. This paper focuses on the mineralisation models and the most probable extraction processes for the treatment of the major primary gold deposits found in Precambrian, Palaeozoic and Mesozoic environments.

Gold mineralogy and fineness

To understand gold mineralisation styles, it may be useful to review gold mineralogy and the host minerals of gold since most of the elements constitution gold compounds and the host minerals are closely related. Of the gold-bearing minerals, the commonest and most important are those of the composition (Au,Ag) where Au is greater than 50 per cent. In some deposits, however, the Ag content is greater than Au. The next important gold compounds are tellurides.

Gold fineness is defined for simplicity as [Au/(Au+Ag)]1000 and varies considerably. The cause of variation of gold fineness may be attributed to many factors such as pressure, temperature, depth of gold formation (Fisher, 1950, Antweiler and Campbell, 1977), paragenesis, mode of formation, composition of mineralisation fluid, metamorphism and epimineralisation events (Morrison et al., 1991).

The following deductions can be made on careful examination of gold-bearing minerals: (1) that the commonest Au-bearing minerals are Au-Ag alloys containing Cu (in trace amounts) of Group IIb of the Periodic Table of the elements; (2) that the second important group of elements forming metallic compounds with gold is the platinum group of metals (PGM) belonging to Group VIII. These metals have higher melting and boiling points than that of gold; (3) that the elements that form intermetallic compounds and other complexes with gold belong to the representative elements of Group IVA to VIA. The notable elements of these groups are Ti, Pb, Sb, Bi, S, Se and Te whose melting and boiling points are lower than that of Au.

In extracting gold from its ores, therefore, it is essential to consider not only the gold but also the other elements that make up the gold-bearing minerals, as well as the host minerals of the gold. These elements and their minerals take part in the extraction reactions and some of the elements e.g. Ag, Cu, Zn, Pb, Hg, Sb, As, Bi, PGM, remain as impurities to varying degrees in the gold bullions produced.

Host minerals of native gold

Host minerals of gold can be divided into two - the rock-forming minerals and ore minerals.
Rock-forming minerals as hosts for gold: - The common rock-forming minerals acting as host minerals for native gold are quartz, carbonates (calcite, ankerite, manganocalcite, dolomite), chlorite, sericite, graphite, carbonaceous matter and tourmaline. Those having occasional association with gold include amphiboles, apatite, feldspar, garnet, kaolinite, mica and talc (Schwartz, 1944). Gold may also occur in association with gypsum, fluorite, alunite, pyroxene, serpentine and wollastonite.

Gold occurs in all types of igneous rocks from the ultramafics to the felsics and as a result may be found in association with any of the minerals constituting these rocks. In metamorphosed environments, gold is usually associated with chlorite, sericite, talc and mica. In sedimentary environments, gold is often associated with the resistant minerals such as quartz, mica, zircon and iron oxides (hematite and magnetite).

Ore minerals as hosts for gold: - Although minor in relation to the rock-forming minerals, ore minerals tend to host a substantial amount of gold in many gold deposits. Ore minerals that commonly host gold are pyrite, pyrrhotite, arsenopyrite, chalcopyrite, galena, sphalerite and sulfosalts. Pyrite, arsenopyrite, pyrrhotite and copper sulphide minerals form the commonest host ore minerals of gold. Some of the elements constituting these ore minerals form alloys with gold.

Gold may associate with these minerals in a variety of ways. It may occur physically within the minerals in coarse to submicroscopic sizes and chemically as gold compounds and in solid-solutions. Some of the gold may also occur in fractures, along cleavages and at mineral grain boundaries. Fine gold encapsulated in ore minerals and/or present in solid-solutions presents the greatest problems in liberation and extraction.

