

THE GEOLOGY OF THE SHAMROCKE MINE AND
SURROUNDING AREA, RHODESIA

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ABSTRACT

The geology of the Shamrocke area is described relative to its regional setting and position within the stratigraphic succession of the Lomagundi System. The stratigraphy in the immediate vicinity of the Shamrocke Mine is detailed and discussed relative to the work of others south of the project area and in other regions. The petrography of the rocks of the Shamrocke Mine area is described and the results of a great deal of mineralogical work recorded. Maps of the project area are presented at various scales from field and photogeological evidence.

The thesis area is situated on the South Zambezi Escarpment of Rhodesia, and the geology described included the basal succession of the Lomagundi System and the pre-Lomagundi Escarpment Series. The Shamrocke Mine is located on a copper orebody associated with a granulite or granofels zone within the Dolomite Series of the Lomagundi System. This ore zone granulite appears to be a metasomatised calcareous grit some 1000 feet above the upper contact of the Deweras Series (basal Lomagundi) and within the graphitic schist and phyllite, below a dolomitic horizon in the Dolomite Series.

The Lomagundi succession in the Mine area unconformably overlies the pre-Lomagundi gneiss and meta-arkose of the older, metamorphosed and deformed Escarpment Series. The basal meta-arkose, meta-quartzite and coarse schist of the Deweras Series ascends southwards through the Dolomite Series (graphitic phyllite and schist, granulite, calcareous grit, dolomite, limestone), and the Argillaceous Series (schist, phyllite, quartzite), the beds dipping steeply to the south at an angle of between 50° and 70° . Post-Lomagundi plagioclase amphibolite (altered, intrusive meta-diorite) forms large semi-concordant and transgressive sills throughout the area, particularly along the contact between the Deweras and Dolomite Series.

The Shamrocke Mine is on the northern limb of a large synclinal structure, the Rusere Syncline, which forms a large embayment of Lomagundi rocks into the pre-Lomagundi gneisses and granodiorites northeast from the Mine. The fold is overturned to the east and southeast.

The copper mineralisation within the area and in the areas to the south is considered to be invariably associated with the basal rocks of the Lomagundi System. It occurs within both the Deweras and Dolomite Series rocks and more often than not lies close to the contact between these two Series.

The sulphide mineralisation of the Shamrocke orebody is considered, from the results of the present study, to be metasomatically emplaced during carbonate metasomatism, either from an extraneous source or from within the ore zone rock itself. The present writer favours the origin of the copper sulphide to be original syngenetic sulphide of the basal rocks of the Lomagundi depository, which has been mobilised and metasomatically relocated, possibly by the effects of regional metamorphism related to intense deformation. It is perhaps not fortuitous that the majority of the copper occurrences in the area occur where the basal beds of the succession have been cross-folded. The copper ore comprises a simple suite of minerals, the main constituents being chalcopyrite, cubanite and pyrrhotite.

The deposit is compared relative to the other copper deposits of the Lomagundi System.

TABLE OF CONTENTS

	<u>Page No.</u>
INTRODUCTION	1.
PHYSIOGRAPHY	3.
NOMENCLATURE	6.
<u>A. REGIONAL GEOLOGY</u>	
A.1. GEOLOGICAL SETTING & REGIONAL STRATIGRAPHY	8.
Outline of the Geology	8.
Previous Work.	10.
REGIONAL STRATIGRAPHY.	11.
The Lomagundi System	11.
The Escarpment Series	16.
A.2. THE STRUCTURE OF THE RUSERE SYNCLINE	18.
Regional Structure from Photogeological Study	18.
The Rusere Syncline	20.
A.3. REGIONAL METAMORPHISM	23.
A.4. REGIONAL CORRELATION	26.
<u>B. THE GEOLOGY OF THE SHAMROCKE AREA</u>	
B.1. THE STRATIGRAPHIC POSITION OF THE SHAMROCKE MINE RELATIVE TO OTHER COPPER OCCURRENCES WITHIN THE LOMAGUNDI SYSTEM	29.
B.2. DETAILED STRATIGRAPHY	33.
The Escarpment Series	33.
The Lomagundi System	36.
The Deweras Series	36.
The Dolomite Series	37.
The Argillaceous Series	42.
B.3. STRUCTURE OF THE ORE ZONE	44.
B.4. PETROGRAPHY	45.
Descriptive Petrography	45.
Selective Staining	59.
Modal Data	63.
B.5. MINERALOGY	66.
Non Opaque Minerals	66.
Plagioclase Felspar	66.
Amphiboles	76.
Biotite	95.

	<u>Page No.</u>
Quartz	98.
Minor Constituents:	99.
Apatite	99.
Rutile	99.
Sphene	100.
Staurolite	100.
Epidote	101.
Calcite and Dolomite	102.
Garnet	103.
Graphite	103.
Opaque Minerals	104.
Description of the Ore Minerals	104.
Quantitative Mineralogical Analysis of the Ore	111.
Textures and Paragenesis	111.
B.6. PETROLOGY	123.
Chemical Data	123.
Silicate Analyses	123.
Spectrographic Analysis	131.
Metamorphism and Petrogenesis	132.
B.7. THE SHAMROCK OREBODY	138.
Mode of Occurrence of Orebody	138.
The Composition of the Ore Zone	138.
Mineralisation of the Orebody	140.
Difficulty of Correlation	142.
The Genesis of the Orebody	144.
SUMMARY AND CONCLUSIONS	153.
ACKNOWLEDGEMENTS	164.
REFERENCES	

INTRODUCTION

Location: The Shamrocke Mine is situated in the Urungwe District in the northern part of Rhodesia at the confluence of the Angwa and Nyashiri Rivers some 35 miles northeast of Karoi (Latitude $16^{\circ}25'$ south and Longitude 30° east). The Angwa River is one of the major rivers dissecting the south Zambezi Escarpment and flows through the broken country typifying that escarpment and the Shamrocke area. (See Figure 1A and B).

Historical Review: The Shamrocke copper orebody was discovered in 1958 by an African prospector who introduced it to Nyashiri Copper (Pvt.) Limited, a local prospect company. That company pegged 15 blocks of claims over the area. Rand Mines Rhodesian Exploration Company (Pvt.) Limited investigated the claims from 1958 to 1961, and included in this exploration both detailed and reconnaissance work over some 500 square miles of the South Zambezi Escarpment (Exclusive Prospecting Orders Nos. 80 and 81). Panchromatic aerial photography was carried out over the E.P.O. areas at a scale of 1 : 30,000 and the photography mosaicked. An aerial geophysical survey was flown over this area utilizing magnetometric and radiometric methods (scintillometer). Following initial trenching and sampling, a drilling programme commenced in May 1959 and by December 1960 a total of 42 boreholes comprising some 40,000 feet of drilling was completed. The deepest borehole intersected the orebody at a dip distance of 2,400 feet. Prospect mining commenced in January, 1960 with an adit drive into the hillside along the strike of the orebody, with cross-cuts and underground diamond drill holes probing horizontally across the orebody at regular intervals. Vertical boreholes were drilled from the hangingwall side of the cross-cuts to intersect the orebody below the adit level. Two shallow winzes were sunk from outcrop to connect with the adit drive and to explore the orebody below adit level to some 300 feet below surface. The underground development explored a strike length of 1200 feet and all workings were surveyed, geologically logged, and sampled. A total of 4492 feet of underground development was completed and 40 underground boreholes were drilled totalling 5,074 feet.

Detailed geological mapping on a traverse grid was undertaken over the Shamrocke claims, augmented by geochemical soil sampling. Geological mapping and geochemical stream sediment sampling was undertaken over some 150 square miles in the immediate vicinity of the Mine and northwards.

