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REVIEW OF GOLD MINING AND PRODUCTION IN AFRICA

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REVIEW OF GOLD MINING AND PRODUCTION IN AFRICA

I. BACKGROUND

1. Gold has been mined and traded in Africa for several centuries. It played an important role in the trade and culture of ancient Egypt, Ghana and Zimbabwe.

2. More recently within the last hundred years the search for and the exploitation of gold was an important factor in the colonialization of countries like South Africa, Zimbabwe, Botswana and Ghana. Also it has had significant influence on political and economic developments in these and other African countries.

II. GEOLOGY

3. Gold deposits are found in different types of rocks and formations ranging from pre-Cambrian to late tertiary. The rich gold deposits in Africa belong mainly to the pre-Cambrian formations.

Gold occurrences can be grouped into seven broad categories:

1. <u>Gold quartz lodes</u>

4. This group comprises deposits of deep-seated hydrothermal origin in which gold-quartz veins have replaced wall rock or have filled open fissures in fracture zones in largely pre-Cambrian rocks. Anowated gold-bearing sulphides are a common feature with lode deposits. Examples of this type of deposit in Africa are some of the gold deposits in Zimbabwe, north eastern Zaire, Tanzania and Ghana.

5. Lode deposits have been a major source of gold produced in this century and have accounted for 20 to 25 per cent of the total gold produced in the period.

6. Pre-Cambrian formations on the African continent are particularly favourable to hosting the lode type of deposits. It is, therefore, likely that several new gold deposits will be discovered in these areas especially through the application of modern geophysical and other prospecting technologies.

2. Epithermal deposits

7. These deposits are largely found in highly altered volcanic rocks of the tertiary age in which gold-bearing hydrothermal veins of quartz, carbonates, barite and fluorite have filled open cavities in the rocks.

8. Gold is either found in its native form or as gold tellurides and is associated with varying but sometimes significant quantities of silver. Epithermal deposits rarely attain depths of one kilometre from the surface. They have not been a major source of gold and are unlikely to be of major significance in future world gold production.

3. Recent placers

9. These deposits occur in present stream valleys or in benches or terraces of pre-existing streams. Some are beach or residual deposits. The deposits are normally composed of unconsolidated or semi-consolidated sand and gravel which carry native gold and some other heavy minerals.

10. Because of the relative ease with which they can be mined and gold recovered, placer deposits have been an important source of gold for several centuries. Their importance has however, been declining with the exploitation of other types of deposits during this century. Placer deposits currently account for less than 10 per cent of the total world gold production.

11. Examples of this group of deposits in Africa include some of the deposits in Liberia, the Ivory Coast, the Sudan, the Congo, Ethiopia, Zaïre, Mali and parts of Ghana.

4. Fossil placers/metamorphic placers

12. Geologically these are very old placer deposits formed in the pre-Cambrian period. The placers were in the course of time lithified to form conglomerates which became part of the bedrock.

13. The deposits consist of small well rounded quartz pebbles embedded in a matrix of pyrite and micaceous minerals. They include gold, uraninite and platinum group metals with associated carbon. Individual conglomerate beds are normally about a metre thick and are deep, reaching up to more than 3 kilometres below furface. Important examples of fossil placer deposits are the Witwatersrand gold deposits in South Africa where they are commonly referred to as bankets. Other fossil placers are found in Ghana.

14. The fossil placer type of deposits constitute some of the major gold ore reserves of the world. Over two thirds of the gold which has been produced in the world since 1886 when gold was discovered on the Witwatersrand has come from the placer type of deposits. Nearly 50 per cent of the known world gold reserves belong to this group of deposits. Prospects for making new discoveries of placer type of deposits in Africa are considerable especially in the African pre-Cambrian shield. The placer type of deposits are likely to continue to be the major source of world gold production for a long time.

5. Disseminated gold deposits

15. These are mainly hydrothermal deposits belonging to either the tertiary, mesozoic or archaen age. They consist of fine grained gold which is found disseminated in silty and carbonaceous dolomitic limestones or in banded iron formation. The gold is frequently found associated with silica, sulphide minerals and small quantities of silver. Traces of arsenic, antimony and mercury also are sometimes found.

16. Disseminated gold deposits, because of their nature, remained undetected by the early prospectors until about fifty years ago. Their present contribution to world total production is still relatively small but is likely to gain greater importance in future as greater attention is given to their search and sophisticated prospecting equipment is used.

17. Examples of these deposits include some of the gold deposits in archaen banded iron formations in Zimbabwe. 18/

6. Base metal gold (by product gold)

18. Gold is frequently found in very small amounts in base metal ores. Gold is recovered as a by-product after the base metal ores are concerntrated, smelted and refined. Presently the by-product gold accounts for 5 to 10 per cent of world gold production and is likely to maintain this share for some time in accordance with base metal production levels.

19. The copper mines in Zambia, Zaire and Mauritania produce by-product gold.

7. Sea water gold

20. Sea water contains very small amounts of gold, probably both in solution form and in suspension. Sea water samples have been found to contain 0.001 to 44 p.p.b of gold depending on the location from where the sample is taken.

III. NATURE OF GOLD ORES

21. Gold is generally unreactive and is therefore only found in the form of a limited number of minerals. It is chiefly found in its native form and in varieties in which it is associated with silver, for example electrum (Au, Ag). Gold also forms tellurides of which calaverite (AuTe), Krennevite (Au_4AgTe_{10}), sylvanite ($AuAgTe_4$) and montbrayite (Au_2Te_2) are some of the most important ones.

22. Traces of gold but also economically recoverable quantities are found in sulphides particularly pyrite, arsenopyrite, galena, sphalerite and chalcopyrite. To a lesser degree gold is also found associated with pyrrhosite, quartz, carbonates, chlorite and carbonaceous materials. The gold is largely found in discrete grains forming inclusions between other mineral grains.

23. Native gold is normally deep yellow in colour. It appears in various shapes and sizes depending on the nature of the deposit. Gold could be plate-shaped, rounded or even wire-shaped in sizes ranging from less than 10 mm in disseminated gold deposits to large nuggets weighing several kilogrammes in placer or quartz vein deposits. Native gold has a specific gravity of 16 to 19.3 depending on the degree of impurities.

24. Silver is the most common impurity in native gold while copper and iron are found to a lesser degree. Gold-silver tellurides are generally whitish or creamy white in colour. They are generally found in association with native gold and other tellurides either in veins and fissures in tertiary volcanic rocks or in greenstones in pre-Cambrian rocks. The important gold-silver tellurides have specific gravities of between 8 and 10.

IV. PROPERTIES OF GOLD

25. Gold has an atomic number of 79 and an atomic weight of 197. At 25°c gold has a density of 19.302. It melts at 1063°c and has a boiling point of 2809°c. Gold is extremely malleable and is ductile. It has high electrical and thermal conductivities and is highly reflective.

26. Gold is not attacked by pure sulphuric acid below 250°C and by hydrochloric acid below its boiling point unless, if in the latter case oxidizing agents are present. Although nitric and hydrochloric acids do not on their own attack gold their mixture in the ration 1:3 (HNO_3: HCl) known as aqua regia dissolves gold readily. Gold is resistant to alkali hydroxide and carbonate solutions but is attacked by alkaline cyanide solutions in the presence of oxygen or other oxidizing agents.