Simple (non-refractory) and refractory gold ores

Simple gold ores are those that respond readily to direct cyanidation producing gold recovery in excess of 90 per cent. Refractory gold ores, on the contrary, are difficult to treat and on direct cyanidation produce gold recovery of less than 90 per cent. There are various degrees of refractoriness of gold ores classified by Vaughan (1989) as mildly (80-95% recovery), moderately (50-80% recovery) and highly (0-50% recovery) refractory. The refractoriness of gold ores may be due to one or a combination of the following: (1) formation of chemical bonding of gold with other elements to form gold compounds; (2) solid-solution of gold in pyrite and arsenopyrite; (3) fine to submicroscopic gold locked within sulphide minerals, silicates, silica and oxides; and (4) ores containing preg-robbing materials e.g. carbonaceous material, clay and cyanide and oxygen consuming minerals such as pyrrhotite, chalcostite, covellite, arsenic and antimony sulphides.

PRECAMBRIAN GOLD MINERALISATION TYPES

In this discussion the ancient placer deposits including the giant Archaean placers of Witwatersrand and Pongola in South Africa, Jacobina and Moeda in Brazil and Tarkwa in Ghana will not be considered. The discussion will focus on Au-quartz vein deposits and iron formation-hosted gold deposits of the Archaean and Proterozoic greenstone terrains.

Au - quartz vein deposits

Important world deposits of this type are found in the Archaean greenstone terrains of Canada (Abitibi greenstone and Hemlo amphibolite facies), South Africa (Barberton greenstone), Zimbabwe (greenstone and granulite facies domains), India (amphibolite facies at Kolar), and Western Australia (greenstone and amphibolite facies at Yilgara and Murchison). The deposits are predominantly lode type gold deposits having high grades ranging from 2 to 50 g/t Au and 200 g/t Au, locally. The gold content may vary from 1 to 1500 tonnes. These deposits are described as 'gold-only' deposits (Hodgson and MacGeetham, 1982) because of their extreme Au enrichment relative to other metallic elements such as Ag, Cu, Zn and Pb that are also commonly present in the ores. Exceptions to the above include the deposits of Noranda (producing Cu, Au, Ag), Machnulty (Au, Ag and Cu) and Hollinger (Ag, Au and scheelite). The characteristics of some of the Archaean Au-quartz type deposits are shown in Table 1.

Gold in this type of ores may occur as native gold (>80% Au) and/or electrum in quartz - carbonate veins carrying commonly pyrite, arsenopyrite, pyrrhotite and minor to trace amounts of scheelite, tellurides, stibnite, galena, sphalerite, chalcopyrite, hematite, magnetite and anhydrite which may be locally abundant in specific ores shoots. Most of the gold is found in milky and fractured quartz, pyrite, pyrrhotite and arsenopyrite. Where a high proportion of the fine gold is locked within pyrite and arsenopyrite the ore is rendered refractory.

A suite of immobile elements (e.g. Al, Ti, V, Y
Zr) and relatively immobile elements such as Fe, Mg, Cr, Ni, Sc may be present in the wallrock alteration. The strongly mineralised zone in the sub-amphibolite facies grade may develop quartz-carbonate veining and silicification containing minerals such as ankerite, biotite or sericite, albite, rare green mica containing V or Cr, phlogopite, calcite, tourmaline and graphite locally abundant (Foster, 1991).

The Archaean native gold shows characteristic association with Ag, As, Sb, B, Te and W, with generally low contents of base metals and Mo (Kerrech, 1983; Phillips and Grove, 1983). The Au:Ag ratios of the native gold are usually around 10:1.

Mineralisation types of the Archaean Au-quartz vein deposits

The mineralisation of the Au-quartz vein deposits may be categorised into two:

1. Au - quartz ± carbonates, with trace amounts of base metal sulphides

Probable extraction processes

Cyanidation is the extraction process considered in this text although other extraction processes of limited industrial application are available (Afenya, 1999).

1. Au - quartz carbonates, with minor base metal sulphides

Gold in this type of mineralisation is predominantly associated with quartz and to less extent carbonates. Most of the remaining rock-forming minerals usually have well defined cleavages and are brittle and therefore do not present gold liberation problems. Mineralisation of this type is responsible for non-refractory ores that may be treated as follows: comminution ± gravity separation + cyanidation with CIP + elution + Zn dust precipitation or electrowinning (Table 2).