Rand Mines Rhodesian Exploration Company (Pvt.) Limited did not exercise their option to purchase the property. The Lonrho Group then obtained the

controlling interest in the claims and have held this interest until the present time when they are currently developing the mine for production.

The Present Study

The writer was privileged to be a member of the Rand Mines Rhodesian Exploration Company's geological team which investigated the Shamrocke deposit and E.P.O.'s 80 and 81 from 1959 to 1961. During this exercise he personally mapped the area southwards of the Mine to the Deta River and west of the Angwa River; and the eastern two-thirds of the area north of the Mine shown on the geological maps of the Shamrocke Area (Figures 5 and 6). The writer was closely concerned with the drilling and underground development programmes, logging the majority of the boreholes and some of the underground workings.

The geological maps as presented have been upgraded by subsequent information from the present study and augmented by photogeological analysis. The photogeological analysis was carried out using recent (1965) 1 : 25,000 panchromatic aerial photographs of the Rhodesian Surveyor General's office, and covered the area from Chidwara in the south, following the basal rocks of the Lomagundi System, accommodating the extended tongue of the Rusere Syncline and westwards through the Shamrocke Mine and again northwards to the Mukwishe River. This study included the detailed stereoscopic annotation of the photographs of all aspects of the geology with special emphasis on the structure. The photogeological map presented extends northwards from Chidwara.

The petrographical and mineralogical study of the rocks of the Shamrocke Mine included the preparation and examination of upwards of 250 thin sections and 23 polished sections. Microscopic study included extensive use of the Universal Stage in the examination of the plagioclase feldspars and amphiboles, and laborious measurement of the refractive indices of the amphiboles by oil immersion methods. Staining techniques were applied to distinguish between quartz-orthoclase-plagioclase and between calcite and dolomite. A small number of reflectivity measurements were done on the polished ores. Three full silicate analyses were undertaken (one by the writer).

The detailed field examination of the Shamrocke deposit, together with the geological mapping, was carried out over 20 months; approximately 6 months were spent at Rhodes University studying the petrography and mineralogy; and the consideration of the results and the preparation of the thesis has been undertaken sporadically to date.

PHYSIOGRAPHY

Topography

The Shamrocke area comprises well dissected country of the South Zambezi Escarpment in the northern part of Rhodesia. The South Zambezi Escarpment is generally well dissected by rivers flowing towards the Zambezi valley floor, producing a young relief along the escarpment between the mature rolling plains of the Karoi-Miami area and the Zambezi valley floor itself. The rivers in the area are sufficiently deeply dissected to produce topography of steep V-shaped valleys and narrow ridges. This terrain is very difficult to traverse, access by vehicle being impossible without road construction and access on foot is made difficult by the steep relief and rubble-covered slopes.

Drainage.

The main river in the area is the Angwa River flowing approximately north-south, joined by the other major rivers; from the east the Deta in the southern portion of the area, the Nyashiri River at the Shamrocke Mine, the Mukwishe River immediately north of the Mine, the Chidara River and the Maura River at the northern extremity of the project area. From the west the Rukute River flows into the Angwa north of the Mukwishe-Angwa junction, and the Chituhwe River joins the Angwa towards the Maura-Angwa confluence. Besides these major rivers small streams and gullies are ubiquitous throughout the area. The Deta River in the south tends to meander slightly in a wide more mature floodplain valley, while the other rivers of the area show a V-shaped valley section, of young relief. The rivers west of the Angwa River flow generally east-northeast toward the Angwa and the escarpment edge while those rivers east of the Angwa tend to flow in a northwesterly direction.

Soils

The soils in the immediate vicinity of the Shamrocke Mine and southwards and south-eastwards from the mine (occurring on the metamorphic terrain of the Lomagundi System) are generally greyish and reddish-brown clayey loams and sandy loams, fine-grained and somewhat silty. The soils found on the Escarpment Series

rocks north of the Mkwih Hill are shallow lithosols, usually very stony and on steep slopes. North of the Maura River the soils are sandy, usually with heavy textured sub-soils with low inherent fertility.

Access

As previously discussed, access by vehicle is impossible without road construction. Access on foot is hampered by steep rubble-covered slopes and deep gullies. Heavy vegetation in the gully areas in the summer make access difficult, whereas in the winter the vegetation becomes very sparse and movement through the area is somewhat easier.

Vegetation

South of the Maura River and in the Shamrocke area the vegetation is typical of the South Zambezi Escarpment from the project area through the Kariba area to Livingstone (northwest of Wankie in the eastern part of Rhodesia). The vegetation can be described as Escarpment Woodlands or Brachystegia, usually with a high proportion of *B. Boehmii* or *B. Allenii*. Northwards from the Maura River there is a narrow tract of country populated by the *Commiphora-Combretum*, which passes outside the project area to the north, and into the typical valley floor vegetation of thickets of *Bussea-Combretum*.

Rainfall and Temperature

The mean annual rainfall of the area is between 24 and 32 inches per annum, which is similar to the greater part of central Rhodesia. The seasonal variation of the rainfall is such that it has its peak during November - December - January - February and shows a 15% to 20% variation. The annual mean temperature is approximately 75 °F with the mean maximum temperature in October, 90° to 95°F, mean maximum temperature in July 77° to 81°F and mean maximum temperature in January 81° - 86°F. The relative humidity shows a mean average of 60 - 65%. The wind direction is generally from the northeast.

Population

There is a small settlement at the Shamrocke Mine which comprises a European mining community and African labour compounds. Outside this mining

community there is a very low African population. Within the study area there are African villages at Rusere, east of the Mine and east of the Angwa River; a small lonely settlement on the Angwa River immediately north of the Angwa-Mukwishe junction; a very minor settlement in the Bedzuanga area and a very small settlement on the Maura River. Both southeast and west of the Shamrocke Mine area the African population increases, both in the Urungwe Reserve towards Miami and in the European areas southeastwards towards Doma. The African languages spoken in this area are both Shona and Sena. The Shamrocke area is intermediate to both these language groups. Shona being spoken both south and west from the Mine and Sena to the north and east.

Wild Game

The study area is surprisingly devoid of natural game. The South Zambezi Escarpment area generally has little game, due mainly to the lack of water in the winter season. Originally the area was cleared of game by shooting by the Game Department for tsetse fly eradication. Elephants are found in the Dete and Maura valley areas, with some small and large antelope throughout the area. Lions are encountered north of the Mukwishe River and in the Rukuti River area. The area now forms part of the Urungwe and Zambezi Game Reserves. Northwards from the Mukwishe River tsetse fly occur; to the east of the Angwa River this species is generally *Glossena Mortisans*, and west of the Angwa *Glossena Pallidipes*.

Climate and Health

The climate in the winter season is dry and extremely pleasant, with warm days and fairly cold nights. There is very little rain in the winter period. The summer season is extremely hot, humid and unpleasant. It is pertinent to note the advantage of camping on the higher ground away from the rivers. Precaution against malaria in the summer season is imperative. The rivers of the area are bilharzia infested. The African population are far from healthy, with the majority suffering both low fever from malaria and infected by bilharzia.

