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STRUCTURAL CONTROL OF MINERALIZATION IN THE AGNES GOLD MINE, BARBERTON MOUNTAIN LAND

by

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ABSTRACT

The various workings which constitute the Agnes Mine are situated in sediments of the Moodies Series, which form part of the southern limb of the Moodies Syncline. The area was subjected to at least three separate phases of deformation. The first deformation produced the Moodies Syncline, a tight isoclinal fold, the steeply inclined axial plane of which was probably oriented in an easterly or northeasterly direction. The second phase gave rise to steeply plunging large- and small-scale minor folds, and to a slaty cleavage which is present only in localities of more intense deformation. Structures belonging to the third phase are not widely developed, and take the form mainly of conjugate folds and faults. No evidence has been found in the area of a fourth phase observable in certain localities elsewhere in the Mountain Land.

Almost all the gold produced comes from three separate reefs - Ivy, Agnes, and Woodbine - which are located in a zone 700 feet wide at the base of the Lower Shale. The mineralized horizons lie parallel to the plane of the foliation. The reefs occur along the contacts of rocks of differing competencies. The main control in the localization of the ore-bodies is exerted by structures developed during the second phase of deformation. The ore-shoots, and the pay-streaks within them, all pitch eastwards at 45° - 60°, parallel to the pitch of the lineations formed during the second phase. Richer concentrations of gold are associated with patches where the pitch of the lineations steepens by 5° - 10°. This steepening has resulted from differential movement of strata in localized zones where there were numerous minor variations in the strike and dip of the original foliation. On a broader scale, all the ore-bodies lie within a zone characterized by well-developed axial plane cleavage of the second phase. Where this cleavage is not observable, no mineralization has been found. Below a depth of 2000 feet, the nature of the mineralogy changes from an ore consisting almost entirely of pyrite to one containing noticeable amounts of chalcopyrite and sphalerite, especially where visible gold is present. Associated with this change in mineralogy there appears to be a sympathetic decrease in the fineness of the gold. On the whole, wall-rock alteration surrounding mineralized zones is inconspicuous.

STRUCTURAL CONTROL OF MINERALIZATION IN THE AGNES GOLD MINE, BARBERTON MOUNTAIN LAND

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STRUCTURAL CONTROL OF MINERALIZATION IN THE AGNES GOLD MINE, BARBERTON MOUNTAIN LAND

INTRODUCTION

The investigations undertaken in and around the Agnes Gold Mine, southwest of the town of Barberton, the results of which are described in this report, form part of the general program of research into the nature of gold mineralization in the Barberton Mountain Land, currently being carried out by the Economic Geology Research Unit. This particular study was aimed at testing the applicability, in underground workings, of the methods of structural analysis embodying the measurement of minor structures. The primary objectives of the work were to determine what influence geological structures have on the localization of ore-bodies, to attempt to unravel the tectonic history of the rocks of the Moodies Series in which the mineralization occurs, to ascertain the mode of development of the ore-shoots, and to learn, from a detailed mineralogical study of the ores, whether there is any variation, or zoning, in these bodies.

A. HISTORY OF MINING IN THE AREA

Gold mining in the area dates back to 1882 when the Pioneer Reef was discovered by Auguste Robert (French Bob) on the farm Oorschot 29, adjacent to Ameide 30 on which the present Agnes Mine is situated (see Fig. 1). At that time G.P. Moodie, formerly Surveyor General of the South African Republic, threw open thirteen farms in the Kaap Valley to prospecting. During the following two years the Moodies hills were intensively prospected, and a large number of likely prospects were opened up, including the Ivy Reef, the Ivy Extension, the Snowden Reef, the Highlands Reef, the Woodbine Reef, and Lester's Reef, all of which are situated on the property of the present Agnes Mine (see Fig. 2). One enterprising group, the Ben Lomond Company, initiated an attempt to "put in a drive at a very low level in order to strike the Ivy Reef at depth", but, as in so many other schemes of that time, its capital was rapidly exhausted, and the project fell through. However, over sixty years later the present owners of the Agnes Mine, Eastern Transvaal Consolidated Mines Limited, extended the Ben Lomond Adit, and today it is the main means of access to the lower levels of the mine.

Towards the end of 1886, due to the high royalties exacted by Moodie, most of the individual diggers and small syndicates were forced to seek new deposits elsewhere, and a number of larger companies were formed by the owner to operate the various workings. By the end of 1898 the Moodies Gold Mining Syndicate, the major company, was virtually defunct, and almost all the mines in the area ceased working during the three years of the South African War. In 1908 the Agnes Mine was started by A. J. Knuckey. Various other reefs, such as the Ivy and Woodbine, were still worked on tribute from Moodie until 1915. From this date onwards, all the smaller properties were gradually absorbed into the Agnes Gold Mining Company, under the ownership of W. R. Rowe and O. W. Gibson, and the property came to assume its present size. In 1951, after they had completed the Ben Lomond Adit, Eastern Transvaal Consolidated Mines Limited, took over the Agnes Mine, and are still working it.

From the commencement of operations up to October, 1961, the workings now constituting the Agnes Gold Mining Company Limited have crushed approximately 1,150,000 tons of ore from which have been produced 250,000 ounces of gold, at an average recovery grade of 4.35 dwt./ton.

B. LOCATION AND PHYSIOGRAPHY

The area covered by surface mapping is approximately 8 square miles in extent, forming a strip 4 miles long and 2 miles wide, situated between longitude 30° 58'E. and 31° 02'E., and latitudes 25° 49'S. and 25° 52'S., on portions of the farms Oorschot 29 and Ameide 30. It runs along the northern edge of the

Moodies Hills and is some six miles southwest of Barberton (see Fig. 1). The Agnes Mine is served by two secondary roads. The lower road leads to the mine offices, reduction plant, and the Ben Lomond Adit. The upper road, ascending the Moodies Hills by a tortuous, zig-zag route, serves the upper workings of the mine which are known as Agnes Top. In addition, the area is well traversed by a number of forestry roads and old tracks leading to numerous abandoned workings.

The mineral rights over the whole area belong to Eastern Transvaal Consolidated Mines Limited.

The Moodies Hills, which extend westwards from Concession Creek to the farm Estada 85, form a small irregular plateau, rather than a group of distinct hills or ridges. The average elevation is of the order of 4800 feet, some 2000 feet above the floor of the Kaap Valley. The highest point is Brighton Kop (5938 feet), some three miles west of the Agnes Mine. The plateau-like feature lies immediately north of the Saddleback Range which is approximately 600 feet above the average level of the Moodies Hills. Between the two lines of hills is the deep, narrow valley along the upper reaches of Concession Creek. The overall topographic effect of the Moodies Hills is to soften the abrupt descent from the high peaks of the Barberton Mountain Land to the De Kaap flats. Nevertheless, on the edge of the Moodies quartzites which form the backbone of the hills there is often a precipitous drop down to the valley of Pioneer Creek. The development of this valley was probably controlled by the contact of the harder quartzites of the Moodies Series and the softer schists and serpentinites which form the northern side, and extend over the low ridge separating it from the Kaap Valley. The contact runs more or less along the floor of the valley which is bounded on the south by towering quartzite ridges cut by steep narrow gorges. In the more shaly members of the Moodies Series long low ridges have been formed by a number of parallel diabase dykes which cut transversely across the sedimentary formations. The surface of the plateau is also deeply dissected in places by the Ivy, Highland, and Alpine Creeks, giving rise to a number of deep precipitous kloofs running both parallel to the quartzite ridges, and cutting obliquely through them. These creeks all flow in a general southeasterly direction to join with Concession Creek which, in turn, runs into the Queens River, a tributary of the Kaap River.

The average rainfall of the area, which lies just within the mist belt, varies between 40 inches and 45 inches per annum, and is considerably higher than that of Barberton, which is approximately 30 inches.

The area has no characteristic vegetation, and is mainly grassland, although in the kloofs and the headwaters of the creeks small patches of temperate evergreen forest persist. Afforestation with pine and gum trees is proceeding rapidly over the larger part of the area.

C. PREVIOUS WORK

Prior to the outbreak of World War I in 1914, no comprehensive account had been published of the geology of the Barberton Mountain Land, despite the amount of knowledge brought to light by the intensive prospecting and mining operations. Some of the earliest references to the region are contained in the articles and books of Penning (1883), Mathers (1887), and Kässner (1899), but these, together with later papers by Kynaston (1905) and Draper (1913) made only limited contributions to the understanding of the geology of the Mountain Land, in general, and added nothing to the detailed knowledge of the geology of the present area, in particular. The results of the first systematic mapping program, started in 1905, are contained in Hall's (1918) classic memoir in which the Agnes Mine and the Moodies Hills are described in considerable detail with respect to both the stratigraphy and the nature of the mineralization.

The area was next discussed in Special Publication No. 15 of the Geological Survey of South Africa (Visser et al, 1956) which presented the outcome of the remapping of portion of the Mountain Land during the period 1938-1948. Although Hearn (1943) prepared a thesis during the interval between the two Geological Survey publications, which described the producing gold mines belonging to Eastern Transvaal

Consolidated Mines Limited, no reference was made to the Agnes Mine as this property was only acquired by the company a number of years later. Revisions in the stratigraphic succession and in the relative ages of the various formations in the Moodies Hills were suggested by Gribnitz, Poole and Voges (1961). Subsequent to the completion of the field work connected with the present investigations, the adjoining area to the south-southwest, centred on the Montrose Mine, was studied and reported on by Herget (1963), and the area between the Agnes Mine and the town of Barberton was mapped by Eastern Transvaal Consolidated Mines Limited (R. Cooke, verbal communication).

The techniques employed in the present investigation have been described by Ramsay (1963). Although his investigations did not extend sufficiently far south of the Consort-Fairview-Sheba area to include the Agnes Mine, yet the modes of structural deformation recognised in the former location, and the pattern of tectonic history deduced have been used as the bases upon which the interpretations and conclusions of the Agnes Mine studies have been built.

D. ACKNOWLEDGEMENTS

Appreciation is expressed to the management of Eastern Transvaal Consolidated Mines Limited for granting permission for undertaking this study, and especially for financial assistance. In particular, thanks are due to Dr. K. H. Gribnitz, Chief Geologist, for help and co-operation received at all times. The efforts of the Manager and staff of the Agnes Gold Mine to make available all information required are gratefully acknowledged.

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GENERAL GEOLOGY

A. STRATIGRAPHIC SUCCESSION

The geology of the area surrounding the Agnes Mine is shown in Fig. 2. The stratigraphic column for the area, as deduced from the results of the present investigations, is as follows :

Pre-Transvaal dykes		diabase	up to 250' thick
Remobilised Kaap Valley Granite		contact zone of basement	3000' wide (?)
Swaziland System	Jamestown Series	serpentinite, gabbro	thickness n.d.
	Moodies Series	conglomerates, quartzites, shales, magnetic shales, jaspilites	7500' thick
	Fig-tree Series	banded cherts, shales, greywackes, banded ironstones, "green schists"	4500' thick
	Onverwacht Series	talc-carbonate schists, chlorite schists, dolomites, dolomitic serpentinites, banded cherts, talc-chlorite phyllites	thickness n.d.
Kaap Valley Granite		hornblende granodiorite	extent n.d.

The Kaap Valley Granite is not exposed in the area. The Jamestown and Onverwacht rocks occur in the extreme north, and were not investigated in any detail. Neither were the members of the Fig-tree Series which are restricted to the southernmost portion of the area. All the significant gold mineralization is developed in rocks of the Moodies Series, and, consequently, only this formation was subjected to close examination. These sediments form part of the overturned southern limb of the Moodies Syncline, believed to be the western continuation of the Eureka Syncline which runs from the Belfast Mine northwards to the Clutha Mine where it is bent at almost a right angle, after which it continues in an easterly direction up to its closure on the farm Lilydale 454 near Louw's Creek. In the Moodies Hills only one incomplete limb of the syncline is present. The remainder of the southern limb and the whole of the northern limb are missing, due, probably, to the effects of faulting.

The scheme of stratigraphic classification used above is that devised and currently employed by the Economic Geology Research Unit (D.A. Pretorius, verbal communication). It differs appreciably from that drawn up by the South African Geological Survey for the standard 1 : 50,000 maps of the Transvaal side of the Barberton Mountain Land (Visser et al, 1956), but it is generally similar to the columns accepted by the mine geologists in the Barberton area (Gribnitz, Poole and Voges, 1961; Herget, 1963), and by the Swaziland Geological Survey (J. G. Urie, verbal communication). The main points of difference with the standard published maps are :

(a) The Kaap Valley Granite, as is the case with the Nelspruit Granite to the northeast (Ramsay, 1963), is considered to pre-date the Swaziland System, and to have formed the basement upon which the Archean sediments and extrusives accumulated. That the Kaap Valley Granite is intrusive into members of the Swaziland System can be well seen on the lower road to the Ben Lomond Adit, where tongues of granite invade the Onverwacht schists, and where xenoliths of the latter material are completely surrounded by granite. The South African Geological Survey have accepted this evidence as proof that the whole of the Kaap Valley pluton is intrusive into, and therefore of later age than, the Swaziland System. The present contention is that appreciable movement along fault planes adjacent to the granite-

sediments contact, during one or more phases of the tectonic history of the area, has resulted in the preferential heating up of the granite, its subsequent remobilisation, and, finally, its intrusion into the sediments which suffered only a very limited amount of contact metamorphism under these peculiar conditions of granite emplacement.

(b) Most of the rocks classified by the South African Geological Survey as belonging to the Jamestown Igneous Complex, and as being intrusive into the Onverwacht, Fig-tree, and Moodies Series, are now thought to be of sedimentary and extrusive origin, and to form a layered sequence which underlies the Fig-tree Series. The only rocks which now appear to be of post-Moodies and pre-granite remobilisation age are the intrusive bodies of serpentinite, gabbro, and other basic material which are grouped as members of the reconstituted Jamestown Series.

(c) The various schists, phyllites, cherts, dolomites, dolomitic serpentinites, and altered lavas, formerly assigned to the Jamestown Igneous Complex, are now considered to belong to the Onverwacht Series (Herget, 1963; Anhaeusser, 1963; Viljoen, 1963). Gribnitz, Poole and Voges (1961) have put forward the suggestion that they might belong to a separate formation - the Oorschot Series - which lies between the Onverwacht and Fig-tree Series, while the Swaziland Geological Survey (J. G. Urie, verbal communication) are inclined to believe that they form the lower portion of the Fig-tree Series. It is apparent that further work is required to settle the question of the correlation of the schists, phyllites and lavas, but there appears no doubt from the results of recent detailed structural mapping that they are among the oldest rocks of the Mountain Land, and do not belong to the relatively younger Jamestown Series.