Gravity separation has been commonly used to remove coarse gold prior to fine grinding and cyanidation (agitation leaching). Depending on the porosity of the ore and ease of gold cyanidation, heap leaching may be pursued. The most popular practice employed now after cyanidation is the use of carbon-in-pulp (CIP) to adsorb the aurous cyanide from lime adjusted pulp (pH 10-12). The loaded carbon is separated from the pulp by screening and acid (dilute HCl) washed if necessary and the aurous cyanide stripped from the carbon by caustic cyanide solution (pH 11-12.5) at high temperature and pressure. The Anglo-American Research Laboratory (AARL) and Zadra elution styles are used for elution by many processing plants. The gold is then recovered from the pregnant eluate by either zinc dust precipitation or electrowinning. The product is smelted and cast into gold bullions.

2. Au - quartz ± carbonates - pyrite- arsenopyrite, with minor Cu, Zn, Pb sulphides

Most of the gold in this type of mineralisation occurs in quartz, pyrite, arsenopyrite and pyrrhotite but it is gold locked within pyrite and arsenopyrite that renders the ore refractory. Where pyrite paragenetically precedes both arsenopyrite and gold mineralisation, some of the gold may be found in fractured pyrite making gold liberation from the pyrite easier than from the arsenopyrite. If the gold occurs partly in solidsolution with pyrite and arsenopyrite then even fine grinding would not liberate the gold. Under such a condition it would be necessary to modify or break down the sulphides in order to liberate the gold. Few Precambrian gold deposits for instance, Ashanti Goldfields (Proterozoic age) in Ghana and Maria Preta in Brazil, contain in addition preg-robbing carbonaceous materials. Thus the chief pernicious minerals to watch in the extraction of gold from this type of mineralisation are pyrite, arsenopyrite, pyrrhotite and carbonaceous material.

Prior to the 1970s the technology available for treating these refractory gold ores was roasting which oxidises the sulphide minerals and destroys the carbonaceous matter. The treatment processes in use then were the usual comminution, gravity separation followed by flotation of the remaining gold and the sulphide minerals and simultaneous depression of the carbonaceous material. The flotation concentrate containing essentially gold, pyrite, arsenopyrite, pyrrhotite and some of the carbonaceous material is roasted and finally cyanided. Owing to stringent environmental regulations and the availability of new technologies, one or a combination of the following treatment options (1) comminution + gravity concentration + flotation + roasting (SO2 and As2O3 gas scrubbing) + cyanidation with CIP; (2) comminution ± gravity concentration + flotation + bio-oxidation + cyanidation with carbon-in-leach (CIL); (3)
comminution \pm gravity concentration + flotation + pressure oxidation + cyanidation with CIL or CIP (Table 2) may be employed.

For circuit (1), roasting is employed only if it is absolutely necessary. It is then mandatory to scrub the flue gases produced. The roasted product is cyanidated and CIP and carbon stripping are used instead of the old techniques of filtration and de-aeration prior to gold recovery. Regarding circuit (2), bio-oxidation is used if greater proportion of the sulphide gold is locked within pyrrhotite and arsenopyrite, minerals having fast bio-oxidation rates. Since bio-oxidation may not adequately render the carbonaceous material (if present) passive, it is prudent to use CIL during cyanidation. For circuit (3), pressure oxidation (a more rigorous process) is employed if most of the gold is locked within crystallised pyrite since pyrite has slow bio-oxidation rate. If preg-robbing carbonaceous material is present in the ore, pressure oxidation may not adequately deactivate it and therefore CIL may be used.

Where the Archaean gold ores have undergone oxidation the gold may be adequately liberated and so rendering the ore non-refractory. Under such conditions the gold may be treated by heap leaching or gravity concentration followed by cyanidation or direct cyanidation (using agitation leaching) with CIP. The gold can be recovered from solution by Zn dust precipitation or electrowinning.