V. EXPLORATION FOR GOLD

1. Traditional methods

27. Traditional mineral exploration methods involving mapping, pitting and trenching to collect samples in outcrops, alluvials and other promising formations have successfully been employed in gold exploration. One of the simplest ways of determining the presence of gold in stream sediments or crushed quartz vein samples has been the employment of panning.

28. In panning the sample is washed in the dish and eventually a small fraction of heavy minerals present in the sample is retained in the dish. If gold is present even in specks it can be recognized by its distinctive yellow colour. In doubtful cases, gold can be distinguished from the commonly associated pyrite mineral by application of some nitric acid which dissolves pyrite but does not act on gold.

2. Photogeology and remote sensing

29. Aerial photographs, satellite photographs and imagery can be of assistance in geological mapping and in defining favourable areas for mineralizations like copper, lead and zinc mineralizations with which gold might be associated.

30. For example sulphide deposits are sometimes found to inhibit some vegetation a feature which can be detected on aerial photographs while placer deposits may show changes in the tone of colour in the photographs.

3. Geochemical exploration

31. Geochemical prospecting for heavy minerals like gold requires special sampling because of its nature in mineral deposits. As already outlined gold may occur in discrete grains or even nuggets but is very sparsely distributed in nature. Two samples from the same rock may therefore give quite different gold values.

32. To minimize this possibility, large samples of 5 to 10 kg are normally taken and heavy mineral fractions of the main samples are obtained by panning. The heavy mineral fractions are then gound and chemically analysed for gold.

33. Sometimes a pathfinder element is used in geochemical exploration for gold Arsenic for example has been found to be a useful pathfinder element. Surveys carried out on gold mineralization in Zimbabwe showed that gold areas could clearly be defined by arsenic anomalies in which the arsenic content was 400 times that of gold. 1/

4. Geophysical exploration

34. Both airborne and ground geophysical survey methods, in particular electromagnetic methods, have widely been used in the prospecting for base metals and associated gold ores.

35. Airborne surveys by fixed wing aircraft or helicopters are used to locate geophysical anomalies over a wide area. The anomalies are then more closely evaluated by normal ground mapping and sampling, ground geophysics and geochemical prospecting. If promising, the anomalies are evaluated further by drilling.

36. Because of the high expenses involved in airborne surveys it is necessary that areas to be flown be carefully selected on the basis of their potential in hosting the kind of minerals being sought.

37. Seismic methods have been used in locating fault structures, determining overburden depths or in tracing sedimentary beds for stratabound deposits. The vibroseismic geophysical exploration technique based on seismic exploration is reported to have been successfully employed in resolving geological structures in some of the deep South African gold mine deposits. 2/

5. Drilling and exploratory mining

38. Drilling and exploratory mining are frequently found necessary to facilitate adequate evaluation of a deposit prior to mine and plant design. Exploratory shafts or adits and limited cross cuts are developed to get more accurate information on a deposit and to collect sufficient samples for grade determination and metallurgical test work, including pilot plant tests.

39. Special difficulties are encountered in the assessment of deep ore bodies like the banket deposits on the Witwatersrand and in Ghana because of their nature and depth.

40. Diamond drilling to great depths is difficult and expensive and could give inaccurate information on the narrow interbedded conglomerate reefs found in these deposits. In such cases advantage has been taken of information derived from adjacent mines through comparison of data and in some cases drives are made from existing mines in order to explore new ore bodies. Where this has not been possible it has often been found necessary to sink prospect shafts and drives inspite of the large costs involved. 3/

VI. MINING

41. Although the bulk of the gold being produced on the African continent is from the medium to large underground mines in South Africa, Ghana and Zimbabwe, small-scale mining is important in several African countries which are endowed with small yet rich gold deposits.

42. In the medium-scale operations, dozers and dredges have been employed to exploit some of the placer deposits. Examples of dredging operations can be found in Ghana, Zaire, Liberia, Sudan and Ethiopia.

43. When reefs are outcropping or reasonably near surface open-pit-mining is considered. Further mining to greater depths if the reef or other kind of deposit persists in depth is done by underground development after the open pit has attained its ultimate economic depth.

44. Sometimes near surface ore is weathered. Such ore can be mined separately from the primary ore by open cast and heaped for leaching.

45. Several underground methods have been used in gold mining depending on the geological setting of the deposit, its width, dip, depth at which it occurs or extend to, the competence of the country rock, hydrological conditions and other factors including the degree of mechanization seen to be appropriate.

VII. DEEP MINING FEATURES

46. Mining of the fossil placer deposits or bankets typified by the Witwatersrand deposits has demanded special innovations and research in mining technology in order to facilitate their economic exploitation.

47. The reefs as already described are mostly thin, being 1 to 200 cm in width with over 80 per cent of them averaging less than 50 cm. They are deep-seated mostly over 2,500 metres from the surface and some extend to depths of 4,500 metres where rock temperatures of over 55°c are encountered. The reefs extend laterally and dip for several kilometres at dip angles ranging between 7° and 40°.

48. The rise in gold prices in the last decade opened possibilities for the economic exploitation of some of the thinner and deeper reefs or lower grade reefs but with requirements for relevant technological developments.

49. Deeper mining has necessitated increased refrigeration and ventilation in mines to counteract higher temperatures. Complex and expensive stope support has had to be installed in response to increased rock pressures. Bigger and faster haulage systems have had to be installed in order to cope with increased stope distances from the shafts and higher tonnages necessary to process in order to offset the effects of lower grade on total mine gold production.

50. Considerable effort has therefore been placed in improving mining systems, mine layouts and design as well as in finding more efficient ways of utilizing manpower. In this latter aspect programmes have been undertaken to introduce mechanization in the deep mines where in the case of South Africa labour costs form nearly 50 per cent of the total mine costs. 4/

51. The efficient transportation of men, ore and materials in deep mines has received considerable attention. In the South African mines about 100 million tonnes of rock is hoisted to meet an annual gold production of about 700 tonnes. For some years a system in which hoisting was done in two lifts each with a maximum length of about 5,000 ft was preferred. The eventual introduction however of efficient multirope winding systems and twin rope double drum hoists led to the more popular use of single shaft long winding systems.

52. In order to minimize the tonnages of ore to be hoisted to the surface consideration has been given to the installation of gold metallurgical plants underground. This is especially more feasible in mines where the tailings can be used for backfil underground and where compact plants can be designed. The gold concentrates are pumped to the surface. 5/

53. An average of about 10 tonnes of air is required for ventilation purposes for each tonne of rock broken in deep mines. Because of the high rock temperatures, rapid heat transfer, auto-compression and humidity prevalent at great depths which all adversely affect the cooling power of the air refrigeration is done to the air before it is circulated to working stopes and after use before it is recirculated. Refrigeration is normally done near the underground working places so as to reduce the total volume of air needed and also to minimize the quantities of air which have to pass through the shafts.

54. Some general principles for application in deep mine layouts which could help reduce dangers of rockbursts have been outlined: 3/

(i) As much as possible unmined areas should not be left to serve as pillars. When it is necessary to do so the pillars should be large enough to bear the expected stresses and to facilitate their eventual extraction;

(ii) Main arteries and tramways should be either in the hanging wall or preferably in the footwall remote from working faces;

(iii) Stoping should as much as possible be concentrated in a particular area and the faces should be designed to advance in line in the form of a long wall even at the expense of losing desired average ore grades.