(d) The Moodies Series is believed to be an integral part of the Swaziland System, and not a system on its own. Because of a major transgressive overlap of the Moodies rocks on the Fig-tree Series in places, the South African Geological Survey (Visser et al, 1956) decided to recognise two systems in the Mountain Land. The presence of the unconformity has been substantiated by many investigators, but it is thought by the Economic Geology Research Unit to represent an intraformational unconformity within a normal geosynclinal sequence, and, hence, not necessarily diagnostic of two separate systems. This view is in conformity with the classification of the Swaziland Geological Survey (Urie, 1956), in which the Fig-tree Series represents the normal pre-orogenic sediments of the geosynclinal phase, and the Moodies Series represents synorogenic sediments derived from the sub-aerial erosion of the Fig-tree Series, and deposited after an initial orogenic pulse had elevated and locally deformed the earlier rocks.

The Kaap Valley Granite is intrusive into the Onverwacht Series along its remobilised contact. Across the whole of the area the Onverwacht Series is faulted against the Moodies Series, and there is thus no means of determining the true relationship between the Onverwacht rocks and the normally overlying Fig-tree Series. In the southwestern corner of the area, although exposures are poor, it can be seen that rocks of the Moodies Series transgress across shales and banded ironstones of the Fig-tree Series, affording proof of the unconformity between the two series. The best exposed contact between the two groups occurs in a road-cutting in the same general locality, and here the basal conglomerate of the Moodies Series appears to lie conformably on massive and banded Fig-tree cherts. However, some of the chert might be secondary in origin, representing a chertified mylonite along a fault plane, with the result that a true contact might not be present. Furthermore, if a marked angular unconformity did originally exist, it might have been almost completely obliterated by the intense folding of the beds resulting in their present near-vertical attitude. The mechanism by which an unconformity can be reduced to a pseudo-conformable structure has been described by Ross (1962). Serpentinites, gabbros, and amphibolites of the Jamestown Series were found to occur only in the extreme north of the area, where they are intrusive into schists of the Onverwacht Series. The dykes in the area have been classified as post-Swaziland and pre-Transvaal in age because of their consistent direction of strike of between 30^{o} and 35^{o} west of north. The Geological Survey maps of Barberton show that, up on the escarpment, all the dykes which cut through the Transvaal sediments trend in a northeasterly direction.

Age measurements on biotite from a pegmatite in the Kaap Valley Granite on the farm Somerset 229 have yielded a figure of 3010 ± 150 million years. However, it cannot presently be stated whether this represents the age of crystallization of the granite, or the age of a later period of metamorphism superimposed on the granite (L. O. Nicolaysen, verbal communication). A sample of galena from the Rosetta Mine, about 1½ miles northeast of the Agnes Mine, has also been geochronologically studied. This mineralization occurs in quartz-sericite and talc-carbonate schists of the Onverwacht Series, and is strikingly different from that in the Agnes Mine. Using the lead isotope ratio method, the galena gave an age of 3340 million years using Hautermann's model, and 3250 and 3320 million years using Russel-Farquhar's model. However, too much reliability cannot be placed on results obtained from this method (L. O. Nicolaysen, verbal communication). The lack of similarity between the nature of the mineralization in the two mines suggests that more than one period of ore deposition might be involved, as a result of which the questionable age of the Rosetta mineralization might in no way reflect the time of emplacement of the Agnes ores.

B. SWAZILAND SYSTEM

(a) Onverwacht Series

This group of rocks occurs as a narrow belt between the northernmost exposures of the Moodies Series and Pioneer Creek, the northern boundary of the area mapped. The main rock-types are talc-carbonate and chlorite schists (probably representing original basic lavas), banded cherts, and talc-chlorite phyllites. Generally, these rocks, with the exception of the banded cherts, are highly sheared. None of these rocks appears to occupy a continuous horizon. They tend to occur as irregular lenses, patches, and scattered remnants. Very often, as is the case with the Rosetta and Golden Hill workings to the northeast, the Onverwacht rocks serve as suitable hosts for mineralization.

In the Fig-tree rocks in the southern portion of the area, grey talc-carbonate schists (not differentiated) occupy the cores of minor anticlines. It is possible that these might represent the topmost members of the Onverwacht Series, as schists of similar appearance and composition have been recognized in undoubted Onverwacht sequences elsewhere in the Mountain Land.

(b) Fig-tree Series

This series is present along the southern boundary of the area, where it has been investigated over a width of only 500 feet from its contact with Moodies rocks. It has no particular relevance to the geology of the Agnes Mine itself. The exposures in the area form part of the zone of Fig-tree rocks, 4500 feet thick, which lies between the Moodies and Saddleback synclines, both of which are composed of Moodies sediments. It appears that a considerable thickness of the Fig-tree Series in this area might have been eliminated by the Saddleback Fault, since the average thickness of the Series is generally of the order of + 7,000 feet, but the possibility cannot be ruled out that the original depositional thickness might have been less than this average due to the area having been closer to the edge of the depository than the type-areas. For the most part, the beds shown on the map consist of banded cherts, minor shale horizons, and schists of the Zwartkoppie Zone which forms the basal portion of the Fig-tree Series. The fact that the upper portion is not exposed indicates the extent to which the Moodies Series has transgressed over the Fig-tree rocks, or its non-deposition in this area, or the degree of elimination by faulting.

The chert is a dense, fine-grained, siliceous rock, commonly dark grey in colour, and showing banding. The bands are alternately whitish-grey and dark grey, almost black. These banded cherts apparently pass gradationally into banded ironstones across the strike of the beds. The banded ironstones are typically alternating bands of white chert, 0.25 - 0.50 inches thick, and bands of shale, ferruginous

shale, or haematite, of similar thicknesses. These, in turn, pass gradationally into normal shales of the Fig-tree Series, with thin laminae of chert or siliceous material, and then into massive, reddish-brown, fine-grained shales, seldom exhibiting any sedimentary features, such as graded bedding or lamination.

Whereas the banded ironstones display the most intricate and complex folding, the banded chert and shales in contact with them appear to be relatively undeformed. This anomaly can possibly be accounted for by the large differences in competency of the three rock-types. The banded cherts, on account of their massive, compact nature, did not lend themselves easily to folding, but rather ruptured irregularly to form breccias. The shales, on the other hand, having a relatively low degree of competency, yielded to any directed stresses by flow or by cleavage. In the third instance, the banded ironstones, being composed of alternating layers of competent and incompetent material, were ideally suited to deformation by folding, especially similar folding, since the shaly bands, although able to flow easily, were still controlled to a large extent by the thin, rigid layers of chert on either side of them. In especially tight folds the chert bands are frequently observed to have exceeded their limit of plasticity, and to have snapped into a number of elongated segments, resembling boudins, completely surrounded by shale which has flowed into the gaps between the chert fragments.

Underlying the overturned chert "bars" which dip very steeply to the south there invariably occurs a zone of green and grey schists. The green schist in contact with the chert is believed to be the basal member of the Fig-tree Series, while the grey schist, thought to belong to the Onverwacht Series, occupies the central zone between two bands of green schist and chert. In the area surrounding the Sheba Mine, where these structures have been studied in detail, Koen (1948) has shown that the green and grey schists fill the cores of anticlines formed by the chert bars. In the Agnes Mine area, due to poor outcrops, no actual closures, or hinge zones, of anticlinal folds in the chert bars were observed, but the disposition of the schists and banded cherts renders it likely that the same types of structures are present. The green schist is a rock with a white-to-grey siliceous groundmass between pale-to-bright schistose streaks. Koen (1948) concluded that it is probably an altered greywacke, and is composed of slender green crystals of amphibole, altered to chlorite, set in a groundmass of siliceous and sericitic material. Ramsay (1963), Viljoen (1963), and Anhaeusser (1963) thought that many of the so-called "green schists" represent deformed laminated cherts, of secondary origin, derived from the replacement of greywacke, calcareous sediments, and talc phyllite. The possibility also exists (Gribnitz, Poole and Voges, 1961) that some of the green schists represent highly sheared and sericitised chert bars.

(c) Moodies Series

The Moodies Series, which covers the greater part of the area under consideration, consists of quartzites, conglomerates, impure shales, slates, and allied rock-types. Most of these rocks are intermediate in composition between shales and quartzites, with almost no pure members of either group. Marked changes in facies have been observed along strike on numerous horizons.

In this area, the total preserved thickness of Moodies sediments is approximately 7500 feet. Elsewhere in the Barberton Mountain Land the total thickness of the complete Moodies succession is of the order of 10,000 feet. Of the 7500 feet present around the Agnes Mine, approximately 3500 feet consist of arenaceous sediments, and 4000 feet of argillaceous material. The following five sub-divisions, as proposed by the South African Geological Survey (Visser et al, 1956), have been recognised :

(v)	Middle Shale	2200 feet
(iv)	Middle Quartzite	1200 feet
(iii)	Lower Shale	1800 feet
(ii)	Lower Quartzite	1800 feet
(i)	Basal Conglomerate	0 - 700 feet

The topmost members of the series - the Upper Quartzite and Upper Shale - are missing in the Agnes area.

(i) Basal Conglomerate

The main development of conglomerate is in the extreme southwestern corner of the area. North-northeast of this locality only sporadic lenses are present, and over the greater portion of the contact Moodies quartzites rest directly on Fig-tree rocks. In the southwest the conglomerate zone is some 700 feet thick, although only the lowest 100 feet conform to a true conglomerate with well-rounded and well-sorted pebbles. The majority of the pebbles vary between two inches and four inches in diameter. They consist mainly of black chert, banded chert, jasper, quartzite, and granitic material, with only occasional flat pebbles of shale, banded ironstone, and schist. Some pebbles of an earlier conglomerate were found in this basal conglomerate. They consist largely of fragments of chert having very angular outlines and resembling a breccia. Pebbles constitute over 70 per cent of the rock. The matrix is composed of quartz, felspar, and some sericite.

The remainder of the conglomeratic zone above the basal 100 feet corresponds to a greywacke conglomerate, as defined by Krumbein and Sloss (1951). It is particularly poorly sorted, containing pebbles and fragments of widely different sizes, which are composed of black and pale greenish chert, bright red jasper, quartzite, schist, granitic material, and quartz porphyry. The pebbles constitute less than 40 per cent of the rock. Many of the pebbles and fragments are poorly rounded. The matrix is a heterogeneous mixture of sand, silt and clay. Quartz, felspar, chlorite, sericite, and mica are prominent, with the cementing material being secondary silica. Any indications of bedding appear to be entirely absent, although the exposures seem to have the shape of very flat lenses which grade laterally into grits and cross-bedded quartzites.

The pebbles show almost no sign of elongation or flattening, or any other type of tectonic deformation. However, in other members of the Moodies Series in the area, especially in the less competent rock-types, a pronounced fabric has frequently been developed as a result of flattening and re-alignment of clastic particles.

(ii) Lower Quartzite

The basal conglomerate is succeeded by a group of predominantly arenaceous rocks, approximately 1800 feet thick, which are moderately coarse-grained and very often cross-bedded. Although it is considered as one unit, there is considerable lithological variation in this horizon, both along and across the strike.

The lower portion is often calcareous (up to 18 per cent dolomitic material), the zones of carbonate-rich rock taking the form of elongated lenses which pinch and swell along the strike. Towards the top of the quartzite horizon the carbonate content decreases (about 7 per cent), but, in thin-section, grains of dolomitic material may be observed. Numerous shaly intercalations are also present, which increase in frequency of occurrence towards the top of the horizon. Generally, the quartzite is whitish-brown in colour, and contains semi-rounded grains of quartz, microcline, and plagioclase felspar, lying in a matrix of sericitic and carbonate material.

(iii) Lower Shale

At the base of the Lower Shale there occurs an impersistent zone of banded jasper, again taking the form of elongated lenses. Where the jasper attains its maximum development, pyrite and gold mineralization is present, as in the Reliance and Durham Allan's workings. Along the strike the jasper bands grade almost imperceptibly into fine-grained quartzite with a pale red colour.

Above the jasper bands the sediments become progressively more argillaceous. The shales are brownish and greenish-grey in colour, and usually thin-bedded. In the more arenaceous varieties, however, the individual layers become thicker. There are numerous fine partings of dark material in the

sediments, which have gently curving and ellipsoidal outlines (traces). In thin-section it can be seen that these partings consist of sericite and dark material which, from X-ray examination, appears to be chloritic and carbonaceous matter. It is evident that considerable movement has taken place along these partings, since the sericite flakes are all orientated in a direction parallel to the plane of the parting.

Subgreywackes, intercalated with the shales, are composed of poorly rounded quartz grains, up to 0.2 mm. in diameter, and occasional angular fragments of plagioclase and microcline felspar. In most of the beds of this type, the carbonate content is appreciable. In some instances up to 40 per cent of the rock consists of dolomitic material which is present both as discrete grains, apparently of sedimentary origin, and as a major constituent of the matrix. The remainder of the matrix is composed of sericite and secondary quartz.

Ferruginous and magnetic shales occur towards the top of the Lower Shale. They are reddish and blue-grey in colour, and contain abundant haematite and grains of magnetite. Small, rounded grains of quartz constitute approximately 50 per cent of the rock. The average grain size is usually less than 0.08 mm. Carbonate material is present in the matrix, but to a far lesser degree than in the subgreywacke types. Associated with the shales are a number of irregular bands of bright red jasper which appear to have the shape of elongated lenses grading into magnetic shale along strike. Euhedral grains of magnetite are present in the jasper.

The ore-bodies of the Agnes Mine occur over a zone roughly 700 feet wide horizontally, beginning approximately at the base of the Lower Shale Horizon.

(iv) Middle Quartzite

Immediately above the uppermost jasper bands and magnetic shales lies the Middle Quartzite horizon which is approximately 1200 feet thick. It is generally purer than the Lower Quartzite, and very often has a bluish colour, due to the presence of dark-coloured quartz and black chert. Cross-bedding is well developed in a number of separate beds. Throughout the whole of the horizon scattered chert pebbles, usually of the order of one inch in diameter, are present. In thin-section, the typical, fairly coarse-grained quartzite is seen to be composed of poorly-rounded quartz grains and well-rounded grains of microcline and albite felspar, with an average diameter of 0.6 mm. Grains of black chert are also present. The matrix consists of fine quartz and felspar grains, sericite, carbonate, and some secondary quartz.

At the top of the Middle Quartzite horizon is a well-defined conglomeratic band, some 30 to 40 feet thick. The pebbles consist largely of banded and black chert, and of bright red jasper, usually not exceeding 3 inches in diameter. In places this conglomerate bears a close resemblance to the basal conglomerate, suggesting the possibility that the Moodies exposures might represent a tight isoclinal fold. However, from a consideration of cross-bedding, which is fairly abundant in the Middle Quartzite, it is apparent that the direction of "younging" of the sediments is not compatible with such a postulated structure. Therefore the above-mentioned conglomerate can be taken as occupying an horizon stratigraphically above the basal conglomerate.

(v) Middle Shale

These shales are generally more thinly laminated than those of the Lower Shale, and often have a distinct reddish colour on weathered surfaces. Where bands and lenses of subgreywacke are developed, they are usually olive green in colour, and have a substantially lower carbonate content (approximately 5 per cent) than those of the Lower Shale horizon, which have a dark grey colour. Two narrow bands of magnetic shale are present, in which occasional lenses of red jasper are developed.