Banded Iron formation-hosted gold deposits

This type of deposits occurs in the Archaean and Proterozoic terrains. Classic examples of this type of deposits are the Proterozoic deposits of Homestake at Lead, South Dakota, USA; the Archaean deposits of Merro Velho (Brazil) and Lupin (northwest Canada). Other deposits of this type are the gold deposits of Carshaw, Walga and Geraldton in Ontario, the Water Tank Hill and Nevoria in Western Australia, Vubachikwe in Zimbabwe and Barberton in South Africa. The deposits occur in stratabound, metamorphic and intensely folded environments and exhibit lenticular shapes parallel to the steep plunge of the folds. The mineralisation is associated with banded iron formation (BIF) containing hematite, Ca-Mg-Fe carbonates, quartz sandwiching the platy silicate minerals and the sulphide minerals - arsenopyrite, pyrrhotite and pyrite which carry the gold. The sulphides may be massive in some areas. Since a substantial proportion of the gold is locked within the iron sulphide minerals, the ores are normally refractory. The mineralisation may be described as Au - quartz - carbonate - arsenopyrite - pyrrhotite - pyrite in BIF.

Extraction processes of gold in the BIF

Au - quartz - carbonates - arsenopyrite - pyrrhotite - pyrite, with minor base metals.

Gold in this mineralisation type is found in iron sulphides including arsenopyrite, sandwiched between hematite and carbonates with sulphides aligning parallel to the foliation of the ore. It is believed that the gold is syn- or epi-genetic and so it is possible for some of the gold to occur in the hematite/magnetite and carbonates. On grinding the ore, the gold and iron sulphides associated with the carbonates and the platy silicates (micas, sericite) are readily liberated. But gold locked within the hematite and magnetite may be more difficult to liberate. It is likely that this type of ore may cause differential grinding problems. After grinding, the ore is floated to produce iron sulphide concentrates containing gold; the flotation concentrate may be roasted or pressure leached and the pulp which is usually acidic is neutralised with lime and cyanided with CIP or CIL. Stripping is employed to produce a pregnant eluate from which the gold is recovered as described earlier (Table 2).

MINERALOGY OF PHANEROZOIC GOLD DEPOSITS

Mineralogy of mesothermal deposits (Paleozoic and Mesozoic)

Here the term “mesothermal” deposits covers Phanerozoic deposits previously classified as turbidite-hosted, greenstone-hosted, metamorphic vein and mesothermal vein deposits by adopting Nesbitt’s (1991) broad classification. The mineralogy of the mesothermal deposits considered here includes Meguma Group deposits and Chetwynd deposits of Canada, Southern Appalachians and the Mother Iode system of USA, Ballarat and Bendigo deposits of Australia, South Island of New Zealand, Jia Pi Guo districts deposits of China and deposits of Urals in Russia.

Phanerozoic mesothermal deposits are found in accreted, deformed and metamorphosed (typically sub-upper-greenschist facies) continental margin or island arc terrains. The deposits generally range from several thousand to a few million tonnes of ore with ore grades typically between 5 and 25 g/t Au. Similar to the Archaean deposits, the mineralisation types of mesothermal deposits are structurally controlled and occur in quartz veins often exhibiting banding, vuggy
texture and vertical mineral zonation (Nesbitt, 1991) and occasionally occur in stockworks and are disseminated.

The early phase mineralisation consists of quartz, Ca-Mg-Fe carbonates (calcite, dolomite, ankerite and siderite), arsenopyrite, pyrite, albite, sericite and chlorite with scheelite, stibnite, pyrrhotite, tetrahedrite, chalcopyrite, tourmaline and graphite. The paragenesis of the late mineralisation phase is often gold, galena, sphalerite, and tellurides.

