ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
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"BARREN" MASSIVE SULPHIDE DEPOSITS IN THE MPHOENGS SCHIST BELT, RHODESIA : A CASE HISTORY

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ABSTRACT

Mineral exploration carried out in the Mphoengs Schist Belt, 140 km southwest of Bulawayo, has led to the discovery of prominent gossans outcropping discontinuously over a strike length of 18 km. Investigations, which have included diamond drilling, revealed the presence of extensive massive sulphide deposits occurring as strata-bound pyrite-pyrrhotite bodies interbedded with a succession of metavolcanic and metasedimentary rocks, the latter forming part of a northward protruding arm of the Tati greenstone belt on the southwestern edge of the Rhodesian craton.

The sulphide mineralization occurs in close association with thin, but persistent, carbonate units in a sequence of rocks that includes a variety of amphibole and chlorite schists, quartz-feldspar porphyries, agglomerates and tuffs as well as banded iron-formations and phyllites.

The main minerals making up the sulphide bodies are pyrrhotite and pyrite. Abundant magnetite is intergrown with the sulphides and marcasite, chalcopyrite, and cubanite occur in only minor amounts. Core samples were analysed for Cu, Ni, Au, Ag, Co, Pb, Zn and Sb but the ores were found to be essentially barren of precious and base metal mineralization. A large tonnage low grade source of sulphur was, however, established.

Details of the geology, geochemistry, and mineralogy of the Mphoengs sulphide deposits are provided - the study being offered as an example of a barren Archaean pyrrhotite-pyrite iron-formation.

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INTRODUCTION

Sulphide facies iron-formations are widely distributed in the volcanic-rich Archaean greenstone belts of the shield areas of the world. However, as pointed out by Goodwin (1973), the sulphide facies is frequently overlooked because of its lack of resistance to weathering and thin discontinuous stratigraphic habit. In many parts of the Canadian Shield for example, airborne electromagnetic surveys, aimed at seeking base metal sulphide deposits, have revealed "literally thousands" of sulphide facies iron-formations in recent years. Descriptions of these occurrences, which generally take the form of massive or disseminated, stratiform, pyrrhotite or pyrrhotite-pyrite beds, usually remain concealed in numerous government, company, or personal files. Many pyrrhotite-pyrite deposits are mostly devoid of base or precious metal mineralization and, as a consequence, have only rarely been described in the geological literature (Alcock, 1938; Byers, 1948; Friedman, 1959; Goodwin, 1964, 1973; Kilburn and Wilson, 1955).

The various Archaean iron-formation facies (oxide, carbonate, sulphide, silicate) are readily attributed to volcanic processes in terms of the source of the chemical components (Beukes, 1973; Goodwin, 1973; Gross, 1965). Archaean volcanism is likewise held responsible for the majority of the massive, stratabound, pyritic base metal sulphide deposits containing variable amounts of chalcopyrite, sphalerite, and galena as well as the precious metal association of gold and silver (Hutchinson, 1973; Hutchinson et al., 1971; Sangster, 1972). The differences between the productive base metal deposits and the non-productive pyrrhotite or pyrrhotite-pyrite iron-formations have never satisfactorily been established. The question, posed over 17 years ago by Friedman (1959), as to why the pyrrhotite-pyrite deposits are barren whereas the other sulphide deposits of similar geology, origin, and spatial distribution are base metal producers appears no nearer a solution. Friedman appealed for more facts pertaining to the geology of pyritic and pyrrhotitic deposits in the hope that, eventually, some discriminatory features might emerge which would provide an answer to the problem. Unfortunately, no such response has been forthcoming.

In southern Africa, and more specifically in the Archaean terrane of the Rhodesian craton, numerous sulphide facies iron-formation units have been investigated as possible base metal deposits (Anhaeusser, 1976). In some places, as for example in the Bulawayo, Gwanda, Shangani, Midlands, and Salisbury greenstone belts, outcropping gossans have been prospected and costly drilling programmes have revealed the presence of massive pyrrhotite-pyrite bodies containing only trace amounts of copper, lead, zinc, nickel, gold and silver.

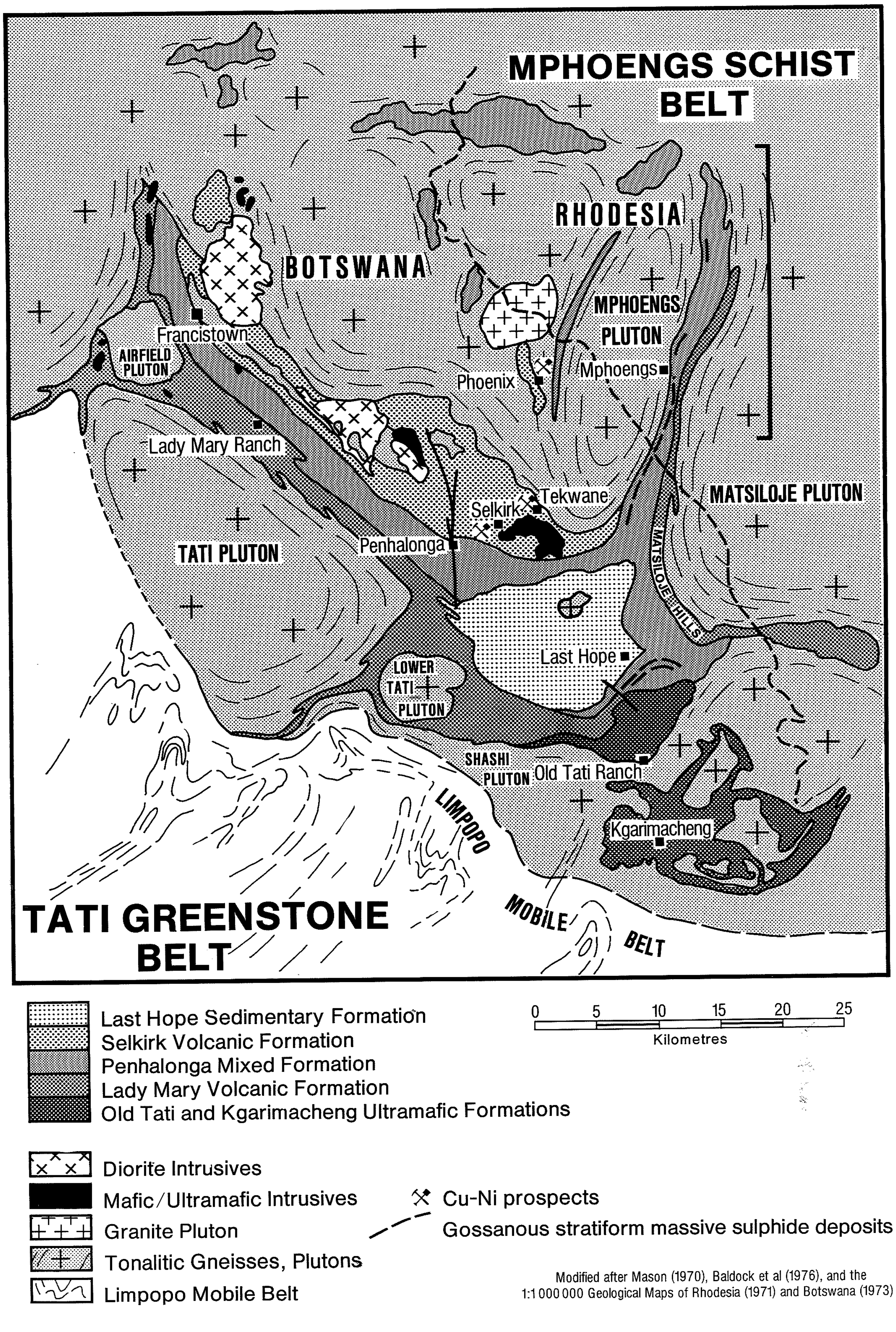
Ideally, to assist exploration efforts, it would be useful to establish as accurately as possible, from the gossans themselves, the nature and base metal content of the sulphides lying below the oxidized surface cappings. Here again little data is currently generally available and most exploration companies have ultimately been compelled to resort to drilling to establish the nature of the sulphide mineralization at depth.

The account which follows attempts to document sulphide facies iron-formation deposits located in the Mphoengs Schist Belt, 140 km southwest of Bulawayo in Rhodesia, and approximately 40 km due east of Francistown in Botswana (Figure 1). The documentation of these stratabound massive sulphide occurrences, which consist largely of pyrrhotite and pyrite, will, it is hoped, provide the stimulus for subsequent more exhaustive approaches to studies of "barren" versus "productive" sulphide facies iron-formations.

HISTORY OF EXPLORATION

The area under consideration covers a northerly striking schist belt protuberance, referred to as the Mphoengs Schist Belt, and which forms part of the more extensive Tati greenstone belt situated in northeastern Botswana (Figure 1). As far back as 1866 Carl Mauch, a German geologist and explorer, first announced the discovery of gold in the Tati area. Since then, the Tati greenstone belt has attracted the attention of prospectors and exploration companies, most of whom concentrated their efforts in exploring for, and exploiting the numerous gold deposits located in the area. Mason (1970), and Baldock et al. (1976), have shown the location of most of the old mines and prospects in this area. The recorded gold production for the entire Tati goldfield has amounted to approximately 205 269 ounces (6 415 kg). A number of small gold workings, including the Gertie, occur in the Mphoengs Schist Belt. Recorded production from this mine, which is located approximately 4 km southeast of the Kweneni Gossan (Figure 2), has amounted to 9 913 ounces of gold (310 kg).

More recently exploration companies operating in this area have focused their attention on base metal mineralization (copper-nickel) following the discovery of the Selebi prospect in 1963 and the Pikwe deposit in 1966 (Gordon, 1973). These and other deposits (Marsh, 1975) are mainly


MPHOENGS SCHIST BELT
RHODESIA
BOTSWANA
MPHOENGS PLUTON
Francistown
AIRFIELD PLUTON
Phoenix
Mphoengs
Lady Mary Ranch
MATSILOJE PLUTON
Tekwane
Selkirk
Penhalonga
TATI PLUTON
MATSILOJE HILLS
Last Hope
LOWER TATI PLUTON
SHASHI PLUTON
Old Tati Ranch
Kgarimacheng
LIMPOPO MOBILE BELT
TATI GREENSTONE BELT
Last Hope Sedimentary Formation
Selkirk Volcanic Formation
Penhalonga Mixed Formation
Lady Mary Volcanic Formation
Old Tati and Kgarimacheng Ultramafic Formations
Diorite Intrusives
Mafic/Ultramafic Intrusives
Granite Pluton
Tonalitic Gneisses, Plutons
Limpopo Mobile Belt
Cu-Ni prospects
Gossanous stratiform massive sulphide deposits
0 5 10 15 20 25
Kilometres
Modified after Mason (1970), Baldock et al (1976), and the
1:1 000 000 Geological Maps of Rhodesia (1971) and Botswana (1973)

associated with amphibolite and serpentinite host rocks and lie to the south of the Tati greenstone belt in the central zone of the Limpopo Mobile Belt. At about the same time, reinvestigations in the Tati area led to the realization that the old Phoenix gold prospect was also a nickel-copper deposit (Mound Struck). Further exploration led to the discoveries of the disseminated copper-nickel orebodies at Selkirk and Tekwane (Figure 1), all of which were investigated by the Anglo American Corporation. Also in 1967, Special Grant No. 361, which covered 4 870 km^2 of the south-western Rhodesian Lowveld between the Ramaquabane and Tuli rivers, was granted to Rhodesian Selection Trust Exploration Ltd. The area of the grant, which included the Mphoengs Schist Belt, was covered by photogeological mapping and soil sampling for copper and nickel as a follow up to the company's success in the Selebi-Pikwe area. According to Morrison (1975) numerous small anomalies were found and some were investigated, but no significant mineral deposits were discovered. The area was finally abandoned early in 1969, mainly because of political pressures. Later the same year Southern Exploration (Pvt.) Ltd., was granted an Exclusive Prospecting Order (E.P.O. No. 292) which covered the north-trending Mphoengs Schist Belt. Singled out for further attention, by Mr. Morrison of the Rhodesian Geological Survey, were three areas within the R.S.T. Special Grant No. 361 that had yielded anomalous geochemical copper-nickel values. One of these areas in particular (the southern portion of the Mphoengs Schist Belt) received the most attention in the follow up exploration programme. It is largely the results of this work, which terminated during the second half of 1971, that are reported in this paper (Ryan, 1971). Supplementary findings, based on work carried out during 1972 and 1973 by Gold Fields Prospecting Co. (Pty.) Ltd., have also been used in this documentation. Additional sampling of the gossans and surrounding country rock was also undertaken by the writers early in 1976.

REGIONAL GEOLOGY OF THE TATI GREENSTONE BELT

Previous Work

Carl Mauch, the discoverer of the Tati goldfield, was the first to recognise and outline the Tati greenstone belt and the Limpopo "gneiss belt". The map which Mauch prepared between 1870 and 1872 was reproduced in 1935 by Harger. Apart from unpublished reports and sketch maps by members of the Botswana Geological Survey no systematic geological mapping of the area was undertaken prior to the investigations carried out in the region by Mason (1970). Since 1970, further regional mapping of the Tati greenstone belt has been undertaken by Key (in press), some of the results of which have been incorporated in a paper reviewing some of the economic geology of Botswana (Baldock et al., 1976). A simplified geological map of the Tati greenstone belt and surrounding granitic terrane has been compiled from these and other sources and is shown in Figure 1.

General Geology

The Tati greenstone belt, situated on the southwestern flank of the Rhodesian craton, is typical of the Archaean greenstone or schist belt remnants still preserved in southern Africa. These remnants, as outlined by Anhaeusser et al. (1969), commonly occur as arcuate schist belts surrounded and intruded by a variety of granitic rock types, the latter frequently represented by diapiric tonalite gneiss plutons. The granitic rocks flanking the southern and western portions of the Tati greenstone belt have been influenced by the later Limpopo tectonothermal events which were also responsible for the development of the high grade metamorphic gneisses (upper amphibolite and granulite facies) of the Limpopo Mobile Belt. These tectonothermal events were superimposed on one another approximately 2,7 b.y. ago and again later at about 2,0 b.y. ago. There is also a suggestion that earlier metamorphic events took place prior to 3,1 b.y. ago (Van Breemen and Dodson, 1972) or even prior to 3,4 b.y. ago (B. Ryan, personal communication, 1975). No direct age measurements are, however, available for the rocks of the Tati greenstone belt. According to Mason (1970), the Tati greenstone belt consists of a complex synformal enclave of metavolcanic and metasedimentary schists surrounded by a variety of granite types, the latter consisting mainly of tonalites, but also including granodiorites and adamellite plutons as well as smaller diorite stocks.

At the base of the greenstone belt succession the Old Tati and Kgarimacheng Formations consist of a series of interlayered ultramafic schists, serpentinites, and mafic schists, together with subordinate banded iron-formations and aluminous quartz-sericitic schist units. Overlying this assemblage is the Lady Mary Volcanic Formation which consists mainly of metabasaltic schists, mafic pillow lavas, and thin pyroclastic units. Subordinate ultramafic schist layers occur interlayered with the mafic metavolcanics. Sheared mafic tuffs, prominent banded iron-formations, and thin limestone beds are also grouped into this formation (Baldock et al., 1976) although Mason (1970) separated these components into what he termed the Matsiloje Formation. Evidence from Rhodesian E.P.O. reports (Morrison, 1975) appears to support the view that the eastern flank of the Tati greenstone belt is comprised of a more ultramafic-mafic assemblage than that originally proposed by Mason (1970). Banded iron-formation interlayers, such as those forming the prominent Matsiloje Hills (Plate 1A), as well as the other components of Mason's Matsiloje Formation, would not be out of place if considered as part of the Lady Mary Volcanic Formation or either of the earlier ultramafic formations.

The Penhalonga Mixed Formation, as defined by Mason (1970), heralds a change in the nature of the volcanicity, with the metabasaltic rocks giving way to more andesitic types. Pyroclastic rocks predominate in the lower part of the succession, being separated from the overlying more massive meta-andesitic rocks by a highly aluminous pyroclastic zone containing concentrations of pyrophyllite, chloritoid, and kyanite, the latter mineral having been mined at Halfway Kop, situated approximately 7 km southeast of the Lady Mary Ranch (Figure 1). Apart from the pyroclastic components, the lower succession also contains subordinate calc-schists, limestones, quartz-sericite schists, and cherts. The upper part of the succession, which extends northwards into the Ramaquabane valley and then on into the Mphoengs Schist Belt, consists mainly of mafic to felsic volcanic and pyroclastic rocks together with minor sedimentary interlayers of quartz-sericite schist, limestone, banded iron-formation, and several gossanous horizons, the latter representing the surface expression of stratiform sulphide facies iron-formations interbedded with carbonaceous phyllites and impure limestones. The Selkirk Formation represents the top of the Tati volcanic pile and consists mainly of a thick succession of felsic lavas and pyroclastic rocks. Quartz porphyries and quartz-feldspar porphyries of dacitic composition predominate in the sequence and occur together with recrystallized rhyolites. Signs of sulphide mineralization (pyrite) in these felsic volcanics are not uncommon (Mason, 1970) but the Selkirk and Tekwane deposits (Figure 1) are related to a metatroctolitic stock faulted against quartz-diorite (Baldock et al., 1976). At Selkirk the copper-nickel mineralization is concentrated in the nose and along the axis of a synformal structure, expressed at the surface by massive gossan outcrops.