(d) Jamestown Series

Rocks of this age are restricted to the area lying north of the Moodies Fault. They are represented by serpentinites and, more rarely, gabbroic rocks which display obvious intrusive relationships with the altered sediments and lavas of the Onverwacht Series. The serpentinites vary in colour from pale greenish-grey to bluish-grey and bluish-black, with the green variety predominating in the locality south of Pioneer Creek. Occasionally, in the more sheared portions of the serpentinite, there are small occurrences of slip-fibre asbestos. In almost all cases the serpentinite bodies are highly weathered on surface, giving rise to a nondescript, chocolate-brown type of rock.

C. LATER INTRUSIVES

Hypabyssal rocks in the form of numerous dykes and one sill are present in the area. In the vicinity of the Agnes Mine, the only deduction that can be made about the age of these intrusives is that they are post-Jamestown. However, from the Geological Survey map of the whole Barberton area (Visser et al, 1956) it is apparent that they do not cut the sediments of the Transvaal System which form the escarpment on the western and northwestern side of the Kaap Valley pluton. The diabase sill which outcrops approximately 900 feet south of the Woodbine Shaft and which is seen cutting across the road to the Agnes Top workings appears to have been injected conformably to the bedding of the Moodies sediments, and along the contact of the Lower Quartzite and the Lower Shale. Examination of its intersection with the Woodbine Dyke does not reveal any definite information concerning their relative ages. Their similar mineralogy is taken to be indicative of their belonging to the same period of igneous activity.

As is the case with the majority of the pre-Transvaal dykes in the rest of the Barberton area, those in the vicinity of the Agnes Mine generally conform in strike to a definite direction of approximately 30° - 35° west of north. Another noteworthy feature about the emplacement of the dykes is that there is a tendency for these intrusions to terminate abruptly on entering a less competent formation. In the Agnes area this is especially noticeable with dykes cutting through Moodies sediments and terminating near the contact with less competent Fig-tree shales. Of the five dykes which are present, one terminates approximately 1000 feet from the Moodies - Fig-tree contact, three terminate on the contact, and only one continues through into the Fig-tree Series.

The widths of the dykes vary between 50 feet and 250 feet. The intrusions usually dip at very steep angles so that their outcrops are generally straight. From mining operations it has been found that some dykes show signs of weathering and decomposition down to depths of 2000 feet. This is probably due to the fact that large quantities of water often percolate downwards along the contacts of dykes and sediments.

Mineralogically, the dykes conform to typical diabase, consisting of monoclinic and orthorhombic pyroxene and biotite, both of which preponderate over the felspar (generally labradorite). All the silicate minerals are partly, or wholly, altered to secondary products. Most of the dykes carry varying amounts of sulphide minerals, either as isolated specks, or, more commonly, as masses of up to two inches in diameter along the contacts. The sulphides consist essentially of pyrrhotite, with lesser amounts of pentlandite and chalcopyrite. No gold appears to be present.

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STRUCTURAL GEOLOGY

A. REGIONAL TECTONIC HISTORY

The structural history of the Lily, Eureka, and Ulundi synclines, lying to the northeast of the Agnes area, has been interpreted by Ramsay (1963), Viljoen (1963), and Anhaeusser (1963) as embracing four separate phases of deformation. It is believed that these phases have affected the whole of the Mountain Land, and, therefore, the overall tectonic pattern, as deduced by these investigators, has been used as a framework to which all structural observations in the Agnes area have been referred.

(a) First Phase of Deformation

This phase is represented by a series of major and minor folds - F_1 - which originally trended northeastwards or north-northeastwards. It was responsible for the development of the Eureka Syncline and, possibly, the Ulundi Syncline, although Ramsay (1963) considered that the latter might have been initiated at an earlier stage, since there is evidence that the Fig-tree Series was subjected to folding and erosion before the deposition of the Moodies sediments. The F_1 folds are overturned, and have axial planes which dip steeply to the south or southeast. There is apparently no cleavage associated with this period of deformation. The directions of maximum compression producing the first and second phases were close in their orientation, and it is possible that these movements might have been pulses in a single orogeny.

(b) Second Phase of Deformation

After the formation of the F_1 folds, the major compressive stress direction appears to have changed its orientation slightly to a north-northwest direction. The effects of this second phase are seen mainly in the form of a slaty cleavage and, in some cases, a schistosity which is superimposed on the F_1 folds. The steep inclination of the strata on the limbs of the first-formed folds prevented large folds being developed during the second deformation. In local cases, where F_2 folds were produced, they have the appearance of minor folds superposed on the limbs of the larger F_1 structures. Ramsay (1963) found that the orientation of the axes and axial planes of these minor folds does not conform to the alignment of similar features which undisputedly belong to the F_1 phase. That these minor features are F_2 folds was confirmed by the fact that their axes and axial planes are oriented parallel to lineations and slaty cleavage formed during the second deformation. Ramsay (1963) found that low-grade regional metamorphism was associated with this period of deformation, and that the Nelspruit Granite was intruded at this time, thermally metamorphosing the adjacent strata. There is evidence that the main gold mineralization took place at a late stage of this deformation.

(c) Third Phase of Deformation

The third deformation was responsible for the development of the marked arcuate shape of the F_1 folds and the F_2 slaty cleavage. These structures were folded about axes steeply inclined to the southeast - F_3. Anhaeusser (1963) has shown that evidence of the third deformation becomes progressively weaker away from the locus of maximum bending of the earlier folds into their present arcuate form. The general orientation of the direction of compression responsible for the third deformation was approximately at right angles to those which produced the earlier structures.

(d) Fourth Phase of Deformation

The final deformation resulted in the folding of the F_2 slaty cleavage and schistosity about horizontal axes by large- and small-scale folds - F_4. Further manifestation of this fourth phase is apparent in the development of fairly widespread conjugate folds and faults. The direction of maximum compression was oriented approximately vertically, in contrast to the horizontal compression which produced the F_1, F_2, and F_3 structures.

B. TECTONIC HISTORY OF THE AGNES AREA

Since the mineralization in the Agnes Mine area is confined entirely to members of the Moodies Series, detailed structural analyses were undertaken only in rocks of this age. The interpretations, therefore, apply to the deformation of the Moodies sediments only, and do not necessarily reflect the complete tectonic history of the underlying Fig-tree and Onverwacht rocks. From a general surface inspection of the area and an examination of the structural data measured, it was concluded that the structure throughout the Agnes area is sufficiently homogeneous and consistent to justify its consideration as one structural unit, there being no need for division into sub-areas due to local variations in the structural geology.

The methods used in the interpretation of the structural geology and geometry of the area were mainly those of statistical analysis of data plotted on the lower hemisphere of an equal-area Schmidt-type stereographic projection. The data were represented by the measurements of foliations, axial plane cleavages, lineations, fold axes, and joints at approximately 700 points, the larger porportion of which were in the underground workings of the Agnes Mine.

Three major phases of deformation can be recognized as having affected the Moodies Series in this area. Two of these appear to have occurred prior to the emplacement of the gold mineralization, while the third, and weakest, deformation seems to post-date the mineralization. No evidence could be found of the fourth phase having left its imprint.

(a) Structures of the First Phase

The recognition of any structures related to the first deformation, as envisaged by Ramsay (1963), is particularly difficult in the Agnes area. Northeast of Barberton, where this earliest period of deformation was first recognized, the only structures developed are major and minor folds, there being an apparently total absence of slaty cleavage, schistosity, and lineations produced by the intersection of cleavage, or schistosity, and bedding. Assuming the style of deformation to be similar in the area under consideration, the only structures which could be taken as indicative of a first deformation would be actual major and minor folds, particularly in the hinge zone of the Moodies Syncline. However, only the incomplete southern limb of this syncline has been preserved, and, therefore, the chances of locating major or minor folds associated with the formation of the regional syncline are considerably reduced.

The present overturned attitude of the Moodies sediments in this area indicates that they must have undergone severe deformation at an early stage, before any of the other structures still recognizable were developed. It is probable that the syncline which formed at this stage was isoclinal in nature, as were the Eureka and Ulundi synclines, so that any slaty cleavage which might have been produced was possibly oriented so close to the original plane of the bedding that the two were rendered indistinguishable. In the Agnes Mine true bedding planes are very seldom preserved, and the term "foliation" is a more accurate description than "bedding". The regional strike of the foliation in this area is 088°, and the dip 87°S. It can be assumed that the attitude of the axial plane of the Moodies Syncline was close to this orientation, although the possibility does exist that the strike of the axial plane was more in a northeasterly direction prior to the period of deformation (F_3) which resulted in the arcuate structures of the Eureka and Ulundi Synclines. The Saddleback Syncline which lies to the south of the Agnes Mine, has an axial plane striking northeastwards.

(b) Structures of the Second Phase

As is the case in the area northeast of Barberton, structures belonging to this phase are by far the most prominent around the Agnes Mine. Cleavage-bedding and boudinage lineations, slaty cleavage, and occasional minor folds are the types of structures most frequently developed. In the Shebang locality, approximately one mile southwest of the Agnes workings, the relative ages of the deformations can be well seen in an F_1 foliation which has been folded by a minor syncline belonging to the second phase.

Both underground and on surface, the most conspicuous type of minor structure is a linear one which, on first inspection, closely resembles ripple-marking. From systematic measurements of the direction and angle of pitch in the plane of the bedding it is apparent that the structures strike approximately east-west and plunge at 40° - 60° eastwards. This is verified by stereographic plots of these lineations in both underground and surface exposures. In Diagrams 1a and 1b it is evident that there are definite maxima at 090°, plunging at about 45° to the east. The detailed nature of these lineations varies at different localities, as is shown on Plates IA, IB, and IC. The last-mentioned photograph represents the type of lineation which has the most wide-spread occurrence. These structures are not continuous, but tend to be aligned en echelon, frequently displaying curved, or even arcuate, outlines.

A statistical analysis of approximately 600 measurements of this linear feature throughout the whole area indicates the unlikelihood of its being a primary sedimentary structure. It is highly improbable that the orientation of a sedimentary feature, such as ripple-marking, would, over an area of this size, be so consistent as to give rise to one very marked maximum only. In underground exposures, linear features such as those depicted in Plate IC may be observed to grade into the types of structures illustrated by Plates IA and IB, which are of undoubted tectonic origin since they represent the intersection of cleavage and foliation planes. Diagrams 1a, 1b, 1c, and 1h illustrate the fact that the axes of both large- and small-scale folds in the area plunge in the same direction as the observed linear features. It is felt that this relationship cannot be fortuitous, and must indicate a tectonic origin for all the observed linear features. If the average strike and dip of the foliation and of the axial plane cleavage are plotted on a stereographic projection, their point of intersection lies in the same position as the maxima for the plots of the lineation and fold axis directions. This is illustrated in Diagram 1c where the average strike and dip of the foliation are taken as 088° and 87°S., respectively, and of the axial plane cleavage as 076° and 76°S., respectively. The resulting line of intersection strikes at 090° and dips at 48°E.

The observed lineations appear to be of two types. The first type (Plates IA and IB) is apparently formed by the intersection of the axial plane cleavage and the bedding, which gives rise to very marked and regular linear features. The second, and most common type (Plate IC) appears to be of a more obscure origin. As far as can be ascertained, these linear features owe their presence to a poorly developed boudin-type structure with en echelon characteristics. Throughout the workings of the Agnes Mine all the sedimentary horizons display thin partings composed essentially of sericite and chlorite, which separate irregular lenticles of coarser material. The thickness of these lenticles varies from a fraction of an inch to one inch, while their length is highly variable. It is thought that these partings constitute bedding-slip planes, similar to those described by Hills (1945), in which there is a tendency for micaceous material to develop, and that the lenticular bodies of coarser material constitute the actual boudins. Because the orientation of these lineations is parallel to the major and minor fold axes in the area, it is considered that they are true b-lineations (kinematic). This is substantiated by Diagram 1g which is a plot of poles to quartz-filled tension joints. It is obvious that these fractures are oriented perpendicularly to the fold axes, and that they are a - c tension joints. Since the lineations are perpendicular to these a - c joints, the former are interpreted as true b-lineations.

Axial plane cleavage is not developed on the same scale throughout the area. It appears to be confined to a zone approximately 1500 feet wide which extends from the large-scale folds west of the Agnes workings in an easterly direction, cutting obliquely through the area of most intense mineralization. Beyond this mineralization the intensity of the cleavage diminishes considerably, and it is seldom observed, even on well-weathered surfaces. Diagram 1d is a contoured plot of poles to this axial plane cleavage, and clearly indicates an axial plane striking at 076° and dipping at 76°S. Cloos (1947) maintained that the intensity of axial plane cleavage is greatest in the axial plane regions of a fold, and that it diminishes away from this locus, which is in accordance with the features mentioned above.

The nature of the folding in the Agnes area appears to vary according to the type of rock involved. In the quartzitic rocks, because of their higher competency, the folding has been predominantly concentric, while in the more shaly layers similar folding appears to have been the dominant mechanism. It is apparent from the ubiquity of bedding-slip planes that concentric folding was active throughout the Moodies succession during the earliest periods of deformation. The slaty cleavage developed indicates that after the initial phase of concentric folding deformation of a similar nature became more important. In the more quartzitic rocks, such as those in the Shebang locality, the sediments were able to preserve their competency for a longer period, and could thus resist the tendency towards similar folding. This is well illustrated by Diagrams 1c and 1f which are beta- and pi-plots, respectively, of the bedding in the folded area referred to above. The beta-plot indicates an elongated maximum which gives a variation of up to 16^{o} in the direction of plunge of the fold axis. The pi-plot shows that it is impossible to draw one great circle through all the pi-poles, but that there is a tendency for the plotted positions of poles to bedding for each fold limb to lie on a separate great circle. The position of the fold axes relative to the two separate great circles gives an angular difference in direction of plunge of approximately 16^{o}. A possible explanation for this feature is that, because of the competency of the quartzites and the isoclinal nature of the folds, the two limbs were unable to accommodate any further deformation by the normal mechanism of folding, and were moved relative to each other along a zone of shearing situated in the axial plane region of the fold. In the field intense shearing in the hinge zones of these particular folds can actually be recognized.

Diagram 1h, which is a composite interpretation of all the observed structural data, permits the determination of the orientation of the kinematic axes with a considerable degree of accuracy. The a-axis, or direction of maximum transport or of minimum compression, was active along a direction inclined downwards at 42^{o} on a bearing of 242^{o}. The b-axis, or direction of intermediate compression, was directed downwards at 45^{o} on a bearing of 090^{o}. The c-axis, or direction of maximum compression, was inclined downwards at 15^{o} on a bearing of 345^{o}. The kinematic axes are oriented perpendicularly to one another, thus fulfilling the ideal requirements. However, it cannot be taken as certain that these deforming forces were operative in the above directions throughout the whole period of folding of the Moodies Syncline. Weiss (1958) maintained that there can be rotation of an active stress field due to increased depth of burial and piling up of sediments. Thus, it is not out of the question that the initial orientation of the tectonic axes, at the beginning of the period of deformation, was somewhat different, and conformed more closely to the commonly accepted stress field orientation, i.e. the b- and c-axes in a horizontal plane and the a-axis in a vertical plane. In the area northeast of Barberton, Ramsay (1963) found that the fold axes and lineations belonging to the second phase also had a steep plunge, and ascribed this to the fact that the first fold limbs were already steeply inclined when the second structures were superimposed on them. The possible relationship of the first and second folds is illustrated in Diagram 2b.