NOMENCLATURE

A brief discussion of the nomenclature used in this thesis has been prompted by the rather difficult task of assigning a name and origin to the even-grained granoblastic and sometimes porphyroblastic felspar-biotite rock of the ore zone. This rock has a groundmass fabric of granoblastic anhedral crystals of plagioclase felspar, with generally some anhedral to subhedral biotite crystals scattered throughout. The quartz content of the granoblastic fabric of these rocks of the ore zone is always less than 6%, and porphyroblasts of amphibole (hornblende, actinolite, cummingtonite, anthophyllite) sometimes occur. This rock can be highly calcareous. Careful consideration has indicated that the most appropriate names applicable to this rock are "granulite" and "granofels". The former term has been accepted in this thesis, due mainly to the fact that this term has been used from the inception of the investigation of the Shamrocke deposit. The very low quartz content, the absence of orthoclase and the predominance of plagioclase felspar makes the rock type relatively unique. This "granulite" may be considered to be probably metasomatised and altered calcareous grit or impure felspathic marl. A possibility is that it could be an altered tuffaceous material from acid vulcanism. The term "granulite" as used in the thesis in no way implies grade of metamorphism.

The following definitions are pertinent to the text :-

Granulite : An even-grained pink to grey granoblastic felspar (plagioclase) - biotite rock, very often calcareous, with generally less than 6% quartz within the ore zone. This rock, outside the immediate vicinity of the ore zone, contains more quartz. Amphibole porphyroblasts often occur (hornblende, actinolite, cummingtonite, anthophyllite). No orthoclase appears to be present.

Schist : Strongly schistose, often graphitic, usually well lineated rock, where the slightly coarser grain size makes the rock less compact and less fissile than the phyllite. Biotite is abundant, the biotite crystals at times being conspicuously sub-parallel, this orientation giving the rock a linear schistosity. Amphibole porphyroblasts sometimes occur together with elongated granular quartz-felspar porphyroblasts (segregations or pseudomorphs). The groundmass

comprises generally phanerocrystalline plagioclase feldspar and quartz.

Phyllite : A fine-grained and compact, often graphitic, schistose and fissile rock, exhibiting a fine-grained almost aphanitic groundmass. Biotite is again abundant and amphibole porphyroblasts are common. The biotite often gives the schistosity surfaces a lustrous sheen.

Meta-Arkose: A felspathic metamorphosed, in part reconstituted arenite, fairly compact in fresh specimen and sandy on a weathered surface.

Meta-Quartzite: A hard compact (at times glassy), reconstituted quartzite, often micaceous.

Gneiss: A coarse-grained irregularly banded rock in which the schistosity is rather poorly defined due to the preponderance of quartz and feldspar over micaceous minerals. In places highly amphibolitic. Possibly original arkosic arenites and argillites.

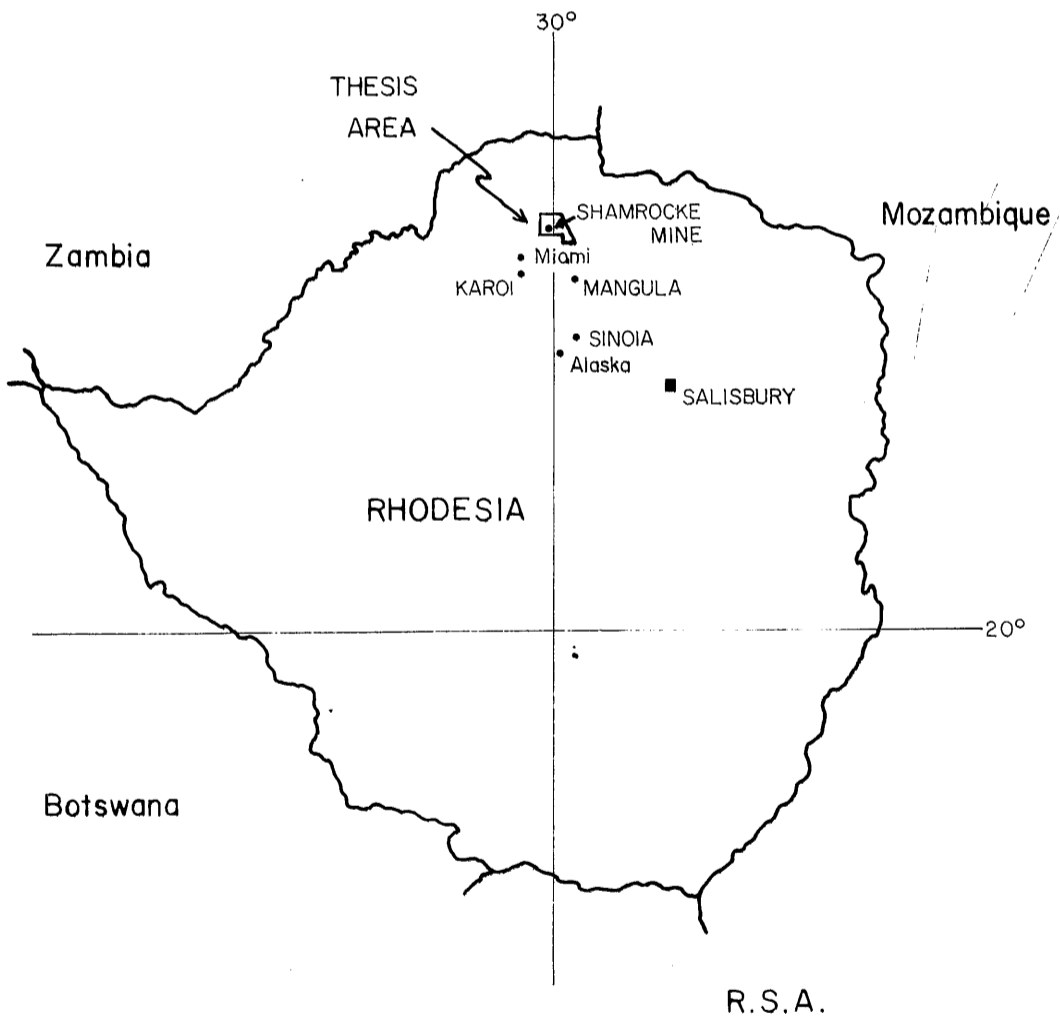
Plagioclase Amphibolites: A metamorphosed intrusive igneous rock, possibly diabase, where the assemblage hornblende-plagioclase is diagnostic. Sometimes weakly schistose due to the parallel alignment of hornblende and biotite. Occasionally calcareous, particularly where they intrude limestone and dolomite.

Limestone: Highly calcareous rocks with a high proportion of calcite. At times the limestone can be very impure with feldspar, quartz and amphibole conspicuous. The dolomite mineral seldom occurs in the limestone. The limestone can be highly silicic.

Dolomite: Usually comprises almost entirely dolomite, which is often pinkish in colour. Can be siliceous and impure with very abundant hornblende and tremolite-actinolite.