55. Considerable advances have been made in the area of mechanization in deep mines. Research has been done to innovate new equipment or adopt equipment in use elsewhere to suit local mine conditions.

56. Productivity in the South African gold mines is of the order of 1 tonne per man-shift and this decreases as environmental conditions become more arduous with increased depth. Employment of hard rock shaft sinking boring machines, applications of specially adapted raise boring machines and narrow vein ore mining machines have been some of the developments made so as to reduce labour requirements in the South African gold mines. 6/

VIII. PROCESSING OF GOLD ORES

57. The methods adopted to recover gold from its ores utilize one or more of the following characteristics of native gold and its other common minerals, chiefly the gold-silver tellurides:

- Gold and its associated silver minerals have very high specific gravities when compared to the common gangue minerals. The specific gravity ranges between 15.5 and 19.3 depending on the amount of the contained gold-silver metals;

- Gold and silver dissolve in dilute alkaline cyanide solutions forming relatively stable compounds;

- Gold is amalgamated by mercury;

- Gold, particularly in its natural alloy form, responds to floatation.

58. The simplest and most common flowsheet for simple gold ores involves either gravity separation or cyanidation of ground ore or a combination of both processes.

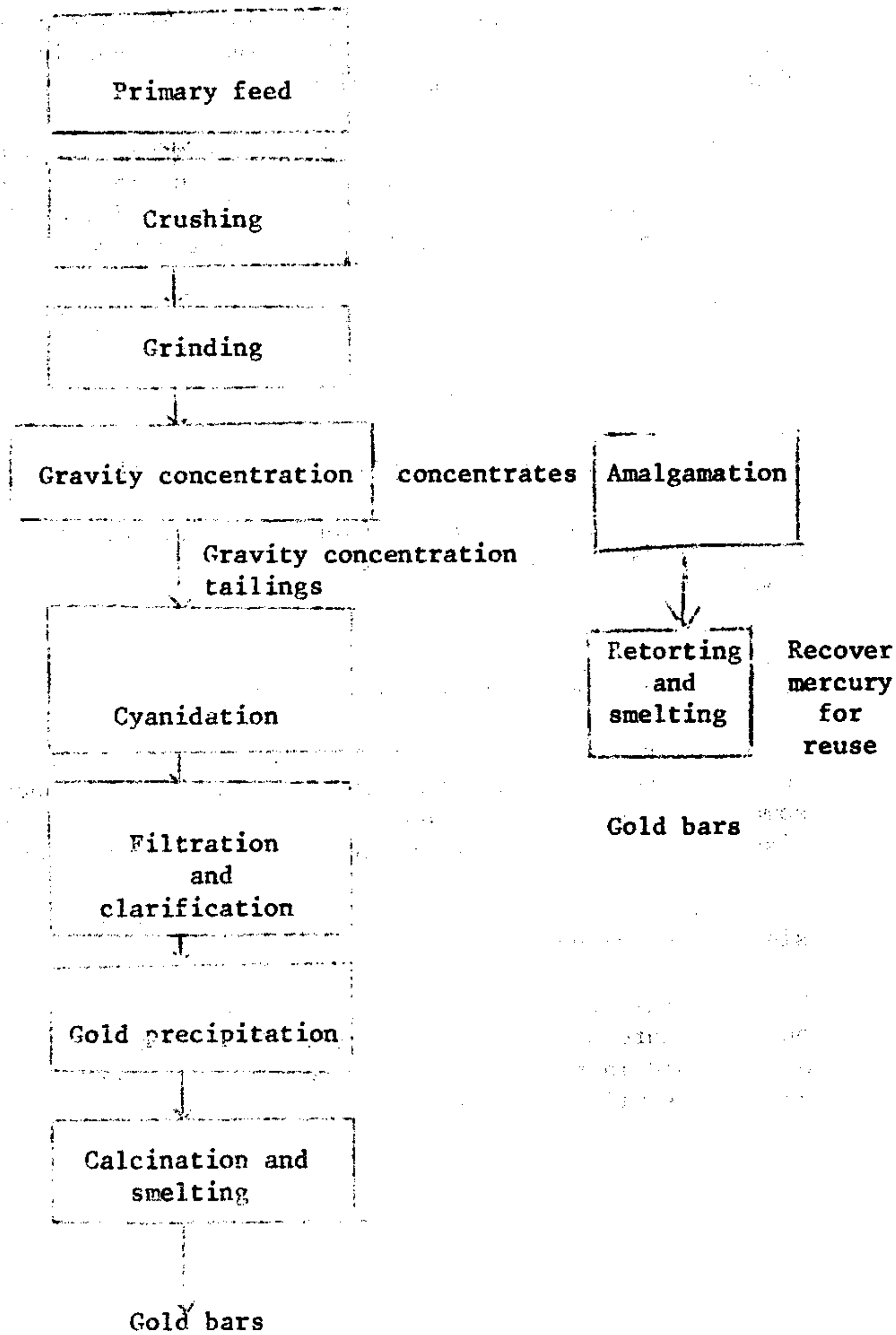
59. Figure 1 shows an outline of a typical flowsheet. The flowsheet given also includes amalgamation of the gravity concentrate.

60. As already noted gold is sometimes closely associated with sulphides which do not dissolve readily in cyanide solutions. In such cases floation is sometimes employed to produce a concentrate which is later roasted to allow the dissolution of the contained gold in cyanide solutions.

61. Tailings from the floatation stage may also be cyanided if they assay significant amounts of gold.

62. Several othervariations in the flowsheet described are feasible depending on the nature of a particular ore. Important factors include the particle size of the gold in the ore and the presence of elements inocuous to the cyanidation process as will be described.

Figure 1. Simplified gold processing flowsheet



1. Gravity concentration

63. When gold is found in coarse form as is common in placer and some of the vein deposits, gravity concentration is used as the primary recovery method for the gold.

64. Methods which have found wide applications both by the smaller operator and the large mine plants include use of riffles, sluices, shaking tables, cylindrical concentrators, jigs, endless belt concentrators and in some cases cyclones.

65. As noted above gravity concentration is frequently employed as a first step prior to grinding and cyanidation. In some of the large plants this is done to eliminate the possibility of appreciable amounts of gold being trapped in the ball mill liners which would pose security risks and to remove any large particles of gold or any gold particles contaminated by other minerals which would not dissolve quickly in cyanide solutions.