A succession consisting mainly of clastic sediments (sandstones, arkoses, shales, phyllites, grits, conglomeratic grits, calcareous grits, and meta-greywackes), and referred to as the Last Hope Sedimentary Formation by Mason (1970), occupies a discrete basin in the central part of the Tati greenstone belt. Also included in this formation are several units of banded cherts or banded ferruginous cherts with lenses of jaspilite. Thin limestones, sometimes relatively pure, but more often ferruginous, also occur in several parts of the Last Hope Formation.

The Tati greenstone belt which, as a whole, is synformal in character, displays a marked stratigraphic assymmetry - the lower units of the Tati sequence being absent on the northern flank of the schist belt. It appears that much of this lower stratigraphy may have been eliminated by gregarious granite diapirism leaving behind only widely dispersed remnants of greenstone in the granitic terrane to the north. Regional structural failure along the NW-SE trending axis of the Tati belt appears, furthermore, to have produced a zone of weakness along which most of the post-tectonic igneous activity was subsequently emplaced (Mason, 1970). As can be seen in Figure 1, a series of ultramafic and mafic intrusives (serpentinites and troctolitic gabbros) as well as diorite sheets and dykes, and late tonalitic stocks, have been injected into the Selkirk Volcanic Formation east, southeast, and north of Francistown.

DETAILS OF THE GEOLOGY OF THE MPHOENGS SCHIST BELT

When viewed in its regional context the Mphoengs Schist Belt can be seen to be a long, narrow, greenstone protruberance, consisting mainly of rock types that form part of the Penhalonga Mixed Formation as well as part of what might be regarded as the Lady Mary Volcanic Formation in the east.

In contrast to the surrounding plains, the Mphoengs Schist Belt appears as a north-northeasterly-trending range of low hills. Elevation variations range between 914 m and 1 036 m above sea level and three large rivers (Ramaquabane, Umpakwe and Ingwezi) drain the bush-covered region. Flanking the greenstone remnant is the Matsiloje pluton on the east and the Mphoengs pluton on the west. Exposures of the Matsiloje pluton along the eastern contact of the schist belt are rare but the Mphoengs pluton is exposed in several localities along the western contact where the drainage system of the Ingwezi river has assisted in providing outcrops. Southeast of the Mphoengs Police Station (Figure 2) tonalitic gneisses display strongly developed, steeply dipping, foliation planes, the latter orientated parallel to the schistosity in the adjacent greenstone belt.

Geochemical data, available from the Mphoengs pluton (Table 1, column 12; Table 2), confirms the tonalitic nature of the intrusive body. Table 2 also provides average partial chemical analyses of the alkali elements from a number of other diapiric granite plutons flanking the Tati greenstone belt. Although no geochemical data is available for the Matsiloje pluton petrological evidence from exposures in Botswana showed the granite to be soda-rich, consisting of an assemblage of quartz, oligoclase, and biotite, with only occasional potash feldspars present (Mason, 1970). Despite poor outcrops Mason also noted that the margin of the pluton is foliated and lineated and has small schist inclusions aligned parallel to the schist belt contact.

The distribution of the volcano-sedimentary rocks that comprise the Mphoengs Schist Belt is shown in a simplified geological map of the region (Figure 2). Extending along the eastern flank of the schist belt are a variety of mafic volcanic rocks (lavas and tuffs - now mainly chloritic schists) with minor felsic interlayers (quartz-feldspar porphyries), oxide facies banded iron-formations or banded ferruginous cherts, phyllites, and ultramafic schists. Outcrops in this region are generally

TABLE 1

CHEMICAL ANALYSES, C.I.P.W. NORMS, AND COLOUR INDECES OF VARIOUS ROCK TYPES ASSOCIATED WITH THE MPHOENGS GOSSANS

	Mafic Volcanics				Felsic Volcanics			Carbonate Sediments			Diabase	Tonalite
	1	2	3	4	5	6	7	8	9	10	11	12
	MP 1	MP 15	MP 18	MP 9	MP 16	MP 14	MP 22	MP 5	MP 13	MP 19	MP 8	MP 21
SiO_2	42,40	49,32	54,72	57,66	64,99	65,96	55,40	19,36	1,86	0,85	46,32	64,50
TiO_2	0,70	0,92	0,68	0,62	0,48	0,60	0,46	tr	tr	tr	0,80	0,48
Al_2O_3	8,82	17,54	15,46	12,06	15,76	16,80	10,50	0,36	0,50	0,28	11,12	16,95
Fe_2O_3	2,14	2,82	2,13	1,86	3,17	0,93	4,58	0,14	2,51	0,04	3,07	1,67
FeO	9,50	9,00	6,30	5,80	0,70	1,90	1,20	0,12	0,40	0,40	11,70	2,20
MnO	0,17	0,16	0,13	0,10	0,26	0,21	0,40	0,90	1,60	0,26	0,21	0,06
MgO	9,35	4,98	6,60	9,91	0,35	1,30	0,35	0,20	1,05	0,30	11,80	0,78
CaO	11,01	10,40	7,53	5,06	8,81	5,98	18,50	44,82	49,98	54,20	9,90	3,80
Na_2O	0,64	0,92	1,40	1,64	2,42	2,26	1,02	0,31	0,73	0,28	1,17	4,44
K_2O	0,07	0,30	0,70	0,52	0,49	0,53	0,78	0,04	0,12	0,07	0,14	1,20
P_2O_5	0,02	0,01	0,06	0,05	0,03	0,10	0,09	0,01	0,01	0,01	0,01	0,12
H_2O^+	5,28	1,27	2,05	2,40	0,46	0,46	tr	0,28	0,32	0,29	2,11	1,00
H_2O^-	0,03	0,12	0,03	0,11	0,05	0,04	0,02	0,05	0,13	0,08	0,10	0,07
CO_2	8,66	0,36	0,36	0,27	0,89	0,98	3,75	31,84	39,59	42,80	0,31	0,31
Totals	98,59	98,12	98,15	98,06	98,86	98,05	97,05	98,43	98,80	99,86	98,76	97,58

Modal Compositions (C.I.P.W. weight norms)

	1	2	3	4	5	6	7	8	9	10	11	12
Cc	34,59	1,67	1,68	1,27	4,03	4,46	16,16				1,44	1,45
Ap	0,04	0,24	0,14	0,12	0,07	0,23	0,20				0,24	0,29
Il	1,17	1,78	1,33	1,22	0,91	1,14	0,83				1,55	0,94
Or	0,36	1,80	4,25	3,18	2,89	3,14	4,37				0,84	7,29
Ab	4,76	7,92	12,17	14,36	20,41	19,15	8,18				10,10	38,61
An		43,56	34,73	23,86	30,58	22,84	20,62				25,17	16,54
Mt	2,73	4,17	3,17	2,79	1,71	1,35	3,64				4,54	2,49
Di		2,57	0,48		1,87		1,78				11,81	
He		2,32	0,23								6,32	
Q	15,48	9,89	15,59	18,23	33,57	38,06	25,27					25,74
Fo											3,56	
Fa											2,41	
Fs	13,82	12,66	9,59	9,08		2,25					12,62	2,16
En	20,45	11,42	16,65	25,53		3,24					19,41	2,00
C	6,84			0,36		4,15						2,51
Wo					1,99		17,13					
H					1,98		1,83					

Colour Index

37	33	30	38	6	7	8				61	7

Analysts : Analytical Services, Johannesburg.

Column :
1. Carbonated metabasalt, Central Gossan.
2. Felspathic amphibolite (metabasalt), Northern Gossan.
3. Actinolite/chlorite schist (metabasalt or tuff), Northern Gossan.
4. Chlorite schist (mafic metavolcanic rock), Northern Gossan.
5. Banded quartz-feldspar porphyry (dacitic), Northern Gossan.
6. Feldspar porphyry (dacitic), Northern Gossan.
7. Carbonated and saussuritized felsic porphyry, Mphoengs Gossan.
8. Banded calc-silicate rock (calcite-diopside-grossularite), Central Gossan.
9. Banded limestone with ferruginous layers, Central Gossan.
10. Marble (crystalline limestone), Southern Gossan.
11. Coarse-grained diabase dyke, Northern Gossan.
12. Leuco-tonalitic gneiss, Mphoengs Pluton, west of Northern Gossan.

TABLE 2

PARTIAL CHEMICAL ANALYSES (AVERAGES) OF SOME DIAPIRIC PLUTONS INTRUSIVE INTO THE TATI GREENSTONE BELT

Diapiric Plutons	No. of Analyses	Na_2O (wt %)	K_2O (wt) %
Mphoengs	2	4,05	1,71
Kgarimacheng	7	4,49	2,18
Lower Tati *	5	4,90	3,33
Airfield *	1	4,11	4,64
Tati *	8	3,27	5,41

* Plutons influenced by K-metasomatism from adjacent Limpopo Mobile Belt. (partial analyses after Mason, 1970).

poor and discontinuous. To the west of this succession is an assemblage comprised of mafic and intermediate to felsic volcanic rocks (lavas, tuffs, and quartz-feldspar porphyries) with interlayers of banded iron-formation (oxide facies), pure and impure limestone (marble, ferruginous limestone, and calc-silicate rocks), and gossanous surface cappings over stratiform sulphide facies iron-formations. All the rocks in the area have been subjected to low grade regional greenschist metamorphism.

Five principal gossanous zones outcrop discontinuously over a strike length of approximately 18 km. In the north is the Kweneni Gossan, while in the south there is the Mphoengs Gossan as well as the Northern, Central and Southern gossans (Figure 2). It is possible that the gossans are developed in more than one stratigraphic unit, or cycle, within the schist belt. The Northern, Central and Southern gossans appear to occur in one unit whereas the Mphoengs Gossan, and possibly the Kweneni Gossan, may occur in a different stratigraphic unit to the west. Duplication of the gossans by stratigraphic wedging or by isoclinal folding about near vertical fold axes in the schist belt also cannot be ruled out entirely. Inadequate exposure, however, makes resolution of this possibility impracticable. Structurally the attitudes of the formations in the Mphoengs Schist Belt are generally vertical to sub-vertical with the dips of bedding and schistosity, in the vicinity of the gossanous zones, being, on average, upwards of 70 degrees to the east.

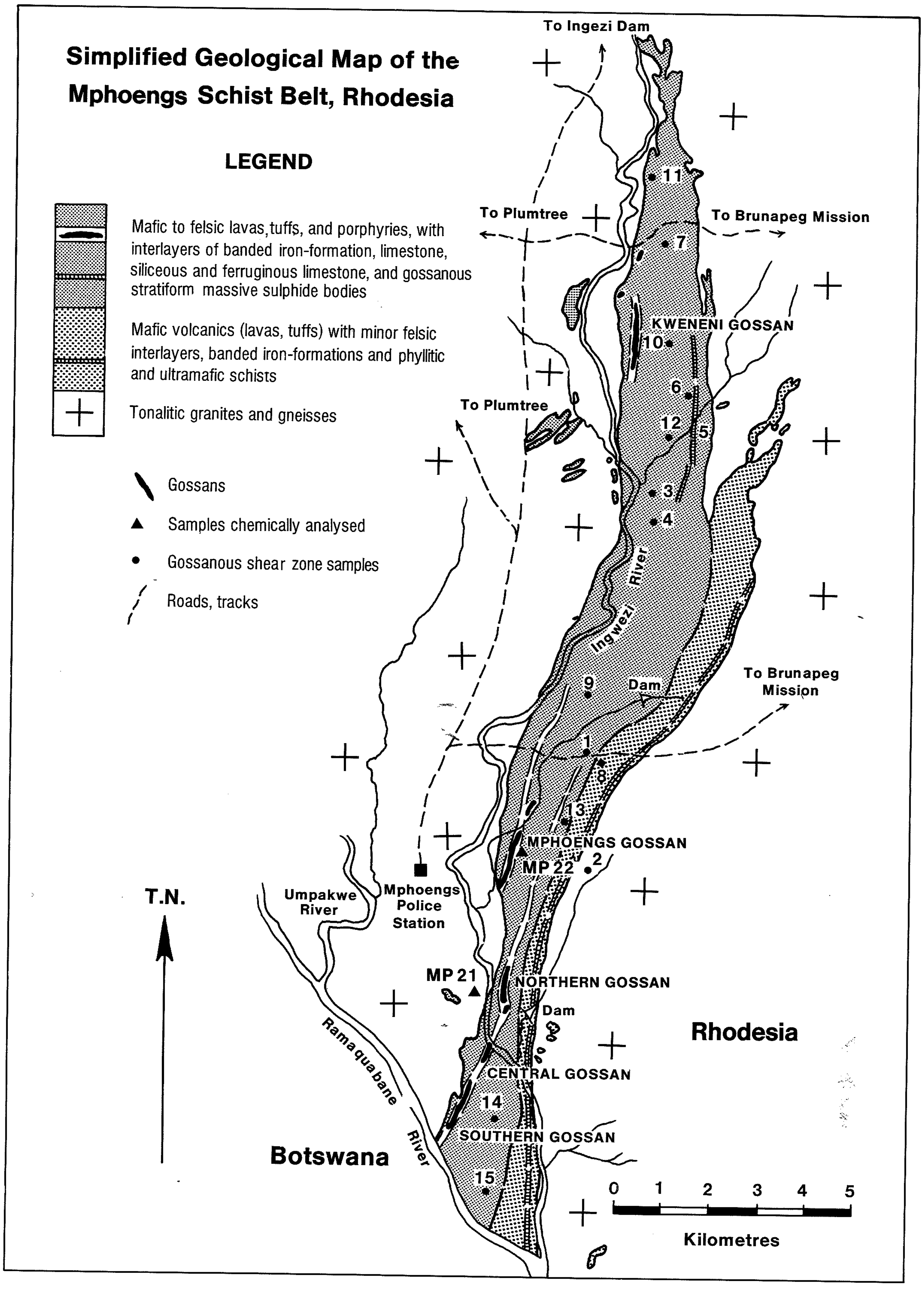
The last events to have influenced the region included the intrusion of a swarm of mafic dykes, the latter being possibly of several ages, and having a dominant E.W. and N.N.W. trend, with a subsidiary E.N.E. trend. Many of the dykes appear to have been intruded along faults as can be seen by the lateral displacement of certain marker beds. The dykes, which include dolerite, diabase, diorite, and altered pyroxenite varieties (Ryan, 1971) cause considerable disruption to the lateral continuity of the gossanous zones (Figures 3-7). A chemical analysis of an amphibolitic dyke cutting the Northern Gossan is provided in Table 1, column 11.

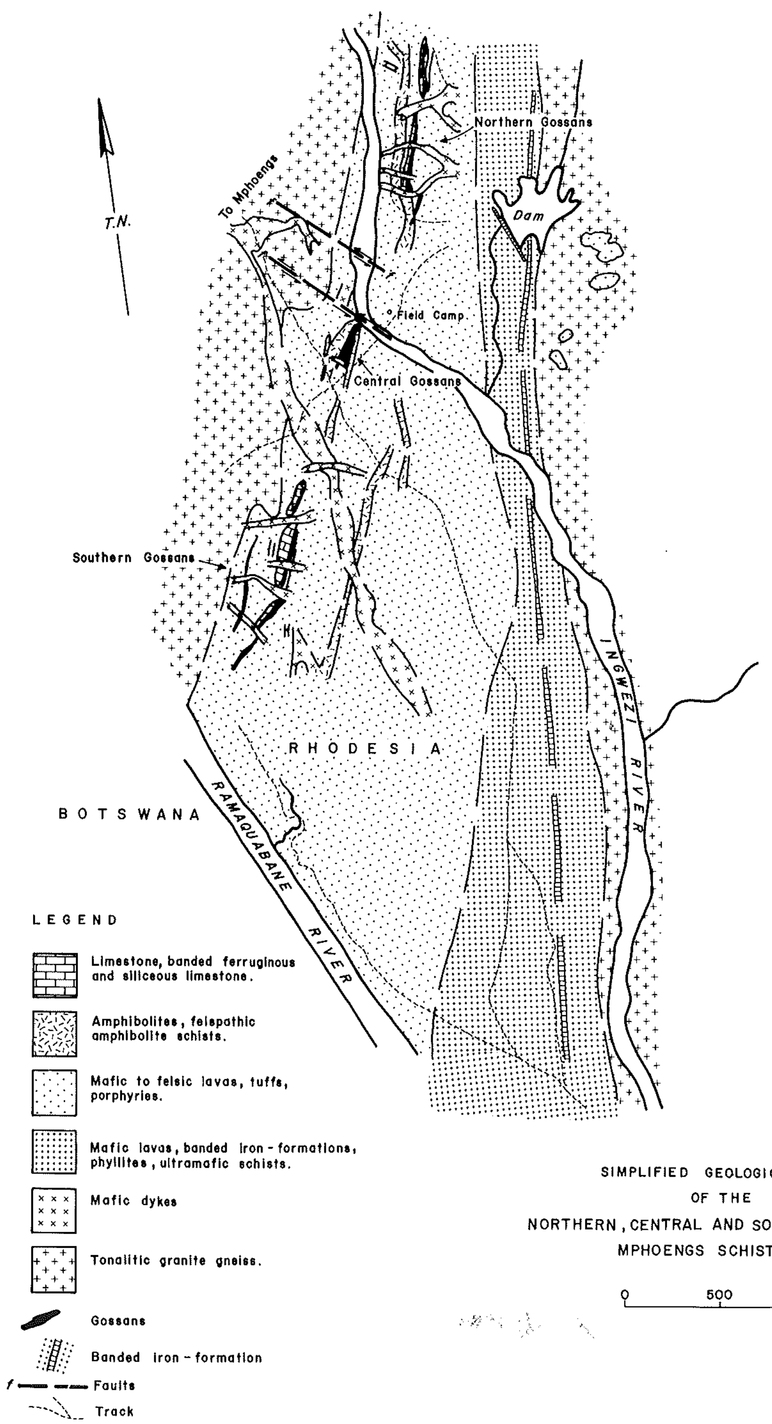
Geochemical Soil-Sampling

As mentioned previously, reconnaissance geochemical soil-sampling investigations, first carried out in the area by Rhodesian Selection Trust, led to the eventual selection of specific areas in the Mphoengs Schist Belt for more detailed follow up work. Subsequent geological investigations in these areas revealed the presence of the discontinuous, but well-developed, line of gossan outcrops extending along the western margin of the schist belt.