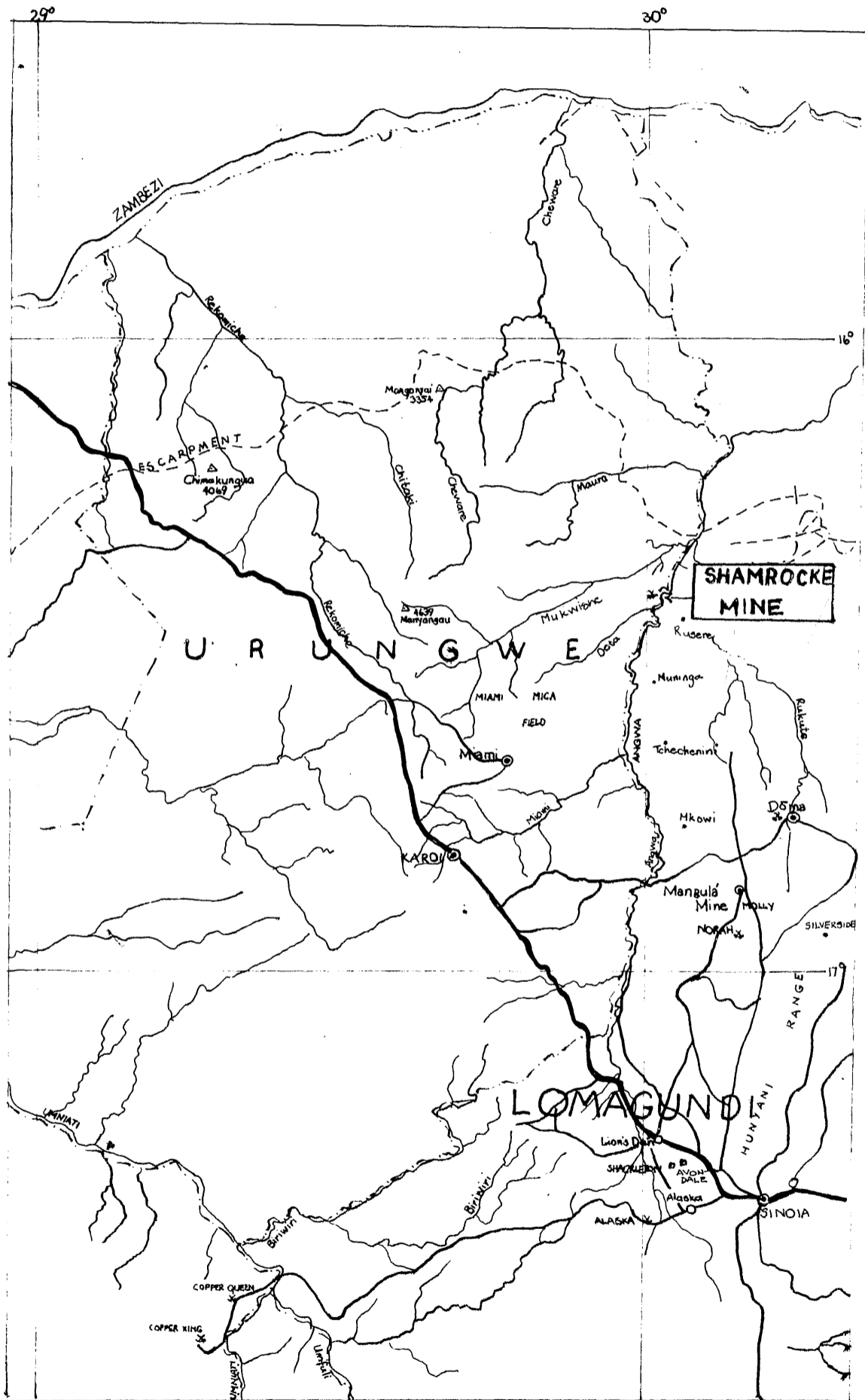
LOCATION MAP

SCALE 1:8,000,000



LOCATION MAP

SCALE 1:1,000,000



7c

PLATE 1.



The Shamrocke Main Outcrop, a gossanous weathered granulite with malachite staining.

A. REGIONAL GEOLOGY.

A.1. GEOLOGICAL SETTING AND REGIONAL STRATIGRAPHY

OUTLINE OF THE GEOLOGY

The project area lies at the northern fringe of the Rhodesian craton and against the southern margin of the Zambezi mobile belt.

The Zambezi mobile belt is an east-northeast trending zone of metamorphic tectonites extending from Botswana in the southwest across the northern part of Rhodesia and southern Zambia; and the Zambezi belt and the Mozambique metamorphic belt intersect one another, in a complex configuration in the Tete area of Mozambique. The Zambezi mobile belt has undergone numerous tectono-thermal events, but is generally considered older than the Mozambique belt.

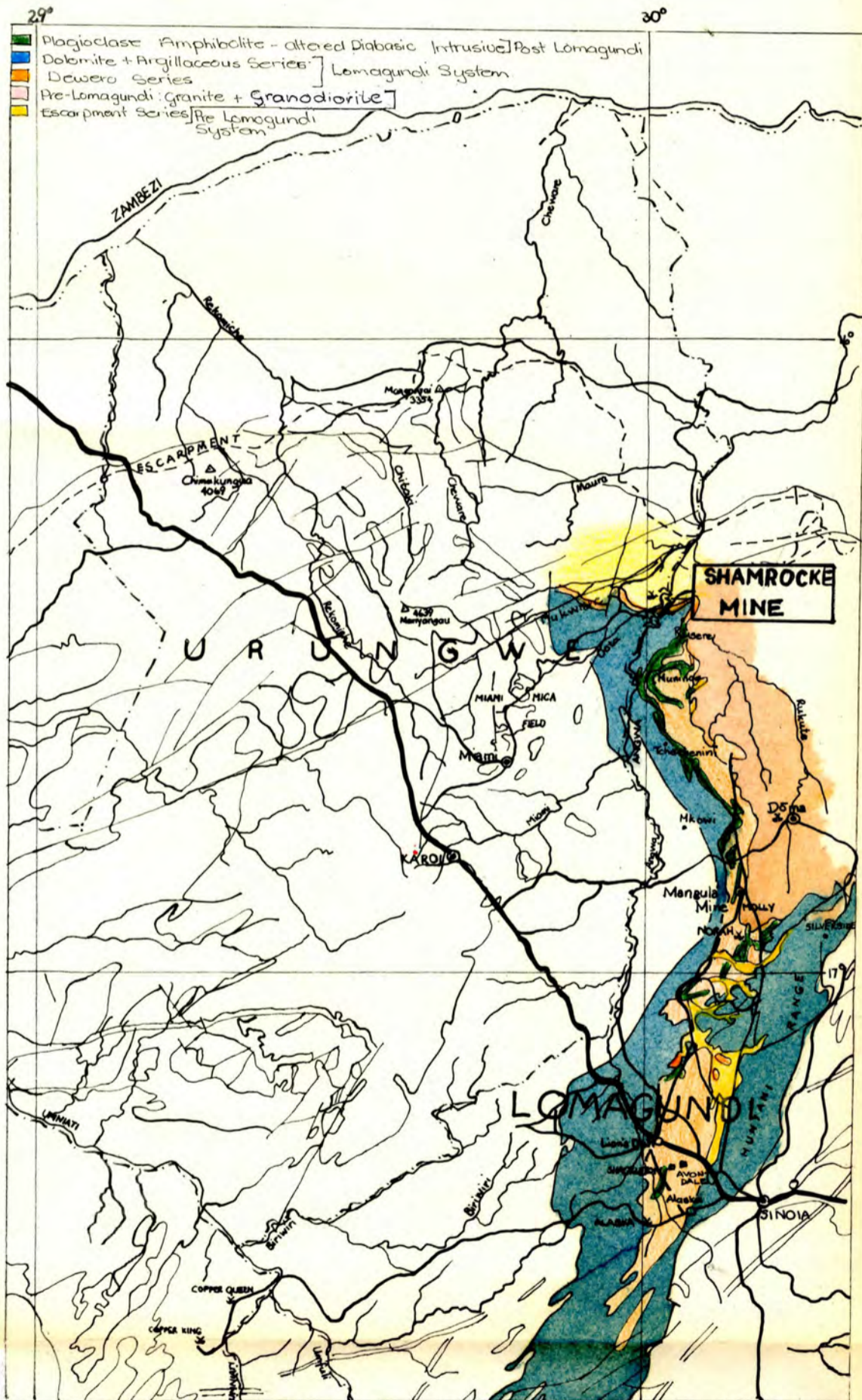
The series of quartzo-felspathic gneisses, amphibole gneisses, meta-quartzites, amphibolites and limestones constituting the Escarpment Series north of the Shamrocké Mine are the probable products of this tectono-thermal metamorphism, and are most likely a metamorphosed and deformed early Precambrian supracrustal sequence of an early Zambezi trough.

