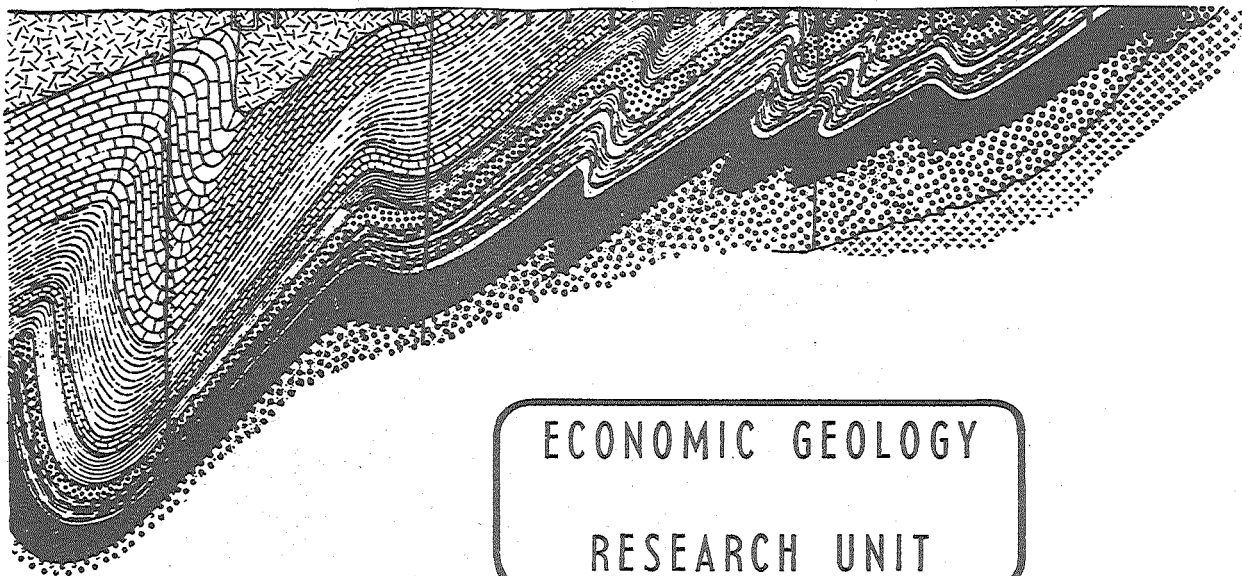




UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG



ECONOMIC GEOLOGY
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INFORMATION CIRCULAR No. 29

SUPERGENE GOLD ENRICHMENT IN THE
BARBERTON MOUNTAIN LAND WITH PARTICULAR
REFERENCE TO THE LILY MINE

C. R. ANHAEUSSER

UNIVERSITY OF THE WITWATERSRAND
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by

C. R. ANHAEUSSER

Research Fellow

ECONOMIC GEOLOGY RESEARCH UNIT

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SUPERGENE GOLD ENRICHMENT IN THE BARBERTON
MOUNTAIN LAND WITH PARTICULAR REFERENCE TO THE LILY MINE

ABSTRACT

A brief account is given of the geology and mineralogy of a small gold mine northeast of Barberton. The mine, essentially an oxidized deposit, is regarded as typical of the numerous small scale mining undertakings that have ceased production with the onset of sulphide ore in the deeper workings of the ore-body.

The relationship between gold fineness and depth in the Lily Mine suggested a form of enrichment in the upper oxidized workings where some exceptionally rich pockets of gold were found concentrated in favourable structural traps. This gold is believed to be essentially of secondary origin, derived from the altered protore and was concentrated by supergene and residual processes of enrichment in the oxidized and semi-oxidized sections of the mine.

The numerous old gold workings in the Barberton area are thought to have been essentially similar types of deposit and it is suggested that many of the richer oxide ore-bodies may indicate a substantially rich gold-sulphide protore hitherto unexamined due to formidable and uneconomic processes of extraction and gold recovery.

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SUPERGENE GOLD ENRICHMENT IN THE BARBERTON
MOUNTAIN LAND WITH PARTICULAR REFERENCE TO THE LILY MINE

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SUPERGENE GOLD ENRICHMENT IN THE BARBERTON MOUNTAIN LAND WITH PARTICULAR REFERENCE TO THE LILY MINE

INTRODUCTION

A detailed account of the stratigraphy, structure, metamorphism and the mineralogy of the Lily Gold Mine was undertaken by the writer (Anhaeusser, 1964), with the aim of trying to establish the reason for the occurrence of several exceptionally rich lenses or pockets of visible gold that were extracted from an ore-shoot in the central section of the mine.

During the course of the investigation factors that were examined suggested that supergene enrichment processes had been operative in the mine which concentrated the gold into rich pockets.

A short description of the geology of the mine is included and the mineralogy of the ore deposit is briefly discussed.

Reasons for advocating that much of the rich gold found in the mine is of supergene origin are presented and some general observations and impressions are given as to the prevalence of supergene gold enrichment processes throughout the Mountain Land.

GENERAL GEOLOGY OF THE LILY MINE

The Lily Gold Mine was, until recently, one of the few remaining small-scale gold mines still in operation in the Barberton District. The mine is located about three miles south of Louw's Creek Station and occurs in rocks of the lower part of the Fig Tree Series. This succession abuts against talcose schists of the Onverwacht Series lying to the north of the mine. Along the contact is the Main Reef Zone which coincides with the Lily Fault and is characterized by sheared, silicified and brecciated rocks.

The Fig Tree succession consists of narrow alternating bands of shale, banded ironstone, cherts, graywackes and their metamorphic alteration products.

In addition to the Main Reef there are several other reefs to the south consisting of vein quartz. These veins fill shear zones in the vertically dipping strata. In the central portion of the mine is a plunging pipe-like ore-shoot that pinches out with depth. The shoot structure is complex, consisting of brecciated country rock with replacement veins of quartz filling the fractures and breccia cavities.

The formations in the mine are deformed and are folded into tight isoclinal structures. The bedding is in all cases vertical or steeply dipping and is affected by two sets of fracture systems, the one vertical and the other a cross-cutting flat fracture type. In some instances the intersection of the two fracture systems was found to have a direct bearing on the occurrence of pay zones.