In order to check and delineate more precisely the nickel and copper anomalies in the target areas, as well as to check the gossans for anomalous trace element content, a more detailed geochemical soil-sampling programme was undertaken in the areas of interest. Traverse lines were spaced 100 m apart and 25 m sample intervals were chosen. Samples were collected at 25 cm depths. In some places traverse lines were shortened to 25 m intervals. Initially samples were analysed for copper, nickel, lead, and zinc, but it was later found that lead was of little diagnostic value and analysis for this element was discontinued. The gossans were also assayed for gold and silver. The results of the geochemical soil-sampling programme in the vicinity of the Northern, Central and Southern gossans is shown in Figure 3.

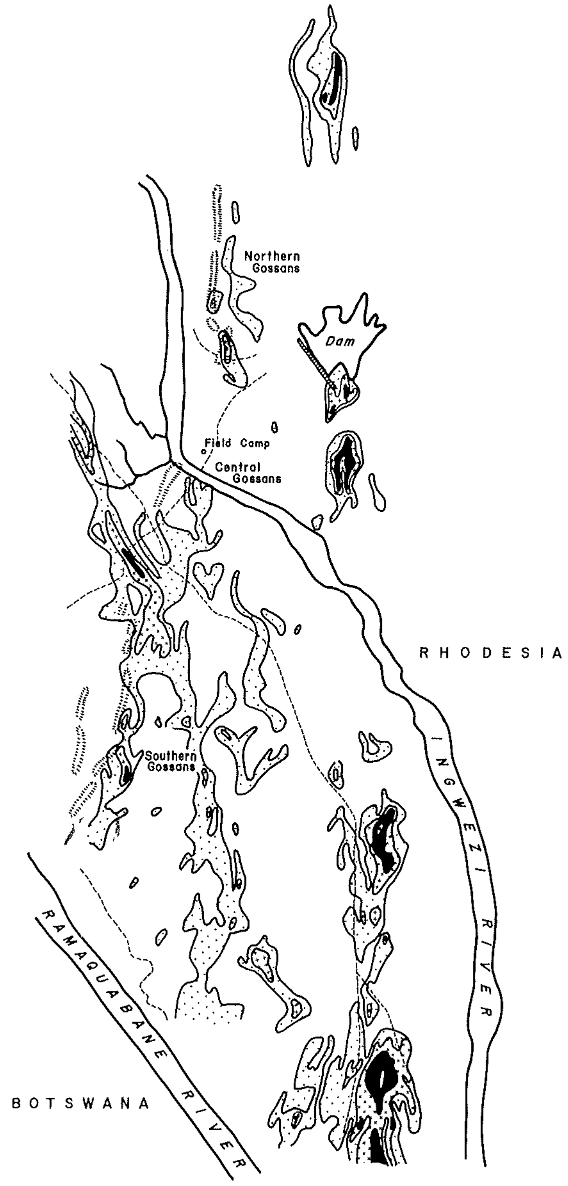
The first map in the series shows the simplified geology of the southern portion of the Mphoengs Schist Belt and emphasizes the gossanous zones and the disruptive nature of several of the intrusive mafic dykes in the area. The map also shows the more mafic volcanic succession developed on the eastern flank of the schist belt and the position of a banded iron-formation unit within the sequence. The three adjacent maps depict, on the same scale, the results of the geochemical soil sampling in the region. The first of these maps shows the plot of nickel distribution. The most


Simplified Geological Map of the
Mphoengs Schist Belt, Rhodesia
LEGEND
Mafic to felsic lavas, tuffs, and porphyries, with interlayers of banded iron-formation, limestone, siliceous and ferruginous limestone, and gossanous stratiform massive sulphide bodies
Mafic volcanics (lavas, tuffs) with minor felsic interlayers, banded iron-formations and phyllitic and ultramafic schists
Tonalitic granites and gneisses
Gossans
Samples chemically analysed
Gossanous shear zone samples
Roads, tracks
To Ingezi Dam
To Plumtree
To Brunapeg Mission
KWENENI GOSSAN
To Plumtree
Ingwezi River
Dam
To Brunapeg Mission
MPHOENGS GOSSAN
MP 22
Mphoengs Police Station
Umpakwe River
T.N.
MP 21
NORTHERN GOSSAN
Dam
Rhodesia
CENTRAL GOSSAN
Ramaquabane River
SOUTHERN GOSSAN
Botswana
0 1 2 3 4 5
Kilometres



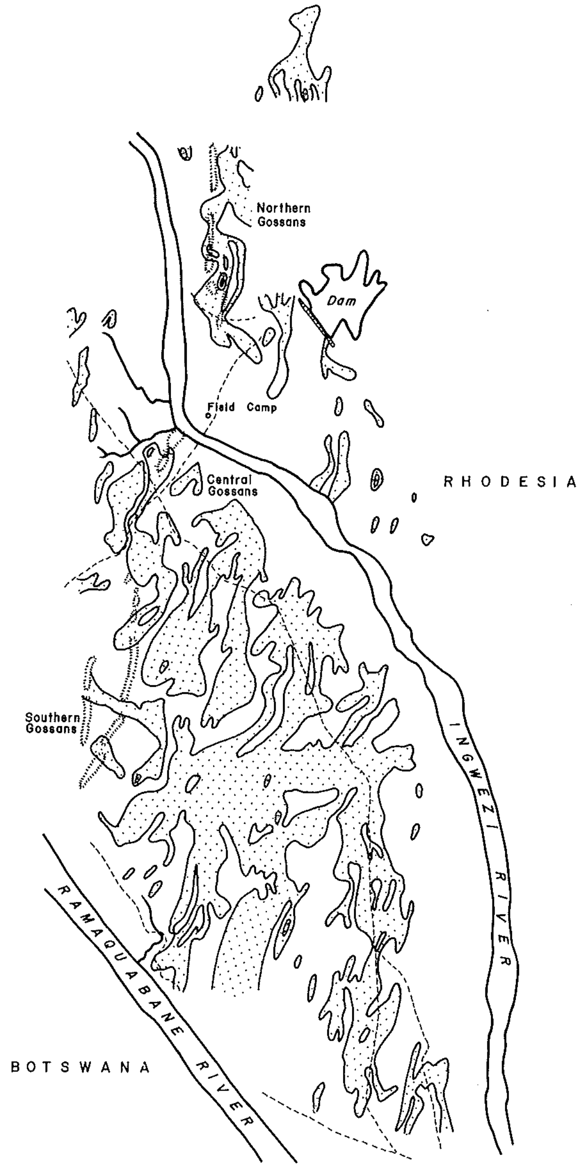
SIMPLIFIED GEOLOGICAL MAP
OF THE
NORTHERN, CENTRAL AND SOUTHERN GOSSANS,
MPHOENGS SCHIST BELT.

0 500 1000m



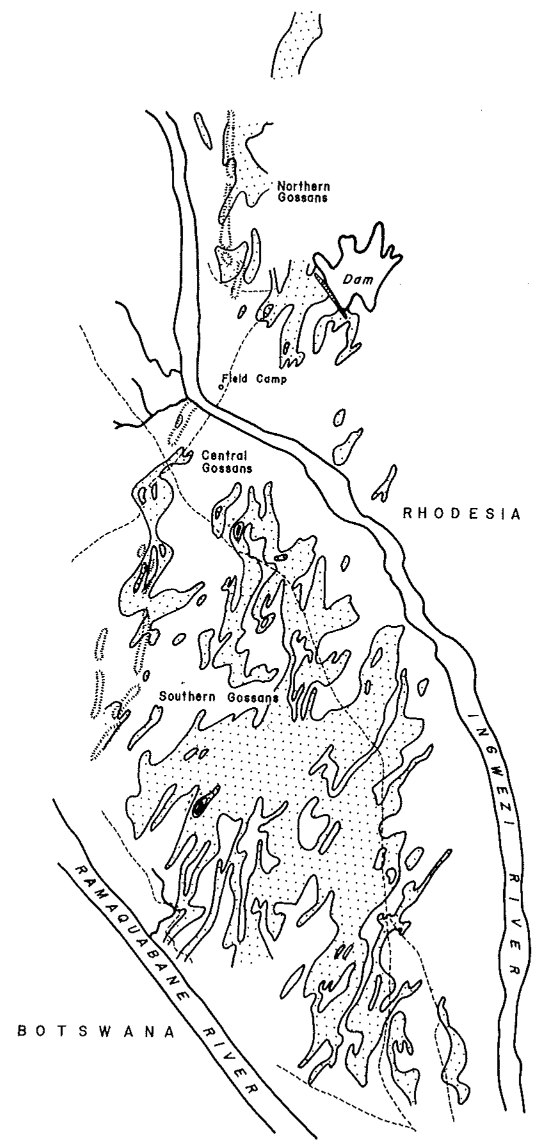
GEOCHEMICAL SOIL - SAMPLING
NICKEL

150 - 250 ppm
250 - 400 ppm
over 400 ppm



GEOCHEMICAL SOIL - SAMPLING
COPPER

70 - 150 ppm
150 - 250 ppm
250 - 400 ppm



GEOCHEMICAL SOIL - SAMPLING
ZINC

70 - 150ppm
150 - 250ppm
250 - 400ppm
over 400ppm

significant anomalies occur on the eastern side of the area in close proximity to the banded iron-formation unit. There is some doubt whether the iron-formation is responsible for the nickel anomalies in this region or whether they may emanate from an adjacent chloritic schist interlayer lying parallel and close to the iron-formation beds. The remaining nickel anomalies are of a low magnitude, the most significant of these being orientated in a N-S direction between the Central and Southern gossans. Clearly this, and the associated anomalies, are related to the E-W trending mafic dykes as well as to the large ultramafic dyke cutting through the area. It is noteworthy that, in general, the gossanous zones do not account for any anomalous geochemical behaviour with respect to either the nickel, copper, or zinc plots (Figure 3).

The distribution of copper and zinc in the remaining two maps shows a high degree of correspondence and forms a broad, low-magnitude, anomalous trend between the Ingwezi and Ramaquabane rivers. The dispersion patterns of these elements are broadly coincident with the more sharply defined nickel trend and, like the latter, are also considered to have been derived from the large ultramafic dyke intruded into the area.

The detailed soil-sampling programme established that the region,as a whole, had a generally subdued geochemical expression. In the case of copper and zinc no readily identifiable increases above background values were apparent. Anomalous nickel trends could be directly related to the subsurface geology with the mafic dykes, in particular, being responsible for most of the above average values obtained in the vicinity of the gossans. It is thus apparent that the gossans themselves are unrelated to the soil geochemical patterns in the region.

DETAILED GEOLOGY OF THE GOSSANOUS ZONES

Following the recognition of the gossans in the Mphoengs Schist Belt detailed geological mapping was carried out over selected areas at scales varying between 1:500 and 1:5 000. The results of some of this work are shown in Figures 4-7. These maps depict the surface geology in the vicinity of the Mphoengs Gossan and the Northern, Central, and Southern gossans respectively.

Limited and discontinuous exposure presented mapping problems in most areas. In some cases, for example in the vicinity of the Southern Gossan, very few outcrops were found away from the gossanous zone which, itself, forms a prominent northeasterly striking ridge fragmented by approximately E-W trending dykes (Figure 7). However, despite the lack of outcrops a distinct stratigraphic similarity between the various gossan occurrences is evident. The best exposed and most representative stratigraphic section across any of the gossanous zones and their surrounding country rocks is that shown for the Northern Gossan (Figure 5). Here the NNE-trending formations, which dip steeply to the east, are again segmented by cross-cutting mafic dykes. In the segment referred to as Harte's Head, good exposures extend from east of the gossan outcrops to the Ingwezi River in the west. Samples collected mainly from this area and supplemented by a few additional samples from the other gossan localities, have been analysed both petrographically and geochemically and have been of assistance in quantifying the nature of the country rocks in the vicinity of the massive sulphide occurrences.

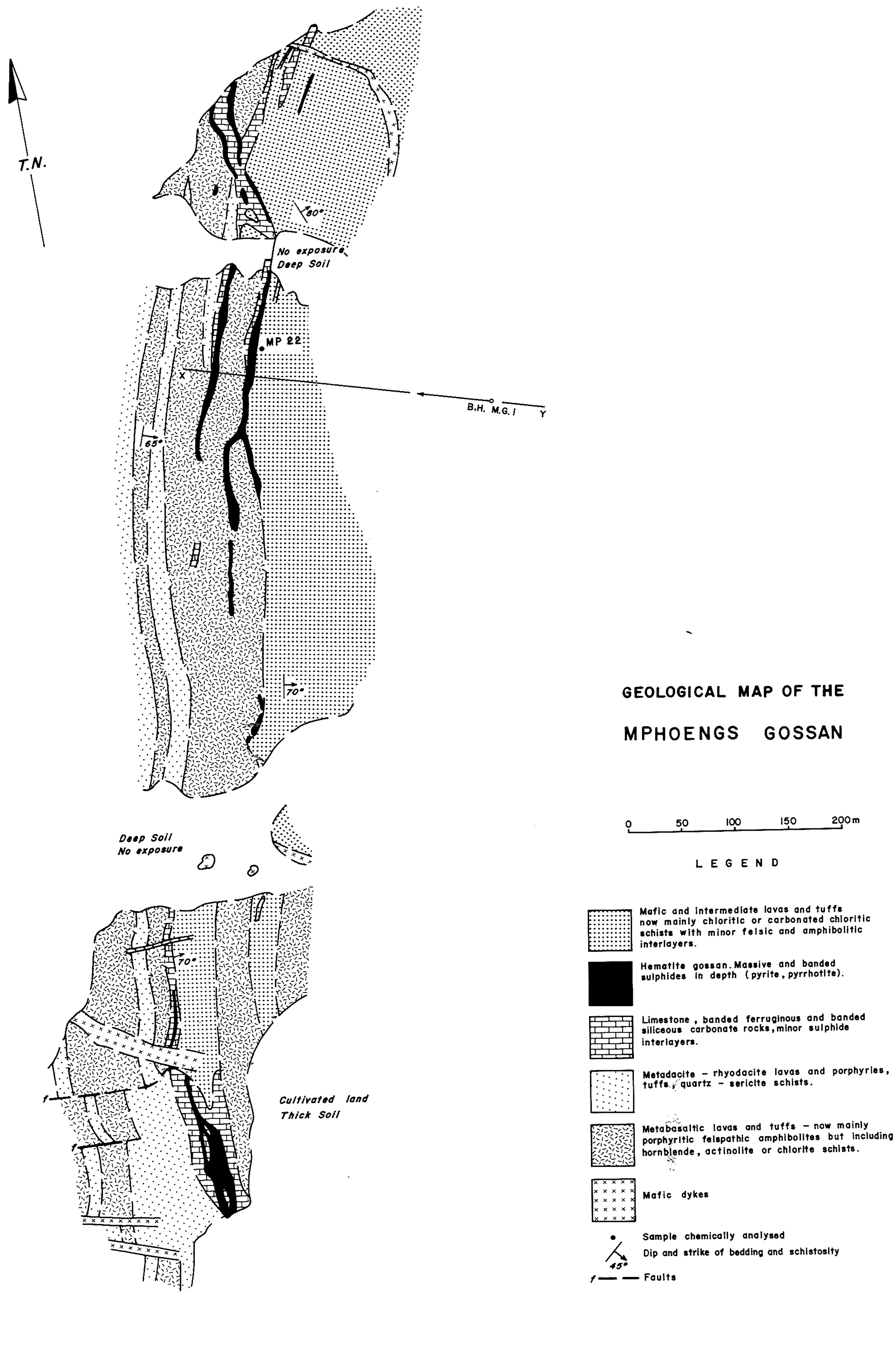
In order to facilitate description of the geology of the gossanous areas the various rock types encountered in the Northern Gossan will serve as a model for the remaining gossan localities. If one accepts the regional geological interpretation of the Mphoengs Schist Belt stratigraphy (linked as it is to the main body of the Tati greenstone belt) then it would appear that the successions are younging from east to west.

That this arrangement applies equally to the western flank of the Mphoengs Schist Belt in the vicinity of the gossanous zones, is by no means certain, as synformal folding about a central schist belt axis could account for a reversal of the younging direction from west to east in this region.