These deposits display vertical elemental zoning involving the elements, Au, Ag, Sb, As, W, Hg, Bi, Mo, Pb, Zn, Cu and Ba. The zonation from high to low temperature is as follows: Au ± Ag, As, Mo, W to Sb ± Au, Hg, W to Hg ± Sb.

The Au:Ag ratios of mesothermal gold are greater than 1. Considerable electron microprobe data for gold from hypo/mesothermal vein-type and hypo/mesothermal polymetallic vein-type deposits in Japan show Au:Ag ratios in the range of 30.8 - 3.1 and 7.9 - 1.1, respectively (Shikazon & Shimuzu, 1988). These authors observed that gold of the hypo/mesothermal vein-type deposits is Ag-rich if the ore is sulphide-rich but it is Au-rich if the ore is sulphide-poor. It was also observed that Bi, Te and Cu minerals are associated with Au-rich electrum, whereas Pb, Zn, Ag, S and Se minerals are associated with Ag-rich electrum. Pyrrhotite and arsenopyrite tend to coexist with Au-rich electrum but pyrite coexists with Ag-rich electrum. Thus gold of mesothermal deposits that mineralises during the late phase with galena and sphalerite may contain higher silver values than the Archaean gold deposits. It should be expected that the base metal contents of mesothermal deposits be marginally higher than the base metals levels in Archaean gold deposits.

Extraction processes for mesothermal deposits (Table 2)
The mineralisation of the mesothermal gold deposits may be classified as follows:

1. Au - quartz ± carbonates, with minor base metal sulphides,
2. Au - quartz ± carbonates - pyrite - arsenopyrite, with minor base metal sulphides;
3. Au - quartz ± carbonates - Pb - Zn sulphides.

Accepting the general paragenesis presented by Nesbitt (1991) that gold, galena and sphalerite were syngenetic and crystallised together with later quartz and carbonates, then Au, galena and sphalerite would be found in fractures of pyrite, arsenopyrite and early carbonates and quartz. It is therefore most probable that gold in mesothermal deposits may be easy to liberate.

Mineralisation type (1) may be found in mesothermal deposits where base metal contents are low. For ores of this kind, the treatment circuit that may be used is: comminution ± gravity concentration + cyanidation with CIP.

Mineralisation type (2) is likely to be found at greater depth where the sulphide minerals have not undergone any significant oxidation. Because the gold is likely to occur in fractures of pyrite and arsenopyrite it is expected that the gold may be quite easy to liberate. Under these conditions the ore may be treated as type (1). If, however, a significant proportion of the gold is locked within pyrite and arsenopyrite then the ore is refractory. A suitable refractory treatment circuit for this type of ore described earlier may be used.

Mineralisation type (3) although containing galena and sphalerite will be treated as a non-refractory ore since Pb and Zn sulphides are brittle and any gold associated with them may be readily liberated on grinding. A simple treatment circuit containing comminution, ± gravity concentration ± amalgamation + cyanidation may be used.

Graphite may also be present in some of the mesothermal deposits but this would not lead to any significant adsorption of aurous cyanide since graphite has small specific surface area.

In summary therefore, mesothermal deposits are similar to Au-quartz vein deposits of the Archaean gold deposits and are processed as 'gold only' deposits.

CONCLUDING REMARKS
1. The commonest element that naturally alloys with gold is silver, followed by Te, Cu and the platinum group elements. The silver content of gold present in Archaean deposits is very low; the silver values of mesothermal native gold of Paleozoic and Mesozoic terrains appear to be of similar or marginally higher values than the Archaean.
2. Gold mineralisation types in the Precambrian and mesothermal (mainly of Paleozoic and Mesozoic) deposits are quite similar and appear to fall into two general categories:
   (i) Au - quartz ± carbonates, with trace to minor Cu, Zn and Pb sulphides,
(ii) Au - quartz ± carbonates - pyrite - arsenopyrite ± pyrrhotite, with minor Cu, Zn, Pb sulphides ± carbonaceous matter.