Although the Main Reef Zone proved to be the most consistent lode in the mine, several other reefs, often containing free gold, were worked. These other reefs nearly always proved to be erratic.

The Main Reef was first worked from surface where the ore was quarried. As the quarry became deeper, it became necessary to drive several cross-cutting adits northwards into the hillside to intersect the ore zone at a lower level. The adits intersected several other reefs to the south of the Main Reef and in the central portion of the mine on 1 Level, four such reefs were located and developed laterally.

The Mill adit in the eastern portion of the mine began as a cross-cut but reverted to a drive parallel to the formations and continued to the area immediately below the development on 1 Level. This level, known as 2 Level, began in oxidized strata which gradually altered westwards into sulphide or fresh rock material.

An intermediate level known as 1½ Level was established in the semi-oxidized zone between the two main levels.

Higher up in the mine above the 1 Level, there are several intermediate levels the more important of which have proved to be the 70 Ft. Level and the Surface Level. Both these, as well as other intermediate levels, occurred in oxidized rock and development was curtailed to the west due to the presence of sulphide material.

The zone of oxidation throughout the mine parallels, approximately, the slope of the surface of the hill and extends to a depth of between 150 and 200 feet before sulphide or fresh rock is encountered. In the pipe-like ore shoot the zone of oxidation was depressed below the average level due to the easy passage of oxygenated solutions in the brecciated, folded and faulted strata (Figure 1).

The nature of the reef fractures and the ore-shoot in the central section of the mine has been discussed elsewhere (Anhaeusser, 1965) where it was shown that a cymoid structure formed as a result of strike-slip or wrench faulting along the Lily Fault. The cymoid structure also provided a favourable structural trap for some of the mineralizing solutions that invaded the mine area.

The Main Reef Zone proved to be the most consistent lode with an average grade in the oxidized ore of between 3 and 5 dwts. Au/ton. The remaining reefs were not consistent but often contained abundant free gold and occasionally rich pods were encountered at intervals along the quartz veins. The pipe-like ore-shoot provided the loci for about six "bonanza" gold pods (Bateman, 1958, used the term "bonanza" to designate exceptionally rich shoots of ore particularly with reference to gold or silver deposits), whereas the brecciated material contained ore with a good average grade. An indication as to the amount of gold produced from both the Lily workings and the Rose's Fortune Section of the Lily Mine is given in Table 1.

The Rose's Fortune Section - about a mile east of the Lily workings occurs in the same stratigraphic position as the latter deposit. Since oxidized ore from the Rose's Fortune Section was found to be identical to the oxidized material from the Lily workings, the ores were blended prior to simultaneous milling. No separate figures were kept for the two workings but approximately 80 per cent of the ore was obtained from the Lily Mine.

The "bonanza" gold pockets were extracted between December, 1959, and November, 1960, when approximately 5,480 fine ounces were recovered and between January, 1961, and October, 1961, when approximately 2,030 fine ounces were extracted. Thus, 7,510 fine ounces of gold, representing approximately 40 per cent of the total gold output of 18,843 fine ounces were recovered from about 6 rich pockets between July, 1958, and 31st March, 1963.

Gold Production from the Lily Mine for the Years 1959 to 1963

TABLE 1

| <u>Period</u> | <u>Tons Milled</u> | <u>Fine Ounces Gold Recovered</u> |
|-----------------------------------|--------------------|---------------------------------------|
| 1st July, 1958 - 30th June, 1959 | 17,288 | 2,470.10 |
| 1st July, 1959 - 30th June, 1960 | 10,660 | 6,729.84 |
| 1st July, 1960 - 30th June, 1961 | 10,469 | 4,903.52 |
| 1st July, 1961 - 30th June, 1962 | 10,713 | 2,740.83 |
| 1st July, 1962 - 31st March, 1963 | <u>9,146</u> | <u>1,999.19</u> |
| TOTAL | <u>58,276</u> | <u>18,843.48</u> |

MINERALOGY OF THE LILY MINE

The ore suite from the Lily Mine contained ten minerals in addition to the gangue or country rock. The most abundant ore mineral found was pyrrhotite, followed in order of abundance by arsenopyrite, magnetite, pyrite, melnikovite-pyrite, chalcopyrite, hematite, limonite, goethite and gold. Silver was notably absent from the sections studied but it occurred as the gold/silver alloy known as electrum. The presence of silver could only be determined by assay methods.

Apart from the pyrrhotite and arsenopyrite the remaining minerals were present only in small amounts.

The gangue varied considerably throughout the mine but generally consisted of quartz, carbonate, amphiboles, tourmaline, chlorite and clay minerals. The quartz occurred in several forms and varied from white to blue-gray and in the hand specimen was either frosted or translucent. Massive bodies of cherty quartz were encountered in all sections of the mine.

A. PYRRHOTITE

Practically all the sulphide ore examined contained pyrrhotite. In places it occurred as massive replacement bodies, especially in the brecciated ores on and below 2 Level. Veins, irregular masses and particles with allotriomorphic form were encountered throughout the mine. The mineral was often concentrated in bands and occurred interstitially between laths and radiating needles of tremolite-actinolite. Under the microscope pyrrhotite was seen either replacing or being replaced by most of the ore and gangue minerals in the suite.

Euhedral crystals and fragments of arsenopyrite were found to be partly replaced or entirely surrounded by the latter pyrrhotite. Etching of the corners of arsenopyrite crystals was common but replacement was seldom complete. The pyrrhotite itself, lacked external crystal form and was usually moulded within its surroundings, or was pseudomorphous after earlier ore minerals and gangue.

Frequently seen associated with the pyrrhotite aggregates were small irregular particles of exsolved chalcopyrite. Pentlandite, often an associate of pyrrhotite, was entirely absent from the Lily ore suite. In only rare instances was pyrite seen together with the pyrrhotite. The former mineral generally occurred as "islands" surrounded and replaced by the latter. In the partially altered zones on 1 Level and in some sections on 2 Level both pyrite and melnikovite-pyrite were found replacing pyrrhotite.