66. Witwatersrand gold mines which employ gravity concentration in their flowsheets recover as much as 43 per cent of the total contained gold in this stage. It is also reported that the overall gold recovery efficiency is greatly improved when the gravity separation step is incorporated in the flowsheet. 7/

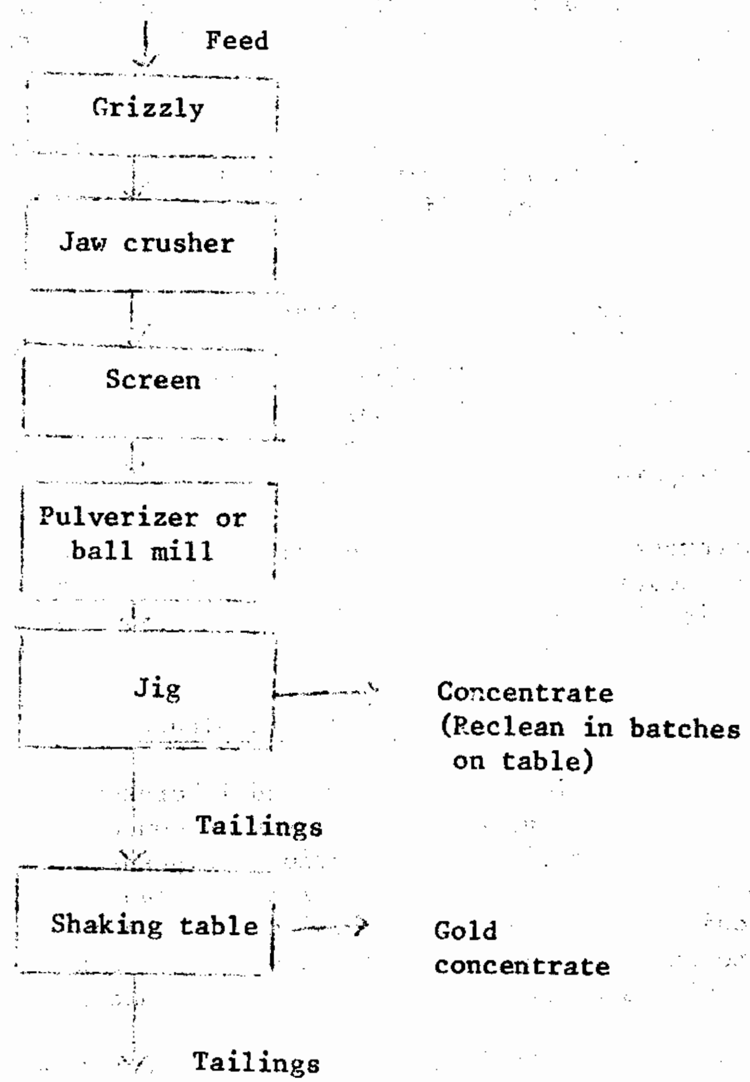
2. Portable gravity concentration plants

67. Where mineralogical examination and laboratory or pilot plant tests have proved reasonable recovery rates by gravity concentration the utilization of suitable portable gravity concentration equipment offers an opportunity for the exploitation of several of the risky African small gold deposits. Some of these deposits have remained unexploited because of their unattractive size relative to envisaged capital costs and other are being worked haphazardly by individual miners using inefficient equipment and methods.

68. Figure 2 shows a typical flowsheet for a small portable or semi-portable gravity concentration plant which can treat up to 50 tonnes or more of alluvial or reef ore per day. The cost of such a plant can be within the reach of small co-operatives or a group of miners particularly if bank or government financing or support arrangements are available. A typical 50 tonne a day plant shown in figure 2 including the necessary power plant can be acquired and installed for about $700,000 (1983).

69. Installation of such a plant can take advantage of existing gradients and the use of conveyers and pumps can be minimized in the system. A small water dam when necessary may be built to provide a source of water supply and a simple water reclamation system can be devised. The plant area can be fenced to improve security.

Figure 2. Flowsheet of typical portable gravity separation plant



70. Where recovery efficiency is low the tailings can be stockpiled for future heap leaching.

71. Mobile gravity concentration plants can make considerable impact on the growth and more rational exploitation of the small gold deposits. Governments or other institutions could, where it is found appropriate, install the small plants to serve as custom plants for small operators. Their use could, besides improving gold recoveries, allow governments to monitor better the activities of the small miners and be better placed to give them increased technical and financial assistance.

3. Amalgamation

72. Gold is wetted by mercury and is drawn into it to form an amalgam due to the low surface tension that exists between it and mercury. Small amounts of gold also dissolve in mercury at room temperature. Gold-silver tellurides do not amalgamate with mercury and cannot be recovered by this method. Dissolved sulphides, oil, grease, arsenic and antimony sulphides and floatation reagents adversely affect good amalgamation.

73. In the traditional method, pulp of ground ore is passed over a sloping copper plate coated with mercury. The gold in the pulp is retained on the copper plate and the amalgam is periodically scrapped off from the plate. In some of the large plants amalgamation is sometimes used to clean high grade gravity concentrates. The concentrate is ground for several hours in a ball or rod mill into which some time is added prior to adding mercury in order to clean the gold particle surfaces. The amalgam which is collected is retorted to expel mercury which is recovered for subsequent use.

4. Retorting of amalgam

74. Cylindrical or pot type vessels, coated with chalk or clay are commonly used in retorting amalgam. The vessels are fitted with a condenser consisting of a tube with a water jacket around it. The amalgam is placed in the vessel and is slowly heated to a temperature of 357°c, the boiling point of mercury.

75. Mercury vapour which is formed is cooked in the condenser and mercury is collected under water in a container fitted at one end of the condenser. Connections of the vessels in the system are carefully done to avoid undue leakages of the poisonous mercury vapour.

76. The retort sponge consisting of gold and silver values and less than 1.5 per cent mercury is removed for smelting.

5. Cyanidation

77. Most gold recovery flowsheets include cyanidation. Gold and silver and gold-silver tellurides dissolve in aerated dilute alkaline solutions of sodium or potassium cyanide in accordance with the general formula:

$$4Au + 8NaCN + O_2 + 2H\ O \quad ---- \quad 4\ NaAu\ (CN)_2 + 4\ NaOH$$

78. Finely ground ore (normally 80 per cent - 200 mesh the appropriate size having been predetermined through laboratory tests) is agitated in open tanks in dilute cyanide solution of a strength commonly between 0.02 per cent and 0.08 per cent (one pound of cyanide per tonne of water being equivalent to 0.05 per cent cyanide). In order to facilitate intimate contact between the cyanide and the ore some cyanide is often added to the ball mill during grinding. Lime is periodically added in the ball mill and agitation tanks in order to maintain an alkaline media needed to minimize hydrolysis of the cyanide. The lime also neutralizes acidic substances that would react with cyanide to produce hydrocyanic acid. Lime also aids pulp settlement during classification in latter stages. Normally 1-2 lb of lime is added per tonne of ore but in cases of very clayey material up to 10-15 lb/tonne is necessary.

79. Dissolution of gold for most ores takes between 8 and 72 hours. The rate depends on the size of gold particles and their degree of liberation and the cleanliness of the gold particle surfaces. Gold-silver tellurides are slow to dissolve than native gold. Under ideal conditions gold dissolution in cyanide has been determined to be 3.25 gm/cm2/hour.

80. Compounds like some of the iron oxides and silver chloride do coat native gold while antimony, manganese and lead compounds form films around gold particles in certain refractory ores thereby inhibiting dissolution of the gold by the cyanide solution. Acid leaching has been found to remove the coatings ad to markedly increase cyanidation recovery.

81. Besides the factors related to the nature of the gold minerals themselves that are important in cyanidation, the characteristics of the gangue minerals are also important. Some of these minerals or the products of their decomposition do react with cyanide thereby causing excessive consumption of cyanide or they react with the oxygen in solution leading to reduced dissolution of gold minerals.