The Lomagundi System is a probable cover sequence to the Zambezi belt tectonites along the northeastern edge of the Rhodesian craton. It is difficult to reconstruct with any measure of confidence the Lomagundi "basin", relative to the mobile belt/craton edge environment. It does however appear reasonable to assume that the Lomagundi sequence was indeed a cover sequence to the older mobile belt terrain, now exposed against the craton edge, and that the deeper-water facies of the Lomagundi sequence dip below the Karroo sediment further into the Zambezi trough. Another and perhaps less likely possibility is that the shallow to moderately shallow water sedimentation with which the Lomagundi rocks could be associated may have covered large portions of the Rhodesian craton, and which was eroded away, and deformed in the northeast by uplift and warping caused by the events in the Zambezi belt.

Southwestwards the basal succession of the Lomagundi disappears below Karroo rocks and may pass beneath these southwards to reappear in the Wankie area, or even further southwest in Botswana. Basement "highs" in the original depository may cause small areas of basal rocks of the Lomagundi to occur, e.g., in the Umniati River area and perhaps in the Wankie area. The Wankie (Gwai River) area may however be the actual exposed edge of the depository.

SKETCH MAP OF THE GEOLOGY OF THE
 LOMAGUNDI SYSTEM BETWEEN THE SANYATI-
 ALASKA AREA AND THE SHAMROCKE MINE
 (After the provisional Geological Map of Rhodesia 1971)

SCALE 1:1,000,000



The Shamrocke orebody lies towards the base of the Lomagundi System on the northern limb of the large Rusere Syncline, forming a large "embayment" of basal Lomagundi rocks wedging into the older rocks to the north and east of this northeast corner of the northern part of the Lomagundi geological province.

The base of the Lomagundi System in the thesis area is the Deweras Series, comprising largely meta-arkoses, metaquartzites and conglomerates. The Deweras Series overlies the older Basement Complex of biotite gneiss (distinctly granodioritic) and granite to the east of the Shamrocke area, and the meta-arkoses and gneisses of the locally named Escarpment Series to the north. Around the extended tongue of the isosynclinal structure of Lomagundi rocks in the extreme northeast, the pre-Lomagundi Basement meta-arkoses and gneisses of the Escarpment Series appear to grade gradually into the unfoliated granodiorites southwards, with what could be an increase in the degree of granitisation and migmatisation.

Overlying the basal Deweras Series of the Lomagundi System is the Dolomite Series, comprising graphitic biotite schist and phyllite, granulite and calcareous grits, dolomite and amphibolite. It is towards the base of the Dolomite Series that the Shamrocke orebody is located in a "granulite" or "granofels" within graphitic schist and phyllite. The Argillaceous Series overlies the Dolomite Series conformably and comprises muscovite, biotite and graphitic phyllites, schists and slates, with subsidiary arenaceous beds, generally comprising blocky compact sandstones and quartzites.

9a

PLATE 2.

2A



An historic occasion - Prospect Mine Bossboy, Kadzini, lights up the first blast at the Shamrocke No. 1 Prospect Adit. January, 1960.

2B



The No. 1 Prospect Adit Portal Area, showing compressor, store and the growing separate ore and waste dumps in left foreground.

PREVIOUS WORK

F.P. Mennell (1910) described a sedimentary series of rocks in the Sinoia area and subdivided these into a Lower Conglomerate Series and an Upper Sinoia Series. Molyneux (1919 p.9) further described these rocks and proposed the name Lomagundi System for the thick sedimentary sequence west of the Hunyani Range. (Maufe (1919) discussed these rocks in his presidential address to the Geological Society of South Africa.) Maufe, Lightfoot and Molyneux (1923) mapped and described the geology west of Sinoia and in 1931, Macgregor continued the use of the term Lomagundi System in describing the geology in the Molly, Norah and Umboe claims area.

Macgregor (1955) elevated the Deweras Series to the level of "System", a nomenclature used by Hitchon (1958) in his mapping at Kariba.

J.G. Stagman (1959) described in great detail the Lomagundi System in the Urungwe and Lomagundi Districts in a tract of country between the Hunyani and Angwa Rivers from 16°45 to 17°00 south latitude. In 1959, Rand Mines Rhodesian Exploration Company (Pty.) Limited examined two exclusive prospecting orders (EPO's Nos. 80 and 81) covering some 500 sq. miles in a belt approximately 7 miles wide from Rusere in the east along the Zambezi Escarpment as far as the Sinoia-Chirundu Road in the west.

During 1960 and 1961, D. Workman of Leeds University, working on a Ph.D. thesis with the Research Institute of African Geology, mapped the area from Mkawi northwards to Rusere, describing the geology from the granites and gneisses in the east, westwards to the Angwa River. His Ph.D. thesis, submitted in 1961, closed the gap between the rocks of the Rusere area and the area mapped by Stagman. In 1961, Workman again visited the area and mapped the tight tongue of the Lomagundi System in the nose of the Rusere Syncline, from Rusere towards the northeast and along a portion of the northern limb of the syncline towards the Angwa River. He presented his findings as two short papers in the Seventh Annual Report of the Research Institute of African Geology, Session 1961-1962.

J.B.K. Jacobsen presented an M.Sc. Thesis in the Geological Department, University of the Witwatersrand in 1962, entitled "The Geology of the Lomagundi District". Jacobsen (1962) discussed the Lomagundi System between the Umfuli River near Hartley in the south and Mkawi in the north, an area north of the area described by Phaup and Dobell in 1938 and covering the same area as described by Stagman (1959). In this thesis a new subdivision of the Lomagundi System was suggested by Jacobsen, which in part could be considered revolutionary.

10a

PLATE 3

3A



View along the Nyashiri Meta-quartzite ridge (foreground) with Mkwihi Ridge in background, the latter comprising largely Deweras Series Meta-arkose and schist.

3B



Shamrocke Camp and Prospect Adit area (1960) taken from Nyashiri Ridge across the Rusere Syncline to Chidwara.

PLATE 4.

4A



Portal to the No. 1 Prospect Adit (April 1960) in the footwall graphitic schist and phyllite.

4B



Face of the advancing Main Adit Drive showing the dip of the ore-body at 60° to the south. A band of dark graphitic and partly schistose granulite is seen between coarse white calcite on the hangingwall side and pink calcareous granulite. The coarse sulphide mineralisation can be seen glinting in the light.

10c

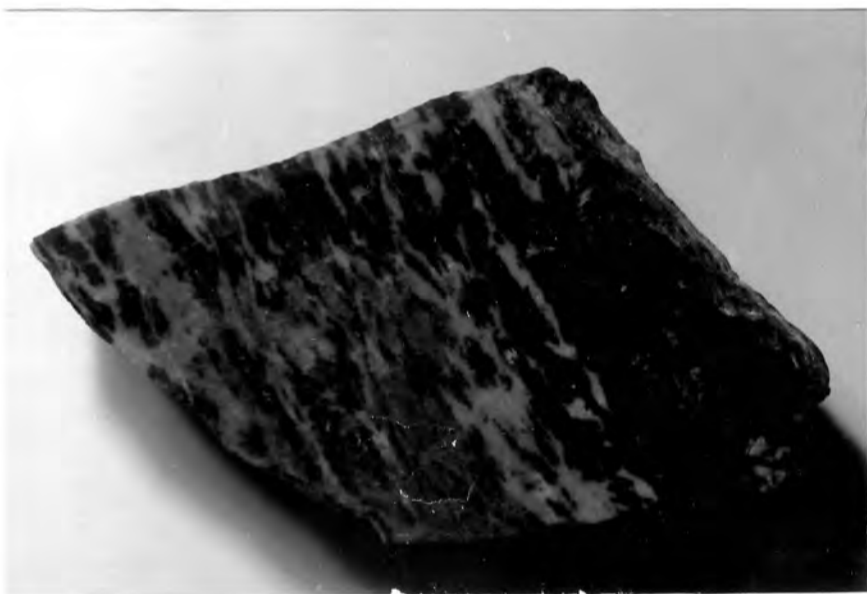
PLATE 5.