B. ARSENOPYRITE

Arsenopyrite commonly accompanied pyrrhotite but never in any great amount.

Like the pyrrhotite it occurred at times as bands in the ore but this was rare. The mineral occurred essentially as individual or aggregate groups of idiomorphic crystals. The arsenopyrite was fairly resistant to replacement but some etching of the grains by pyrrhotite was noted. Pyrite was found replacing arsenopyrite in ore obtained from the semi-oxidized sections of the mine.

C. CHALCOPYRITE

This mineral was nearly always associated with pyrrhotite but never occurred in great amounts. Its presence was suspected prior to microscopic examination due to the minute displays of iridescence seen on tarnished ores. Laths of irregular, intimate inter-growths of the chalcopyrite with pyrrhotite as seen under the microscope, showed mutual boundary relationships and suggested the contemporaneous formation of the two minerals. Chalcopyrite was also seen together with pyrite and melnikovite-pyrite where it occurred replacing the latter mineral.

D. PYRITE

Pyrite was noted only in a few specimens of the ore. The mineral occurred as aggregates or individual crystals allotriomorphic to idiomorphic in form. Specimens from 2 Level contained pyrite together with pyrrhotite and melnikovite-pyrite. Generally the relationship between pyrite and pyrrhotite was not clearly ascertained.

The pyrite often exhibited replacement textures and a few idiomorphic crystals were suggestive of pseudomorphism after arsenopyrite.

E. MELNIKOVITE-PYRITE

Melnikovite-pyrite consists essentially of a gel of FeS and FeS_2 , with or without the presence of some arsenic (As).

This mineral was not very common and was found mostly in zones of partial alteration. It occurred closely associated with pyrite, arsenopyrite and chalcopyrite. The mineral had a "colloform" texture (the term implies a colloid or gel texture) and occurred as botryoidal, reniform or mammillary shapes arranged in concentric layers (Figure 6). Pyrite was seen grading into irregular allotriomorphic aggregates of melnikovite-pyrite. Quartz particles often formed the cores of the concentric layers. A few radial cracks were noted but concentric spheroidal cracks were more common. Pyrrhotite was seen to replace both melnikovite-pyrite and arsenopyrite in the same section and the melnikovite-pyrite in turn was found to corrode and replace the arsenopyrite aggregates.

Melnikovite-pyrite, an unusual mineral, has only been reported from a few occurrences throughout the world. It has been described by Schneiderhöhn and Ramdohr (1931) and is considered by them to have formed by supergene processes. Before them, however, Smitheringale (1928) described crystalline aggregates arranged in circular form about centres of quartz or chlorite from the George Gold-Copper Mine, Stewart, British Columbia.

De Villiers (1957), in addition to describing the melnikovite-pyrite in the Lily Mine, also found it to be fairly common in the Barbrook Mine and in the Pigg's Peak Mine in Swaziland. Schweigart and Liebenberg (1965) also described the occurrence of melnikovite-pyrite in ores of the Fairview and Sheba mines, and the mineral was regarded by these authors as a second generation pyrite.

It appears from the literature as well as from the present study that the mineral is restricted to zones of alteration where supergene effects have been operative.

F. MAGNETITE

Magnetite was seldom noted in the pyrrhotite ores but occurred locally, especially in some folded areas on 1 Level. The ore was found to be strongly magnetic and occurred in massive banded form in the strongly folded shales. Microscopic examination showed that the magnetite occurred as idiomorphic crystals entirely disconnected from one another in the sedimentary and silicate matrix. Even in the tight hinge zones of folds the grains showed no evidence of having been deformed and apparently developed subsequent to or synchronous with the deformation. A few grains of hematite were seen with the magnetite, the former clearly derived from the latter by oxidation.

G. HEMATITE

Hematite was seen under the microscope in polished sections of samples from both oxidized and semi-oxidized ores. In the latter ore it was found to be clearly pseudomorphous after magnetite with at times, the entire crystal having been replaced whereas in other instances cores of unaltered magnetite were enclosed in hematite.

The presence of pseudomorphs of hematite after magnetite in partly sulphidic ore is clearly evidence of oxidation of the magnetite.

H. LIMONITE AND GOETHITE

These two ferruginous minerals frequently occurred together and were formed in situ by hydration of the iron oxides of the banded ironstones and magnetite-hematite minerals. The limonite is largely responsible for the variety of colours ranging from earthy yellow to brick-red found in the oxidized parts of the mine. Both minerals are very soft and occur filling fracture planes and cavities in the ore zones. The minerals also display colloform banding and botryoidal structures in cavities in the brecciated zones.

All the ferruginous mineral assemblages mentioned above (i.e. magnetite, hematite and limonite - goethite) are present throughout the mine and were for the most part original primary constituents of the sedimentary sequence. Some of the magnetite and hematite was probably introduced by hydrothermal solutions but it appears more likely that the original material in the sediments became recrystallized.

I. GOLD

Gold occurred widely, but erratically, throughout the workings. It was associated with sulphide ore from 2 Level and below where it was found in the rock as veins sometimes 1/16th of an inch thick. More generally, however, the gold was associated with quartz only. Where it occurred as free gold it was usually extremely rich and was frequently found as flattened leaves, plates, particles or veins (Figure 7).

The gold itself revealed no obvious textures but was largely moulded by its environment. Disseminated particles of gold at times formed stringers a few microns wide in quartz veins. Frequently the gold behaved similarly to the pyrrhotite in that it occurred interstitially between bladed amphibole crystals or as replacement fillings in quartz (Figures 4, 5, 6).

Idiomorphic crystals of arsenopyrite, fractured as a result of shearing were found either partly replaced by, or often entirely surrounded by, gold. Under high powered magnification minute gold particles were seen to be trapped within arsenopyrite-gudmundite crystals from the winzes below 2 Level.