82. Base metal silicates, oxides and carbonates are soluble in cyanide solution. Although some of the common sulphides like sphalerite, chalcopyrite, arsenopyrite and pyrite are relatively insoluble in cyanide solutions, many of the secondary copper and zinc minerals, and arsenic and antimony sulphides are readily soluble. Besides consuming cyanide, antimony and arsenic sulphides have a deleterious effect in that their decomposition products inhibit the reaction of native gold surfaces with cyanide and oxygen ions. Addition of lead nitrate

can minimize the efforts of these compounds. The effects of pyrrhotite which is quite soluble in cyanide solution can be minimized by aeration in alkaline solution prior to cyanidation.

83. As already noted it is sometimes necessary to roast sulphide concentrates obtained from floatation prior to cyanidation. Roasting of the concentrates however produces water-soluble sulphates and various reducing agents like sulphide and ferrous ions which are formed out of the decomposition of the sulphide minerals which consume cyanide and lime. The calcined floatation concentrates are therefore normally washed first to remove these water-soluble substances prior to cyanidation.

84. Carbonaceous matter is also undesirable in the cyanidation process as it precipitates dissolved gold. Remedies to this problem include coating of the carbonaceous material with hydrocarbons, floatation of the gold and sulphides whilst depressing the carbonaceous material, floatation of the carbonaceous matter before gold and sulphides floatation or oxidation of the carbonaceous matter by chemicals or roasting. 7/

6. Floatation

85. In some gold ores, the gold is intimately associated with sulphides and would require grinding to considerable fineness and eventual roasting of the ore to ensure good cyanidation recoveries. Flotation is therefore often employed in gold recovery plants to collect a relatively small weight of gold and sulphide concentrate which can then be treated by amalgamation, cyanidation or roasting and cyanidation.

86. Xanthates are more commonly used as collectors. The flotation concentrate may be amalgamated or directly cyanided depending on the proportion of gold locked up in the sulphides. If significant amounts of gold are locked up in sulphides then the concentrate is roasted first prior to cyanidation.

87. Where cyanidation is done prior to flotation, residual cyanide normally has a depressing effect in the flotation of the sulphides. The sulphides in such cases are reactivated with sulphur dioxide.

7. Heap leaching by cyanidation

88. One relatively inexpensive method by which gold can be recovered from its ore is by heap leaching. A weak cyanide solution is distributed over a heap of gold ore and the gold-enriched solution is collected at the bottom of the heap for eventual gold extraction.

89. It is important that bench and pilot scale tests be conducted first to prove the applicability of this method to a particular ore. Besides the general factors that have already been described as influencing gold dissolution in cyanide solution, the percolation rate of the solution through a heap of ore is important. Clayey or very fine ore particles adversely affect the percolation rates.

90. Necessary leaching periods are therefore varied. It has been reported that in a number of cases 67 per cent to 95 per cent of gold present in ores has been extracted in four to 42 days. 8/ Some research has been done to determine ways of improving percolation rates of leaching solutions through crushed gold and silver ores containing very fine ore particles or clayey materials.

91. One solution tried has been to mix the crushed ore with small amounts of portland cement after which a suitable amount of water is added. The cement acts as a binder of the small particles. After a curing period,the ore is leached.

92. Heap leaching has found considerable application to weathered ore and to old tailings containing gold values.

8. Precipitation of gold from solution and smelting

93. One of the oldest methods of precipitating gold and silver from cyanide solutions is by passing the solution upward through a 'zinc box' filled with freshly prepared zinc shavings. The zinc box is either of steel or wood.

94. The gold is precipitated in accordance with the following formula:

$$NaAuCN_2 + 2NaCN + Zn + 2H_2O \qquad NaZnCN_4 + Au + H_2 + 2\ NaOH$$

Another reaction $Zn + 4\ NaCN + 2H_2O \qquad Na_2Zn\ CN_4 + 2NaOH + H_2$, tends to consume more zinc than its present gold equivalent.

95. The precipitate which is in the form of a slime is periodically collected from the bottom of the zinc boxes and is placed in a vat with sulphuric acid to dissolve excess zinc and any copper or lead. The mixture is stirred until any reaction ceases. The vat is filled with water and the precipitate allowed to settle and the clear liquid is siphoned off. This is repeated about twice before the precipitate is filter-pressed and dried.

96. The dried precipitate is then smelted in graphite crucibles using borax, sand and sodium carbonate as fluxes. Zinc and other impurities form a slag with the flux which on pouring into a mould readily separates from the gold. The gold button is remelted and cast into ingots. The slag is returned into the system for reprocessing. The gold ingots obtained assay about 900 or more fine.

97. Use of zinc shavings for precipitating gold is particularly suitable for small plants with limited technical personnel. More modern plants use zinc dust which is continuously added at predetermined rates to a deaerated filtered pregnant solution in order to precipitate the dissolved gold.

98. Mineral dressing equipment manufacturers have for some time been in position to supply compact and sometimes portable gold cyanidation plants utilizing the carbon in pulp process which are considerably cheaper than the equivalent capacity zinc dust precipitation plants. Such plants could find wide application in the continents' small to medium size gold deposits. In some cases local materials like coconut shales can be used as raw material for the preparation of activated carbon.

9. Carbon in pulp and bacteria leaching processes

99. Activated carbon is increasingly being used in recovering gold from cyanide solutions and gold contained in pulps or slimes. Activated carbon normally in granular form is used to absorb gold and silver contained in solution and later the precious metals are stripped from the carbon. Desorption of the precious metals from the carbon is done by using alkaline sodium sulphide, hot alkaline cyanide solution or alkaline alcohol.

100. In one patented process a high pressure method is used to strip gold from the carbon to produce a solution containing 1,000 times more gold per unit volume than in the original pregnant solution. Eventually gold is recovered from solution by electrolysis. The carbon is reactivated by roasting and quenching.

101. Bacteria capable of dissolving gold have been discovered. The bacteria have been found able to dissolve up to 2.15 mg of gold per litre of solution in a period of two or three months. Mold fungi have also been used to recover gold from acid solution.

102. Impure gold obtained from the smelting of the gold precipitate in the cyanidation process or from amalgamation can be refined to high purity by electrolysis using the Wohlwill process or more commonly by chlorination using the Miller process. The Wohlwill process is suitable if the content of silver is low. The gold is electrolysed in a chloride solution. Gold forms the anode and is dissolved and deposited in pure form at the cathode. The silver present forms a chloride which may coat the anode, a problem which may be reduced by the application of an alternating current in the system.

103. The system is operated at a temperature of 70°C with a cathode current of 10-15 a/dm^2. The electrolyte normally has about 90 g/1 gold in the form of $HAuCl_4$ with a small amount of free HCl. The fold deposited at the cathode is about 99.95 per cent pure. It is later melted into bars.

104. In the Miller process chlorine gas is bubbled through molten gold and any base metals present form chlorides which volatilize. Silver forms a chloride which floats on top of gold and can be poured off in the molten state. 99.6 per cent pure gold is retained. This method is not suitable if platinum is present. Some gold concentrates or precious metal scrap can be refined by first dissolving the contained gold in aqua regia.

$$Au + 3HNO_3 + 4HCl \quad HAuCl_4 + 3NO_2 + 3\ H_2O.$$

105. Nitrogen oxide is removed by heating and then gold is precipitated from solution by reduction using sulphur dioxide or ferrous sulphate. Any platinum present can be recovered after the complete precipitation of the gold.