5A



Typical, grey-pink biotite granulite of the Ore Zone.

5B



The coarse porphyroblastic feldspar-amphibole rock - very often found at contact between granulite and footwall and hangingwall schist and phyllite.

In 1966, D. Workman published further thoughts on the metamorphism of the Lomagundi System in the Northern Lomagundi District.

The present writer has attempted to correlate the various rock types of the Shamrocke area stratigraphically with the work of Workman, Stagman and Jacobsen. Because of lack of familiarity with the Lomagundi System south of latitude $16^{\circ}45'$, no attempt has been made to discuss critically the stratigraphic sequence and correlation put forward by the various writers. Instead, the sequence and correlations of these writers are discussed relative to the position of the Shamrocke rocks in the Lomagundi sequence, in order to indicate the position of the Shamrocke orebody relative to other copper occurrences within the Lomagundi System.

REGIONAL STRATIGRAPHY.

THE LOMAGUNDI SYSTEM

A Discussion on the Correlation of the Lomagundi Stratigraphic Sequence of Various Writers.

The suggested stratigraphic sequence and correlation of the rocks within the Lomagundi System are given in Table 1. Here the subdivisions suggested by Jacobsen, Stagman and Workman are shown together with the subdivision suggested by the writer for the Lomagundi System from Rusere to the Mukwishe River.

The work by Jacobsen (1962) and Stagman (1959) describes the geology from the Umfuli River immediately west of Hartley in the south to Mkowi some 15 miles north of Mangula. Workman's work describes the country from just north of Mkowi to north of Rusere and around the northern limb of the Rusere Syncline to the Angwa River. The present project area follows this northern limb of the Rusere Syncline across the Angwa River in a westerly direction, curving gently northwards towards the Mukwishe River.

For many years the recognition of the basal beds of the Lomagundi System has been discussed by various writers. In 1931, Macgregor suggested that the granite east of Mangula pre-dated the Lomagundi System, and that the conglomerate at the base of the arkoses along this contact must be the base of the Lomagundi System. Stagman (1959) suggested that this granite east of Mangula could in fact be an older pre-Lomagundi granite rejuvenated and intruded in part into the Lomagundi System. This led Stagman to accept the arkoses and conglomerates as the basal beds

of the Lomagundi System in this area (his Eastern Facies) and placed these rocks as the Basal Group of his Arenaceous Series, pointing out at the time that these rocks are the equivalent of the Upper Group of the Deweras Series as described by Phaup and Dobell in the Lower Umfuli area (1938). In 1961 Stagman re-assigned these rocks to the Deweras Series overlying the basic amygdaloid of that series, at the same time suggesting that this be called the Deweras Series. Viljoen (1961) and Jacobsen (1962) suggested that the Mangula granite was intrusive into and not pre-Lomagundi, and that its occurrence therefore does not prove that the arkoses at Mangula are basal beds. Jacobsen, (1962) by copious sampling and detailed study of the mineral assemblages, showed that this conglomerate against the Mangula granite was dissimilar to the tillite at the base of the dolomite further east, and accepted this tillite as the base of the Lomagundi System. Jacobsen further suggested that this tillite was in fact the conglomerate at the base of the Upper Group of arkosic sediments of the Deweras Series of Phaup and Dobell (1938), and concluded that the Lower Group of amygdaloidal greenstones of the Deweras Series, below a marked unconformity, was pre-Lomagundi and he further suggested the elevation of these greenstones with their basal conglomerate to the status of Deweras System.

The suggestion by Jacobsen that the tillite at the base of the dolomite is in fact the base of the Lomagundi System led to a major deviation from the accepted sequence, showing the dolomite of his Dolomite Series older than his Arenaceous Series, which in turn he correlates in part with the Deweras Series of Stagman and Workman. Jacobsen has shown very clearly his reasons for this correlation and he did a great deal of detailed mineralogical study to compare the conglomerate and tillite. By suggesting this Dolomite Series to be older than his Arenaceous Series, he had to explain the existence of dolomites east of the Arenaceous Series in the west of his map by suggesting a large synclinal structure with thrusting at its western limb. Stagman's map (1959) shows the dolomite to be younger than the arkoses; these arkoses, being equivalent to Jacobsen's Arenaceous Series, must suggest a large anticline to explain the dolomites lying east of the arkoses. These two interpretations are in conflict, and although Jacobsen has put forward a detailed study of the structure of the area, with much sound reasoning, the idea that the dolomites could be older than the arkose and conglomerate at the base of his Arenaceous Series, which the present writer considers to be Deweras Series, simply cannot be fitted into the structure and

stratigraphic sequence evident northwards, west of the granites and gneisses at Rusere, and in the Shamrocke area.

The newly published Provisional Geological Map of Rhodesia (1971) shows the base of the Deweras Series well against the Angwa-Mukwishe River confluence north of the Shamrocke Mine and describes the terrain from the Mkwichi Hill northwards to the Mukwishe River as Deweras rocks. The maps presented in this thesis are not in entire agreement with the official geological map and it will be interesting to see what further work in the area suggests.

This somewhat lengthy discussion of the base of the Lomagundi System is most relevant to the stratigraphic position of the Shamrocke orebody within the Lomagundi System. The meta-arkose and schist immediately north of the Nyashiri Ridge and between the Dolomite Group and the older Escarpment Series, has been correlated by the present writer with the upper part of the Deweras Series of Workman (1962) and the upper part of the Arenaceous Series of Stagman (1959), as shown at the northern edge of his map on Wolverhoek Farm (Upper Deweras Series in his 1961 subdivision). According to the sequence of Jacobsen these rocks would be at the base of the Arkose Stage of his Arenaceous Series, and the Dolomite Series, with which is associated the Shamrocke orebody, would then be equivalent to Jacobsen's marl and siltstone of the upper portion of his Arkose Stage.

After careful consideration, it has been decided to accept the subdivision of Stagman and Workman and to accommodate the rocks of the Shamrocke area within a modification of that subdivision. It is not claimed that Jacobsen's interpretation of the sequence is incorrect, as the experience of the present writer in the Mangula and Sinoia areas is limited. The age of the Dolomites can, however, only be accepted as younger than the Deweras meta-arkose from the evidence to the north.

Overlying the Deweras Series and separated from it by what has been described by Stagman (1961) as a major unconformity in the south, and a minor unconformity in the north, lies the Dolomite Group or Series as termed by Stagman (1961) Workman (1961) and the present writer. In Workman's 1961 work, he differentiated a Lower Dolomite Group overlain by a Main Quartzite Group of an Arenaceous Series, and immediately above this, he put his Dolomite Group as the lowest member of his Argillaceous Series. Subsequent to his detailed mapping of the north-eastern portion of the Rusere Syncline, he in 1962, placed this group of metamorphosed dolomite and schists in his Argillaceous Series.