THEORETICAL CONCEPTS FOR ENRICHMENT

Numerous papers have been written discussing the processes, both physical and chemical, necessary to produce secondary enrichment of gold. It should be realized immediately that when discussing supergene enrichment of gold, its scale and intensity should not be compared with that of sulphide secondary or supergene enrichment processes. Gold is notably a noble metal but this does not preclude some dissolution from taking place.

Krauskopf (1951) working on the solubility of gold, confirmed earlier findings of Emmons (1917), Ogryzlo (1935), Zvyagintzev and Paulsen (1938 and 1940) and Smith (1943), who found that the greatest and most essential requirement was that the gold be oxidized. They found naturally occurring oxidizing agents, capable of oxidizing gold to consist of MnO_2 , O_2 , Fe^{+++} and Cu^{++} , but at ordinary temperature neither H^+ nor SO_4^{--} were sufficiently strong oxidizers to dissolve gold appreciably. Krauskopf (1951) suggested that in sulphide solutions gold occurred as a stable, complex ion, probably AuS^- whereas in alkaline solutions it was insignificantly soluble unless a sulphide was present. He also stated that in acid solutions gold may be transported as the ion AuCl_4^- , provided reducing agents were absent. In addition gold may also occur in solution as AuCl_3 . i.e.

$$\text{Au} + 3\text{Cl} = \text{AuCl}_3 + 27 \text{ K cal/g. mol.}$$

Krauskopf (1951) prescribed the requirements for dissolving gold and stressed that an acid solution containing Cl^- and a strong oxidizing agent must be present. Furthermore, he considered that solution and transportation of gold in acid solution was probably the mechanism of supergene movement of gold. More recently, Phillips (quoted in Garrels, 1960) portrayed the effects of sulphide and chlorite complexing of gold on an Eh-pH diagram. Many of the relations were based on Krauskopf's study of the solubility of gold. Ionic activities at low and high chloride and sulphur contents of the system were depicted. In the presence of high chloride gold was found to be somewhat soluble in acid oxidizing solutions as AuCl_4^- . With high sulphur, a little gold dissolved as the AuS^- complex over a wide range of strongly reducing conditions. Garrels (1960), considered that both the relationships were of geological interest; the first because of the possibility of transport of gold during oxidation of sulphide ores, and the second because of the problem of transporting gold in vein forming fluids.

Rankama and Sahama (1950) stated that gold is readily dissolved and transported, probably largely in colloidal solutions, which may deposit it even at low temperatures. Any gold dissolved from gold ores in the zone of oxidation, they added, would be redeposited in the cementation zone in which a secondary enrichment may sometimes take place.

The effects of temperature and pressure on the solubility of gold have been investigated by McCaughey (1909), Ogryzlo (1935), and Zvyagintsev and Paulsen (1940). The findings indicated that any gold solution appears to be able to hold more gold at high temperatures than at low temperatures. Thus, simple cooling of the solution provides an adequate mechanism for the deposition of the metal from vein solutions. Also from general considerations it appears that in most solutions gold is more soluble at high pressures than at low pressures, and can accordingly be precipitated by release of pressure.

Precipitation of gold from solution may further take place by reaction with sulphides or partly altered sulphidic material or even organic matter. (Emmons, 1918).

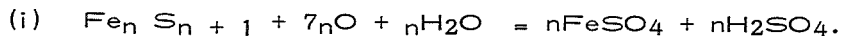
The time factor involved in gold dissolution has not received much attention and very little is known regarding this matter. Gold solubility is small under laboratory conditions even when the most favourable chemical conditions for its dissolution are arranged. Just what effects geological time has on the dissolution of gold, where suitable chemical environments are available, remains an unknown, yet probably significant factor.

PRACTICAL CONCEPTS

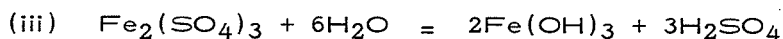
A. SUITABLE ENVIRONMENT

Having the theoretical as well as experimental knowledge of the chemistry involved for gold dissolution and precipitation to take place, all that now remains is an examination of the chemical environment present in the Lily Mine itself. As was seen from the experimental work gold requires an acid environment for solution to take place. Acid is generated by oxidation of sulphides - particularly iron sulphides. The main ore mineral in the mine was shown to be pyrrhotite with minor amounts of arsenopyrite, pyrite and chalcopyrite also present.

The pyrrhotite, although possessing a variable amount of sulphur, still reacts similarly to pyrite on oxidation forming ferric sulphate and sulphuric acid. Bateman (1958):-



The reaction goes further and ferric sulphate hydrolyzes to ferric hydroxide and more sulphuric acid.



Chlorine, according to Emmons (1917), although essential for reaction and solution to take place, need only be present in small amounts. He mentioned that sufficient chlorine was usually available in natural waters and in salts in rock strata.

The banded ironstones and shales of the Fig Tree Series contain some manganese and would aid the production of "nascent" chlorine necessary for the effective dissolution of the gold. The sulphide minerals thus, could supply an acid environment with the altered pyrrhotite probably producing dilute sulphuric acid and ferric iron Fe^{+++} , as well as minor amounts of copper Cu^{++} , which would become available as effective oxidizing agents. The gold thus taken into solution would probably be reprecipitated, as previously indicated, by reaction of the solution with sulphides or partially altered sulphidic material where too little MnO_2 was present to overcome the effects of the precipitating agents, ferric sulphate and pyrite.

The availability of suitable structural traps and brecciated zones in the mine also assisted the concentration of gold from solution.

PRESENTATION OF EVIDENCE

Practically all the smaller mines and prospects in the Barberton Mountain Land ceased production once the oxidized ores of the mines gave way to sulphide ores. The cessation of gold production from these mines has been interpreted as being primarily due to the nature of the ore from the point of view of extraction.

Initially oxidized ore was mined and this material presented no complications as it was free milling and gold recovery inexpensive. The unoxidized or sulphidic and arsenical ores on the other hand, being refractory, resulted in higher production costs.