Mineralisation type (i) is responsible for non-refractory ores for which the common treatment processes are: comminution ± gravity separation + cyanidation with CIP and elution + Zn dust precipitation or electrowinning. Mineralisation type (ii) normally gives rise to refractory ores for which the treatment processes are as follows: comminution ± gravity separation + flotation ± roasting ± bio-oxidation ± pressure oxidation + cyanidation with CIP/CIL and elution + Zn dust precipitation or electrowinning.

ACKNOWLEDGEMENT

The assistance given by the Mining Engineering Department, PNG University of Technology, Lae in preparing this paper is gratefully acknowledged.

REFERENCE


Table 1a: Mineralisation of some selected large to giant Archaean lode gold deposits from greenschist facies domains (Grove, D. I. and Foster, R. P., 1991).

<table>
<thead>
<tr>
<th>Deposit (in Greenschist facies domain)</th>
<th>Host Rock</th>
<th>Mineralisation types in lodes</th>
<th>Alteration minerals in the ore zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Abitibi, Canada Holinger, Timmins &gt; 600 t Au</td>
<td>Mafic flows; minor felsic flows and pyroclastics; quartz-feldspar porphyries</td>
<td>Quartz veins hosting Au + pyrite + pyrrhotite ± Pb ± Zn sulphides.</td>
<td>Sericite + ankerite ± chlorite ± calcite; quartz and albite.</td>
</tr>
<tr>
<td>2. Kerr Addison, Larder Lake, Canada &gt; 320 t</td>
<td>Mg-high basalts, tholeiitic basalts, felsic porphyry to syenite dykes, clastic sediments</td>
<td>Stockworks ladder veins containing Au + quartz ± carbonate + pyrite + scheelite + arsenopyrite</td>
<td>Ankerite + albite + muscovite</td>
</tr>
<tr>
<td>3. Zimbabwe: Cam and Motor, Kadoma</td>
<td>Tholeiitic basalt/andesite, Mg-high basalts, dolerite intrusion, minor clastic sediments</td>
<td>Quartz veins and stockworks containing Au + pyrite + arsenopyrite + stibnite ± sphalerite ± scheelite</td>
<td>Quartz + ankerite; serpentine in high-Mg rocks</td>
</tr>
<tr>
<td>4. Phoenix, Kwekwe</td>
<td>Dunite - peridotite intrusive complex</td>
<td>Quartz veins; minor stockworks and silification containing Au + pyrite + arsenopyrite ± Cu, Pb, Zn sulphides ± scheelite ± tetrabedrite</td>
<td>Magnesite ± fuchsite ± talc</td>
</tr>
<tr>
<td>5. Yilgarn, Australia Golden Mile, Kalgoorlie</td>
<td>Tholeiitic dolerite sill</td>
<td>Quartz veins carrying Au + pyrite + scheelite, arsenopyrite and anhydrite; late tellurides</td>
<td>Muscovite + ankerite + pyrite, silification + quartz veining</td>
</tr>
<tr>
<td>6. Sons of Gwalia, Leonora</td>
<td>Tholeiitic to high Mg basalts</td>
<td>Quartz veins containing Au + pyrite + arsenopyrite ± pyrrhotite; minor chalcopyrite</td>
<td>Muscovite + biotite + ankerite + pyrite; quartz veining</td>
</tr>
</tbody>
</table>

Table 1b: Mineralisation of some selected large to giant Archaean lode gold deposits from greenschist facies domains (Grove, D. I. and Foster, R. P., 1991).