From an examination of the Shebang locality it is apparent that, soon after this period of folding and cleavage formation, the bulk of the gold mineralization was introduced. The ore-bodies take the form of saddle reefs emplaced in the crests of folds. It seems unlikely that the mineralization was introduced earlier, and subsequently folded, since there is no evidence of any grains of pyrite, the predominant ore mineral, having been bent or fractured.

The original stress field associated with the second deformation was still active for some time after the emplacement of the mineralization, and prior to the onset of the third phase. This is suggested by the development of the parallel system of diabase dykes which cut the mineralization, but are, in turn, faulted by the later period of deformation. These dykes have a consistent strike of approximately 330^{o} which direction is close to the deduced orientation of 345^{o} for the c-axis, or direction of maximum compression, allowing for the possibility of the reorientation of the stress field during the last stage of the second phase of deformation. The dykes therefore appear to occupy a system of a-c tensionsl openings.

(c) Structures of the Third Phase

There are a number of instances, both underground and on surface at the Agnes Mine, where the slaty cleavage, lineations, mineralized zones, and dykes formed and emplaced during the second phase are disturbed by conjugate folds and faults belonging to a later period of deformation. These latter features are related to a different stress field which was probably active at a time when the rocks of the Moodies Series were in a more brittle condition. Both the folding and the faulting appear to be local, small-scale

phenomena.

In the vicinity of the Ivy and Woodbine workings, only one set of monoclinal folds is developed, these having a right-lateral movement. Further westwards, approximately vertically above the Ben Lomond Adit, a number of well-developed, complete conjugate folds are present. Still further towards the west, near the Alpine workings, only the left-lateral set of monoclinal folds appears to be developed. The axial planes of the right-lateral and the left-lateral monoclines dip at about 80^{o} to the east and west respectively, and strike at 036^{o} and 306^{o} respectively, the fold axes being either vertical or inclined at a very steep angle to the south. The amplitude of these folds varies from one inch to six feet. They clearly deform the earlier set of lineations.

Diagram 1i is a stereographic plot of the poles to these axial planes, and from this data the probable orientation of the stress field responsible has been deduced. It appears that the same stress field has also been responsible for the larger proportion of the faults encountered in this area, since the two predominant fault systems have the same general strike and dip as the axial planes of the conjugate folds, as well as the same relative movement on these planes. The displacements on the two fault systems seldom exceed 10 feet. Diagram 2a, showing a portion of 17-Level Woodbine Drive East, illustrates the two fault systems and their relative movement directions. In over 50 per cent of the cases, these faults displace marker horizons in an opposite sense to that indicated by the drag of the beds on either side of the fault plane. This is interpreted as being due to a later readjustment, or rebound effect, on the fault plane.

The intersection of the two axial planes in Diagram 1i gives the b-direction, or direction of intermediate stress, as 74^{o} on a bearing of 180^{o}. From the bisection of the obtuse angle between the two axial planes, the c-direction, or direction of maximum compression, is indicated as 1^{o} on a bearing of 082^{o}. The bisection of the acute angle between the axial planes points to the a-direction, or direction of minimum compression, as being 17^{o} on a bearing of 352^{o}.

Ramsay (1962) has concluded that conjugate folds are frequently found in rocks deformed during the later phases of orogenesis, and are often related, both in space and in time, to the development of faults, thrusts, and joints. They may, in some instances, develop under conditions of regional tension. This is possibly the case in the Agnes area where the a-direction of the stress field responsible for the formation of the conjugate folds and faults is oriented very close to the c-direction of the earlier major period of deformation. This might be due to the complete relaxation of the major compressive force during the closing stages of the development of the Moodies Syncline, with the result that, because of the preservation of some degree of elasticity in the folded sediments, the original direction of maximum stress became, in effect, a direction of least stress or, possibly, even tension.

In the Sheba Hills, northeast of Barberton, the conjugate folds have steeply inclined axial planes and axes, and the directions of maximum and minimum compression have similar orientations to those in the Agnes area, corresponding closely with the stress field responsible for the third deformation (Ramsay, 1963). In the Ulundi Syncline the orientation of the conjugate folds is more complex, some of the fold axes being very steep, while others plunge at low angles. Between the Consort and Lily mines the conjugate folds have almost horizontal axes, indicating a vertical orientation for the direction of maximum compression, and suggesting a fourth phase of deformation (Viljoen, 1963; Anhaeusser, 1963).

(d) Structures of the Fourth Phase

There is no obvious evidence in the Agnes area of any structures which belong to the fourth phase of deformation (e.g. crenulation folds; minor folds or conjugate folds having horizontal or sub-horizontal axes). Herget (1963) was also unable to find any such structures in the area surrounding the Montrose Mine. At the Fortuna Mine, near Barberton, R. Cooke (verbal communication) has observed crenulation folds with sub-horizontal axes, which appear to have been formed during the fourth phase. Westwards, towards the Pioneer and Mount Morgan mines, such folds are no longer apparent.

(e) Late Tectonic Features

Evidence for a final phase of tectonism is provided by the presence of a well-developed system of joints. This system, which consists of two, or possibly three, distinct sets, obviously post-dates any of the periods of deformation mentioned previously, since there is ample evidence, both on surface and in the underground workings, of these joints cross-cutting all earlier structures. These fractures appear to be exclusively of the shear-joint type, exhibiting tight, planar surfaces on which no apparent movement has taken place.

Diagram 1j is a stereographic plot of the poles to 80 of these joints, the major proportion of which were measured in underground exposures. It indicates a single and a double maximum, both of which lie in the plane of the regional bedding, showing that the joint planes are all oriented at right angles to the bedding. It is uncertain whether the double maximum represents two distinct sets of joints, or whether there is a local variation in the dip of one set, because in no instance were two sets of flat-lying joints having different dips observed at one locality. However, it is believed that the double maximum indicated on the stereographic plot is due entirely to a local variation in dip of one set of joints. If a point mid-way between J_2 and J_3 is taken as the pole to the mean direction for the flat-lying joints, it is possible to determine the orientation of the stress-field responsible for the formation of the joint system, assuming that the joints are related. The direction of maximum compression (P-max) and the direction of minimum compression (P-min) will lie in, or very close to, the plane of the regional bedding, while the direction of intermediate compression (P-inter) will be oriented almost horizontally and at right angles to the regional bedding. There can be no direct indication of the orientation of P-max since the two joint sets intersect almost at right angles, within the limits of accuracy of the stereogram. It can be assumed that the P-max direction will bisect one of the angles between the joint sets, but there is no method of determining which angle, since no movement has taken place in these planes. Therefore, there are two possible orientations of P-max, either of which appears equally acceptable, one at 61^{o} on a bearing of 266^{o}, and the other at 29^{o} on a bearing of 086^{o}. Irrespective of which of these values is correct, it is apparent that this stress field is totally different from those operative during the preceding periods of deformation, rendering it unlikely that the period of joint development bears any relation to the major period of orogenic deformation of the Moodies Syncline.

(f) Summary of Tectonic History

After the deposition of the Moodies sediments the first period of deformation resulted in the whole of the Swaziland System being folded into a tight syncline about an axis trending in an easterly-to-northeasterly direction. Later, possibly during the same orogeny, a second deformation gave rise to large- and small-scale folds, and a slaty cleavage of limited extent. These structures produced a well-developed set of lineations plunging at 45^{o} - 60^{o} in an easterly direction. After the introduction of the mineralization, which occurred towards the end of the second deformation, a number of diabase dykes were emplaced along a series of tensional openings oriented parallel to the major deforming stress.

A third phase of deformation resulted in the development of a system of conjugate folds and faults. The direction of maximum compression during this period was oriented approximately at right angles to that of earlier deformations. A fourth stress field, observed elsewhere in the Mountain Land, does not appear to have left its imprint on the Agnes area. Finally, a pronounced system of joints was developed in a stress field, the parameters of which it has not been possible to determine.

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ECONOMIC GEOLOGY

A. NATURE OF THE ORE-BODIES

The main concentration of mineralization in the Agnes area is confined to a zone roughly 700 feet wide extending northwards into the Lower Shale horizon from its base. In this broad zone there are a large number of individual horizons, or reefs, which are occasionally interconnected, but more commonly separated by barren country rock. During the 75 years in which mining operations have taken place in this area, there are records of at least twenty separate reefs having been worked. The majority of these reefs have only been worked sporadically, and have never been followed to any great depth. At present the major part of the mining activity in the Agnes Mine is confined to three main horizons. These are - from north to south - the Woodbine Reef, the Ivy Reef, and the Agnes Reef.

On the geological map (Fig. 2) of the area it is apparent that the three main horizons, as well as other minor mineralized zones, are arranged in en echelon fashion in, or very close to, the plane of the regional bedding. On all these horizons payable mineralization is not present continuously along strike, but is confined to definite shoots, all of which pitch to the east at angles varying from 45^{o} to 60^{o}.

The stratigraphic positions of the more important reefs are as follows :

Middle Moodies Quartzite			
Lower Moodies Shale	quartz-sericite schist		1100'
	banded jaspilites	Woodbine Reef	30'
		Ameide Reef	90'
	dark shale becoming coarser-grained towards top	Ivy and Watt's Reefs	120'
	fine-grained greenish shaly quartzite	Agnes Reef	460'
Lower Moodies Quartzite			

The Woodbine Reef, which outcrops over a distance of some 600 feet on surface, has been traced down to 17-Level, a distance of 1150 feet vertically below surface. The reef horizon is located towards the stratigraphic top of a zone of banded jaspilites in a country rock of fine-grained, khaki-coloured quartz-sericite schists. Generally, the presence of red jasper bands and the development of payable mineralization are mutually exclusive. As a zone of mineralization is approached, the bright red jasper bands gradually pass over into a more coarsely crystalline, watery-coloured quartz. The ferruginous nature of the jasper bands possibly renders them amenable to replacement by sulphide solutions, with resultant formation of abundant pyrite. The ore-shoots are made up of a zone of alternating lenticular bands of sulphide and quartz-sericite schist. The sulphide bands are seldom continuous over any great distance. They are irregular on a small scale, but are part of a uniform zone when viewed on a broader scale. Locally, darker coloured, lenticular quartz veins, also parallel to the foliation and containing sulphide mineralization, constitute the reef zone. At the present stage of development on the Woodbine horizon it appears that there are two distinct ore-shoots, both of which dip consistently with the foliation at about 84° to the south. These two shoots also pitch eastwards at approximately 60°. This has resulted in the more easterly of the two being cut off by the Woodbine Dyke, although, from exploration on the other side of the dyke on 9-Level, it appears that the ore-shoot may continue further to the east.

To the west of the Woodbine workings, separated by some 700 feet of barren jaspilite, there occurs another zone of mineralization known as the Ameide Reef. This reef has been followed down to 11-Level, and has also been encountered in development on 14- and 17-Levels. The mineralization is also confined to the jaspilite zone, but it appears to occupy a horizon closer to the stratigraphic base of this zone than the Woodbine Reef.

The Ivy Reef outcrops along a strike length of approximately 800 feet, and has been shown to extend down to 24-Level, or 2600 feet below surface. The workings are situated some 3500 feet west of the Woodbine Reef, and approximately 120 feet stratigraphically below the latter. The reef horizon occurs in a dark-grey, sericitic shale, with numerous fine partings of sericitic and chloritic material. The shale has a substantial carbonate content, usually of the order of 25 per cent of the rock. The sulphide mineralization occurs as elongate blebs and stringers which have their maximum development adjacent to a narrow quartz vein varying in thickness from 0.25 inch to 4 inches. Occasionally, thin bands of sulphide occur in the quartz vein itself, but these are generally associated with remnants of the wall-rock. Away from the quartz vein, the sulphide mineralization gradually decreases in intensity, until, at a distance of approximately 4 inches, it is present only as disseminated specks in the country-rock. It has been found that the strike length of the Ivy Shoot tends to decrease with depth. This feature is well illustrated on the vertical section (Fig. 3) and the assay section (Fig. 4) both of which indicate that, from a strike length of 800 feet on surface, the shoot narrows down to approximately 150 feet on 24-Level. The assay section also indicates that the portion of the Ivy Shoot which is mined consists of a number of smaller pay-streaks carrying very high values (+ 800 in. dwts. over 10 inches) which are separated by patches of lower values. Another feature which is apparent from the assay section of the Ivy Shoot is that the smaller, individual streaks and the whole shoot pitch at approximately 50° to the east, although towards the lower levels this angle seems to steepen considerably. The Ivy Reef has a general dip parallel to the foliation at an angle of approximately 87° to the south, but it does occasionally roll over and dip very steeply to the north without, apparently, cutting across the foliation.

Approximately 2000 feet east of the Ivy Shaft, and possibly on the same horizon as the Ivy Reef, there are smaller workings on what is known as Watt's Reef. This horizon has been followed down to 11-Level. In the cross-cut from the Agnes Reef to the Woodbine Reef on 17-Level, a poorly-mineralized quartz vein occurs in a position which corresponds to the projected position of Watt's Reef. This mineralized zone is situated at approximately the same stratigraphic distance from the Agnes and Woodbine reefs as the Ivy Reef itself.

The Agnes Reef outcrops for a distance of approximately 1000 feet, and has been proved down to 19-Level, or 1700 feet below surface. In plan, the Agnes workings are situated mid-way between the Ivy and Woodbine workings, and approximately 120 feet stratigraphically below the Ivy horizon. The Agnes Reef is located on, or close to, the contact of a thick band of quartzitic rock and a more shaly zone. When it wanders from this contact, it does so into the more quartzitic horizon, and not into the shaly zone which occurs on the northern side of the reef. The actual reef is associated with a strong shear zone filled with smoky quartz and mylonitic material. The quartzitic wall-rocks are intensely sheared and fractured, giving the appearance of a stockwork, with the fractures containing dark-coloured quartz, and having no apparent preferred orientation. Sulphide mineralization occurs as scattered specks close to the quartz-filled fractures, and also in the mylonitic material. Towards the western extremity of the

ore-shoot the main fracture appears to split into a number of smaller ones, all of which swing to the west-southwest at an angle of approximately 10° from the main fracture direction. The trace of the locus where the west-southwest-striking fractures leave the main shear zone pitches to the east at about 45°, which is also the general pitch of the main ore-shoot and of the lineations in this zone. When followed down dip, the Agnes Reef changes its attitude continually from steeply inclined northwards to steeply inclined southwards. This is due to the fact that the reef does not adhere strictly to the quartzite-shale contact, but wanders into the quartzite for distances of up to 15 feet away from the contact.