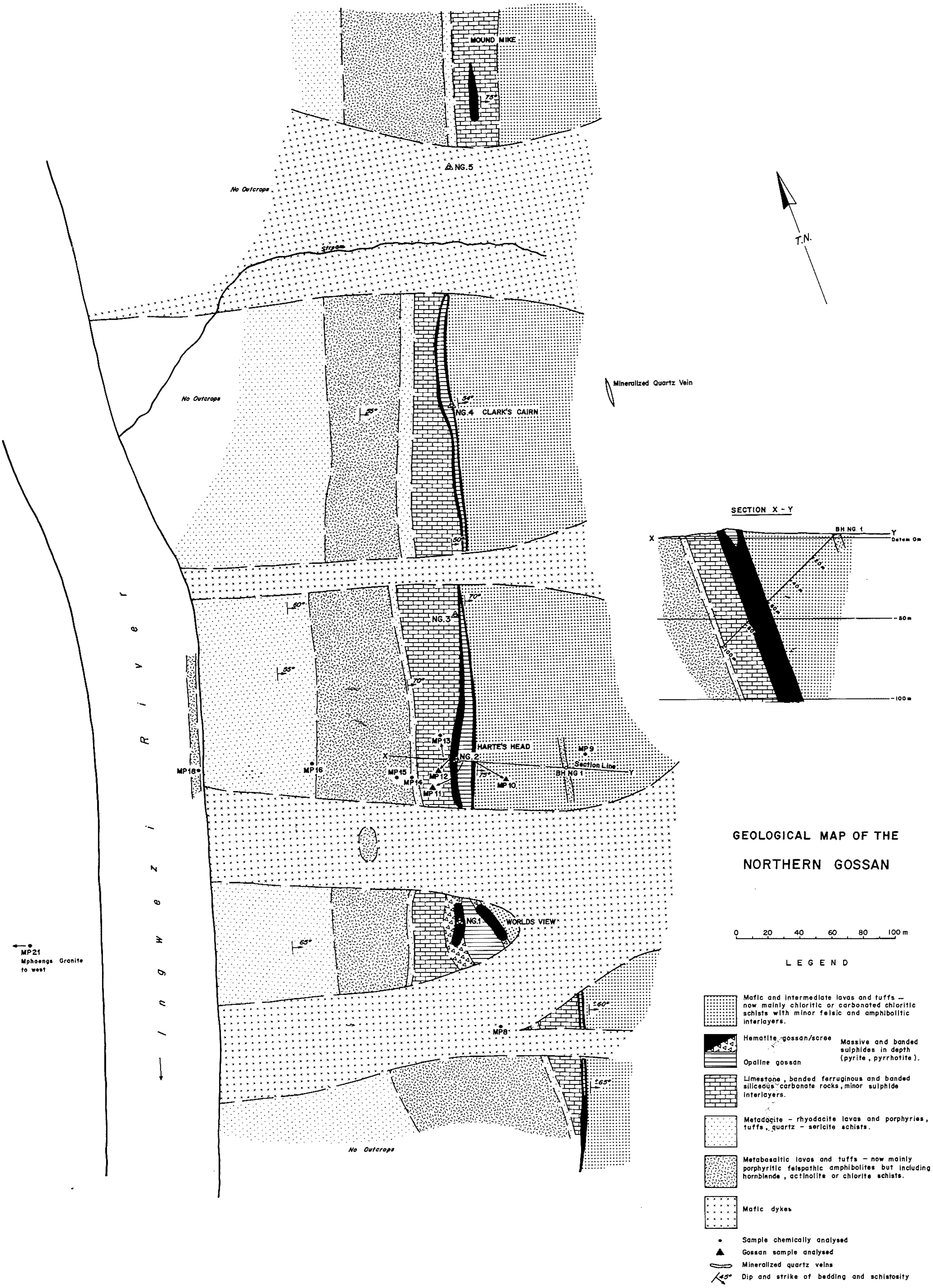
Volcanic Rocks

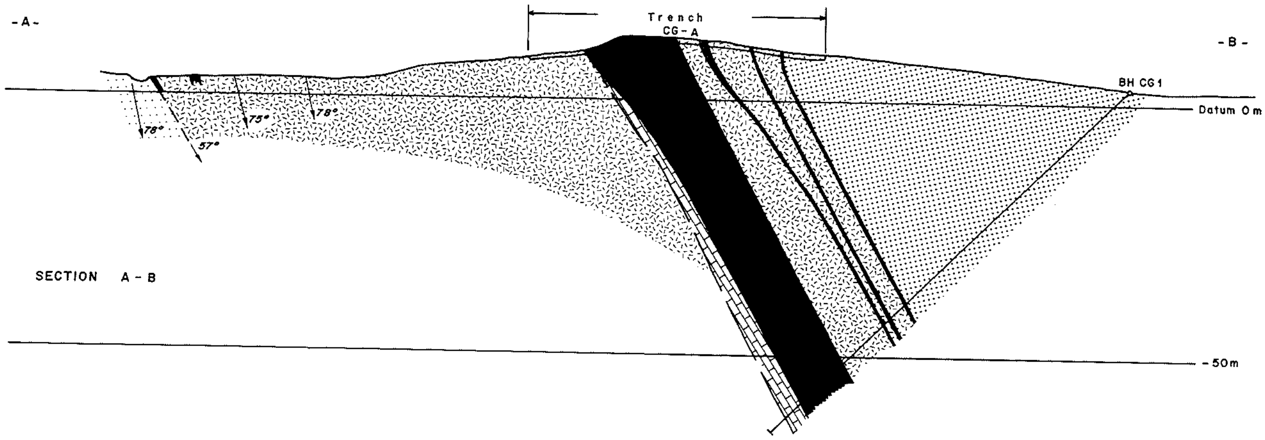
From the Ingwezi River eastwards the stratigraphy comprises an alternating succession of mafic and felsic lavas and porphyries followed, eventually, by a variety of carbonate rocks and the sulphide facies iron-formation unit. East of the gossans, which cap the sulphide zone, are further mafic rocks together with subordinate interlayers of felsic porphyry. The mafic volcanics in the succession fall compositionally in the transitional range between basalts and andesites (Table 1). Most of the rocks have, however, suffered some alteration, including carbonation, and only rarely are primary minerals seen. Although there is no consensus of agreement among advocates of the colour index as a basis for classification it would seem that a colour index of between 30 and 40 would effectively separate basalts from andesites (Baragar and Goodwin, 1969). The mafic volcanic rocks from the Mphoengs area fall into the transitional range between these values (Table 1).

A wide variety of textures and mineralogical variations are encountered in the mafic units. The rocks range in mineralogical composition from predominantly chloritic schists (as in the areas

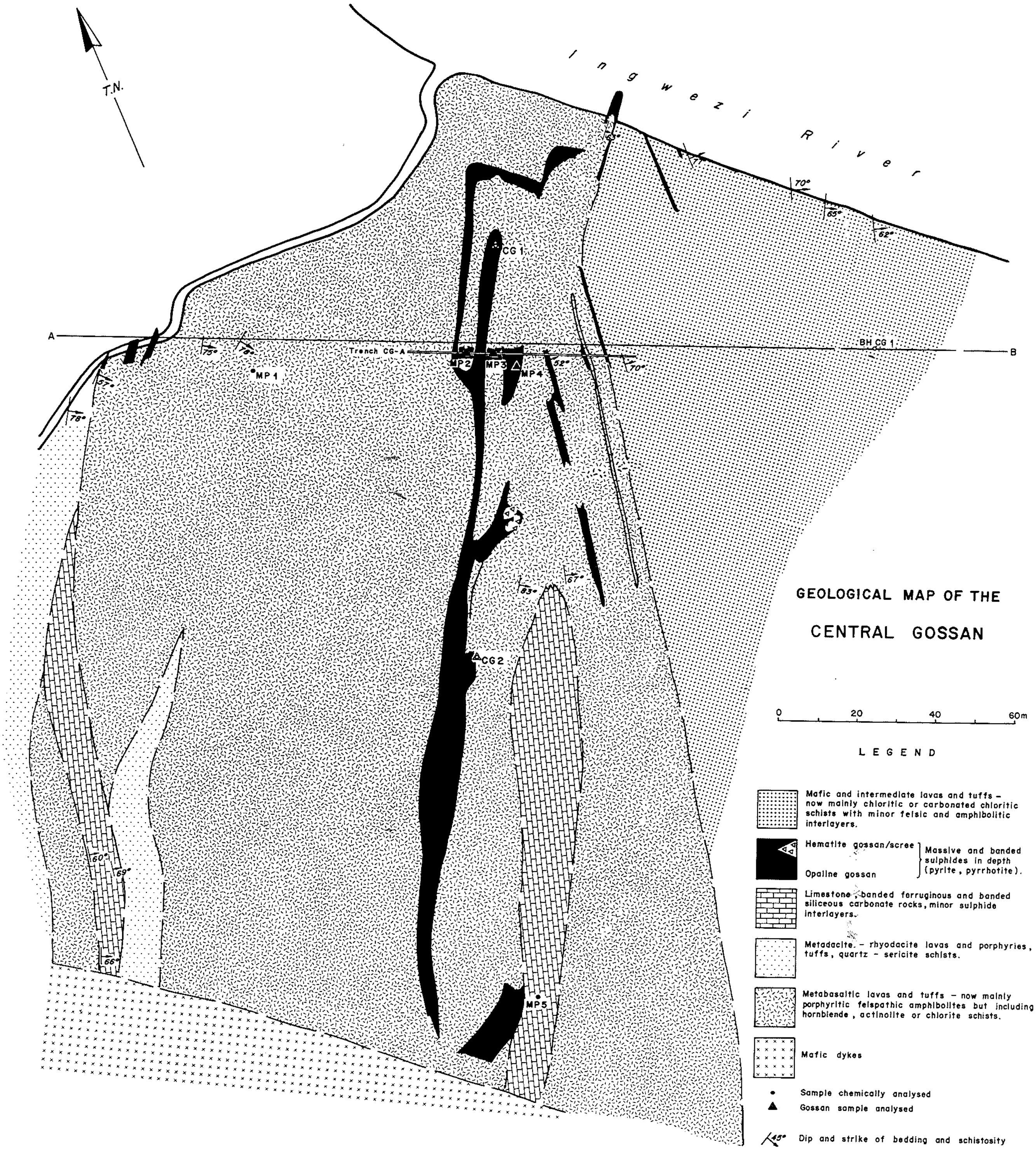


GEOLOGICAL MAP OF THE MPHOENGS GOSSAN

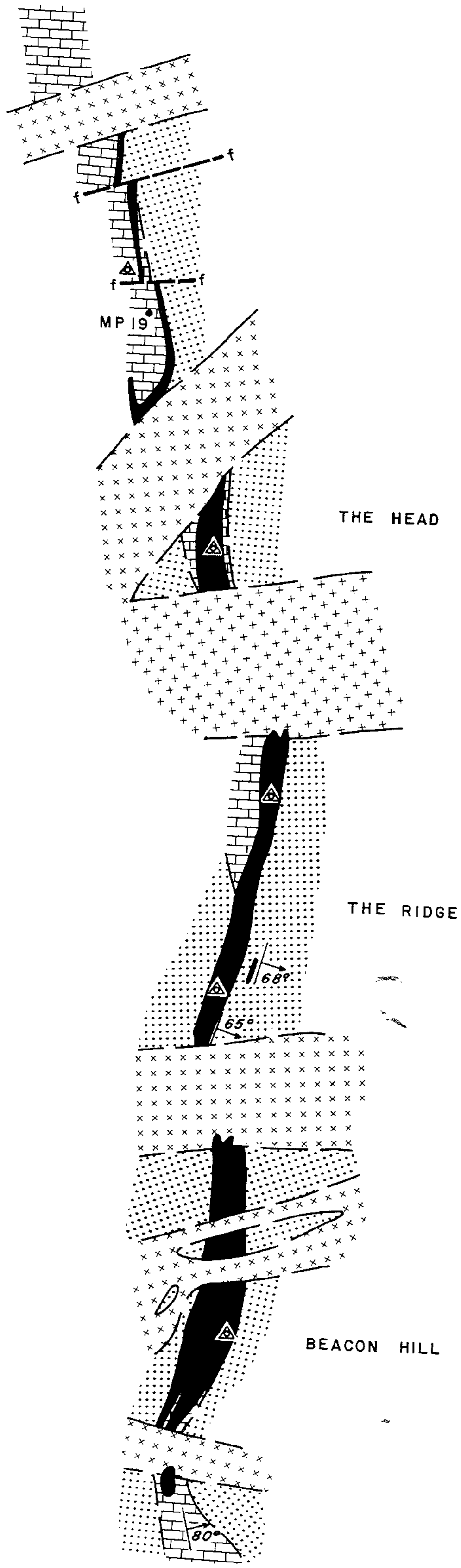

MOUND MIKE
NG.5
No Outcrops
Stream
No Outcrops
T.N.
Mineralized Quartz Vein
NG.4 CLARK'S CAIRN
SECTION X - Y
X
BH NG 1
Y
Datum 0m
-50m
-100m
NG.3
Ingwezi River
MP13
HARTE'S HEAD
MP9
NG.2
Section Line
MP18
MP16
MP15
MP14
MP12
MP11
MP10
BH NG 1
NG.1
WORLDS VIEW
MP21
Mphoengs Granite to west
MP8
No Outcrops
GEOLOGICAL MAP OF THE
NORTHERN GOSSAN
0 20 40 60 80 100 m
LEGEND
Mafic and intermediate lavas and tuffs — now mainly chloritic or carbonated chloritic schists with minor felsic and amphibolitic interlayers.
Hematite gossan/scree
Opaline gossan
Massive and banded sulphides in depth (pyrite, pyrrhotite).
Limestone, banded ferruginous and banded siliceous carbonate rocks, minor sulphide interlayers.
Metadacite - rhyodacite lavas and porphyries, tuffs, quartz - sericite schists.
Metabasaltic lavas and tuffs — now mainly porphyritic felspathic amphibolites but including hornblende, actinolite or chlorite schists.
Mafic dykes
Sample chemically analysed
Gossan sample analysed
Mineralized quartz veins
Dip and strike of bedding and schistosity

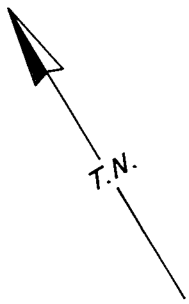


-A-
Trench
CG-A
-B-
BH CG1
Datum 0 m
SECTION A-B
-50m



T.N.
Ingwezi River
CG1
A
B
Trench CG-A
BH CG1
MP1
MP2
MP3
MP4
CG2
MP5
GEOLOGICAL MAP OF THE
CENTRAL GOSSAN
0
20
40
60m
LEGEND
Mafic and intermediate lavas and tuffs - now mainly chloritic or carbonated chloritic schists with minor felsic and amphibolitic interlayers.
Hematite gossan/scree
Opaline gossan
Massive and banded sulphides in depth (pyrite, pyrrhotite).
Limestone, banded ferruginous and banded siliceous carbonate rocks, minor sulphide interlayers.
Metadacite - rhyodacite lavas and porphyries, tuffs, quartz - sericite schists.
Metabasaltic lavas and tuffs - now mainly porphyritic felspathic amphibolites but including hornblende, actinolite or chlorite schists.
Mafic dykes
Sample chemically analysed
Gossan sample analysed
45° Dip and strike of bedding and schistosity





GEOLOGICAL MAP OF THE SOUTHERN GOSSAN

0 50 100 150 200m

L E G E N D

- Undifferentiated metavolcanics - mainly amphibole and chlorite schists with minor interlayers of intermediate to felsic schists and/or porphyries.
- Hematite/opaline gossan. Massive and banded sulphides in depth (pyrite, pyrrhotite).
- Limestone, banded ferruginous and banded siliceous carbonate rocks.
- Mafic dykes
- • Sample chemically analysed
- 80° Dip and strike of bedding and schistosity
- f — — — Faults

east of the gossans) to rocks predominantly of medium- to coarse-grained amphibolitic or feldspathic amphibolitic character (as in some areas close to the gossans and to the west of these - (Figures 4 and 6). Amphibolitic units also occur interlayered with the chloritic schists and, similarly, chloritic schists are found interlayered with the more massive porphyritic feldspathic amphibolite units. These compositional and textural differences undoubtedly reflect alternating lava flows of varying composition coupled possibly with stages of tuff development. The rapid variations in lithologies, including also the variations found in the more felsic components, is characteristic of the cyclical volcanism reported from numerous Archaean greenstone belts in the world (Anhaeusser, 1971; Goodwin, 1968; Viljoen and Viljoen, 1969).

The intermediate to felsic successions are best developed west of the gossans in the Northern Gossan area (Figure 5). A wide zone of quartz-feldspar porphyries and acid-to-intermediate schists (Plate 1B) occur immediately to the east of the Ingwezi River. Here, in addition to the porphyritic lavas, there also occur sheared interlayered pyroclastic rocks (Plate 1C), and well-banded intermediate and acid tuffs (Plate 1D). Narrower bands and lenses of quartz and feldspar porphyry also occur as interlayers within the feldspathic amphibolites found west of the Mphoengs Gossan (Figure 4) and adjacent to the carbonate unit in the Northern Gossan area (Figure 5). Subordinate quartz-feldspar interlayers were also encountered in the chloritic schists in a number of localities east of the gossan zones (e.g. in the Southern Gossan area and near the Mphoengs Gossan - sample MP22, Figure 4).

Mineralogically the felsic porphyries and agglomeratic tuffs show signs of extensive propylitization. Euhedral to anhedral plagioclase phenocrysts are generally saussuritized or sericitized and epidote or zoisite is a common constituent of the rocks. Quartz occurs either as a matrix mosaic or as phenocrysts in the porphyries. Carbonate is another common constituent, being particularly prominent in sample MP22 (Table 1, column 7). This sample also displayed abundant disseminated pyrite.

Despite their generally massive appearance in the field the felsic porphyries have undergone considerable internal deformation and in thin section it is not uncommon to find rotated phenocrysts and boudin, or augen-like, textures. Considerable flattening of the formations is also evident and agglomeratic beds are barely recognizable, the fragments being drawn out and attenuated in the plane of the regional foliation (Plate 1C).

Chemically the felsic volcanic rocks are mainly dacitic in composition (Table 1, columns 5-7) and all possess colour indices less than 10 - the latter value being generally regarded as the dividing index between andesites and salic rocks (Baragar and Goodwin, 1969).