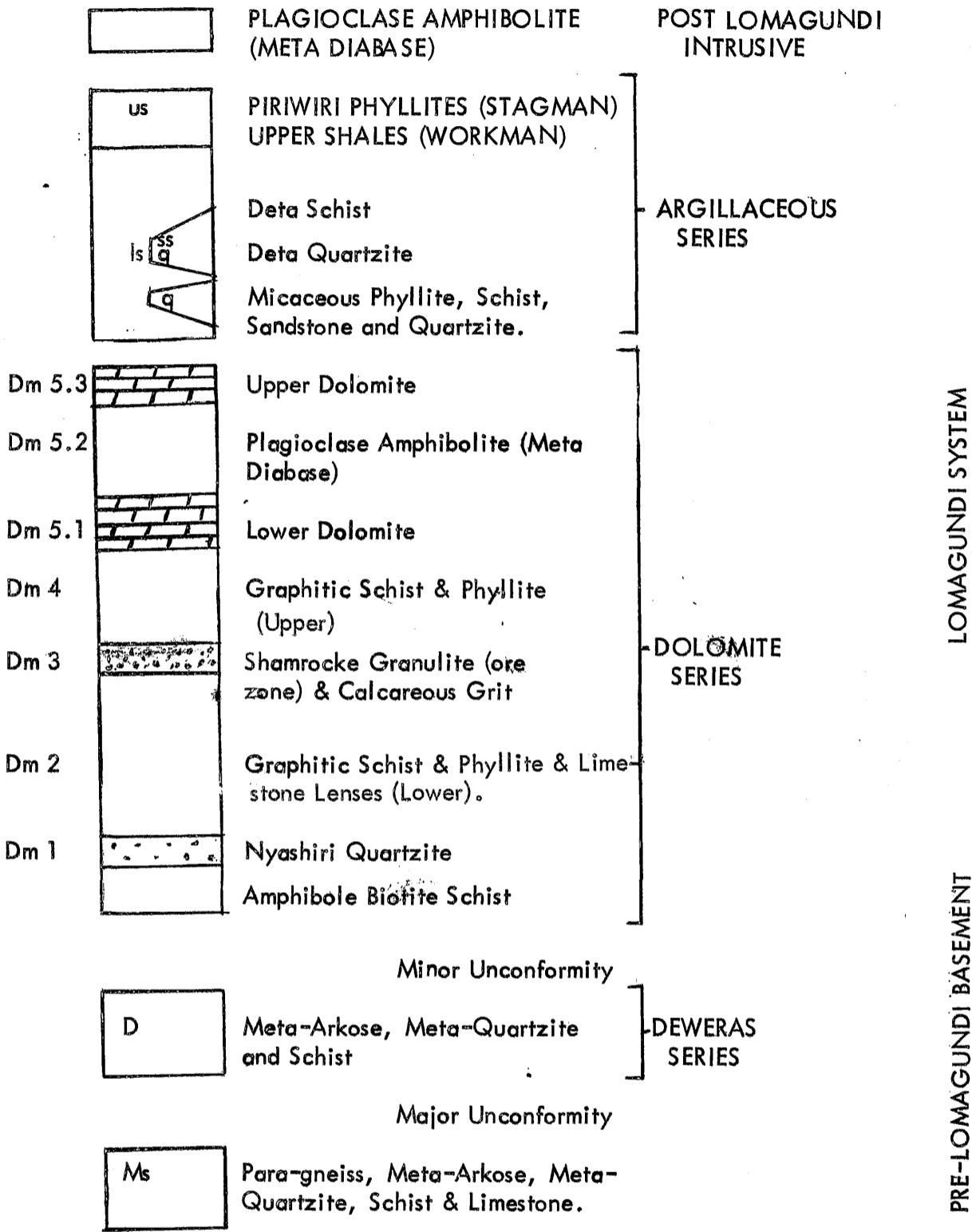
The slates, quartzites and Mountain Sandstone above the Dolomite Group towards Mangula are considered to be the upper portion of the Upper or Argillaceous Series by Stagman (1961), Workman (1961), and the present writer. Jacobsen has again deviated from this accepted sequence and considers these rocks to belong to a younger system, his Hunyani System. Jacobsen points out that these rocks appear everywhere unconformably on either the Argillaceous or Piriwiri Series, and are not cut by post-Lomagundi igneous intrusions. He also considers these rocks to have been deposited subsequently to the deformation of the Lomagundi System. The area where Jacobsen described his Hunyani System is well south of the Shamrocke area and is west of the area mapped by Workman. This younger Hunyani System may exist in the type area, but similar rocks immediately south of the Shamrocke Mine show no discernible unconformity between them and the Dolomites Series, and in the Shamrocke area, these rocks are cut by large transgressive plagioclase amphibolite intrusives of the post-Lomagundi type.

The problem of the relative age of the Piriwiri Series remains. As these rocks lie well to the south of the area under discussion here, no opinion can be expressed. It can only be stated that Workman (1961 and 1962) and Jacobsen (1962) have considered this series to be the youngest member of the Lomagundi System, while Stagman (1959 and 1961) and Wiles (1961) consider the Piriwiri rocks to be pre-Lomagundi, Wiles preferring to classify them as the Piriwiri System.

The Table of Formations of the recently published 1 : 1,000,000 Provisional Geological Map of Rhodesia (1971) accords the Lomagundi, Deweras and Piriwiri rocks separate designation as either System or Group and restricts the term "Lomagundi" to a System or Group comprising striped slates and minor quartzites of an Argillaceous Formation and dolomites and orthoquartzites of a calc-arenaceous formation.

TABLE 2.

THE STRATIGRAPHIC SEQUENCE IN THE VICINITY OF THE SHAMROCKE MINE



(Not drawn to scale).

The Stratigraphic Sequence in the Shamrocke Area as suggested by the Present Study.

For the purpose of the present study, the Lomagundi System is considered to be divided into three Series. The lowest Deweras Series overlies the pre-Lomagundi Basement rocks unconformably. The sequence ascends through the Dolomite Series and the Argillaceous Series.

(i) The Deweras Series

The Deweras Series comprises mainly metamorphosed arkoses with occasional conglomerate beds. The conglomerates have been recognised eastwards and southwards from the Shamrocke Mine, one near the base and one near the middle of the Series. Arenaceous mica-schists, hard compact meta-quartzite and schists occur. The meta-arkoses are generally compact and granular. The meta-volcanics found east of Mangula and in the southern areas west of Hartley are apparently absent in this northern area, unless some amphibole schists and/or granulites are ever identified as acid tuffs.

(ii) The Dolomite Series

The Dolomite Series, which in places towards the base has a narrow band of hard compact meta-quartzite, comprises largely graphitic, dolomitic and calcareous schist and phyllite. Large dolomite and calcite bands are common and in places the dolomitic rocks form large expanses of country, as in the extreme northeast within the Rusere syncline. Calcareous grits occur within the graphitic schists and these are in places metamorphosed to a granoblastic grey-pink felspar, biotite "granulite". The uppermost band of dolomitic rock is considered to be the top of this Series.

(iii) The Argillaceous Series.

This Series extends southwards and westwards beyond the Angwa-Deta River confluence and makes up the greater part of the Lomagundi System. Stagman in 1959 subdivided this Series into Striped Slates and the Piriwiri Series. In this northern Lomagundi province, it has been accepted by some observers that these Argillaceous Series

PLATE 6.

6A.



Banded Amphibole Gneiss of the Escarpment Series northwest of Angwa-Mukwishe River confluence.

6B.



Deweras Series Meta-arkose southwest of the Mkwih Hill.

PLATE 7

7A.



Nyashiri Meta-quartzite outcropping on the Nyashiri Ridge and dipping steeply, 70° to the South.

7B.



Outcropping boulders of Plagioclase Amphibolite on a rise south of the Shamrocke Mine.

rocks extend to the top of the Lomagundi Series. Many workers consider the Piriwiri Series to be part of the Lomagundi System. In this area, the Argillaceous Series consists of micaceous and graphitic schists and phyllites, with sporadic development of white to buff-coloured compact sandstone and quartzite which form blocky outcrops. Alternating schists and quartzites at the confluence of the Deta and Angwa Rivers could be referred to locally as the Deta Schist and Quartzite Group within this Series.