B. MINERALOGY AND PARAGENESIS OF THE ORE

Mineralogically, the ores from the three main horizons in the Agnes Mine are almost identical, and, except for their mode of occurrence, may be considered as one ore-type in the pyritic group, according to the classification of de Villiers (1957). In comparison with some of the other gold deposits in the Barberton area, e.g. New Consort Mine, Rosetta Mine etc., the mineralogy of the Agnes ore is simple, consisting almost entirely of pyrite, with minor amounts of chalcopyrite, sphalerite, and gold, set in a gangue composed mainly of quartz, with subordinate amounts of ankerite.

The mineralogy, the relationships between minerals, and the probable paragenetic sequence of ore deposition were studied by means of polished sections of specimens of reef from the various horizons. The confirmatory identification of minerals was carried out by X-ray analysis.

(a) Pyrite

This is by far the most common sulphide in the ore, and the only one identifiable in hand specimens. Generally, the pyrite occurs in the wall-rock immediately adjacent to the quartz vein, although small amounts do occur in the quartz filling as well. When found in the latter position, the pyrite is generally confined to wisps, or ribbons, of wall-rock, especially the darker partings of sericite and chlorite which have been caught up in the quartz filling. The grains of pyrite vary in size from 2 mm. to 10 microns, and usually take the form of irregular stringers arranged parallel to the foliation. In the Ivy and Agnes Reefs, these stringers range in thickness from a cluster of grains, up to 3 mm. wide, to an irregular line of individual grains resembling a fine dust. In the Woodbine and Ameide Reefs, bands of pyrite up to 2 cm. in width are not uncommon. Individual grains frequently exhibit euhedral outlines, while zoned crystals are common (Plate ID). Most of the pyrite is earlier than the other ore minerals, and even earlier than most of the quartz-carbonate gangue. The pyrite seldom occurs in the actual vein material, but attains its greatest concentration on the contact of the quartz veins and the wall-rock. In thin-sections, the grains of pyrite occurring in the wall-rock often exhibit marked pressure shadows which are elongated in the plane of the foliation. This indicates the early age of the pyrite, and the fact that part of the pyrite mineralization took place before the end of the second phase of deformation.

The zonal nature of some of the pyrite crystals suggests that the period of pyrite mineralization might have overlapped to some extent with the emplacement of the quartz gangue and, to a lesser degree, of a small part of the gold, chalcopyrite, and sphalerite mineralization. Plates ID, IE, and IF illustrate typical zoned pyrite crystals composed of alternating layers of pyrite, quartz, and occasional gold, chalcopyrite, and sphalerite, arranged around a central nucleus of pyrite. This type of zonal texture has possibly resulted from the successive, or alternating, deposition of the various minerals present. During an extensive period of pyrite mineralization there were minor breaks in which quartz, gold, chalcopyrite, and sphalerite were deposited. It is also possible that this type of zonal structure might represent replacement of particular zones of different composition in an original pyrite crystal by the above-mentioned minerals. That the pyrite from the Agnes Mine is inherently zoned can be shown by etching grains with dilute nitric acid to produce the pronounced zonal structure seen in Plate IIA.

Considering the normal paragenetic sequence of mineral deposition (Lindgren, 1937), it seems probable that the pyrite in the Agnes Mine was all deposited prior to the introduction of the other ore minerals. The distinct zonal nature of the pyrite has been brought about by differential replacement by other minerals at a later stage.

(b) Sphalerite

Sphalerite occurs in extremely small amounts in the ore, generally within the actual quartz vein. If visible gold is present, the sphalerite tends to occur more abundantly, especially in ore from the Ivy Shoot below 20-Level, and generally occupies interstitial positions between quartz grains. In the absence of gold, the sphalerite usually occurs as zonal replacements in pyrite grains which have been caught up in the vein filling. Where grains of sphalerite in the vein material are in contact with, or in close proximity to, chalcopyrite, typical ex-solution textures between sphalerite and chalcopyrite are frequently developed. These textures take the form of a myriad of minute blebs, or blades, of chalcopyrite dispersed throughout the sphalerite. In some instances the inclusions are oriented in a definite crystallographic direction (Plate IIB), but more often the crystallographic distribution is not apparent, and the chalcopyrite blebs are scattered more or less uniformly throughout the sphalerite, giving an "emulsion" or "mottled" texture (Plate IIC).

Buerger (1934) has shown that, above temperatures of 350°C - 400°C, sphalerite and chalcopyrite are capable of some degree of solid solution, and that at these temperatures unmixing occurs. It would thus appear that during the various phases of mineralization in the Agnes Mine temperatures were in excess of 350°C.

(c) Chalcopyrite

Chalcopyrite is present in the ore in slightly greater proportions than sphalerite. Like the latter, chalcopyrite tends to occur within the material filling the veins, generally occupying interstitial positions between quartz grains, and, to a lesser extent, replacement zones in grains of pyrite.

In the polished sections examined there appears to be a tendency for the chalcopyrite content of the ore to increase with depth. This was especially noticeable in the case of the Ivy Reef from which it was possible to take samples over a far greater depth range than in the other reefs. In samples from 11-Level Ivy (approximately 1000 feet below surface), chalcopyrite is present in minute traces as replacement blebs in pyrite. Samples from 17- and 19-Levels Ivy (1600 feet and 1800 feet below surface, respectively) also show chalcopyrite to be present in trace quantities as replacements in pyrite, but, in comparison with the ore from 11-Level, the proportion of chalcopyrite is slightly greater. Specimens from 20-, 21-, and 22-Levels show a consistent relative increase in chalcopyrite content, although the actual quantities are still extremely small (about 2 per cent of the ore minerals). In polished sections of ore from 22-Level Ivy, containing visible gold, the chalcopyrite content increases markedly so that it constitutes approximately 20 per cent of the ore minerals present. In this case, the bulk of the chalcopyrite occurs within the vein filling, and the mineral is intimately associated with gold and sphalerite (Plates IIE and IIF). The shape of the chalcopyrite grains is highly irregular, and their size varies from 0.01 mm. to 0.5 mm. A certain amount of chalcopyrite still occurs as zonal replacements in pyrite grains. Although this quantity is very small, it is relatively greater than in samples from higher levels.

On the whole, the textural relationships between chalcopyrite and sphalerite indicate that their periods of emplacement were probably contemporaneous, with the possibility that chalcopyrite deposition continued for a slightly longer time. Although in most cases where chalcopyrite and sphalerite are in contact, the boundaries are generally mutual and completely non-diagnostic, there are rare instances where chalcopyrite appears to cut into, and replace, sphalerite.

(d) Gold

Unlike sphalerite and chalcopyrite which may be detected in almost every polished section, although present in very small amounts, gold was found to occur in relatively few specimens. In most cases it was observed that, unless gold was visible to the naked eye, the chances of detecting any by microscopic examination of polished sections were extremely unlikely. In rare instances, however, specimens which appeared to contain no visible gold, when examined under the ore microscope, revealed small blebs varying between 0.01 mm. and 0.04 mm. in size, and occurring as replacements in pyrite. The replacements are sometimes zonal in nature, but, in other cases, take the form of irregular isolated patches (Plates IF and IID). The remainder, and by far the greater proportion, of the gold present in the ore occurs as irregular grains and stringers ranging from 0.01 mm. to 0.8 mm. in size, and occupying interstitial positions between quartz grains, and, occasionally, between pyrite grains. On the whole, the gold tends to exhibit a mutual relationship with chalcopyrite and sphalerite, but, from temperature considerations and the fact that gold sometimes replaces chalcopyrite (Plate IIE), it seems reasonable to assume that the larger part of the gold was deposited subsequent to the other two minerals. This assumption is borne out by the general occurrence of the gold, chalcopyrite, sphalerite, and pyrite as discrete grains which seldom display any intimate intergrowths or complicated textures.

Microscopically, there does not appear to be any noticeable difference in composition of the gold from different levels; nor is there any apparent difference between free gold and that enclosed in pyrite. However, from the records of average gold fineness, a relationship between depth and fineness, is suggested (Diagram 2C). Unfortunately the records of gold fineness in the Agnes Mine are in the form of average annual values, and, therefore, each value cannot be correlated with a specific depth. However, it is reasonable to assume that, apart from minor variations, the general tendency is for succeeding annual fineness values to represent progressive increases in the depth of mining.

A smoothing of the graph shows a general increase in gold fineness from approximately 905 parts per thousand to 925 per thousand during the period 1908-1950. After 1950 there is an abrupt change in the graph, the approximate value for 1951 being 970 parts per thousand. It is thought that this change can be directly ascribed to the completion of the Ben Lomond Adit, and consequent mining from a depth considerably below that from which ore was drawn in previous years. If this assumption is correct it seems that the relationship between gold fineness and depth is very marked. From 1951 to 1958 there is again a steady increase in the fineness to a value of 980 parts per thousand. After 1958, however, there is a marked progressive drop to 950 parts per thousand in 1963.

The general increase in finess of the gold between the years 1908 and 1958 is in accord with the normal pattern found in hydrothermal deposits. The higher silver content of gold from shallower depths is believed by Fisher (1945) to be due to the fact that, because gold is less soluble than silver, it will precipitate from the ore fluid first, and that silver will be transported to higher levels where the pressure and temperature are lower. The reversal in the trend between 1958 and 1963 is difficult to explain. From the end of 1961 onwards a certain amount of shallow ore from the Tiger Trap and Golden Hill workings was milled at the Agnes mill, and the gold recovered was included in the latter's annual production. It is possible that this gold had a low fineness, but the proportion of ore produced from these extraneous sources was relatively small, and it is therefore doubtful whether this factor along could be responsible for a drop of more than thirty parts per thousand in the average value. Furthermore, although the Tiger Trap and Golden Hill workings are situated near the present land surface, and in this sense might be considered as shallow in terms of elevation above sea-level, they lie at approximately the same elevation as 17-Level in the Agnes Mine. It is not improbable, therefore, that these ores have a fineness comparable to that from workings on 17-Level. In addition, between 1958 and 1961, before ore from other sources was treated at the Agnes mill, the average fineness had already dropped by nearly thirty parts per thousand. In 1960 the Woodbine section of the Agnes Mine was re-opened, and ore was drawn from old workings, mainly from 9-Level and above. Figures for 1913 and 1914, when ore above 9-Level on the Woodbine horizon was last worked, show the average fineness of gold to be

936 parts per thousand. For an ore of this quality to cause a drop in the overall fineness from 980 to 956 parts per thousand, it would be necessary for slightly more than half of the total tonnage milled to come from the Woodbine section above 9-Level. During the year July, 1959, to June, 1960, it is known that approximately one-sixth of the total tonnage milled was drawn from the Woodbine section. Such a contribution would result in a drop in fineness of only 7 parts per thousand.

It appears therefore that a change in the ore derived from the Agnes workings is the major factor responsible for the abrupt drop in fineness. The reef from the Ivy Shoot shows a definite mineralogical change with depth. From 22-Level downwards there is an increase in both chalcopyrite and sphalerite, especially where visible gold is present. As the Agnes and Woodbine shoots have not been developed below 17-Level, it is not possible to say whether a similar change with depth takes place in these horizons.

C. TRACE ELEMENT CONTENT OF THE ORE

Spectrographic analyses of three samples of ore gave the following results, the symbols referring to line intensities :

	Ag	Al	As	Cu	Fe	Mg	Mn	Ni	Pb	Si	Sn
free gold - Ivy Reef	W	-	T	VW	W	-	T	VW	W	M	W
rich pyritic ore - Woodbine Reef	T	M	W	VW	VS	S	M	VW	T	VS	W
low-grade pyritic ore - Woodbine Reef	VW	M	W	VW	VS	S	M	VW	-	VS	M

VS - Very Strong S - Strong M - Moderate

W - Weak VW - Very Weak T - Trace

Other elements sought, but not detected, were : B, Be, Bi, Cd, Co, Cr, In, Mo, Sb, V, and Zn. In the case of the low-grade pyritic ore from the Woodbine Reef, although no lead was detected in the untreated sample, subsequent analysis of chemically enriched portions of the sample showed lead to be present in moderate quantities.

D. WALL-ROCK ALTERATION

In the Agnes Mine there appears to be no evidence of the immediate wall-rocks having undergone alteration to any noticeable degree as a result of the emplacement of the mineralization. Where the Agnes Reef wanders away from the quartzite-shale contact into the more quartzitic material, there appears to be a faint bleaching of the rock from a greenish-grey to a lighter green colour due to formation of chlorite. This change generally occurs over zones less than 10 feet wide.

A possible reason for the apparent absence of wall-rock alteration is that it has been blanketed by a low-grade regional metamorphism which has been superimposed over the whole area as a result of the intense deformation of the Barberton Mountain Land and the intrusion of the Kaap Valley and Nelspruit granites. In the Agnes area this regional metamorphism has given rise to the widespread development of sericite and, to a lesser extent, chlorite. During the period of mineralization, the temperatures and pressures reached could not have been any greater than those responsible for the regional metamorphism.

E. SUMMARY AND CONCLUSIONS

The bulk of the mineralization in the Agnes Mine appears to be confined to the basal 700 feet of the Lower Shale horizon. Generally, the reefs lie in, or very close to, the plane of the foliation. At present, three main reef horizons are mined - Woodbine, Ivy, and Agnes - all of which pitch at angles of 45° - 60° eastwards in the plane of the foliation.

The ore appears to be typically hydrothermal in nature, consisting largely of pyrite, with minor amounts of sphalerite, chalcopyrite, and gold. The gangue is composed of quartz and lesser amounts of ankerite. Considering the mineral assemblage and the probable temperature of formation, the deposits appear to belong to the upper mesothermal class of ore deposits. In depth, notably below 21-Level (2000 feet below surface), the ore changes its character, becoming richer in copper and zinc. Associated with this change there appears to be an abrupt drop in the fineness of the gold. Spectrographic analyses of samples of different types of ore do not show any particular elements to be associated exclusively with material rich in gold. The effects of wall-rock alteration associated with the mineralization are masked by the imprint of regional metamorphism on the whole of the Moodies succession in this area.

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RELATIONSHIP BETWEEN STRUCTURE AND MINERALIZATION

A. GENERAL RELATIONSHIPS

The geological map (Fig. 2) of the area surrounding the Agnes Mine shows that the bulk of the mineralization is localized in the Lower Shale horizon which is contained between the Lower and Middle Quartzite members of the Moodies Series. This Lower Shale has undergone intense deformation, but the quartzites above and below it are relatively undeformed. In the quartzites and coarser argillaceous rocks original sedimentary features, such as bedding planes, cross-bedding and graded bedding, are well preserved and easily identifiable, but in the Lower Shale all primary sedimentational structures have been completely obliterated by intense shearing and boudinage formation in individual beds. In the case of the quartzite horizons, the only locality where the deformation has been sufficiently intense to destroy primary sedimentational features is that surrounding the Golden Shebang workings where the Lower Quartzite has been folded isoclinally into a minor syncline and anticline, and has been intensely cleaved and sheared in the region of the axial planes of the folds. The mineralization occurs in the form of saddle reefs, located in the crest of the anticline, and also as narrow quartz veins orientated parallel to the axial planes of the folds.