<table>
<thead>
<tr>
<th>Deposit (in Amphibolite and Granulite facies)</th>
<th>Host rock</th>
<th>Mineralisation type</th>
<th>Alteration in ore zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Hemlo, Canada &gt; 300 t Au</td>
<td>Probable andesitic to rhyolitic volcanies or pyroclastics” some clastic sediments</td>
<td>Au + pyrite + molybdenite ± sphalerite ± arsenopyrite ± stibnite; a large variety of minor, Pb-, Cu-, Sb-, Hg-, Tl-, and Te-bearing phases in quartz veins</td>
<td>Quartz + muscovite (some V-rich) ± biotite</td>
</tr>
<tr>
<td>2. Giant, Yellow nife, Canada &gt; 177 t Au</td>
<td>Pillowed and massive lava</td>
<td>Au ± pyrite + stibnite + sulphasalt + sphalerite + galena in quartz veins</td>
<td>Sericite ± ankerite ± chlorite ± albite</td>
</tr>
<tr>
<td>3. Big Belt, Murchison, W. Australia 90 t Au</td>
<td>Tholeiitic basalt or dolerite</td>
<td>Au ± pyrite ± arsenopyrite ± stibnite ± chalcopyrite + Pb, Zn sulphides + magnetite</td>
<td>Pyrite + quartz + muscovite, pyrite + k-feldspar, minor sillimanite and rutile</td>
</tr>
<tr>
<td>4. Kolar, India &gt;790 t Au</td>
<td>Mainly basaltic rocks; subsidiary ultramafic rocks and minor chemical sediments</td>
<td>Quartz veins and sheeted veinlets containing Au + quartz ± pyrite ± pyrrhotite ± arsenopyrite ± sphalerite ± galena</td>
<td>Quartz + diopsida ± hornblende ± biotite; minor sericite and chlorite near veins; calcite and tourmaline</td>
</tr>
<tr>
<td>5. Granulite Renca, Zimbabwe 1.5 t Au p.a.</td>
<td>Hypersthene - quartz - feldspar - granulite (enderbite)</td>
<td>Au + pyrrhotite + chalcopyrite ± pyrite ± bismuth ± bismuth tellurite ± maldonite</td>
<td>Serpentine + biotite + sericite ± epidote</td>
</tr>
</tbody>
</table>
Table 2: Probable extraction processes for the mineralisation styles of Precambrian and Phanerozoic gold deposits.

<table>
<thead>
<tr>
<th>Mineralisation type</th>
<th>Extraction processes</th>
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</thead>
<tbody>
<tr>
<td><strong>Precambrian Au – quartz vein deposits</strong></td>
<td></td>
</tr>
<tr>
<td>1. Au – quartz ± carbonates, with trace amount of metal sulphides</td>
<td>Comminution ± gravity separation + cyanidation + CIP + Zn dust precipitation or electrowinning</td>
</tr>
<tr>
<td>2. Au – quartz ± carbonates - arsenopyrite – pyrite – pyrrhotite, with minor amounts base metals</td>
<td>Comminution ± gravity separation + flotation ± roasting ± bio-oxidation ± pressure oxidation + cyanidation + CIP or CIL + Zn dust precipitation or electrowinning</td>
</tr>
<tr>
<td><strong>Banded iron formation (BIF)</strong></td>
<td></td>
</tr>
<tr>
<td>3. Au – quartz – carbonates - arsenopyrite – pyrite – pyrrhotite, with minor base metals</td>
<td>Comminution ± gravity separation + flotation ± roasting ± bio-oxidation ± pressure oxidation + cyanidation + Zn dust precipitation or electrowinning</td>
</tr>
<tr>
<td><strong>Phanerozoic mesothermal deposits</strong></td>
<td></td>
</tr>
<tr>
<td>4. Au – quartz ± carbonates, with minor sulphide minerals</td>
<td>Comminution ± gravity separation + cyanidation</td>
</tr>
<tr>
<td>5. Au – quartz ± pyrite - arsenopyrite - ± pyrrhotite, with minor base metals.</td>
<td>Comminution ± gravity separation + flotation ± roasting ± bio-oxidation ± pressure oxidation + cyanidation + CIP or CIL + Zn dust precipitation or electrowinning</td>
</tr>
<tr>
<td>6. Au – quartz ± carbonates - (Pb, Zn, Cu sulphides)</td>
<td>Comminution ± gravity separation + cyanidation + Zn dust or electrowinning.</td>
</tr>
</tbody>
</table>