Roper (1958) considered that enrichment of gold by residual concentration and supergene chemical agencies in the oxidized zone was of greater importance in that it had enriched certain zones to such an extent that even small scale mining could be attempted. Numerous examples of gold mines that formerly possessed high gold values in the oxidized zone have been listed by Boardman (1950). He mentioned that large bodies of oxidized ore were mined from the Maid-of-the-Mountains, Montrose, Princeton, Florence-Devonian, Eagle's Nest, Barbrook, French Bobs and Maid-of-the-Mist mines. Similarly oxidized ores were mined from the Makonjwa and the Daylight ore deposits as well as the Lily Mine.

The oxidized, free-milling reserves of most of the mines in the Barberton Mountain Land have since been depleted and all that now remains in most instances are low grade sulphide ores, the mining of which appears entirely dependent upon successful and profitable reduction processes being initiated. Investigations in the Lily Mine (Anhaeusser, 1964) of the bulk accumulation of gold within the ore-shoot, and to a lesser extent, in certain of the reefs and shear zones, immediately suggested an unusual mode of deposition. The extraordinary concentration of gold in pockets did not appear to be entirely primary and the probability of residual or supergene enrichment of the lodes was considered.

The upper levels of the mine are entirely composed of oxidized ores and most of the mining operations were curtailed once sulphide material was encountered. In the fresh or sulphide-bearing rock the gold is no longer free milling and extraction costs rise prohibitively as roasting of the ore is necessary. Visible gold, apart from rare exceptions, becomes non-existent in the fresh rock from the deeper parts of the mine, but nevertheless occurs sub-microscopically, encased in sulphides. This is borne out by four samples of sulphide ore from various localities in the mine.

- | | |
|-------------------------------|-------------------|
| (i) Main Reef Zone on 2 Level | 39.1 dwts Au/ton. |
| (ii) Winze below 2 Level | 0.3 dwts Au/ton. |

| | |
|---|-------------------|
| (iii) Ore between the Main Reef and the Winze (2 Level) | Nil |
| (iv) 70 Ft. Level (western zone) | 1.35 dwts Au/ton. |

In none of these samples was gold visible under the microscope.

The Main Reef furnished the highest gold values. This fact is regarded as significant for it is considered probable that a large proportion of the gold mineralization found elsewhere in the mine had its origin in the Main Reef Zone.

The oxidized sections of the mine contained the bulk of the easily extractable gold and the replacement textures of the gold in polished sections studied from most parts of the workings indicated a late introduction for much of this metal (Figures 4, 5, 6).

To present evidence of secondary enrichment, samples of panned concentrates were obtained from four levels in the Lily Mine. These concentrates were collected over a period of six weeks. The samples consisted of daily pannings of ore from development ends and stopes on each level. The concentrates were regarded as representative of the ore at each sample locality. In addition each sample was taken to be representative of the particular depth zone below surface and the 2600 ft. datum plane.

The samples were assayed by Gold Fields Laboratories, Johannesburg, for gold and silver. The tolerance of the method of assay was given by this laboratory as 0.5 parts per 1,000 parts. Two of the samples were obtained from entirely oxidized sections of the mine, a third was collected from the transitional zone between 1 and 2 levels and the fourth sample was obtained from sulphide ore below 2 Level. (See Figure 1 for sample localities).

Table II below gives the average depth of the samples below surface as well as a depth in relationship to a datum plane. In addition, the assay results for the gold and silver samples are listed.

Depth of Levels from which Samples were Taken
and their Gold and Silver Content

TABLE II

| Sample | Level | Average Depth Below Surface | Depth Below 2600' Datum Plane | % Au. | % Ag. |
|--------|--------------|-----------------------------|-------------------------------|-------|-------|
| 1 | 70 Ft. Level | 110 feet | 200 feet | 91.50 | 8.50 |
| 2 | 1 Level | 130 feet | 260 feet | 91.15 | 8.85 |
| 3 | 1½ Level | 160 feet | 340 feet | 90.28 | 9.72 |
| 4 | 2 Level | 230 feet | 420 feet | 89.04 | 10.96 |

From the table above two graphs were drawn (Figures 2 and 3), the one showing the depth of sample against percentage of gold and the other showing depth against percentage of silver. Also indicated on the graphs are the relative positions of the oxidized, transitional and sulphide zones with respect to the samples. Calculations of the correlation coefficient between the fineness of gold and the depth below surface and between the

fineness of gold and the depth below the 2600 ft. datum plane gave values of -0.995 and -0.984 respectively, both of which are regarded as being significant. Hence, these correlation coefficients show that a significant relationship exists between the fineness of gold and the depth at which the sample was taken in the Lily Mine.

The gold from the upper levels clearly possesses a greater fineness than the gold extracted from depth. With increasing depth below surface the silver content of the bullion increases. The fate of the silver in the upper levels is not known as an opportunity was not available for a more thorough study to determine whether the Ag content of the shales in the areas where gold enrichment took place was significantly different to the Ag values of Fig Tree shales in unmineralized areas. Hence, it is impossible to say definitely whether the increased fineness of gold near the surface is due to the enrichment of the original ore by the addition of gold or whether it is due to the extraction of silver from the original ore by leaching processes.

However, in general it has been found by several investigators, among them Fisher (1945), that gold fineness or purity increases with depth, indicating that at higher temperatures gold is precipitated before silver. In the Barberton Mountain Land Gay (1964), confirmed this observation when he found the gold fineness in the Sheba Mine increased steadily with depth. Thus, in hydrothermal gold deposits, the silver content should under normal circumstances, increase from below upwards towards surface. The gold-silver relationship in the Lily Mine is, therefore, in direct contrast to these findings.

Some mention should also be made of the nature of the gold occurrences in the oxidized workings of the mine. In the narrow quartz vein reefs the gold was often present as "visible" gold and occurred filling cracks in the quartz or forming thin platy flakes between the quartz vein and the sheared wall rock (Figure 7).

In the brecciated shoot the gold was often found in pockets occurring as flakes, sheets, and stringers often so matted together that at times, several hundred ounces of gold could be recovered from a single hand specimen. The visible gold extracted from the various reefs and the pipe-like ore-shoot was mostly recovered by amalgamation whereas the gold from the remaining ore was liberated by grinding and mostly recovered by cyanidation.