If the limits of the zone of isoclinal folding and intense axial plane cleavage are demarcated on the geological map, and projected east-northeastwards along the direction of the axial planes of the folds, all the reefs which are exploited in the Agnes Mine are contained between these boundaries. It appears, therefore, that the mineralization in the Agnes Mine has been localized, firstly, in the more shaly horizon which has been subjected to the most intense deformation, and, secondly, in a particular portion of this horizon where the axial plane cleavage, due to folding, has been most strongly developed.

These conclusions apply only to the various workings constituting the Agnes Mine. Further to the west, the Ivy Pioneer, Reliance, Durham Allan's, Alpine Lead, Black Lead, and Alpine workings lie on, or close to, the contact of the Lower Moodies Quartzite and the Lower Shale, and the conditions responsible for the localization of the mineralization must, therefore, in part, be different to those in the Agnes area. That the area around the Alpine workings was affected by the second phase of deformation is evident from the fact that, although there is no noticeable development of cleavage, lineations are present which are identical in their nature to those encountered in the Agnes Mine. In the underground workings of the Alpine Mine, Hall (1918) observed that "this (Alpine) quartzite is sometimes well ripple-marked". These "ripple-marks" are believed to be the same as those which, in the Agnes Mine, have been shown to be tectonic structures.

B. LOCALIZATION OF INDIVIDUAL ORE-BODIES IN THE AGNES MINE

In the three reefs of major importance - Ivy, Agnes, and Woodbine - there are a number of common features which appear to be responsible for the localization of individual ore-bodies. Firstly, each reef tends to be aligned parallel to the foliation of the sediments, rather than to the axial plane cleavage generated during the second phase of deformation. One local exception is the western extremity of the Agnes Reef where it splits into a number of smaller fractures, all of which swing to the west-southwest at an angle of approximately 10° to the main direction of the reef. These fractures are aligned parallel to the direction of the F_2 axial plane cleavage.

A second feature which is common to all three reef horizons is that they are located on, or very close to, the contacts of rocks having different competencies. This applies particularly to the Agnes Reef where there is a marked difference between the opposing sidewalls. The south sidewall consists of

a fine-grained, greenish quartzite, while the north sidewall is composed of a distinctly darker sub-greywacke containing grains of quartz and felspar set in a matrix of sericite, chlorite, and some carbonate material. The opposing walls of the Woodbine Reef consist of a fine-grained shaly quartzite and a highly schistose quartz-sericite rock. In the case of the Ivy Reef, thin-sections show a marked difference in the grain size of the material from opposite sides of the reef. The average size of clastic particles from the southern sidewall of the reef is 0.15 mm., and from the northern sidewall 0.075 mm. As the width of the vein-filling and the payability decrease along strike, so the compositional differences in the opposing sidewalls become progressively less marked. Where the rocks on either side of the reef horizon are very similar, the mineralization becomes almost negligible.

A third common characteristic of the major reef horizons is that the payable mineralization is confined to definite shoots which pitch to the east at angles varying between 45° and 60°. This can clearly be seen on the vertical section through the main workings (Fig. 3). The lineations related to the second phase of deformation also plunge to the east, in the plane of the foliation, at angles of $45^{\circ} - 60^{\circ}$. (Since the dip of the foliation is very close to vertical, the difference between the absolute angle of plunge of the lineations and the angle of pitch measured in the plane of the foliation is negligible). It would therefore appear that there is a close relationship between the pitch of the shoots and the F_2 structures. Fig. 4, which is a composite section showing both the distribution of gold values and the pitch of lineations in the Ivy Shoot from 17-Level downwards, indicates, firstly, that there is a close relationship between the overall pitch of the shoot and the pitch of the lineations. It shows further that, as the shoot proper is approached, the angle of pitch of the lineations increases from approximately 50° to $+ 55^{\circ}$. Thirdly, contours of the gold values reveal a relationship between the patches of extremely high values (pay-streaks) and the pitch of the lineations. In almost every streak where the gold values are above 800 in. dwts., the pitch of the lineations is in excess of 60°. The trend of the pay-streaks follows the trend of the lineations in almost every case.

A possible explanation of this significant relationship is that the increases in pitch of the lineations represent slight changes in the original strike and dip of the foliation. Because of the near vertical attitude of the sediments, a change of only 2° in the strike or dip of the foliation could result in a change of up to 8° in the pitch of the lineations. From observations underground, it is evident that such changes in strike and dip do occur, both on a large scale involving the sediments over the whole strike length of the shoot, and on a minor scale over distances of less than 20 feet. These minor changes in strike and dip of the sediments could give rise to slightly larger open spaces or zones of reduced pressure through differential movement along the contact zones of rocks of contrasting competencies.

Structural measurements and assay plans of the Agnes and Woodbine shoots appear to indicate the same phenomena. However, because of the irregular spacing, and the smaller number, of accessible levels on these horizons, the relationship between structure and mineralization cannot be demonstrated as convincingly as in the case of the Ivy Reef.

C. POSSIBLE GUIDES TO FURTHER MINERALIZATION

The relationships between lithology, structure, and mineralization described above permit the following suggestions to be made concerning geological phenomena which might act as useful guides in the future search for new ore-bodies :

(i) optimum conditions for the emplacement of gold reefs appear to exist in those localities exhibiting clear evidence of intense deformation during the second phase of folding (F_2)

(ii) the contacts between rock-types of different competencies are favourable loci; variations in grain-size are just as indicative of differences in competency as variations in lithology

(iii) richer mineralization is more likely to occur where numerous small changes in strike and dip of the foliation take place over relatively short distances

(iv) the tendency for ore-shoots and pay-streaks to develop is greater where the eastwards pitch of F_2 lineations increases to 55^{o} and more from the usual 45^{o} - 50^{o}

(v) wall-rock alteration in the form of bleaching, particularly of more quartzitic rocks, is a possible indicator of the presence of ore-bodies

(vi) variations in fineness of the gold, and in the composition of the accompanying sulphides appear to be functions of the behaviour of the mineralization with depth.

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KEY TO DIAGRAMS

Diagram 1

1a : Maximum of plot of lineations and minor fold axes. Surface. Shebang Locality. (58 measurements)

1b : Maximum from lineation plot. Underground workings. Contoured at 5, 10, 20, 40, 60, and 70 points per one per cent area. (550 measurements)

1c : Attitude of lineations which could be developed by intersection of regional bedding and cleavage.

1d : Maximum of plot of poles to axial plane cleavage. Contoured at 5, 10, 20, and 30 points per one per cent area. (53 measurements)

1e : Beta-plot of bedding plane intersections. Fold in Shebang locality. Contoured at 5, 10, 20, 40 and 60 points per one per cent area. (250 intersections)

1f : Relationship between beta-plots and pi-plots. Shebang Locality. Full dot : poles S. limb. Dot in circle : poles N. limb.

1g : Plot of poles to a-c tension joints.

1h : Interpretation of composite structural data.

1i : Poles to axial planes of conjugate folds.

1j : Plot of poles to later shear joints. Contoured at 1, 2, 3, 4, 5, 8, and 10 points per one per cent area. (81 observations)

Diagram 2

2a : Orientation of conjugate fault system, showing directions of relative movement.

2b : Three-dimensional model showing F_2 structures superimposed on F_1 folds.

2c : Average annual fineness of gold produced from the Agnes Mine.

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KEY TO PLATES

Plate I

IA	:	Cleavage-bedding lineations
IB	:	Cleavage-bedding lineations
IC	:	Boudinage-type lineations
ID	:	Zoned pyrite crystals. (X40)
IE	:	Zoned pyrite (Py) crystal with chalcopyrite (Cp) replacing a particular zone. Sp : sphalerite. (X180)
IF	:	Pyrite (Py) grain showing zonal replacement by gold (Au). (X180)

Plate II

IIA	:	Zoning in pyrite accentuated by etching. (X180)
IIB	:	Exsolution of chalcopyrite (light-coloured blebs) in sphalerite (Sp) along crystallographic directions. (X1000)
IIC	:	Chalcopyrite (Cp) exsolving from sphalerite (Sp) forming irregular "emulsion" or "mottled" texture. Mutual boundary between sphalerite (Sp) and gold (Au). (X800)
IID	:	Gold (Au) occupying interstitial positions between and around pyrite (Py) grains. (X180)
IIE	:	Mutual boundary between chalcopyrite (Cp) and sphalerite (Sp). Gold (Au) possibly eating into and replacing chalcopyrite (Cp). (X180).
IIF	:	Remnant of pyrite (Py) in chalcopyrite (Cp). Chalcopyrite (Cp) appears to be replacing sphalerite (Sp). (X180)

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KEY TO FIGURES

Fig. 1	:	Locality map of area investigated, showing major structures and positions of more important gold mines.
Fig. 2	:	Geological map of the area surrounding the Agnes Gold Mine
Fig. 3	:	Plan and longitudinal vertical section of the main workings in the Agnes Gold Mine.
Fig. 4	:	Longitudinal vertical section through the Ivy Shoot, Agnes Gold Mine, between 17- and 24-Levels, showing the relationship between gold distribution and lineations.

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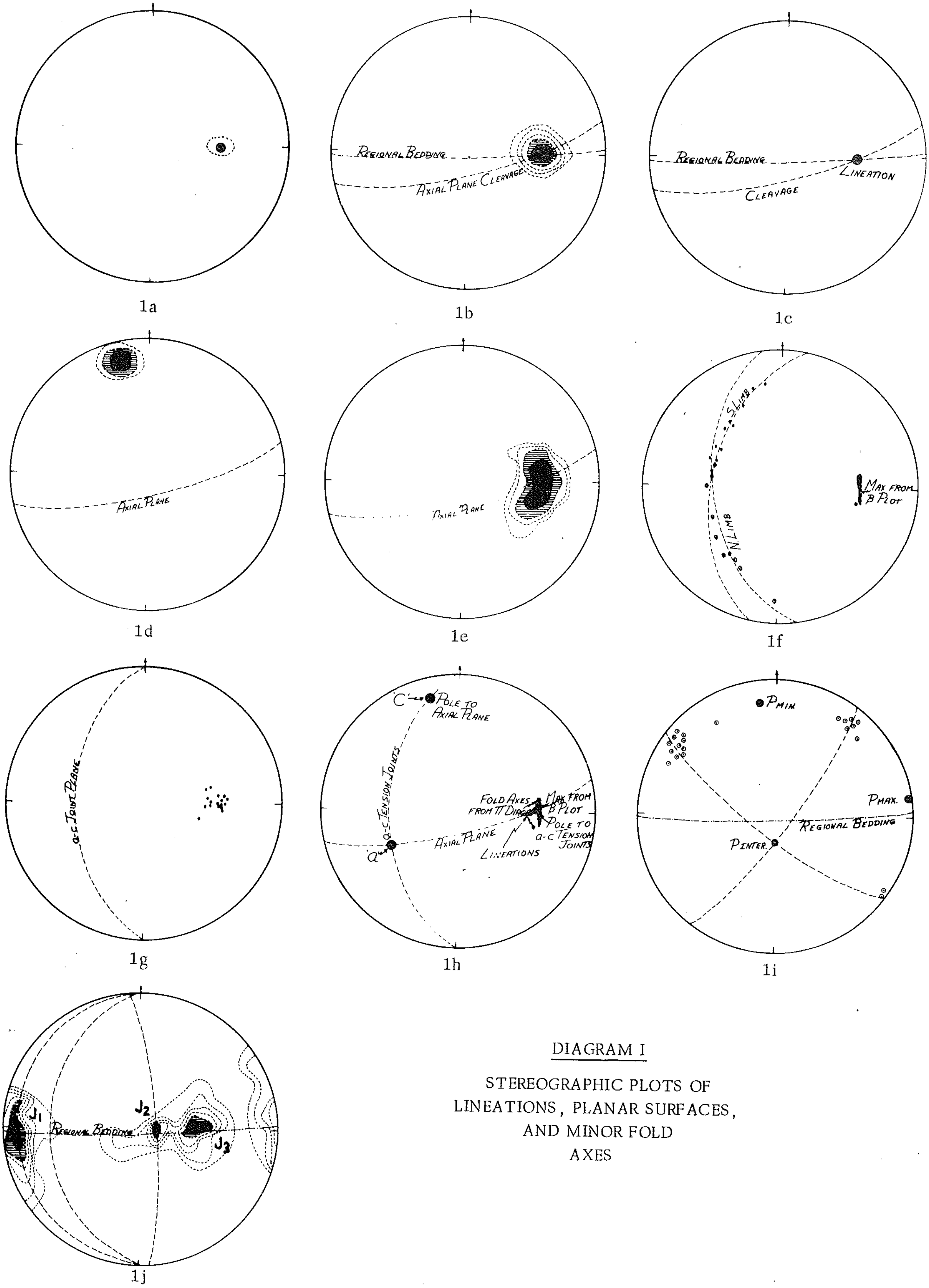
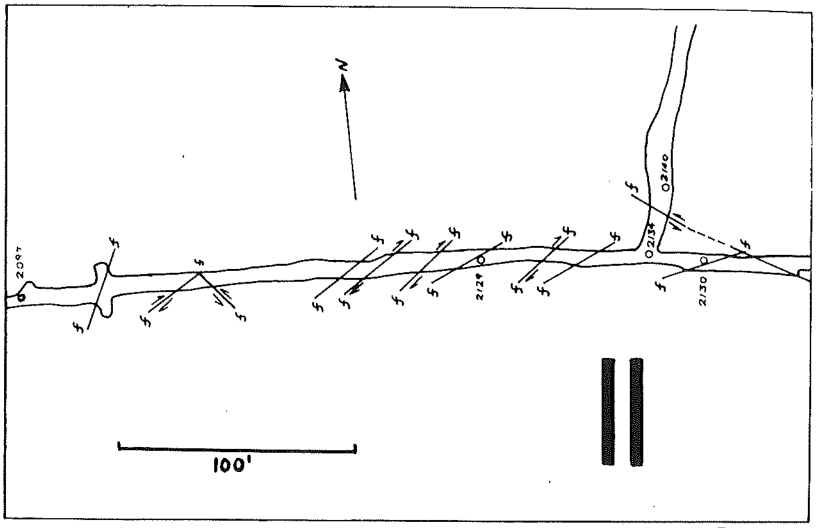
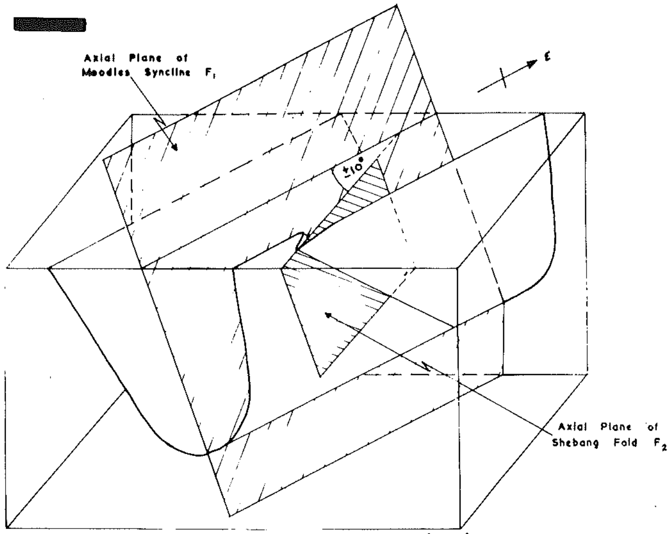