Carbonate Rocks

A variety of carbonate sediments occur in the immediate vicinity of the gossans in the Mphoengs Schist Belt. This close spatial arrangement of carbonates and sulphides is not uncommon and these relations have been recorded in a number of Canadian greenstone belts (Goodwin, 1964; 1973). As Stanton (1972) points out, carbonate is deposited in an Eh range between the ranges required for oxide and sulphide precipitation and, as a result, it is to be expected that carbonate-rich rocks (limestones, carbonate iron-formations) may occur gradational or interbedded with any of the other types.

In the Mphoengs Schist Belt carbonate-rich sediments occur mainly on the western side of the sulphide facies iron-formation units but, as can be seen in Figures 4 and 6, are not restricted to this arrangement. Although folding has disturbed the successions in the carbonate-sulphide zone it is evident from borehole data that the sulphides and carbonates are intimately interlayered in places (Figures 10-12). In Plate 1E, which is a photograph of part of a borehole core sample from the Mphoengs Gossan (drill hole M.G.1, Figure 9) carbonate and pyrrhotite-pyrite layers are shown alternating in bands ranging from a few millimetres to over 2 centimetres in thickness.

The carbonate rocks encountered in the area are of various types. They range from impure varieties containing siliceous and ferruginous components (carbonate iron-formation *sensu stricto*) to almost pure limestones or marbles. Outcrops of the carbonate rocks are generally poor but in a few areas show intricate isoclinal folding (Plate 1F) or delicate millimetre-scale banding or compositional layering (Plate 2A). Elsewhere the carbonate rocks are gradationally interlayered with bands or lenses of hematite, the latter containing irregular patches of magnetite (Plate 2B).

Chemical staining tests with Mitchell's dye (Mitchell, 1956) and potassium ferri-cyanide suggest that most of the carbonates associated with the ferruginous units are limestones and are not sideritic. Much of the hematite-magnetite is considered to be primary, supporting some of the findings reported elsewhere by Stanton (1972).

The impure, siliceous, carbonates, like the one shown in Plate 2A, are metamorphosed to a calc-silicate assemblage consisting of quartz, carbonate, grossularite garnet, and diopside, the latter high relief mineral occurring in minute flaky bladed crystals and confirmed by X-ray diffraction analysis (J.R. McIver, personal communication, 1976). Chemically the calc-silicate rock contains mainly silica (18,36%) and carbonate (76,66%), the remaining elements being present in only limited amounts (Table 1, column 8).

The ferruginous carbonate rock shown in Plate 2B was also chemically analysed, care having been taken to exclude as much of the ferruginous interlayered material as was possible. The carbonate fraction, an analysis of which appears in Table 1, column 9, shows considerably less silica (1,86%) and more carbonate (89,57%) than the calc-silicate rock described previously. Notable increases in the amount of ferric iron (2,51%), MnO (1,60%) and MgO (1,05%) are apparent. The low total iron content of the carbonate associated with the ferruginous interlayers confirms its non-sideritic composition.

Almost pure limestone or marble was encountered near some of the gossanous localities. An analysis of a pale grey coloured marble unit from the Southern Gossan area is listed in Table 1, column 10. The total carbonate content of this rock is 97%, the remaining elements being present in only very small amounts. Unfortunately, the tonnages of material of this grade are limited and the limestone deposits would not justify exploitation.

The Sulphide Facies Iron-Formations (Gossan Zones)

The gossans in the Mphoengs Schist Belt, as described previously, represent the oxidized surface manifestations of stratiform massive and banded sulphide mineralization encountered in depth. The surface exposures of gossan are prominent in most of the areas mapped in detail but do not form continuous outcrops. East-west-trending mafic dykes are largely responsible for disrupting the continuity of exposures, as is the drainage system of the Ingwezi River which separates the Northern Gossan from the Central and Southern gossans (Figures 2 and 3). Outcrops of the Central Gossan extend into the Ingwezi River (Plate 2C) and are then covered by an extensive blanket of sand. Unbroken blocks or segments of gossan vary in length from 20-230 m and range in thickness from 2-30 m.

The gossans form a prominent ridge or mound that provides the only relief in an otherwise featureless terrain. An exception to this is found in the extreme southern end of the Mphoengs Schist Belt where some additional surface relief is provided by the outcropping oxide facies banded iron-formations that extend across the Ramaquabane River and form the prominent Matsiloje Hills in Botswana (Plate 1A).

The gossans vary from massive blackish-brown hematite types displaying prominent box-works and irridescent colours on smooth outcrop faces (Plate 2D), to yellowish opaline gossans that display concoidal fractures. In places, botryoidal limonite is also evident. In some of the southern gossans distinct banding is evident reflecting the primary banding encountered in the sulphide facies iron-formations at depth.

Surface channel samples of the gossans in the Harte's Head segment of the Northern Gossan were analysed to ascertain the chemical differences between the hematite and the opaline varieties of gossans. The results, shown in Figure 8, demonstrate that the hematite gossans are enriched in all nine elements analysed. The central opaline gossans, by contrast, reflect consistently lower values suggesting that this variety of gossan, which consists mainly of secondary silica, has been more extensively leached of metals than the flanking hematite gossans.

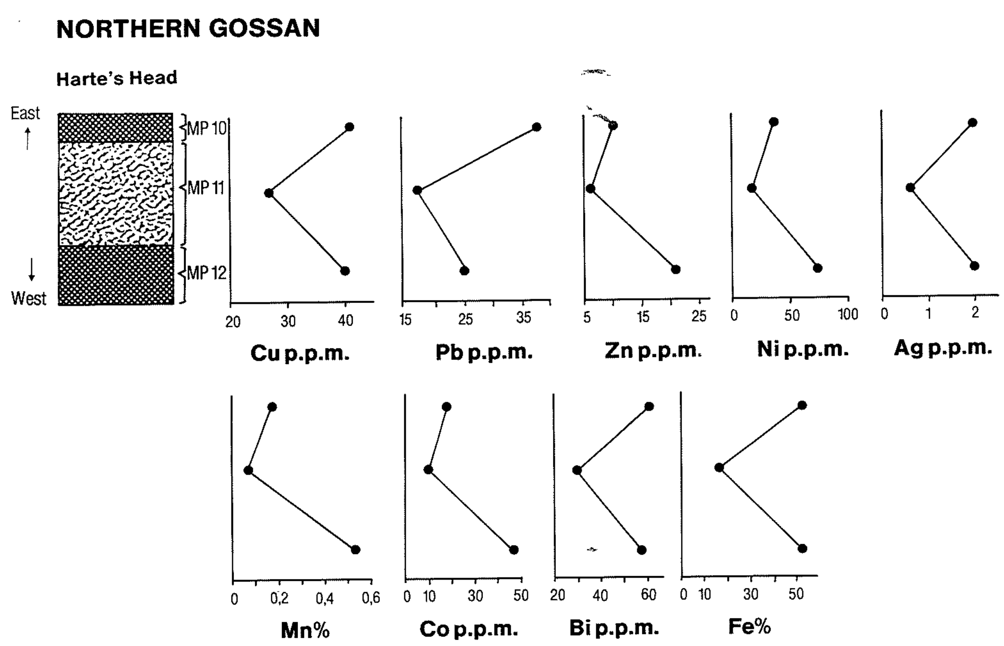


Figure 8 : Diagram showing the relative abundance of various elements from three channel samples taken from the Harte's Head segment of the Northern Gossan. Samples MP10 and MP12 consist of hematite gossan whereas sample MP11 consists of opaline gossan.

Examination of the gossan geochemistry, both in Figure 8 and in Table 3, shows there is a general scarcity of important base metal elements (Cu, Pb, Zn, Ni) in the oxidized zone. The samples from the gossan exposures in the Central Gossan area (trench CG-A, Figure 6) were of a mixed hematite-opaline composition. Due to the complexity of folding in this area and because of the dispersion of the gossan outcrops the samples were analysed mainly to obtain quantitative values of the metal content in the oxidized cappings.

TABLE 3

CHEMICAL ANALYSES OF SELECTED MAJOR AND TRACE ELEMENT ABUNDANCES IN THE CENTRAL GOSSANS

Sample Number	Cu ppm	Pb ppm	Zn ppm	Ni ppm	Ag ppm	Co ppm	Bi ppm	Mn Wt %	Fe Wt %
MP2	62	21	25	31	2	18	48	0,18	53,1
MP3	99	15	14	32	2	19	58	0,15	57,5
MP4	54	15	24	35	2	21	49	0,21	56,6

The Mphoengs Gossan, which has a strike of 1,9 km and dips to the east at about 75°, is generally poorly exposed along much of its length. The gossan, only part of which is shown in Figure 4, is 25 m wide in places but has an average width of 10 m. It is similar in appearance to the other gossans of the area, but occurs as parallel bands in association with limestone. Figure 9 shows a surface plan of the main outcrop area of the Mphoengs Gossan. Carbonate lenses flank the gossan zones on the west but disappear from surface near the drill section line XY.

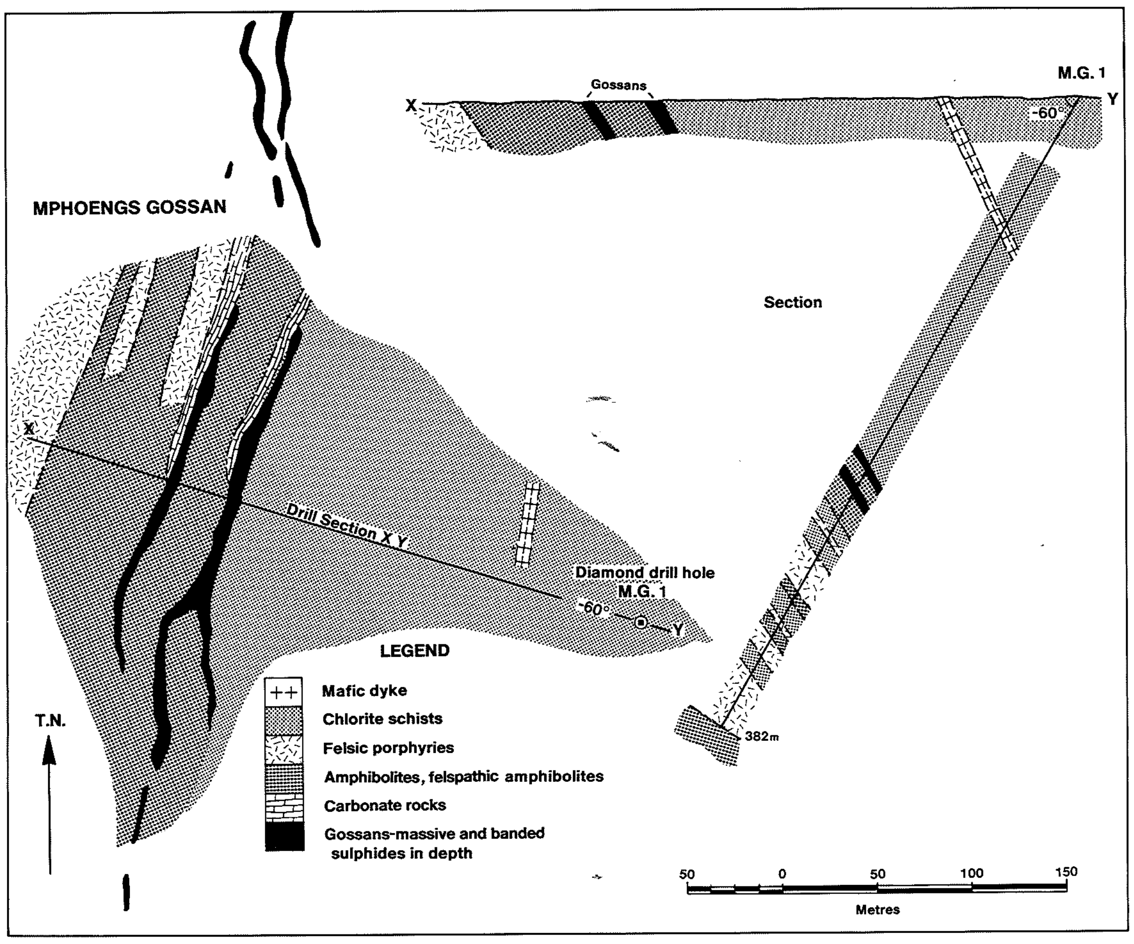


Figure 9 : Geological map and borehole section of the northern portion of the Mphoengs Gossan.

The detailed borehole log (Figure 10) indicates that carbonate rocks are present at depth but here occur mainly on the eastern side of the massive sulphides. It is possible that the parallel bands of gossan may have been produced by folding but the variations in the position of the carbonate rocks most probably reflect original sedimentational lensing or interbedding.

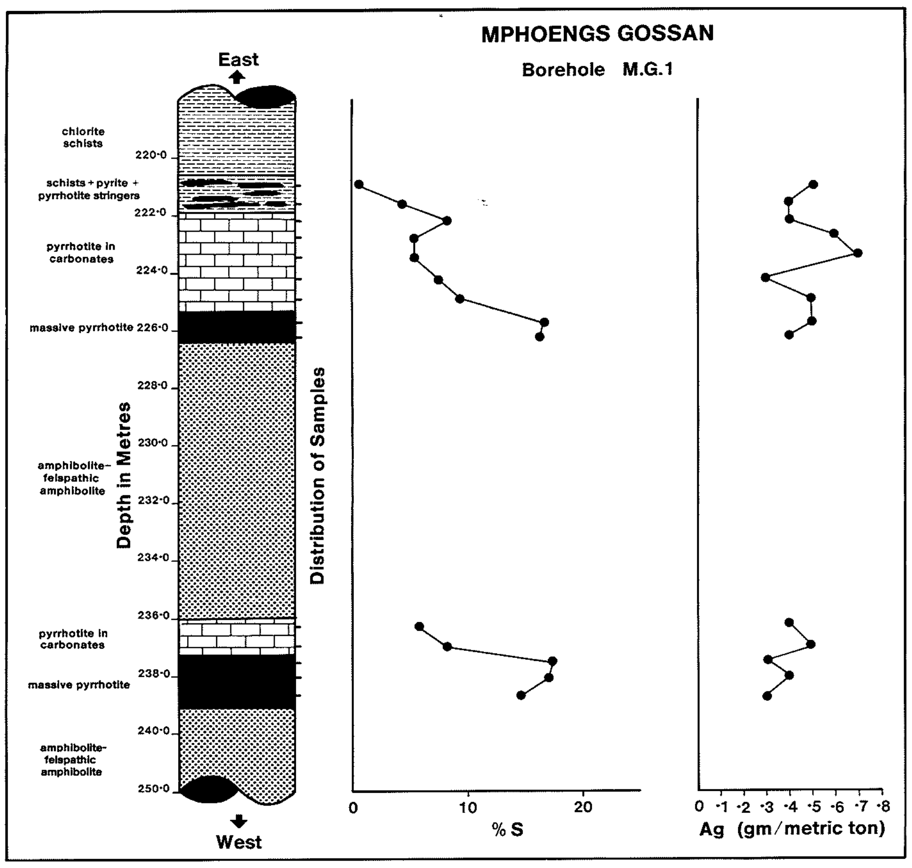


Figure 10 : Borehole sections and graphs showing the distribution of sulphur and silver in the two sulphide units of the Mphoengs Gossan.

Individual blocks of exposed gossans in the Mphoengs Gossan areas have strike lengths of up to 180 m. Sampling carried out in trenches across these gossans again yielded generally poor results, the highest values being 1100 ppm Cu, 230 ppm Ni, and 140 ppm Zn. In addition, only trace amounts of gold and silver were found.

The Kweneni Gossan in the far northern part of the Mphoengs Schist Belt (Figure 2) has a discontinuous strike length of 1,5 km and, as elsewhere, is broken up by mafic, E-W trending dykes. Individual blocks up to 200 m long show a preferred dip of about 75° to the east. The gossan, which varies in width from less than a metre to 30 m, averages about 10-15 m wide. Soil geochemistry along the length of the Kweneni Gossan failed to reveal values in excess of 185 ppm Cu, 130 ppm Ni, and 77 ppm Zn. Trench samples of the gossans themselves revealed that the highest Cu, Ni and Zn values were 490, 300 and 105 ppm respectively. Only trace amounts of gold and silver were recorded.

Geological mapping showed very little limestone outcropping in the area (Ryan, 1971), and the gossans occur interlayered with various amphibolitic rocks and chloritic schists.

Subsurface Borehole Data

In order to test some of the Mphoengs Schist Belt gossans at depth for possible economic mineralization four boreholes were subsequently drilled in the area. Three of the intersections were made by Southern Exploration (Pvt.) Ltd., during the period they held E.P.O. 292 while the fourth hole was drilled later by Gold Fields Prospecting Co. (Pvt.) Ltd. Unfortunately, because the base metal potential of the sulphide iron-formations appeared to be uneconomic the borehole cores were never retained and no systematic study could be made of the sulphide intersections. However, some core samples were ultimately retrieved and these, as well as the original detailed borehole logs, were used to document the mineralogy and the geochemistry of the sulphide facies iron-formations in the area.

From north to south in the Mphoengs Schist Belt drill holes were sited to intersect the sulphides beneath the Mphoengs Gossan (Figures 4 and 9), the Northern Gossan at Harte's Head (Figure 5), and the Central Gossan (Figure 6). Two of the boreholes were sited to intersect the Central Gossan sulphides, one by Southern Exploration (borehole CG1) and the second by the Gold Fields Prospecting group.

The first of these latter holes intersected the massive sulphides approximately 50 m (vertical depth) below surface, but also encountered minor sulphide units to the east, the latter interlayered with various amphibole and chloritic schists (see section AB, Figure 6). The second hole in this area, drilled by Gold Fields, was sited in approximately the same area as the first drill hole but was used to test the main massive sulphide unit as well as the subsurface sulphides responsible for the gossans outcropping near the tributary stream of the Ingwezi River, and located to the west of the main oxidized cappings of the Central Gossan (Figure 6).