No records were kept at the Lily Mine of the fineness of the amalgamated gold as opposed to the fineness of the gold recovered from the cyanide process. It was noted, however, that the amalgamated material always gave a greater percentage gold recovery. In this respect a marked similarity exists with observations made in Tanganyika (now Tanzania) and Nigeria by Mackay (1944). He examined 40 mines and found that in all cases gold recovered by amalgamation was of a greater fineness than that recovered by cyanidation. He concluded that the divergences in the Au-Ag ratio of the coarse or amalgamated fraction and the fine or cyanided fraction were proportional to the secondary enrichment, with the gold formed by this process having less silver than the primary gold of the same orebody.

Proof that gold occurs in solution in the river and mine waters of the Barberton Mountain Land is afforded by Roper (1958). He mentioned that gold was precipitated electrolytically from solution using carbon electrodes. Scrapings from the electrodes which had been immersed for several months in the water present in a disused mine situated on the Ottoman Reef (Rimer's Creek area, immediately south of Barberton Townlands), gave assay values of over 150 ozs. of gold per ton of sample. Roper (1958) further indicated that the presence of gold in the soluble salts of the mine waters had been proved by spectrographic determination. The concentration of the gold was found to be only 0.001 per cent of the soluble salts due, no doubt, to the fact that the pH value of the waters examined was 7.8

GENERAL CHARACTERISTICS OF OLD MINES AND PROSPECTS

It is interesting and significant to note some general characteristics demonstrated by old workings and prospects in the Barberton Mountain Land. Invariably the surface workings consist of broad quarries on the downslope side of the ore bodies. On a somewhat smaller scale stopes often follow the ore zones downwards and become narrower with depth. In many cases stopes occur beneath the quarries.

Mining operations without exception occur in oxidized material and invariably cease once the sulphide zone is encountered. Many of the workings occur in groups especially along major regional fault zones such as the Sheba and Barbrook Faults.

In many cases where exceptionally high gold values were obtained the workings defined an ore shoot or even a series of pipe-like structures. Often these shoots extended the oxidized or semi-oxidized zones, depressing the sulphide boundaries deeper than the average regional depth below surface.

Very often also, the quarries were developed in order to work gold in the zone of alluvial concentration. The quarries being on the downslope side of the ore bodies enabled creep of rock debris and rain wash to transport gold in that direction.

Roper (1958) contended that in this zone of alluvial gold concentration, residual enrichment together with supergene effects gave rise to the high values which led to the peak production of the earlier days. Visible gold was often observed in these ores whereas in the ores mined at present this is seldom the case.

Recently, mining groups have investigated the grade of many of the sulphide bodies that remained unmined by the earlier workers and it would appear that many of the deposits have a low grade protore. Thus, it is almost certain that some form of enrichment must have taken place in the oxidized formations to demand the attention of the early prospectors.

On the other hand, numerous sulphide ores were found to have a sufficiently high tenor to warrant reconsideration from the mining viewpoint. A major disadvantage has been the relatively low tonnage that can be expected from most of the deposits. However, there are several areas where numerous old workings occur together and where it may be possible to obtain sufficient ore to warrant the establishment of a single, central reduction works. Roper (1958) also commented on the use of the grade of the secondary ore to gain some insight into the tenor of the protore. The secondary material, he stated, was in general about twice to three times the grade of the sulphide ore.

The implication of this statement has a decided economic significance as it suggests that mines established to exploit rich secondary or oxidized ores may have a protore of sufficiently high grade to warrant mining under present day conditions. Conversely, it might be expected that mines formerly established to work low grade oxidized material would have a protore with a relatively meagre gold content and would, therefore, not justify mining.

Boardman (1950) noted that it was significant that many of the "old" mines were located high up in the mountain ranges where prominent topographic variations occurred. He further observed that in the highly dissected areas oxidation of the formations extended to greater depths below the high ground, due primarily, to the rapid and repeated deep penetration of oxygenated rain-water, whereas in the valleys sluggish groundwater conditions prevented much oxidation taking place. Hence the conditions for secondary gold enrichment

processes to operate effectively appear to be restricted primarily to areas where efficient oxidation of the auriferous formations can occur.

CONFIRMATORY EVIDENCE SUPPORTING SUPERGENE ENRICHMENT

Confirmatory factors, indicative of supergene processes of enrichment that had taken place in the Lily Mine, are afforded by several mineral associations that can be studied in the ore suite of the mine.

There is firstly microscopic evidence of hematite forming at the expense of magnetite. This process clearly indicates that oxidation had taken place with the production of pseudomorphs after magnetite. Hematite has in turn been further oxidized to limonite and goethite. This entire process took place in the oxidized or semi-oxidized zone of alteration in the mine.

The presence of melnikovite-pyrite in some of the ore is also further indication of secondary processes of solution and reprecipitation within the altered zones. All the mineralogical descriptions of the nature and occurrence of this mineral clearly indicate that it is a second generation mineral formed without doubt as an alteration product of pyrite or pyrrhotite in the zone of weathering or oxidation. The presence of spheroidal contraction cracks and concentric banding suggests further, that the mineral was deposited in colloidal form.

Further testimony as to the suggested supergene nature of the gold in parts of the mine is afforded by the low silver content of the gold bullion found in the upper sections of the deposit. The lack of silver is not ascribed to leaching of the metal from the rich pockets mainly because no silver minerals or compounds were found in any of the polished sections examined from the ore-suite of the Lily Mine.

Hence it is considered that the gold was reprecipitated from solutions low or even entirely devoid of silver.

CONCLUSIONS

The gold recovered from the Lily Mine occurred primarily in veins and reefs and in pronounced zones of disturbance. Clearly the passage of gold bearing solutions was more advantageously afforded by the greater permeability of the breccias and fractures, with primary hydrothermal deposition in these areas probably continuing for longer periods.

After oxidation near the surface, gold from the higher reaches of the deposit could conceivably have infiltrated the brecciated areas in the form of auriferous solutions that reprecipitated in the new environment. This later gold was probably liberated from the altered sulphides in a manner similar to that explained earlier in this paper and made its way down suitable channelways to be reprecipitated and concentrated in structurally controlled loci below.