DIAGRAM I

STEREOGRAPHIC PLOTS OF LINEATIONS, PLANAR SURFACES, AND MINOR FOLD AXES

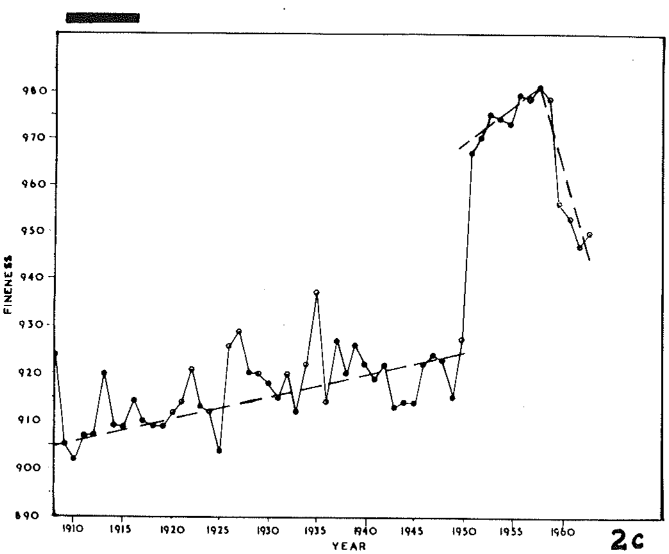


2a

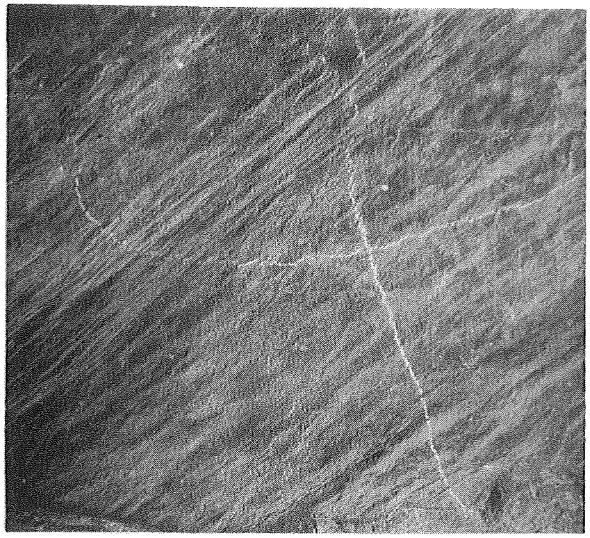


2b

DIAGRAM 2

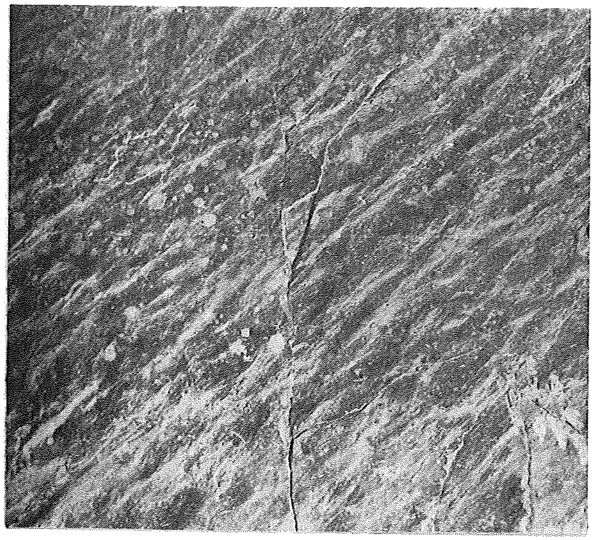


2c

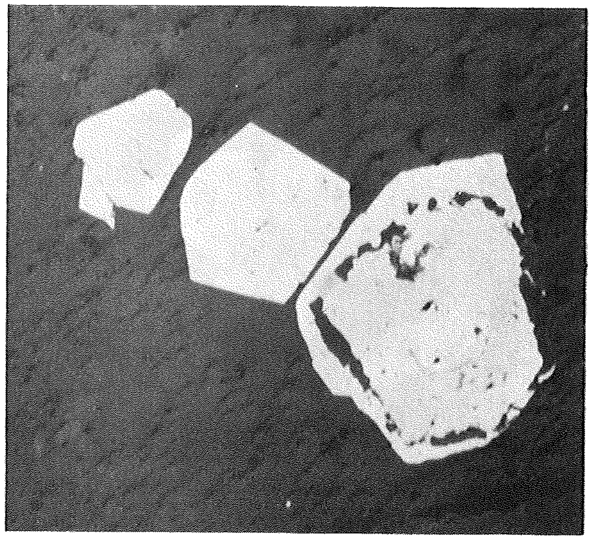


A 2 ft.

B 1 ft.



C 1 ft.



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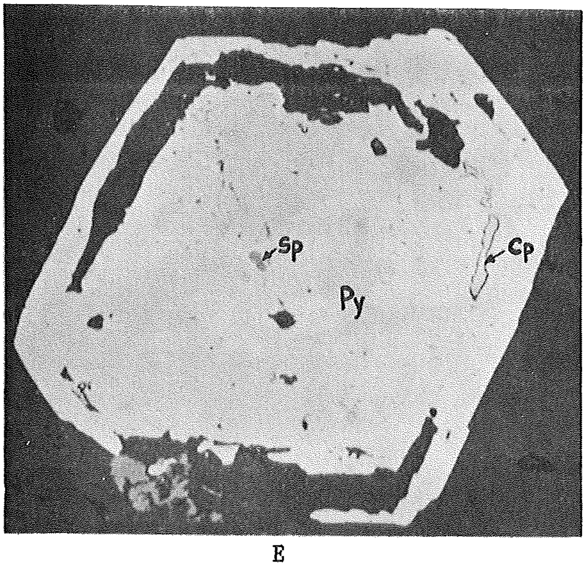
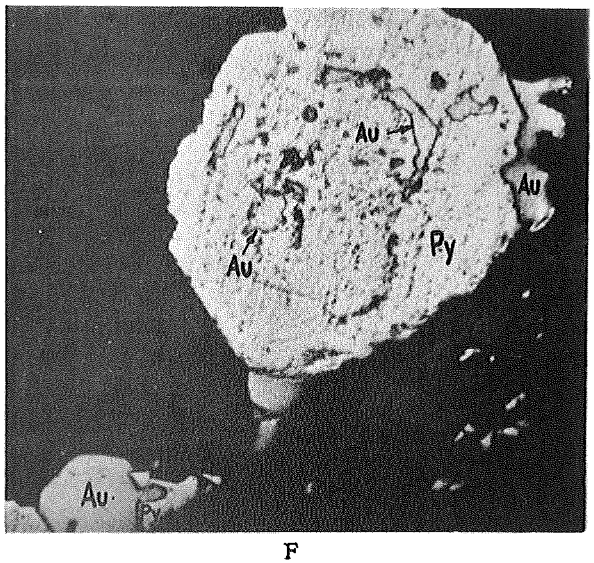
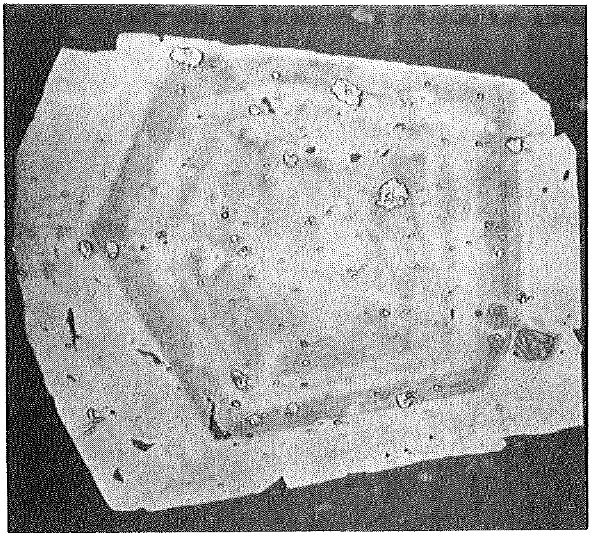


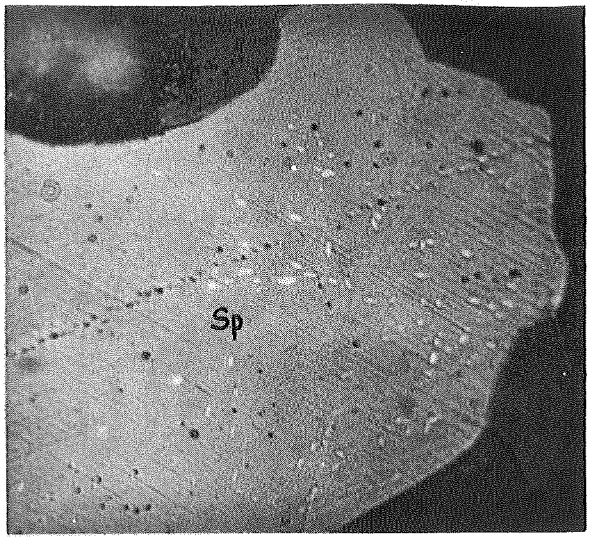
E



F



A



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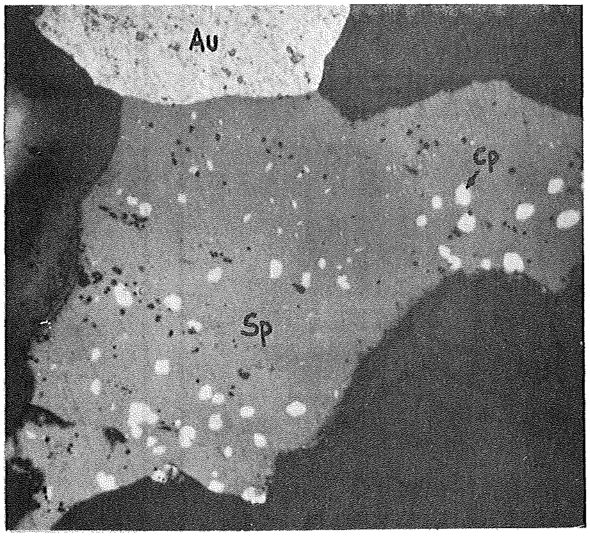

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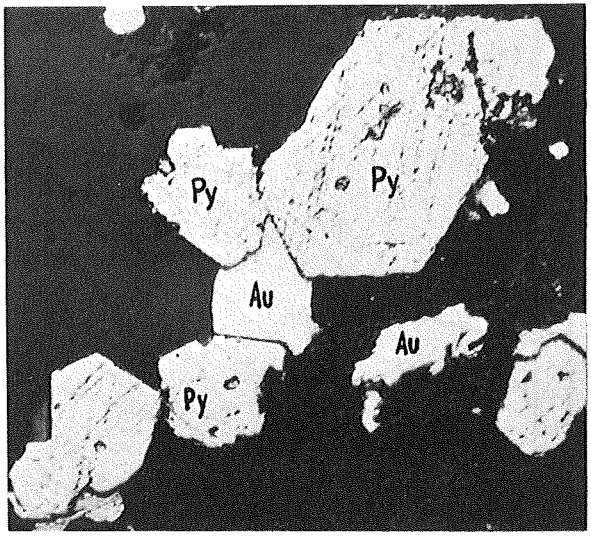

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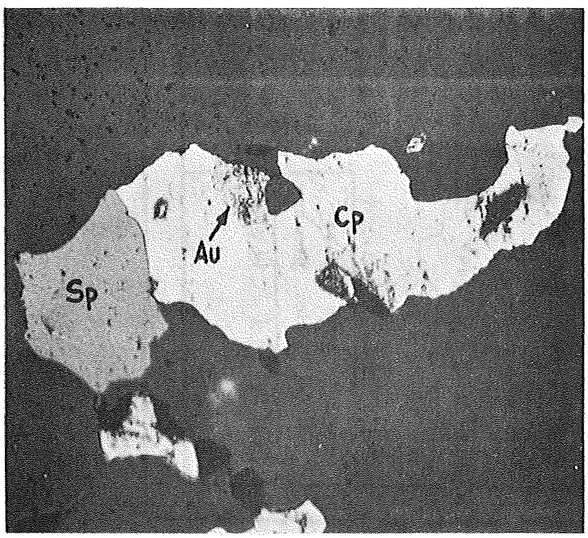

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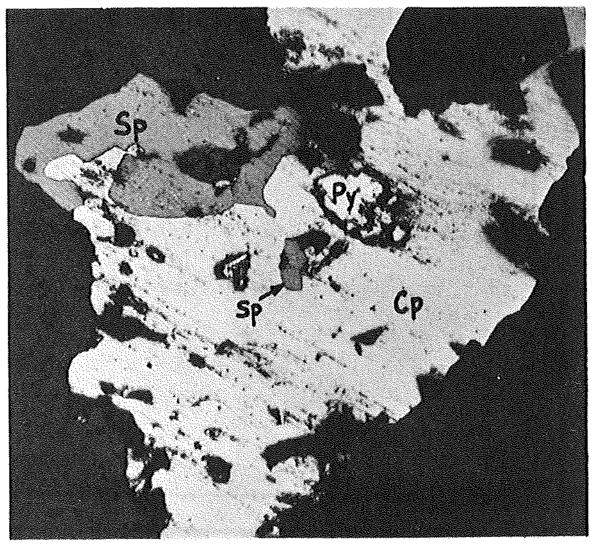