Sections showing the subsurface geology of the Mphoengs and Northern gossans are shown in Figures 9 and 5 respectively. Details of the main sulphide intersections in these areas, as well as in the Central Gossan area, are depicted in the borehole section diagrams of Figures 10-12. Selected geochemical analyses were undertaken of numerous core samples and the results are plotted against their respective positions in the core sections.

The Mphoengs Gossan was drilled to an inclined depth of 382 m (borehole M.G.1). Two zones of pyrrhotite (with minor pyrite and chalcopyrite) mineralization associated with carbonate rocks were intersected between depths of 220 m and 227 m and between 236 and 240 m. The core samples were analysed for Ni, S, Cu, Pt, Au, and Ag but very poor values were recorded. Only sulphur and silver were sufficiently plentiful to warrant inclusion in the Mphoengs Gossan borehole section diagram of Figure 10. The sulphur values of between 15 and 20% S in the massive pyrrhotite units tail off systematically into the carbonate rocks of both the carbonate-sulphide associations. By contrast there is a small, but again systematic, increase of silver from the massive sulphides into the more carbonate rich units.

The Northern Gossan was drilled to an inclined depth of 100 m. A 14 m wide zone of massive sulphides (true thickness of approximately 11 m) was intersected at between 58 and 72 m depths (approximately 50 m vertically below surface). Two additional, but narrow, sulphide bands were located lower in the intersection surrounded by limestones and ferruginous carbonate rocks (Figure 11).

Analyses of the sulphide mineralization again revealed low values for most constituents with the exception of sulphur which varied between 10 and 32 weight per cent of the ore. The fluctuations in sulphur values, seen in the graph, coincide with the relative proportions of pyrrhotite and pyrite in the ore. The highest sulphur values generally correspond with ores containing greater proportions of pyrite whereas lowest sulphur contents coincide with prominent developments of pyrrhotite. In the borehole section shown in Figure 11 the percentage sulphide in the various segments of the column are shown together with the relative abundances of pyrite (py) and pyrrhotite (pyr).

Copper and nickel analyses, shown in adjacent graphs in Figure 11, show consistently low values. Only sulphur is present in any quantity, averaging 28% S over a true thickness of 10,7 m.

Further details of the nature of the sulphide ores were obtained from the Central Gossan area where borehole CG1 was drilled to an inclined depth of 97 m. Three narrow sulphide units, surrounded by amphibolitic schists, were first encountered at depths of 60,7 m, 64,9 m, and 66,4 m. Pyrite, pyrrhotite, and chalcopyrite was recognized in all three layers. At a depth of approximately 77 m the main sulphide unit was intersected. As can be seen in the borehole section diagram (Figure 12) the sulphides occur interlayered with banded carbonate rocks, the latter containing variable amounts of pyrrhotite, pyrite, and chalcopyrite mineralization. The massive sulphides continue to a depth of over 88 m before eventually passing into banded limestones containing lenses and stringers of pyrrhotite and pyrite.

Analyses of the core again showed much the same pattern as reported previously for the other gossanous areas. Copper and nickel values are generally consistently low but also show downward fluctuations corresponding with the carbonate-rich interlayers. Sulphur likewise shows marked downward trends in the carbonate bands but gold, and to a lesser degree silver, shows some enrichment in these layers. Silver is, however, somewhat erratic but it is interesting to note that values as high as 35,2 dwts/short ton Ag were recorded.

The indicated tonnages of sulphide material in the Southern, Central and Northern gossans, per 100 m of inclined depth, are tabulated below. The average sulphur content is estimated to be approximately 18 to 23%. Although the sulphur in the Mphoengs Gossan averages 16 and 17% for the two sulphide bands shown in borehole M.G.1 (Figure 10), the thicknesses of approximately 1 m and 1,8 m respectively, provide little tonnage potential.

Northern Gossan	1 131 000	tonnes per 100 m of inclined depth
Central Gossan	676 200	tonnes per 100 m of inclined depth
Southern Gossan	1 833 750	tonnes per 100 m of inclined depth
Total	3 640 950	

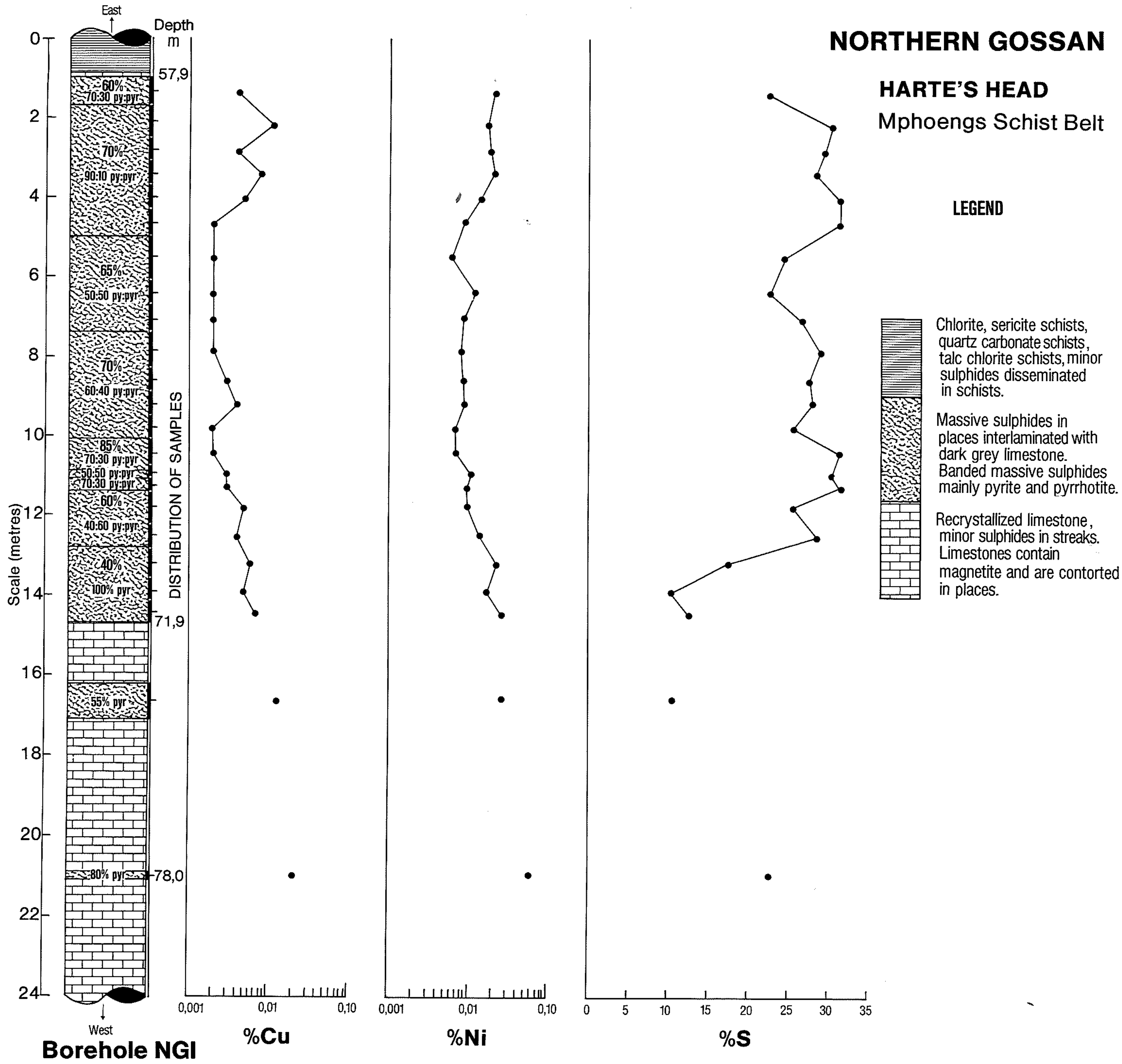


Figure 11 : Detailed borehole section of the massive sulphide unit drilled in the Harte's Head segment of the Northern Gossan. Graphs show the distribution and relative abundances of copper, nickel, and sulphur in the core. The percentage sulphides in various segments of the core are also indicated as are the relative proportions of pyrite (py) and pyrrhotite (pyr) in the ores.

Sulphide Mineralization

Although most of the borehole core intersections of the Mphoengs sulphides were no longer available for study, the writers were fortunate in obtaining a number of polished sections of core (from the Central Gossan area) from Gold Fields Prospecting Co. (Pty.) Ltd. In addition, some samples of the Mphoengs Gossan intersections, drilled by Southern Exploration (Pvt.) Ltd., were available for examination. However, these samples were without depth control markings and could only be used to examine mineragraphic aspects of the ores.

The main minerals making up the sulphide bodies are pyrite and pyrrhotite. Magnetite is, in some places, abundantly intergrown with the sulphides. Pyrite and pyrrhotite occur in variable amounts in all the core samples but magnetite (Plate 2E) was seen in only five of the twelve polished sections examined.

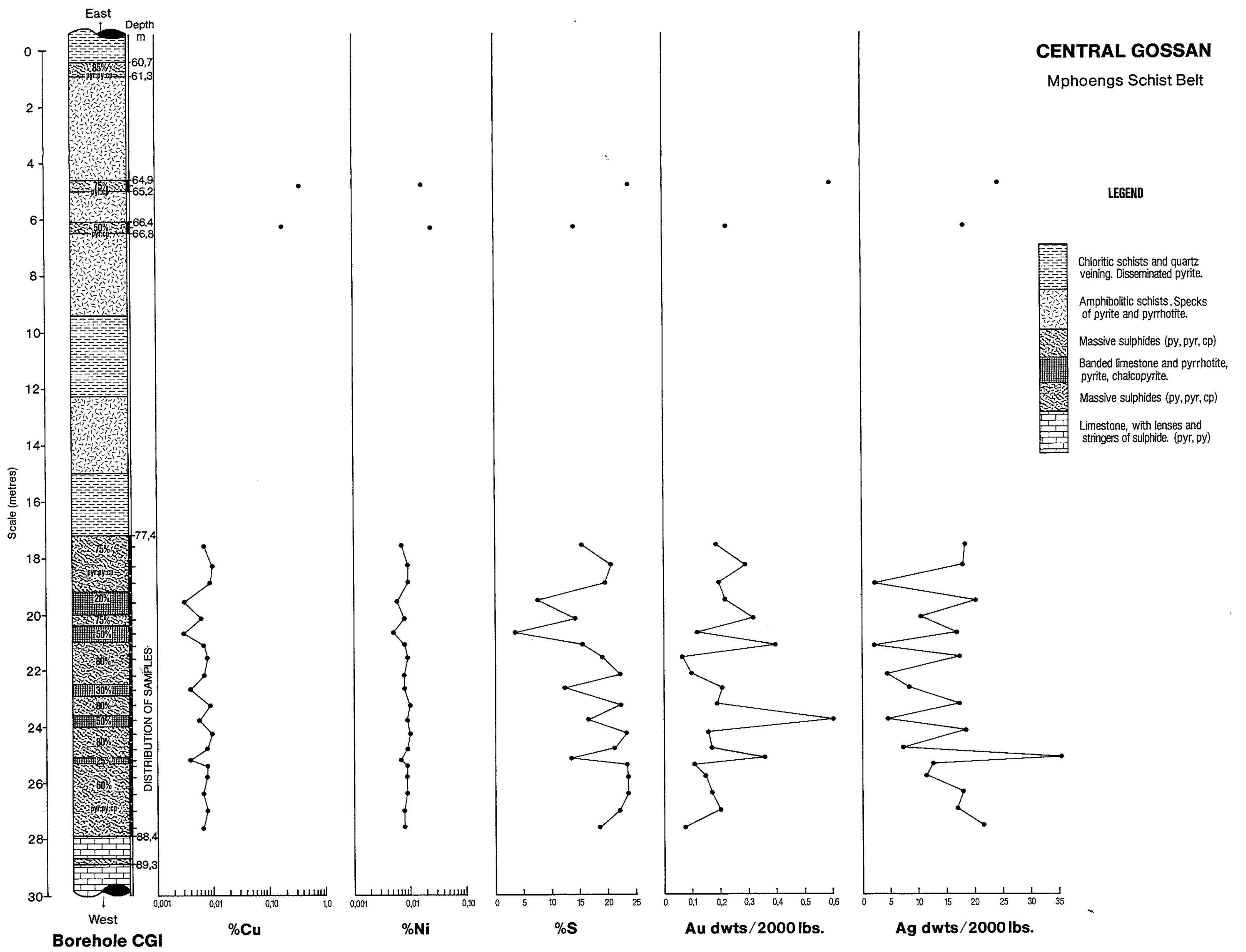


Figure 12 : Detailed borehole section of the banded and massive sulphide intersections in the Central Gossan area. Graphs show the distribution and relative abundances of copper, nickel, sulphur, gold, and silver. The percentage sulphides in the various segments of the core are also shown.

Chalcopyrite was seen in seven of the sections but occurred only as minute veinlets or blebs in the pyrrhotite (Plate 2F) and probably represents a product of exsolution. An isolated grain of what is thought to be cubanite, was also noted.

According to Ramdohr (1969), the presence of cubanite suggests that originally the temperature of formation must have exceeded 250°C. Cubanite is apparently a very unstable mineral and is easily replaced or reconstituted to other minerals (pyrrhotite plus chalcopyrite) without considerable change in chemical conditions. Friedman (1959) also found very minor amounts of cubanite and chalcopyrite in the Samreid Lake iron-sulphide deposits in Canada, suggesting that there may be a characteristic mineralogy applicable to this type of ore occurrence. Other, more dominant, minerals reported by Friedman included pyrite, pyrrhotite, and magnetite. Secondary pyrite and marcasite were reportedly formed at the expense of pyrrhotite in the Canadian example. Marcasite also occurs in the Mphoengs deposits and may be confused with some of the pyrite. The presence of idiomorphic pyrite in the ores is clearly evident, both in hand specimen and under the ore microscope. However, the pyrite is often distinctly anisotropic, a property usually diagnostic of marcasite. According to Stanton (1955), and confirmed by Ramdohr (1969), anisotropy occurs almost universally in pyrite but its effects may be widely obliterated by some polishing procedures.

The pyrite (and/or marcasite) in the ore is generally in the form of idiomorphic to hypidiomorphic crystals. In some specimens examined marginal alteration of the grain boundaries to limonite is evident (Plates 3A and 3B).

All pyrite varieties, when exposed to the atmospheric agents for sufficiently long periods, start to develop marginal rims of limonite (Ramdohr, 1969). This is caused by H_2SO4 solutions, formed from the sulphides, carrying away some of the Fe in the form of ferrous sulphate. Only in the presence of mineral substances capable of neutralizing at least part of the free acid is it possible to subsequently form ferric sulphate, the hydrolysis of which then yields limonite. The abundant carbonates, in and adjacent to the main sulphide units at Mphoengs, would clearly suffice in neutralizing the sulphuric acid and allow the limonite to develop. The chemistry of this reaction probably has wider implications with respect to the development of the gossans in the area. If the carbonates (or any other acid neutralizing agents) were not present in the immediate vicinity of the sulphides it is interesting to speculate whether the gossans would have manifested themselves to the extent presently evident in the various gossanous areas. Without the neutralizers some of the altered sulphides would probably have been dissipated as ferrous sulphate in the regional drainage and groundwater system.

It is not certain whether the limonite rims encircling the pyrite/marcasite crystals reflect alteration at depth in the sulphide deposits or whether the reaction may have occurred subsequently. The core samples have been exposed to surface oxidation for several years and it is equally possible that the alteration seen is a result of this circumstance. The pyrrhotite in the ore does not seem to be affected to the same extent as the pyrite/marcasite. This is probably due to the variability of sulphur in these minerals.

Marcasite, pseudomorphous after pyrrhotite in the Vlakfontein nickel ores of the Western Bushveld Complex, was reported to be extraordinarily susceptible to oxidation (Wagner, 1924). The marcasite, is was shown, vitriolizes rapidly to be replaced eventually by limonite, which often forms complete pseudomorphs after it. On exposure pyrrhotite is also fairly rapidly oxidized in the Vlakfontein ores, yielding ferrous sulphate and free sulphuric acid. However, according to Wagner, it is probable that the bulk of the pyrrhotite here went through the marcasite stage as a preliminary to oxidation. No such transformations were seen in the Mphoengs sulphides but it is possible they may occur.

Although the ore has been referred to as "massive sulphides" this is a relative term and is used to designate the sulphide enriched units from the more banded varieties in which gangue minerals constitute a large percentage of the rock. Most of the ores are, in fact, banded, as can be seen in Plates 3C, 3D and 4A. Plate 3C, consisting of narrow layers and stringers of pyrrhotite in amphibole-rich gangue, would not be regarded as "massive" ore, whereas the examples shown in Plates 3D and 4A are typical of the banded massive sulphides containing upwards of 60% sulphide minerals.

The massive sulphide samples shown in Plates 3D and 4A represent polished slabs of borehole core. These banded or bedded ores are composed predominantly of pyrite and pyrrhotite with gangue minerals of quartz and carbonate.

These sulphidic sediments include both clastic and chemical components and preserve such primary features as graded bedding, soft-sediment deformation features, and fragmental or breccia ore. In this respect they resemble the sulphide wackes reported by Walker et al. (1975) in the Kidd Creek ore deposit north of Timmins, Ontario. These authors describe sulphide sediments composed of sphalerite, pyrite-sphalerite, pyrite, carbonaceous argillite, and carbonaceous chert, and provide evidence from more extensive underground exposures of such primary sedimentary features as graded bedding, load casts, flame structures, scours and soft-sediment deformation features. These primary ore textures indicate that much or all of the massive, banded, and bedded ores in the Kidd Creek deposit accumulated as sediments on the sea floor. Their textural complexities, as envisaged by Walker et al. (1975), resulted from the interplay of syngenetic-sedimentary and near-surface epigenetic processes which existed in the vicinity of a subaqueous rhyolitic volcano.