Much of the gold is considered by the writer to be of supergene or secondary origin especially in the oxidized zones of the mine. The depositional sequence apparently overlaps i.e. some gold formed simultaneously with the sulphides and was trapped within the latter, whereas the remaining gold occurred later in the sequence.

Although the writer advocates the idea of supergene processes of enrichment he does not preclude the possibility that alternative mechanisms could also have been partly involved. The removal in solution of some of the other constituents of the primary ore such as Fe, S, As and Cu could concentrate the gold by the process known as residual enrichment. A gradual accumulation of gold would result from a volume decrease of the rock in which the metal formerly occurred in trace amounts.

Although residual enrichment might well have taken place in some localities the occurrence of the gold in the brecciated ore-shoot cannot entirely be explained by this mechanism. The only remaining alternatives are :

- (i) A primary origin, with precipitation and deposition from hydrothermal solution or,
- (ii) A secondary origin of a supergene nature.

A primary origin for the rich gold pockets which occur solely in the oxidized zone is also an inadequate explanation as further pockets or even traces of gold should have continued with depth. Extended winzing on the ore-shoot in the sulphide zone failed, however, to reveal any further trace of visible gold.

The writer therefore considers that sufficient factual as well as circumstantial evidence has been presented to allow consideration of the process of supergene enrichment of gold in the Barberton Mountain Land.

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Acknowledgement

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List of References Cited

- | | | |
|-------------------|--------------|--|
| Anhaeusser, C.R. | 1964 | The Geology of the Lily Syncline and Portion of the Eureka Syncline between Sheba Siding and Louw's Creek Station, Barberton Mountain Land. Unpub. M.Sc. thesis, University of the Witwatersrand, Johannesburg. |
| Anhaeusser, C.R. | 1965 | Wrench Faulting and its Relationship to Gold Mineralization in the Barberton Mountain Land. Inform. Circ. No. 24, econ. Geol. Res. Unit, University of the Witwatersrand, Johannesburg. |
| | <u>also:</u> | Annex. Trans. geol. Soc. S. Afr., Vol. 68. (1965). |
| Bateman, A.M. | 1958 | Economic Mineral Deposits. John Wiley and Son, Inc., New York. |
| Boardman, L.G. | 1950 | Preliminary Report on the Economic Geology of the Barberton Gold Mining Area. (with text figures). Unpub. Rep. geol. Surv. S. Afr. |
| De Villiers, J.E. | 1957 | The Mineralogy of the Barberton Gold Deposits. Bull. Geol. Surv. S. Afr., Vol. 24. |
| Emmons, W.H. | 1917 | Enrichment of Ore Deposits. Bull. 625, U.S. Geol. Surv. |
| Emmons, W.H. | 1918 | The Principles of Economic Geology. McGraw-Hill Book Company, Inc., New York. |
| Fisher, N.H. | 1945 | The Fineness of Gold - with Special Reference to the Morobe Goldfield - New Guinea. Econ. Geol., Parts 1 and 2, Vol. 40. pp. 449-495 and 537-563. |
| Garrels, R.M. | 1960 | Mineral Equilibria. Harper and Brothers, New York. |

- | | | |
|---|------|--|
| Gay, N.C. | 1964 | The Composition of Gold from the Barberton Mountain Land. Inform. Circ. No. 19, econ. Geol. Res. Unit, University of the Witwatersrand, Johannesburg. |
| | | <u>also:</u> Annex. Trans. geol. Soc. S. Afr., Vol. 68. (1965). |
| Krauskopf, K.P. | 1951 | The Solubility of Gold. Econ. Geol., Vol. 46. pp. 858-870. |
| Mackay, R.A. | 1944 | The Purity of Native Gold as a Criterion in Secondary Enrichment. Econ. Geol., Vol. 39. pp. 56-68. |
| McCaughey, W.J. | 1909 | The Solvent Effect of Ferric and Cupric Salt Solutions upon Gold. Amer. Chem. Soc. Jour., Vol. 31. pp. 1261-1270. |
| Ogryzlo, S.P. | 1935 | Hydrothermal Experiments with Gold. Econ. Geol., Vol. 30. pp. 335-345. |
| Rankama, K., and Sahama, Th. G. | 1950 | Geochemistry. Univ. Chicago Press, Chicago, Illinois, U.S.A. |
| Roper, H. | 1958 | Factors Supporting a Theory of Supergene Enrichment of Gold in the Barberton Area. Unpub. Report (submitted to the Geol. Soc. S. Afr.). |
| Schneiderhöhn, H., and Ramdohr, P. | 1931 | Lehrbuch der Erzmikroskopie. Vol. 2, Gebrüder Borntraeger, Berlin. |
| Smith, F.G. | 1943 | The Alkali Sulphide Theory of Gold Deposition. Econ. Geol., Vol. 38. pp. 561-590. |
| Smitheringale, W.V. | 1928 | Mineral Association at the George Gold-Copper Mine, Stewart, B.C. Econ. Geol., Vol. 23. pp. 193-208. |
| Schweigart, H., and Liebenberg, W.R. | 1965 | Mineralogy and Chemical Behaviour of Some Refractory Gold Ores from the Barberton Mountain Land. Annex. Trans. geol. Soc. S. Afr., Vol. 68. (1965). |
| Zvyagintsev, O.E., and Paulsen, I.A. | 1938 | Concerning the Action of Minerals in Gold Solutions. Comptes rendus, Acad. Sci., U.S.S.R., Vol. 21. pp. 176-178. |

- Zvyagintsev, O.E., and Paulsen, I.A. 1940 Contributions to the Theory of Formation of Vein Gold Deposits. Comptes rendus, Acad. Sci., U.S.S.R., Vol. 26. pp. 647-651.

Key to Figures

PLATE 1

- Figure 1 East-west section of the central portion of the Lily Gold Mine showing the pipe-like ore shoot, the rich gold pockets and the assay sample localities.
- Figure 2 Graph showing the percentage decrease of gold fineness with depth below surface and the 2600 ft. datum plane, Lily Mine.
- Figure 3 Graph depicting an increase in the percentage silver content with depth below surface and below the 2600 ft. datum. Lily Mine.