IX. ASSAYING

106. One important aspect in gold mining and processing is the maintenance of an efficient assay laboratory.

107. Besides geological samples taken in the mine, samples are taken at various key points in the plant and assayed to check on recovery efficiencies and theft.

108. The presence of small quantities of gold can be determined by adding stannous chloride to a chloride solution prepared out of a given sample. When large amounts of gold are present they are prescipitated out of a chloride solution of the sample by passing sulphur dioxide through the solution if platinum group metals are absent or by precipitating the gold with hydroquinone which does not precipitate the platinum metals. The weight of the gold in precipitate form is obtained after washing and drying.

109. Fire assaying is widely used in gold assays. A ground sample of the ore is mixed with a flux containing among other substances carbon and litharge. This mixture is fused for at least one hour in a crucible. Gold and other precious metals and lead form a button at the bottom of the crucible after cooling. The button is then fused on bone ash or magnesia cupel under oxidizing conditions. Lead is oxidized and absorbed by the cupel leaving a bead containing gold, silver and platinum metals originally present in the sample. If silver is present in sufficient amounts it can be parted in nitric acid, leaving gold in porous form.

110. Atomic absorption spectrometry and emission spectrography are also employed in determining gold in samples including cases where it is present in trace amounts. Neutron activation is also used in the estimation of very low concentrations of gold, utilizing the emission of 198 Au as it decays to 198 Hg.

X. GRADES AND SPECIFICATIONS FOR GOLD

111. Gold purity is traditionally expressed in fineness, which defines the proportion of pure gold in an alloy expressed in parts per thousand. On this basis a gold bullion of 995 fineness would be 99.5 per cent pure.

112. On the troy system of weights one troy ounce of gold is equivalent to 20 penny weights or 480 grains. The term karat is used to express the proportion by weight of fine gold in an alloy expressed as a 24th fraction. For example an 18 karat alloy would contain 75 per cent gold.

113. On the metric system gold assays of samples are expressed in grammes per tonne. One troy ounce is equivalent to 31.10348 grammes. A sample assaying 1 dwt/tonne would be equivalent to 1.555 gm/tonne.

XI. USES OF GOLD

114. Gold is used in the jewellery industry, in the electrical and electronics industries, in the aerospace industry, in dentistry and in the chemical industry and medicine. Gold is also used as a medium for speculation and investment.

115. Table 1 shows the amount of gold consumed by different non-government sectors in the non-centrally planned economies during the period 1978 to 1983.

116. In 1983 jewellery took up 64 per cent of the gold available to the non-government sectors in the market economies. Jewellery is made from gold ranging from 21 karat or 87.5 per cent gold to 10 or 9 karat (37.5 per cent). Gold is also used in electroplating jewellry and decorative articles and may be binded to a base metal core to produce rolled gold or plate gold.

117. In the electrical and electronic industries gold coated electrical contacts are employed to ensure reliable performance and where necessary tiny gold wires are used, for example in transistor connections. In all cases gold is used selectively to minimize costs. Silver, platinum and palladium and bright tin-nickel have substituted for gold in some of the electrical-electronic applications but where reliability and durability have been of primary consideration recourse to the use of gold has been made.

118. Gold is also increasingly being used in the jet aircraft and aerospace industries, for example the use of gold-palladium base thermocouples in jet engines.

119. The dental industry utilizes gold alloys containing 25-70 per cent gold. In 1983 this sector used nearly 5 per cent of the total gold available to industry in the market economies. The amount of gold used for dentistry has been fluctuating in response to prevailing economic conditions in main consumer countries.

120. In the chemical industry gold is used for corrosion resistant equipment and to a lesser degree for bonding components. Small amounts of gold are used in medicine.

121. The recent trends in the use of gold as a medium of speculation and investment are reflected in Table 1. For years gold has been acquired by investors as a safeguard against fluctuations in currencies.

122. To a large extent the degree of speculation and investment in gold is influenced by the strength of currencies particularly the United States dollar, interest rates and inflation rates. Low inflation, strong or stable currencies and high interest rates have a negative effect on investments in gold.

XII. MARKETS, SUPPLY AND DEMAND, TRADING PATTERNS, PRICE CYCLES AND PROSPECTS

123. A large part of the world's gold is traded through Zurich and London. Traditionally London has set bullion prices. Other important gold trade centres include Paris, Hong Kong, Bombay, Singapore and Winnipeg.

124. Apart from bullion trade considerable amounts of gold are traded in ores, concentrates and in gold scrap. In many cases metal destined for refining in another country contains some gold values. In such cases the gold is returned to the country of origin or is placed in its account.

1. Supply and demand

125. The main components of commercial gold supply and demand in the market economy countries from 1978 to 1983 are reflected in Table 1. Table 2 shows gold imported by different countries in 1979 and 1980.

126. There has been a modest increase in mine gold production since 1978.while demand in the market economy countries has decreased during the period. Demand reached a bottom level of only 555 tonnes in 1980 when compared to a demand of 1921 tonnes in 1978. Sales from centrally planned economies to market economy countries have also decreased over the period.

127. Demand for jewellery and medals has shown considerable decline over the period while demand for dentistry and miscellaneous industrial uses has shown a more modest decline. The electronics industry has maintained a relatively steady level of demand over the period. Bar hoarding nearly ceased in 1980 but has since considerably increased.

128. The demand patterns observed in all the sectors were in response to high demand for investment in gold mining in the late seventies and to effects of high gold prices and economic recession and high interest rates after 1980 which adversely affected industrial and investment demand for gold.

129. In general high inflation and instability in major currencies have had the effect of encouraging investment in gold while high interest rates and strong currencies especially the United States dollar, have a negative effect.

2. Prices

130. Table 3 shows gold prices for the period 1960 to mid-1984.

131. The price of gold was maintained at $35 an ounce set by the United States government in 1934 up to 1968 when a seven-nation International Gold Pool established a two-tire price system for gold. An official price of $35 an ounce was maintained for monetary transactions involving government owned gold and an open market price which could fluctuate in accordance with supply and demand was allowed to operate.

132. The two-tire gold pricing agreement was dissolved by the International Gold Pool in November 1973. Gold prices were allowed to follow forces of supply and demand and prices rose appreciably. The increase in prices of 1974 led to increased activity in gold exploration, general mine expansion and modernization programmes, working of lower grade ore bodies and in some cases reopening of abandoned mines.

133. A gold market survey done by Gold Fields has identified two distinct six-year gold price cycles since 1970. 10/ The beginning of each cycle was marked by strong economic growth and rising consumption for jewellery. This was in each cycle followed by heavy investment and speculative buying of gold as a safeguard against inflation and political uncertainties resulting in price peaks of 1973/74 and 1979/80. High prices in turn led to considerable selling of held stocks leading to another decline in prices.

134. A third cycle was seen to be developing starting mid 1982 but external economic factors have, except for a brief period in late 1982 and in 1983, kept demand and prices relatively depressed. Prospects are that future gold prices will increasingly follow physical market demand and follow less speculative forces.

3. Prospects

135. Although some gold mines are threatened with closure because of depressed gold prices and some base metal mines producing by-product gold are either closing down or cutting back on production because of weak base metal prices, new gold mines and mine expansions coming on stream are expected to meet any future increases in gold demand.