The Mphoengs sulphide ore-textures greatly resemble those of the Kidd Creek deposit (A. Button, personal communication, 1976) and the environmental conditions outlined for the latter deposit appear to be equally relevant to the origin of some of the Mphoengs bedded sulphides. Additional support for some sedimentary involvement in the deposition of the Mphoengs sulphides can be seen under the ore microscope.

Small clasts of gangue (carbonate and quartz), in which tiny sub-rounded to rounded particles of pyrite are trapped, occur wedged between larger grains of sulphide and gangue (Plates 4B, 4C and 4D). In Plates 4B and 4D it is evident that the sulphide particles are mainly distributed around the outer or peripheral area of the clast which adopts the characteristics of an "armoured mud ball". In

Plate 4C however, the small pyrite particles are dispersed throughout the larger clast aggregate. It is further evident that the massive pyrite and pyrrhotite grains in the areas flanking the clasts are in no way distrubed thereby dispelling the possibility that the pyrite-pyrrhotite particles may have developed by post-depositional tectonic fragmentation of the consolidated sulphide ores.

Gossan Mineralogy

Aspects relating to the mineralogy of the gossans have been dealt with in various statements made through the text and only brief mention will be made of the gossan ore minerals encountered in polished sections. Despite the extreme alteration of the hematite gossans to sponge-like box-works, polished sections were prepared by impregnating the samples with expoxy resin prior to polishing.

Although altered, the original banding of the primary ores is still evident in the gossan samples studied. The hematite gossan consists of a mixture of limonite-goethite and hematite whereas the opaline variety consists mainly of amorphous and cryptocrystalline silica having a variety of yellow, red, and brown colours. The silica has almost totally replaced the box-works and only limited quantities of limonite and hematite remain.

ENVIRONMENT OF DEPOSITION

As has been reviewed by Sangster (1972) conclusions regarding ore genesis of massive sulphide deposits in the early Precambrian have been many and varied. However, since Knight (1957) first proposed the "source bed concept" and suggested that a great number of sulphide deposits had formed contemporaneously with their host rocks a number of authors, including Oftedahl (1958); Stanton (1959, 1960); Gilmour (1965) and Goodwin (1965) advocated a close genetic relationship between massive sulphide ores and volcanism. Today there is an almost general acceptance of the suggestion that massive sulphide deposits in Archaean volcanic (greenstone) belts were formed on or near the surface through the agency of fumarolic emanations (Hutchinson, 1973). In general terms the volcanic exhalative theory advocates that massive sulphide ore formation is an integral part of, and coeval with, the volcanic complex in which the deposits occur (Sangster, 1972).

A similar situation is envisaged for the sulphide occurrences in the Mphoengs Schist Belt where the extensive development of the pyrite-pyrrhotite orebodies appears to have taken place at or near the same stratigraphic horizon over large areas, and extending southwards into Botswana - a distance in excess of 30 km. This factor alone makes a deep-seated or hydrothermal site of ore formations untenable.

The formation of a pyrite-rich sulphide facies iron-formation is favoured by a strongly reducing environment with abundant H_2S or HS^-. Pyrite or pyrrhotite beds thus appear to have formed, in most areas, in the deeper parts of volcano-sedimentary basins (James, 1954). Whether the pyrrhotite developed as a primary phase in such an environment or whether it resulted from post-depositional conversion of pyrite to pyrrhotite by metamorphism, remains a problem. According to Garrels and Christ (1965) the variables affecting the formation of pyrite and pyrrhotite are the total amount of reduced sulphur in solution and the Eh and pH. Temperature dependence for the generation of pyrrhotite may therefore be unwarranted. Friedman (1959) and Stanton (1972) list several authors who describe pyrrhotite they considered to have been formed at temperatures of between 20 and 80°C.

In the past many attempts have been made to use Fe/S ratios of pyrrhotites to provide geothermometric controls on the temperatures of formation of pyrrhotite-pyrite mineral assemblages, but gaps in the knowledge of low temperature behaviour of the Fe-S system have cast doubt on the validity of the results. The sulphides in the Mphoengs area have, furthermore, been subjected to regional metamorphism in the low to medium ranges of the greenschist facies where temperatures of the order of 320-550°C (Winkler, 1974) must have been operative. The superimposed effects of heat on the primary sulphide system would further complicate geothermometry aimed at establishing initial temperatures of ore formation.

ECONOMIC GEOLOGY

The exploration efforts in the Mphoengs Schist Belt have failed to outline any significant base metal mineralization associated with the sulphide iron-formations in the area. As mentioned elsewhere, only sulphur appears to be present in any quantity. Estimates made indicate that there are a possible 3,6 million metric tons of sulphide material, with a raw sulphur content of approximately 18-23% per 100 metres of inclined depth in the Southern, Central and Northern gossans. Under the circumstances prevailing at the present time it would be uneconomical to exploit these occurrences.

Mention has still to be made of a number of gossanous shear zones found along the length of the Mphoengs Schist Belt and which are shown in Figure 2. These occur as discontinuous outcrops over distances ranging between 20-1 000 m. Samples from trenches over the gossanous shear zones were analysed and the results are included in Table 4. Although some of the results proved interesting, indicated tonnage potential of these mineralized occurrences were too small to warrant further attention.

TABLE 4

TRENCH SAMPLE ANALYSES OF GOSSANOUS SHEAR ZONES FOUND ALONG THE EASTERN HALF OF THE MPHOENGS SCHIST BELT

Shear Zone	Exposed Strike Length in Metres	Average Width of Gossan in Metres	Highest ppm Readings				
			Ni	Cu	Zn	Co	Pb
1	254	1,1	420	2 400	3 300	640	1 200
2	40	1,0	240	2 400	850	120	850
3	30	0,5	80	280	180	60	170
4	700	3,6	110	400	550	100	280
5	1 000	4,0	200	460	1 300	90	210
6	475	1,5	60	360	680	50	180
7	220	1,1	370	700	870	150	270
8	20	2,0	130	1 200	1 800	190	330
9	40	3,0	120	230	400	90	100
10	200	2,0	120	110	450	60	140
11	840	1,0	100	250	760	60	150
12	90	5,0	90	320	840	40	200
13	50	1,0	120	900	760	70	50
14	100	1,5	150	85	280	70	100
15	40	1,0	170	105	430	90	80

The oxide facies iron-formations along the eastern side of the schist belt contain signs of gold mineralization and a number of prospect workings occur in the area. Trace amounts of malachite, scheelite, and gold were also recorded in some mineralized quartz veins along the western contact.

DISCUSSION AND CONCLUSIONS

The Mphoengs Schist Belt sulphide deposits, like the Samreid Lake deposit in Ontario, described by Friedman (1959), was chosen as a type example of a "barren" pyrrhotite-pyrite iron-formation. A number of similar sulphide facies iron-formations are known to occur in the Archaean greenstone belts of southern Africa and it is to be hoped that these will not be ignored if any progress is to be made in the understanding of why some deposits are barren of base metal mineralization and others are not.

Conclusions and experience gained from economically unsuccessful deposits may be of future assistance to others confronted with the dilemma of having to decide whether or not to continue the prospecting of outcropping gossans that cap massive sulphide deposits in Archaean volcanic-rich greenstone environments.

It is generally simpler to reflect on the shortcomings of a mineral prospect at the conclusion of any exploration programme. In this particular case it could be argued that, once the Mphoengs gossans had been found, analyses of only a few carefully selected samples would have sufficed in evaluating the deposit as being barren of any economic mineralization potential. Indeed, the aim of this paper is to provoke further efforts that would eventually allow such a simple procedure to take place with total confidence.

The geochemical soil-sampling programme, it has been demonstrated, yielded only very low-order anomalies. These, as was subsequently shown by geological mapping, were almost totally unrelated to the known position of the very prominent gossans. Was this another stage at which the prospect should have been abandoned? Fearful in the thoughts of those who would say no is the possibility that economic mineralization may have a tendency to accumulate in some facies variation of the potentially mineralized unit. Although the exact relationship between massive sulphide deposits and volcano-sedimentary iron-formation (exhalite) is as yet unclear there does appear to be a tendency in the Canadian Archaean for economic sulphide accumulations to occur towards the central (deeper water) portions of basins as defined by the various iron-formation facies (Goodwin and Ridler, 1970; Hutchinson et al., 1971; Sangster, 1972). It is evident that the recognition of specific iron-formation facies variations would assist in establishing more about the depositional environments of the massive sulphide occurrences.

The Mphoengs host rock assemblage, consisting as it does of mafic and intermediate to acid lavas and pyroclasts provides a geological setting analogous to those encountered in the mineralized areas of the Canadian Shield. There appears to be no obvious difference between the two environments. Answers may only emerge with a more rigorous approach to the understanding of the geochemistry of the host rock system and the palaeogeographic and palaeotectonic environments wherein are contained the two varieties of sulphide occurrences.

It has been shown that the Mphoengs gossans represent the surface weathering expression of prominent sulphide facies iron-formation units, the latter occurring as a stratigraphic interlayer in a succession of mafic to intermediate and felsic volcanic and pyroclastic rocks and associated, in particular, with a carbonate unit. The sulphide mineralization consists almost totally of pyrite and pyrrhotite with magnetite intergrown with the sulphides. Subordinate quantities of chalcopyrite, marcasite, and possibly cubanite occur in the ores.

The sulphide-carbonate assemblage has yielded prominent gossans which can be traced discontinuously over a distance of 30 km in Botswana and Rhodesia. The main sulphides, intersected by diamond drilling, indicated thicknesses of up to 14 m and occur gradationally interlayered with limestones and impure carbonate iron-formation lenses. The oxidized surface cappings of the sulphide bodies consist of hematite (plus limonite and goethite) and opaline (amorphous silica and limonite) gossans, both varieties of which display prominent box-work textures on outcrop.

Finally, the sulphide units are barren of base metal as well as precious metal mineralization but contain significant quantities of sulphur. Exploitation of the deposits for sulphur would, however, not be economically feasible at the present time.

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KEY TO PLATE 1

A. View looking south over part of the Mphoengs Schist Belt and showing the gossan outcrops in the foreground and the Matsiloje Hills iron-formations across the Ramaquabane River in eastern Botswana.

B. Photograph showing alternating intermediate and felsic schists in the Harte's Head segment of the Northern Gossan. The geological hammer is positioned on a typical quartz-feldspar porphyry unit.

C. Flattened felsic agglomeratic fragments in a schistose matrix of intermediate composition meta-volcanic rocks. Locality, Harte's Head segment, Northern Gossan.

D. Typical banded felsic and intermediate tuffaceous schist units in the Harte's Head segment of the Northern Gossan.

E. Alternating bands and stringers of carbonate (white) and pyrrhotite-pyrite (dark grey) in a borehole core sample from the Mphoengs Gossan.

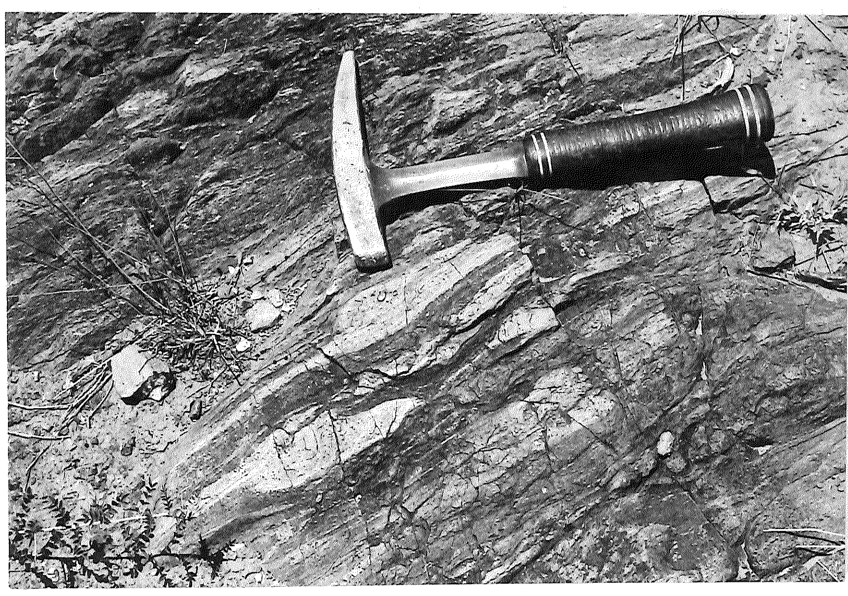
F. Isoclinally folded banded carbonate rocks (impure limestones) with narrow siliceous (quartz, diopside) interlayers. Locality, southern end of Central Gossan.

PLATE 1

A

B

C



D

E

F

KEY TO PLATE 2

A. Close-up photograph illustrating the delicate layering present in some of the calc-silicate rocks associated with the Central Gossan. The light coloured bands consist of calcite and the darker, high relief, bands consist of quartz, diopside, grossularite, and calcite. A chemical analysis of this rock (MP.5) is given in Table 1.

B. Specimen of carbonate iron-formation from west of the Northern Gossan showing folded and gradational interlayers of hematite, limonite, and magnetite (black bands and particles). The carbonate iron-formations are also gradational into the sulphide iron-formations.

C. Outcropping gossan extending into the Ingwezi River, north of the Central Gossan.

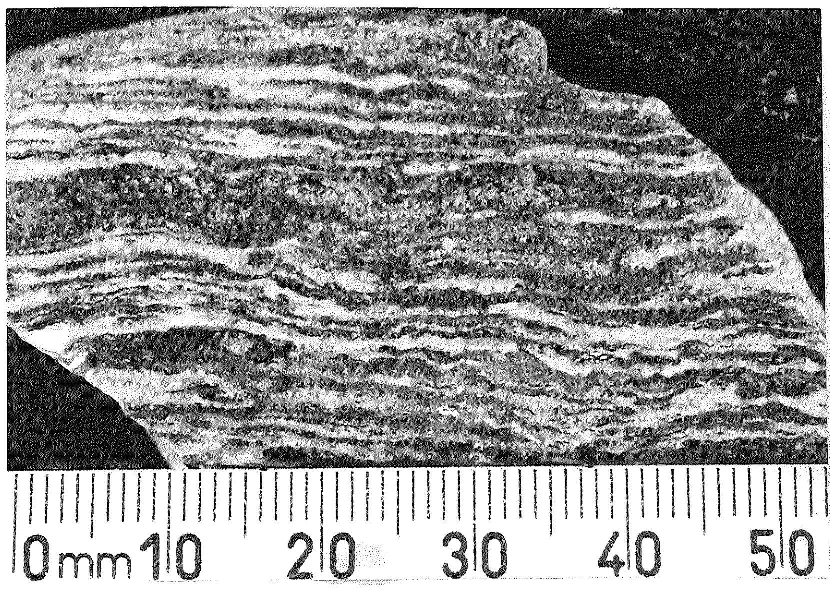
D. Gossan outcrops in the World's View segment of the Northern Gossan. Box-works, consisting of hematite, limonite, and goethite are prominent. Smoother faces sometimes display irridescent colours.

E. Photomicrograph showing the relationship of magnetite (dark grey) to pyrrhotite in ore from the Mphoengs Gossan.

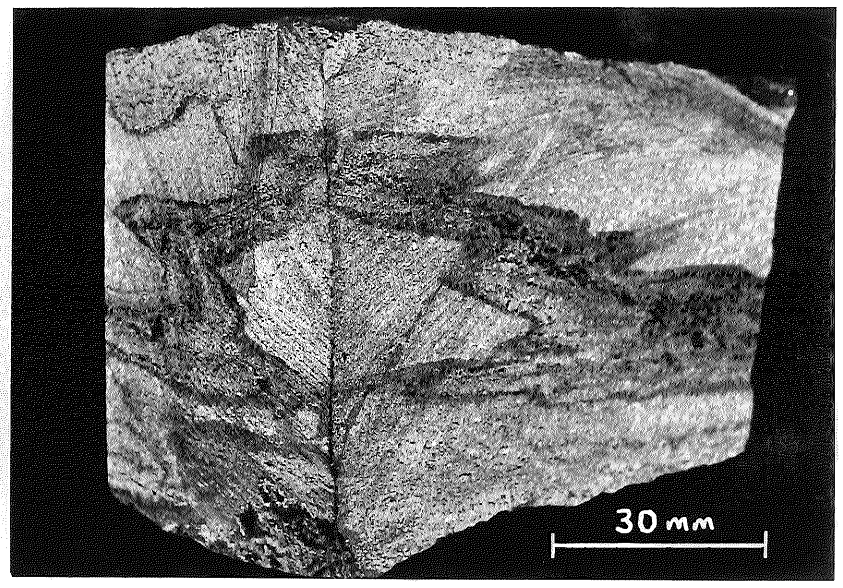
F. Photomicrograph showing a narrow stringer of chalcopyrite (light grey) in pyrrhotite (darker grey). Central Gossan.