F

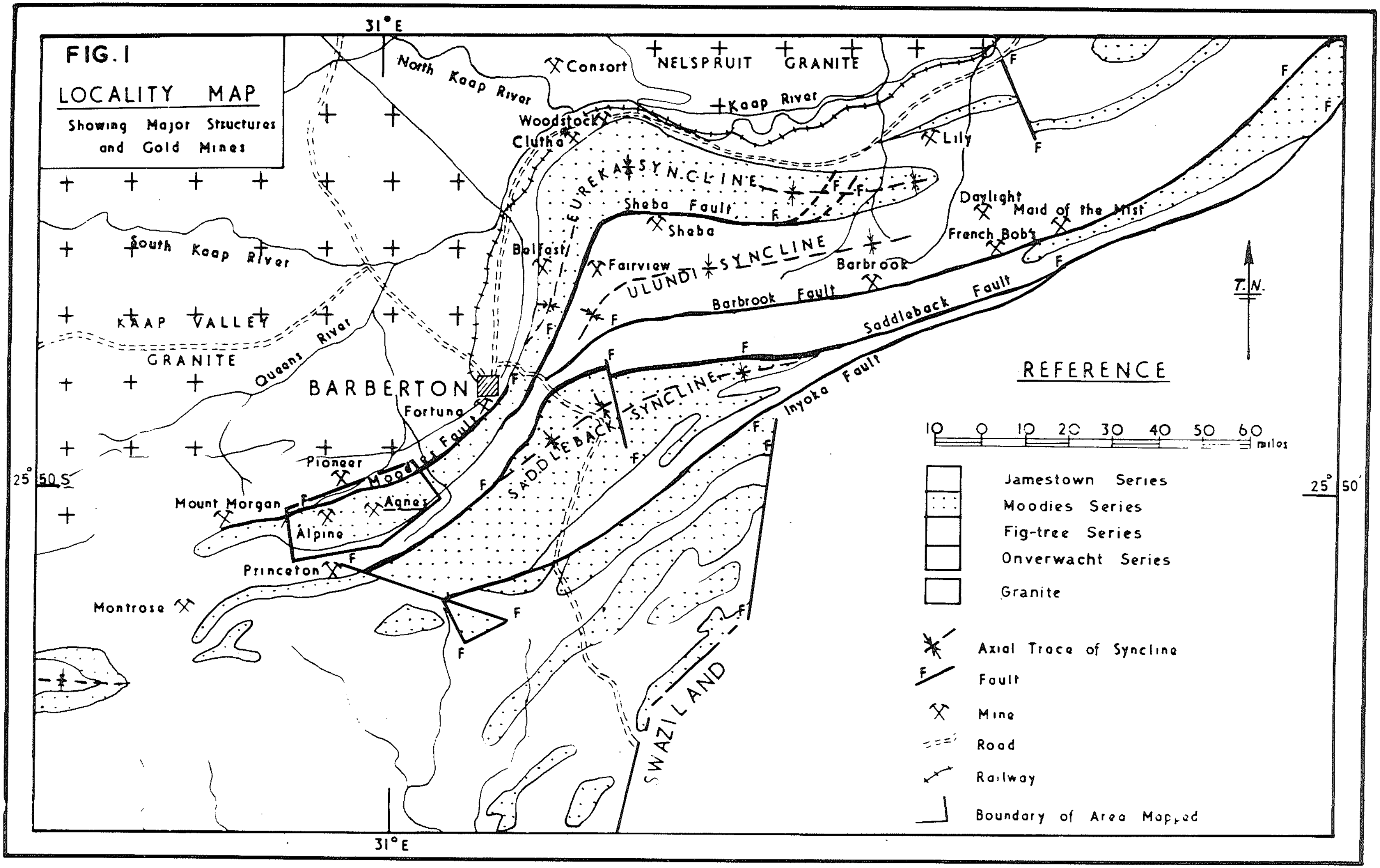
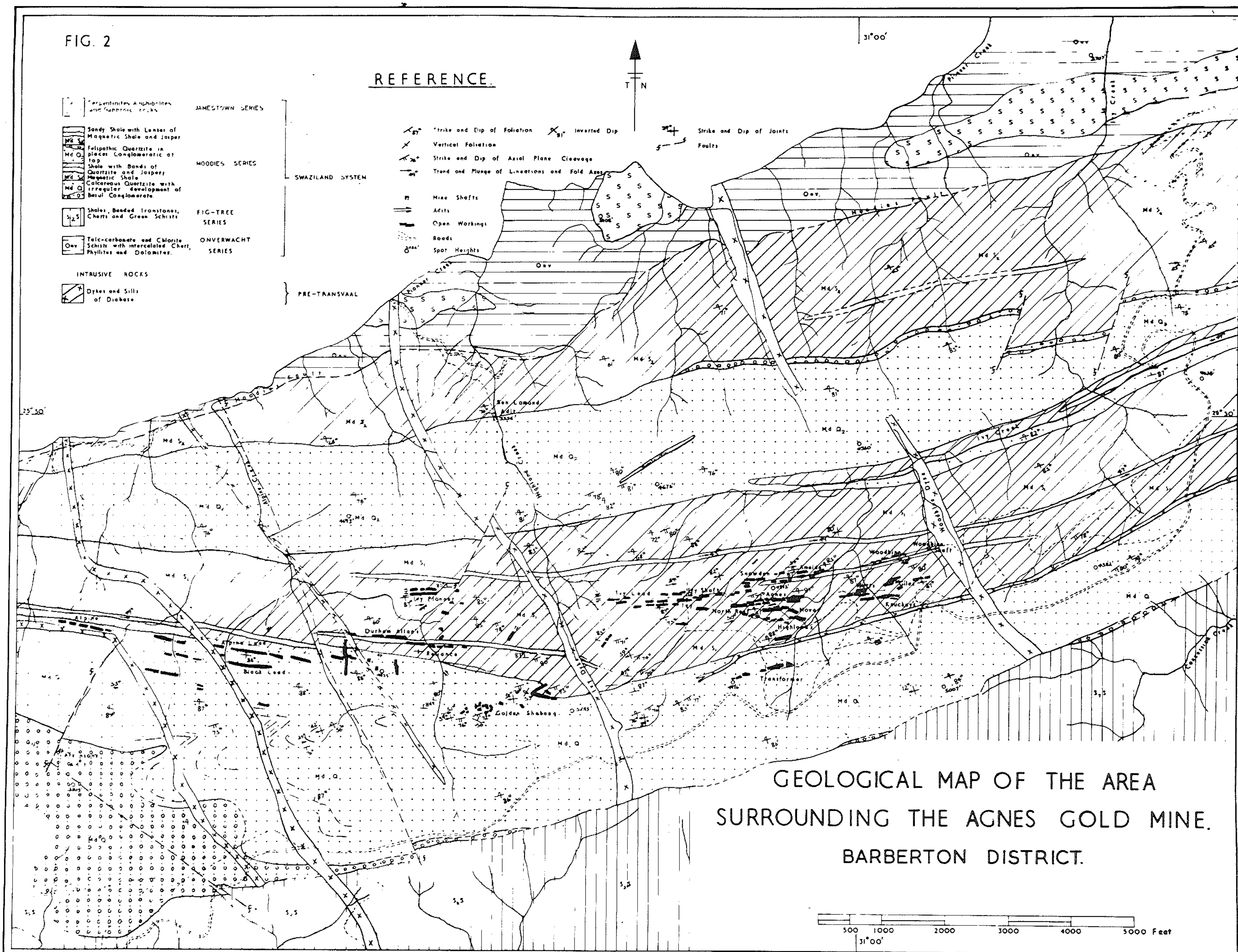


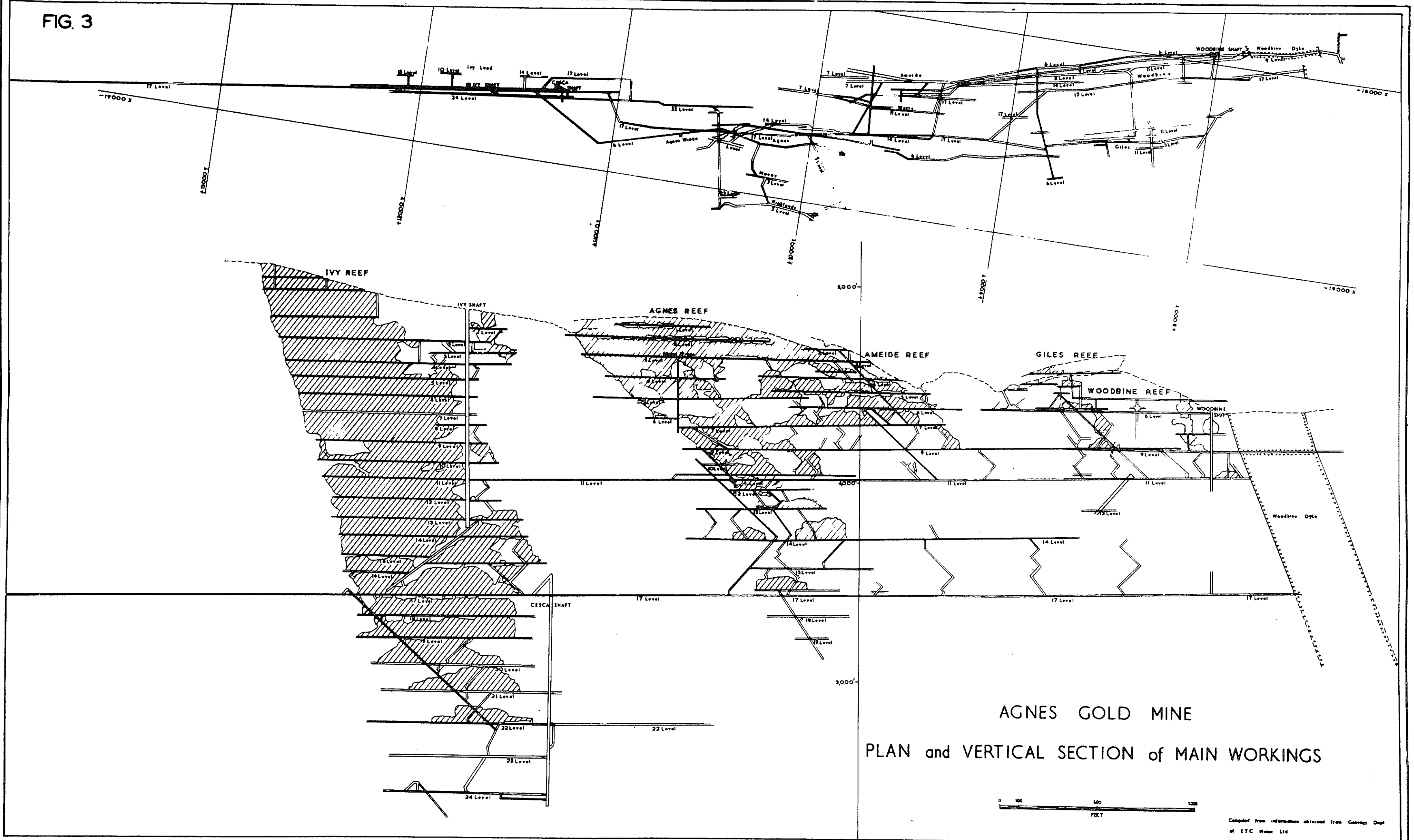
FIG. I
LOCALITY MAP
Showing Major Structures and Gold Mines

FIG. 2



GEOLOGICAL MAP OF THE AREA SURROUNDING THE AGNES GOLD MINE. BARBERTON DISTRICT.

FIG. 3



AGNES GOLD MINE

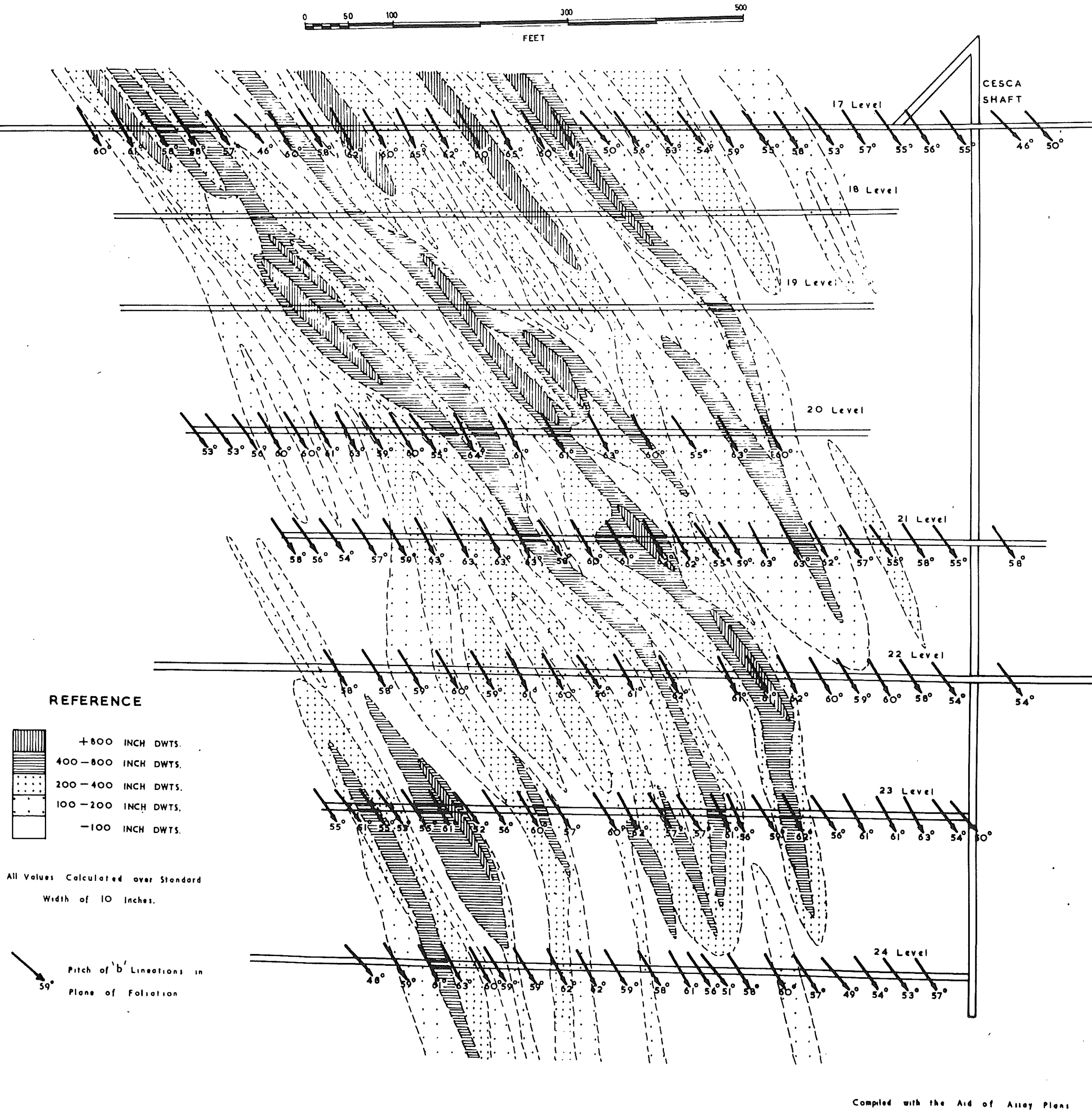
PLAN and VERTICAL SECTION of MAIN WORKINGS

Compiled from information obtained from Geology Dept of ETC Mines Ltd

FIG. 4

AGNES GOLD MINE

SECTION through IVY SHOOT from 17 LEVEL SHOWING RELATION between GOLD DISTRIBUTION and LINEATIONS



Compiled with the Aid of Assay Plans and Sections from E.T.C. Mines Ltd