136. Gold and polymetallic deposits with gold and other precious metals have been primary exploration targets for many mining companies and governments in the past few years inspite of reduced exploration activity for several other mineral commodities. 11/

137. At the same time improvements in scrap recovery methods and recycling are resulting in proportionately less gold being lost every year.

XIII. WORLD GOLD RESERVES AND PRODUCTION

138. World gold ore reserves are estimated to contain nearly 37,000 tonnes of gold which at the current rates of mine production would last about 30 years. Out of this total, about 19,000 tonnes are in Africa, mainly South Africa, 7,000 tonnes in USSR and about 6,000 tonnes in North America.

139. The total world resources which include additional undereloped deposits amount to nearly 60,000 tonnes which are largely in South Africa.

140. Besides the minable resources there is an estimated 70,000 tonnes of bullion and coins held by governments, banks and individuals.

141. Table 4 shows the amount of gold produced throughout the world in 1981 and 1982 while Table 5 shows gold produced by African countries between 1973 and 1982.

142. It will be noted that Africa accounted for nearly 52 per cent of the world mine production in 1982. South Africa alone supplied about 50 per cent of the total. Africa's share of world production has decreased by nearly 15 per cent since 1973. This decline has largely been due to decreased production by main African producers like South Africa, Ghana and Zimbabwe while countries like USSR, Canada, Brazil and Australia have increased their production. South Africa's production has decreased primarily because mines have been working lower grade ore following rises in gold prices. Ghana's production has follen largely because of mine operational problems.

XIV. GOLD IN TAILINGS

143. Prospects of winning appreciable amounts of gold from old tailing dumps are considerable in several African countries with long gold mining histories as a relatively inexpensive alternative for recovering gold locked up in tailing dumps.

144. Gold recovery efficiencies, before cyanidation and technology for treating refractory ores was developed, were low, to the extent that a number of operations lost over two grammes per tonne in tailings.

145. In South Africa extraction of uranium and gold from old gold mine tailings which contain 0.4 to 0.6 gm/tonne of gold has successfully been done by the TERCO process.

146. In Ghana it is estimated that between 85 and 100 tonnes of gold are tied up in old tailings at the Ashanti Goldfield and some other mines.

147. In Tanzania tailings of the old Geita, Kiabakari and Buhemba mines have valuable gold contents. Sampling of some of these tailing dumps has given gold values of up to 3 gramme per tonne. A smaller old gold mine at Canuck has given tailings assays of up to 4 gm per tonne. The old tailings in the old Nyanzian greenstone belt mines could have 20 to 30 tonnes of gold and there are plans to recover this gold by heap leaching processes.

148. Small operators have worked gold deposits in Zimbabwe for many years. Low recovery efficiencies have meant several thousands of kilogramme of gold being lost in tailings.

149. Swaziland in the early 1960s revived some gold operations by working old gold tailing dumps. In the Sudan old mine tailings like those at the Gebeit mine have been re-examined with possibilities of some of them being reworked.

150. Considerable amounts of gold-bearing tailings from the Adjoujt copper deposit formerly worked from 1970 till 1975 and estimated at 2.5 million tonnes have been re-examined recently by UNIDO and are under consideration for reprocessing in the context of the rehabilitation of the mine.

151. Recoverable gold from this source is estimated at between 10 and 12 tonnes together with some silver. The residual gold in the tailings if of the order of 5 gr per tonne.

152. Similar secondary recovery processes are under way at the Poura gold mine in Burkina Faso where 400 kg of gold are expected from the tailings resulting from an earlier mining phase which took place between 1965 and 1969.

Table I

Supply and Demand for Gold to Non-Government Sector in (tonnes)

	1978	1979	1980	1981	1982	1983
Non-Centrally Planned Economies Production	972	959	950	971	1 012	1 088
Net sales from centrally planned Economies	410	199	90	280	207	92
New supply of gold	1 382	1 158	1 040	1 251	1 219	1 299
Net sales by official sector (+)	362	544	-	-	-	119
Net purchases by official sector (-)	-	-	230	276	98	-
Gold used in:						
Carat Jewellery	1 012	740	128	598	716	599
Electronics	90	100	90	89	81	96
Dentistry	89	87	62	62	58	53
Medals, medallions and fake coins (sales)	51	34	16	27	22	24
Official coins (sales)	288	290	186	191	133	176
Bar hoarding	113	172	11	279	294	80
Other industrial and decorative	78	78	62	62	58	58
						1 086

Table 2

Imports of Gold by different Countries

	1979	1980
AFRICA	4 597	-
Ivory Coast	4 597	-
Kenya	2 379	39 000
Morocco	5 916	-
South Africa	5 916	6 151
OTHER		
Austria	27 296	114 936
Australia	-	18 808
Belgium-Luxemburg	780 827	1 856 000
Brazil	104 938	150 000
Burundi	-	-
Canada	2 985 899	2 249 000
Cyprus	..	-
Denmark	-	-
Finland	48 000	-
France	2 848 683	1 343 000
Germany F.R.	7 142 894	4 002 000
Hong Kong	3 394 622	1 153 000
Indonesia	70 730	..
Italy	6 093 710	N.A.
Japan	2 022 106	1 170 000
Malta	20 672	3 918
Norway	46 907	N.A.
Portugal	-	N.A.
Sweden	32 150	-
Switzerland	110 307	125 131
Taiwan	264 916	716 626
United Kingdom	28 707 860	17 712 132
United States	4 629 696	

Source: 1979 Figures - World Mineral Statistics 1975-79, Institute of Geological.
1980 Figures - Mineral Yearbook 1981, US Bureau of Mines.

Table 3

Time - price relationship for gold

Year	Actual annual average price in dollar/tray ounce
1960	35.00
1965	35.00
1966	35.00
1967	35.00
1968	39.26
1969	41.51
1970	36.41
1971	41.25
1973	58.60
1974	97.81
1975	159.74
1976	160.82
1977	125.21
1978	147.60
1979	192.96
1980	(282.41)
1981	612.56
1982	459.64
1983	375.91
1984 (January to March only)	383.84

Table 4

Production of gold world-wide (1981-82)

Country	1981	1982
	('000 troy oz)	
South Africa	21 143	21 380
USSR	9 645	9 867
Canada	1 413	1 840
China	1 690	1 770
USA	1 378	1 422
Brazil	1 068	1 159
Australia	530	727
Philippines	753	784
Papua New Guinea	547	593
Colombia	535	525
Chile	400	513
Ghana	393	418
Zimbabwe	371	416
Dominican Republic	348	371
Peru	220	220
Mexico	199	205
North Korea	160	164
Yugoslavia	140	147
Spain	105	119
Japan	99	103
Sweden	64	76
India	80	77
Zaire	70	70
Rumania	66	68
Indonesia	56	58
France	29	46
Fiji	26	44
Bolivia	66	33
Nicaragua	35	41
South Korea	35	35
Costa Rica	16	18
Finland	21	19
Guyana	19	19
Argentina	12	19
Venezuele	18	18
Zambia	20	16
Ecuador	4	4
Ethiopia	12	12

Table 4 (Cont'd.)