PLATE 2

A



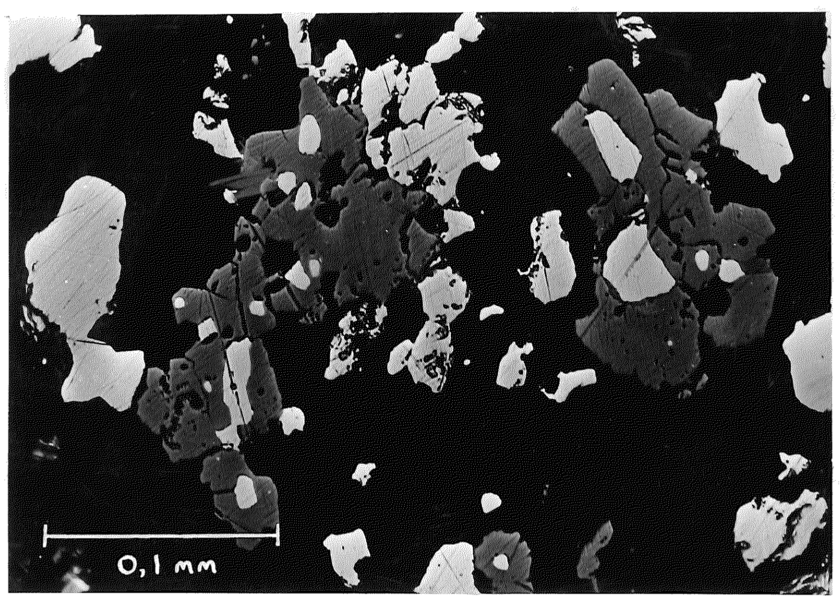
B



C

D

E



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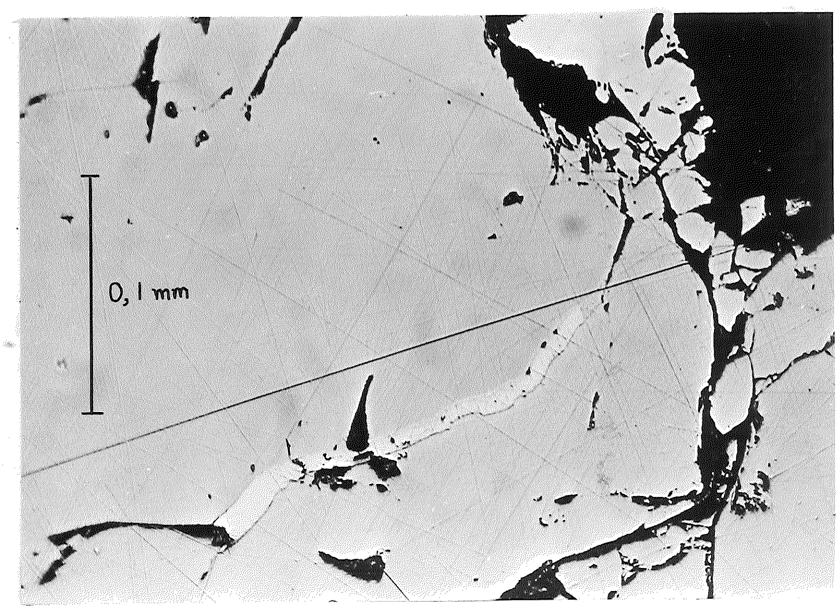
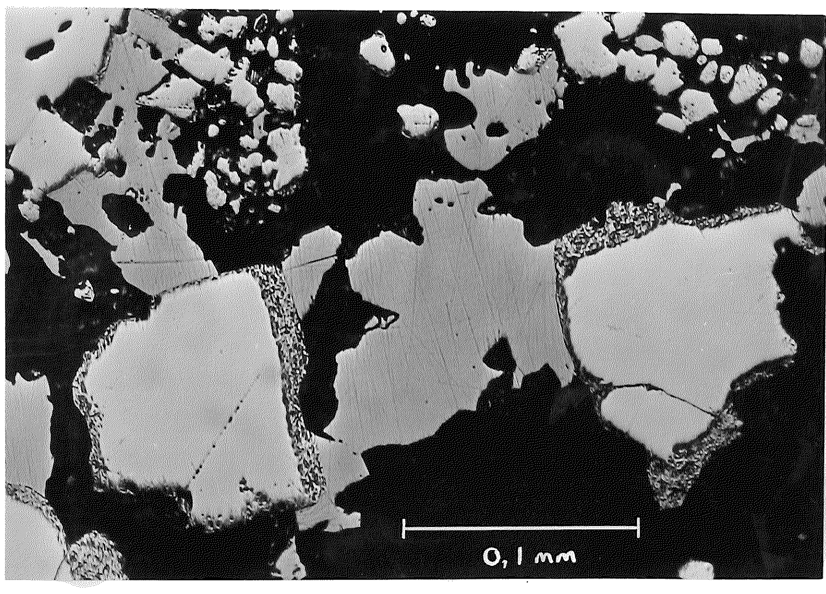
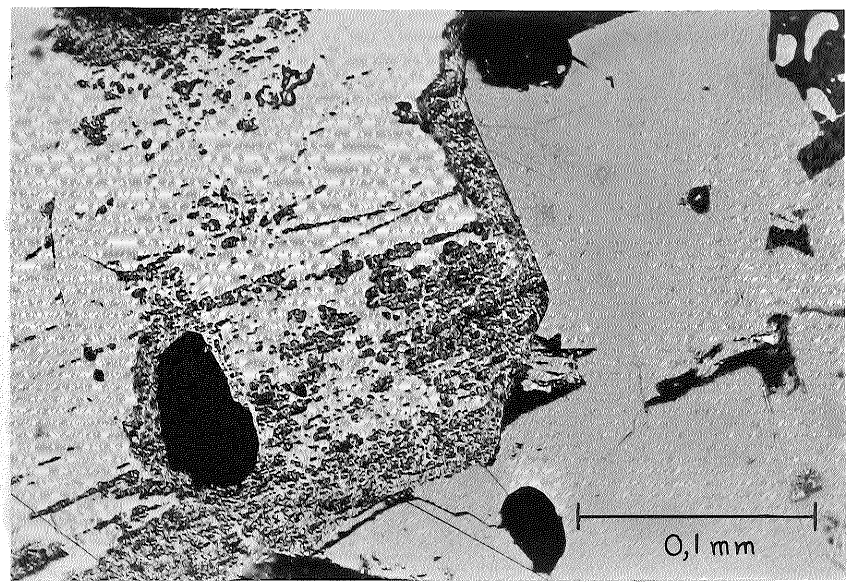


PLATE 3

A



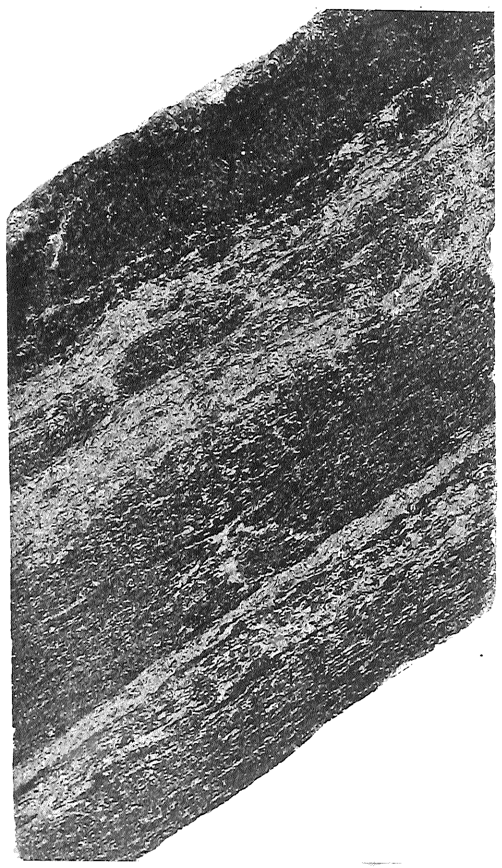
B



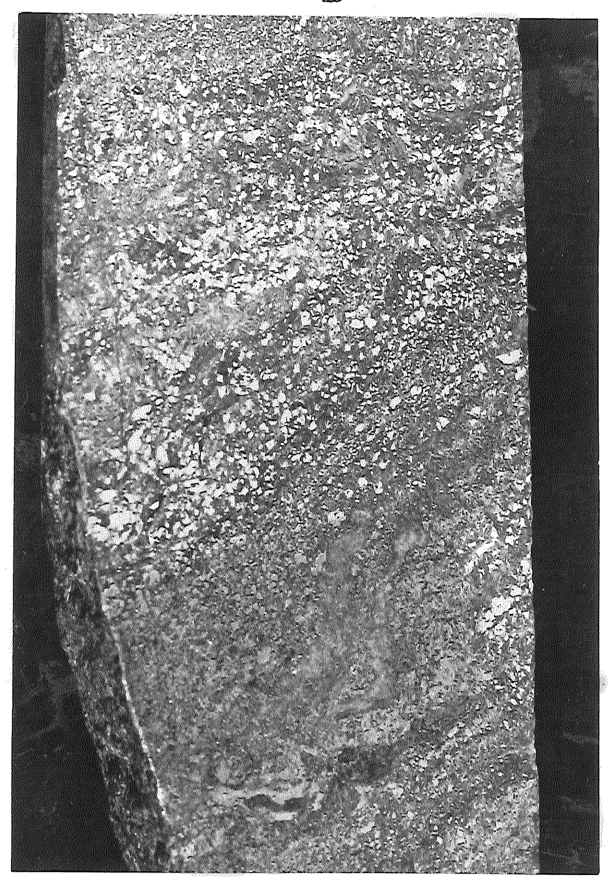
A. Photomicrograph showing hypidiomorphic pyrite/marcasite grains (light grey) surrounded by narrow rims of limonite. Pyrrhotite (darker grey) is also present in the ore but does not show alteration to limonite. Central Gossan.

B. Photomicrograph showing pyrrhotite (dark grey) and idiomorphic pyrite/marcasite (lighter grey), the latter altered mainly around the grain boundaries to limonite (rough texture). Central Gossan.

C



D

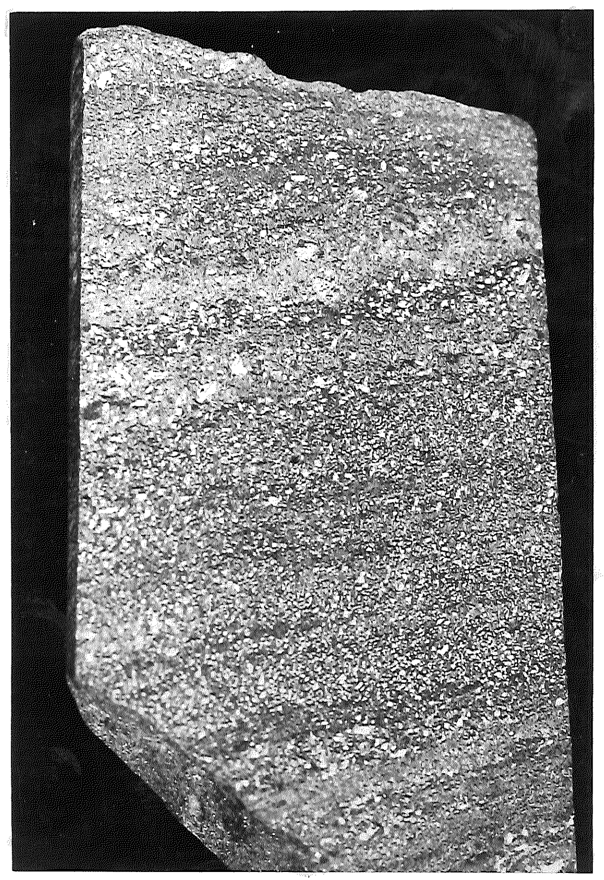


C. Borehole core sample showing bands and stringers of pyrrhotite (grey) in an amphibole schist matrix (darker matrix). The width of the core sample is 42 mm. Locality, Mphoengs Gossan.

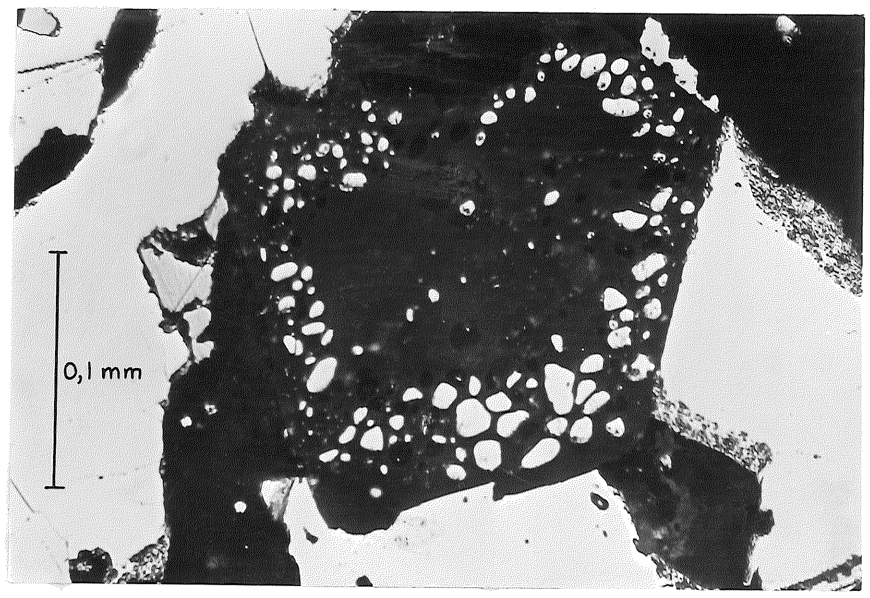
D. Bedded massive sulphide ore from the Mphoengs Gossan. The sulphide sediments (sulphide wackes) include both clastic and chemical components and preserve primary sedimentary features such as graded bedding and soft-sediment deformational features.

PLATE 4

A

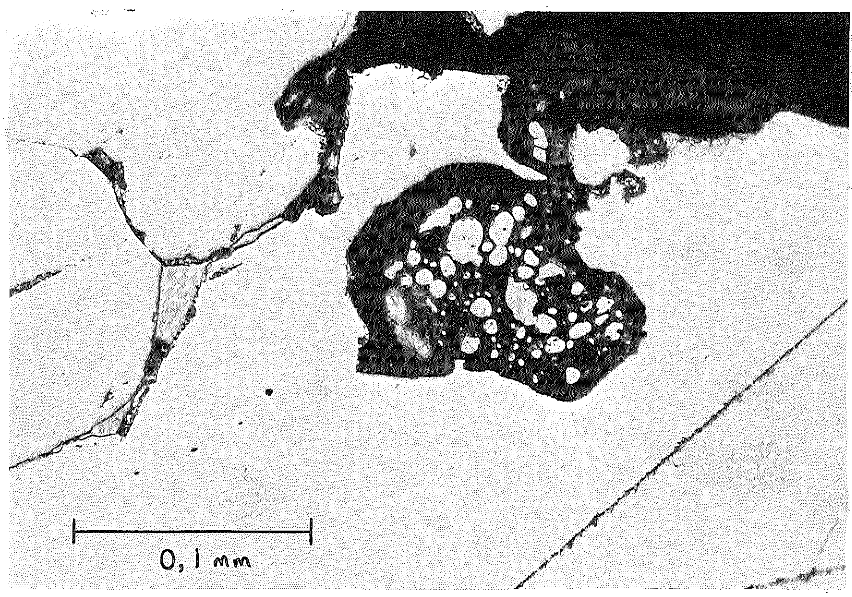


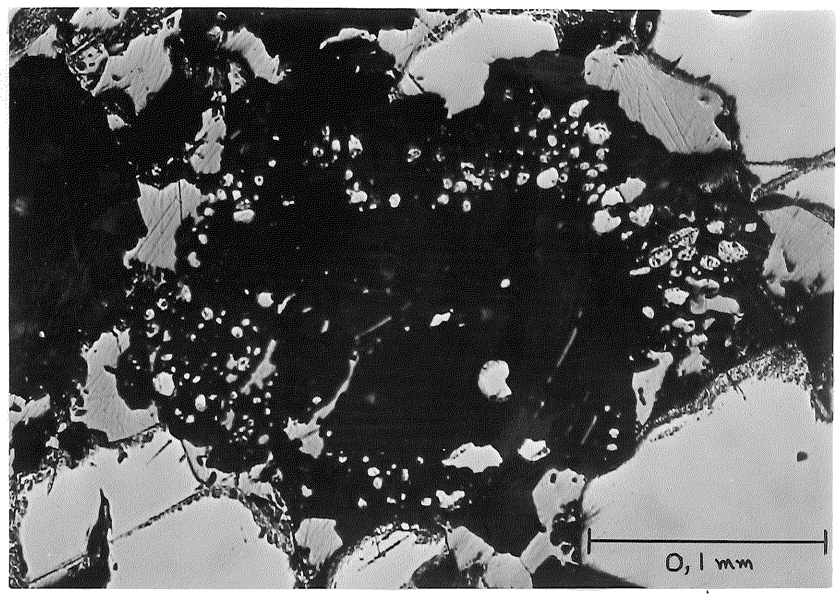
B



A. Borehole core showing banded and bedded sulphide sediments (wackes). Pyrite and pyrrhotite predominate in the ore which is from the Mphoengs Gossan. Graded bedding of the sulphide sands can be seen on the polished slab.

B. Photomicrograph showing pyrite (white) and pyrrhotite (grey) and an "armoured mud ball" inclusion of gangue containing rounded to sub-rounded particles of pyrite. Quartz and carbonate make up the central core of the aggregate. The large pyrite crystals show no signs of brecciation but limonite rims are present on some grains. Central Gossan.





C

D

C. Photomicrograph showing pyrite (white) and pyrrhotite (grey) and an aggregate grain of pyrite and gangue. The particles of sulphide are distributed through the clasts which is almost totally surrounded by pyrite. Central Gossan.

D. Photomicrograph of a sulphide/gangue aggregate (armoured mud ball) showing the rounded sulphide particles concentrated mainly around the grain margin. Pyrite (grey) and pyrrhotite (dark grey) are also evident in the ore. Central Gossan.