PLATE 2

- Figure 4 Gold (grey) occurring interstitial to radiating blades of tremolite-actinolite. Locality - above 1 Level (reflected light x 35).
- Figure 5 Gold (grey) replacing quartz. Locality 70 Ft. Level (reflected light x 35).
- Figure 6 Colloform (concentric) banding of melnikovite-pyrite 2 Level, Lily Mine (reflected light x 150).
- Figure 7 Photograph showing a thin flaky plate-like film of gold (white) in oxidized Fig Tree shales. Locality 70 Ft. Level. Lily Mine.

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PLATE 1

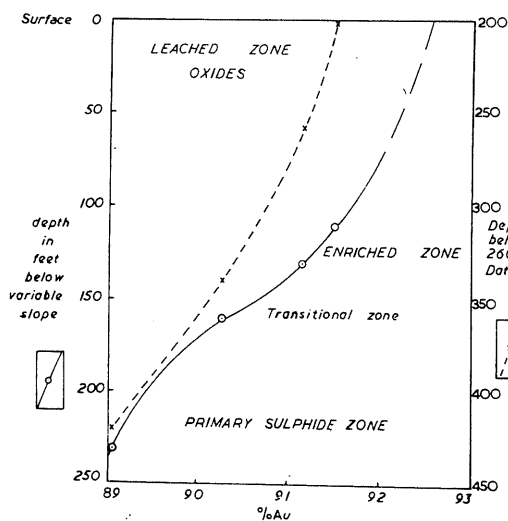
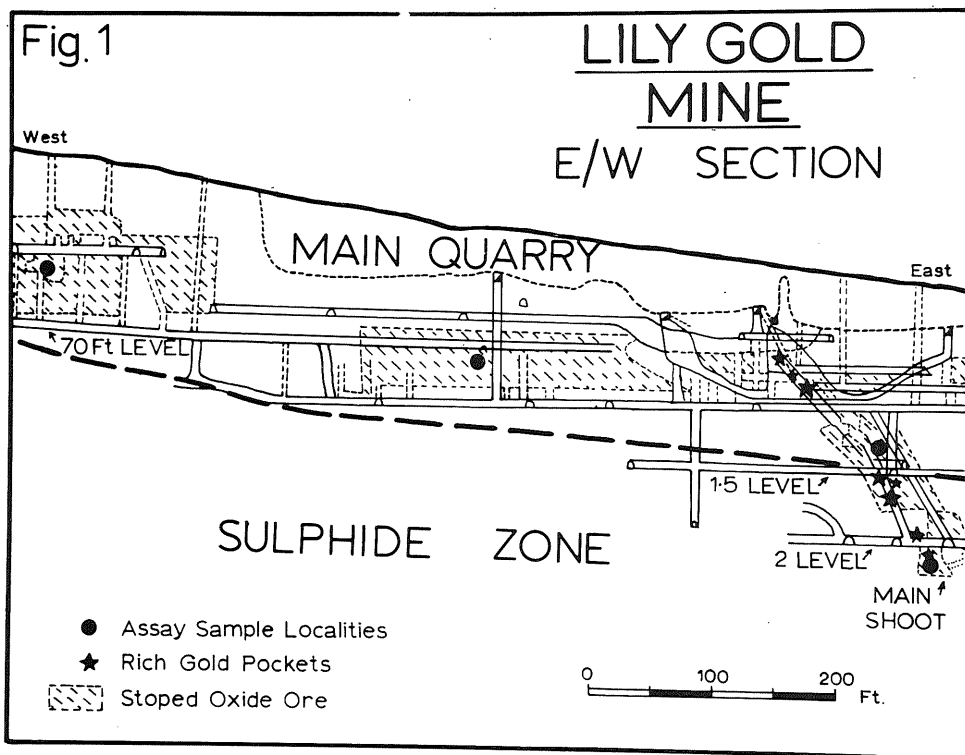


Fig. 2

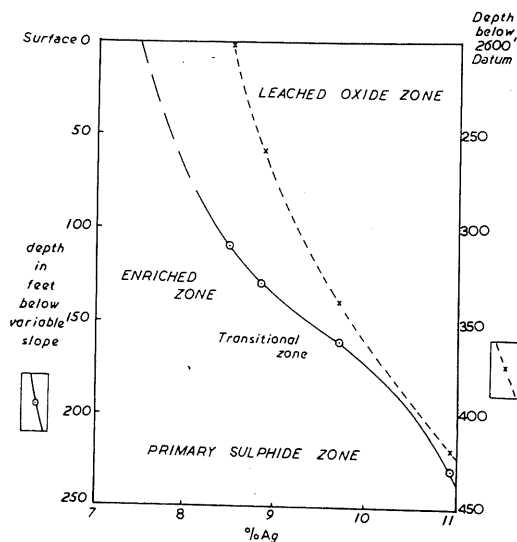


Fig. 3

PLATE 2

Fig. 4

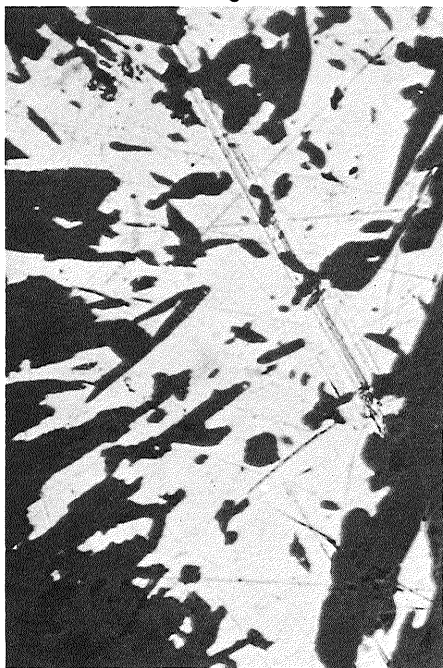


Fig. 5



Fig. 6



Fig. 7