Production of gold world-wide (1981-82)

Country	1981	1982
	('000 troy oz)	
Taiwan	11	11
Portugal	7	7
Honduras	2	2
Congo	7	7
Liberia	7	7
Malaysia	6	6
French Guyana	4	43
New Zealand	6	4
West Germany	3	3
El Salvador	1	1
Sudan	1	1
British Solomon Islands	1	1
Burma	1	1
Rwanda	1	1
Mali	1	1
Gabon	0	1
Tanzania	0	1
Madagascar	0	1
Other African countries	1	1

Source: Metal Bulletin Monthly, June 1983 (Previous Metal features pp.33).

Table 5

Gold production in Africa (in troy ounces)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Angola	2000	2000	1000	1000	1000					
Burundi			368	426	450	450	133	130	100	100
Cameroon	83	64	96	251	182	200	147	72	316	150
Central Af. Rep.	64	64	529	400	100	965	2181	2000	1386	1400
Congo	1254	707	528	482	7000	7000	7000	7000	7000	6000
Ethiopia	19575	15754	19981	30000	7725	8000	7970	9000	11930	13000
Gabon	11221	7298	4207	3086	2572	965	964	553	550	550
Ghana	722531	566617	522889	532473	480884	402034	362000	353000	330000	330000
Guinea	4000	4000								
Kenya	136	235	98	37	89	205	200	125	100	100
Liberia	4	100	4500	4500	4500	NA	1086	7243	16864	12656
Madagascar	-	-	158	160	76	125	125	114	110	100
Malagasy	71	77								
Mali	30	-	30	900	932	965	1000	1500	1500	1500
Mauritania	56000	52000	42000	22120	28000	8000	-	-	-	-
Nigeria	21	113	8	10	10	-	-	-	-	-
Rwanda			425	936	1814	1125	472	944	1204	1400
Sierra Leone								407	3436	8729
South Africa	27494603	24388205	22937870	22935988	22501857	22648558	22617179	21669468	21121157	21355111
Sudan	49	309	300	300	300	300	300	300	300	300
Tanzania	55	42	48	10	10	133	322	346	250	250

Table 5 (cont'd.)

Gold production in Africa (in troy ounces)

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Zaire	133642	130608	103217	102882	81661	76077	69992	39963	70000	65000
Zambia	1608	5755	8500	10755	7845	8457	7933	10575	10545	13439
Zimbabwe	338000	335000	354000	389000	402000	299000	388000	368000	371000	420000
TOTAL AFRICA	28784947	25508943	24001752	24035916	23528997	23562559	23467004	22470641	21947747	22218185
WORLD PROD.	42834755	39659290	38230321	39024485	38906145	39057212	38807269	39197315	41276583	42712547
% AFRICAN PROD.	67.2	64.3	62.8	61.6	60.5	60.3	60.5	57.3	53.2	52.0

Table 6

Ore reserves and operating results for South Africa Gold mimes 1983

Group	Company	On reserves basis ($/oz)	Total ore reserves		Mill Throughout					
					Tonnanse			Gold recovered		Working Profit
			Tons (000)	Value (g)	Milled (000)		Cost per ton (R) 1982	Grade (g per ton)	Cost per ounce ($)	Person (Rands)
					Cmg.	1983	This	This	This	This
	Deelkrali	N.A	2 791	5.9	997	705	58.16	4.5	350.37	8.88
	Doornfontein	N.A	4 619	9.4	1 053	732	67.74	6.8	271.40	34.01
Gold	Driefontein Cons.	N.A	20 213	14.7	2 163	2 850	58.58	12.8	124.76	131.49
Fields	Kloof	N.A	4 581	19.4	2 949	1 025	71.15	15.2	127.39	155.87
	Libanon	N.A	9 724	7.9	1 122	840	53.04	6.0	242.19	35.19
	Venterspost	N.A	9 973	5.8	876	750	58.37	4.2	382.39	3.24
	Etandsrand	425	2 835	8.1	1 004	1 716	48.72	5.7	236.76	39.76
	F.S. Geduld	476	9 832	11.8	1 444	1 018	72.39	6.5	294.44	21.33
Anglo	P. Brand	476	9 652	10.6	1 697	877	55.60	6.6	223.42	40.61
American	P. Steyn	476	15 351	9.5	1 501	950	57.56	6.6	229.75	38.99
	Southvall	425	9 187	13.6	1 878	3 233	53.17	11.3	131.02	120.48
	VaalReefs	425	24 111	10.4	1 141	6 204	50.98	7.0	204.83	55.47
	W. Deeps	425	6 000	17.6	1 950	3 522	67.83	11.2	169.03	102.83
	W. Holdings	476	18,575	8.9	1 246	2 241	43.92	4.3	273.53	18.08
	Blyvour	425	5 109	18.7	2 040	1 157	60.19	7.5	218.06	51.44
Barlo	Durban Deep	386	5 038	5.2	725	2 366	48.03	3.3	404.96	2.72
Rand	E. Rand Prop.	386	6 609	7.4	1 014	2 814	62.84	3.9	444.50	12.20
	Harmony	425	29 550	6.2	787	3 891	49.52	4.1	327.59	17.94
J.C.I.	Randfontein	397	9 283	9.4	1 354	5 928	28.56	5.0	159.44	48.70
	Western Areas	397	5 407	7.4	1 467	3 776	58.60	4.8	340.78	12.67

Table 6 (cont'd.)

Ore reserves and operating results for South Africa Gold mines 1983

Group	Company	On reserves basis ($/oz)	Tons (000)	Value (g)	Mill throughput: Tonnase Cmg.	Milled (000) 1983	Cost per ton(Rands) This	Gold recovered: Grade (g per ton) This	Cost per ounce($) This	Working profit: Person (Rands) This
	Bracken	493	1 800	5.5	693	245	38.44	3.5	290.20	13.51
General Mining Union Corporation	Buffelsfontein	515	10 651	9.8	1 482	1 659	76.12	9.2	225.08	61.10
	Grootviei	433	4 240	5.0	672	1 855	37.62	3.8	275.33	20.57
	Kinrose	493	9 000	7.7	1 078	500	47.53	6.2	202.68	42.66
	Leslie	493	1 700	5.7	724	290	41.23	3.4	325.22	8.27
	Marievale	433	350	4.6	672	367	37.38	3.3	312.63	14.29
	St. Helena	433	11 300	9.0	1 459	2 270	45.24	6.1	207.49	47.84
	Stilfontein	433	3 947	11.0	1 264	1 789	70.80	6.9	286.81	36.04
	Unisel	493	4 100	7.6	1 481	330	42.10	7.0	177.90	59.97
	W. Rand Cons.	433	6 772	6.0	660	2 218	28.55	1.8	444.24	10.80
	Winkelhaak	493	12 000	6.7	1 012	600	38.16	6.2	162.71	52.14
	E.T. Cons	477	1 526	16.8	3 047	150	88.08	10.2	234.40	65.61
Anglpvaal	Hartebeestfontein	452	19 940	12.0	1 353	1 524	72.15	9.9	197.69	77.28
	Loraine	469	6 342	8.2	868	386	76.91	5.0	403.35	12.72
	Cons. Modderfontein	400	406	5.7	751	141	48.66	4.7	282.69	19.67
	South Roodepoort	400	59	7.5	992	96	58.26	4.0	392.19	1.61
	Wit. Nigel	429	1 313	5.5	483	147	46.53	3.3	387.93	1.86

Source: Supplement to Mining Journal, January 27, 1984.