THE ESCARPMENT SERIES

Northwards from the Shamrocke Mine, and underlying the rocks of the Lomagundi System is a vast expanse of older metamorphosed rocks, previously referred to on the 1961 Edition of the Geological Map of Southern Rhodesia as "paragneisses of various ages". For some time it was known that gneissic rocks were to be found on both sides of the Zambezi Valley in this area. Macgregor (1951) suggested that they might be metamorphosed members of the Lomagundi-Katanga System, basing his argument on the increase in metamorphism northwards in the Lomagundi System south of the mid-Zambezi Valley and southwards in the Katanga System north of the river.

During the mapping of this area, it became apparent that these gneisses, meta-arkoses, quartzites and schists belong in fact to an older series of rocks, to be correlated with the gneisses to the north-east of the Rusere area. This gradual change eastwards to a greater homogeneity of biotite-gneisses with the composition of tonalite-granodiorite could be, as stated by Workman (1962) "a gradation from one to the other, through a gradual southward increase in the degree of migmatization". According to Workman, there is probably further gradation southwards into the unfoliated granodiorite of the "Basement Complex" in the Mangula area. This, however, is perhaps the effect of increased distance from the mobile belt terrain of the Zambezi Belt to the north.

As will be discussed in more detail when the metamorphism is described, the Almandine Amphibolite facies prevailing in the Shamrocke area persists through these older rocks of the Escarpment Series. This persistence of similar metamorphic grade over the unconformity can be attributed to the retrogressive effect of the post-Lomagundi metamorphism on the previously highly metamorphosed sediments of these "Escarpment Gneisses".

These rocks of the Escarpment Series cover a vast tract of country to the north of the Shamrocke Mine, extending to the edge of the Zambezi Valley.

Structurally, the Escarpment Series underlies the basal beds of the Lomagundi System north and northeast of Shamrocke, showing a regional east-west strike corresponding to its contact with the Lomagundi, and dipping away steeply to the south. The structure is uncomplicated across the whole width of the series in this area. Northwards the beds are flatly rolling with isolated areas of disturbance. To the northeast the strike swings northwards, corresponding to the swing of the tongue of Lomagundi rocks into these older rocks, until in the vicinity of the Rukute River the strike is apparently north-south with a steep westerly dip. Westwards the attitude of the Escarpment Series rocks corresponds everywhere to the Lomagundi contact, firstly in a northwesterly direction and then again westwards to the edge of the area mapped. A number of shallow synclinal structures were recorded.

The relationship between the Lomagundi System and these gneisses of the Zambezi Escarpment is fully discussed by Workman (1961 and 1962). He states "they (the gneisses of the Escarpment Series) characteristically exhibit such features as true gneissic foliation, pygmatic folding, segregation pegmatites and large felspar porphyroblasts. Rocks in the Lomagundi System with a similar or comparable mineralogy are invariably compact granulites or psammitic schists, with none of these features. Moreover, no relict sedimentary or igneous structures have survived the recrystallisation in the gneisses, whereas these are a common occurrence in the Lomagundi System".

Both Workman in 1961 and 1962, and Stagman in 1959, describe at length the relationship between the granodioritic and granitic rocks and the Lomagundi sediments east of Mangula and northwards to Rusere.

It is pertinent to note that much discussion has taken place as to whether or not the granite to the southeast pre- or ante-dates the Lomagundi System. Macgregor in 1931 and Stagman in 1959 and 1961 suggested this granite to be pre-Lomagundi with perhaps some rejuvenation. In 1961, however, Jacobsen and Viljoen stated their view that beyond doubt this granite is intrusive into and younger than the Lomagundi.

PLATE 8.

17a

8A.



Epidote veining in Plagioclase Amphibolite (Meta-diabase) - in the Angwa-River South of the Shamrocke Mine. Epidote is not often seen in the Shamrocke Area.

8B.



Small-scale flow-folding in Plagioclase Amphibolite - intruded into Meta-arkose above.

A.2. THE STRUCTURE OF THE RUSERE SYNCLINE

Regional Structure from Photogeological Study by the Present Writer (see Figure 4)

During the present study, the area from Mkowi northwards along the base of the Lomagundi System was photogeologically analysed to study the structure of the base of the Lomagundi succession with a view to the possible correlation between structure and mineralisation. As the photogeology closely supported the maps of Workman (1961, 1962 and 1966) in the Southern region towards Mkowi, a photogeological map was prepared from Chidwara northwards and around the nose of the Rusere Syncline to the Shamrocke Mine and westwards and northwestwards to the Mukwishe River. (Figure 4).

In the area from Mkowi in the South to Chidwara in the north (for reference here the maps of Workman 1961 and 1966 are useful), although the rocks are generally overturned to the east, photogeologically, there appears to be very little tight folding, either longitudinally or transverse to the strike. East-west lateral displacement of the "Tchetchenini" or "Mountain" Sandstone occurs along what appears to be a system of large faults with sympathetic folding towards the fault plane. Due to sharp overturned folding in that area, the arenaceous rocks due west of Tchetchenini appear to be repeated Deweras Series; some three miles north of Tchetchenini what appears to be a strong east-west fault may have something to do with this repetition. To the southeast of Muninga there appears to be a tight lateral fold within the arkoses of the Deweras Series. This appears, however, to be only a very local feature.

The photogeological interpretation points to a fairly simple overturned structure, but from ground observation by Workman (1961) it is obvious that in this area folding trending parallel to the regional strike with duplicate overturning is possible.

Moving northwards the strike of the rocks swings sharply eastwards through Chidwara (see Figure 4). This swing eastwards in the vicinity of Chidwara is the beginning of the large embayment of Lomagundi rocks into the pre-Lomagundi basement, which extends through Rusere to the Rukute River and then swings sharply westwards through the Shamrocke Mine.

The departures from the main north-northwest strike of the Lomagundi System in this area are due to cross-folding which is probably parallel to, and caused by, the regional trend of the underlying gneisses, this direction possibly being controlled by the influence of the Zambezi mobile belt. According to Workman

LEGEND

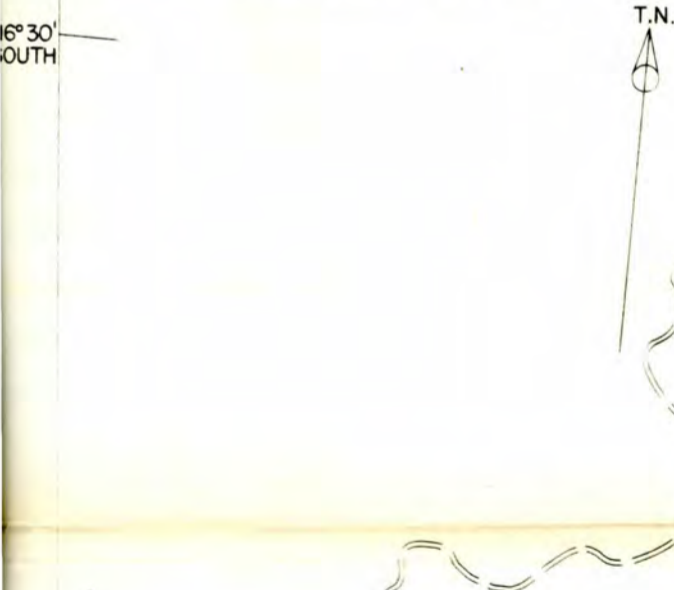
- 70° Observed Field Dip.
- 20°-30°
- 30°-40°
- > 45°
- Vertical.
- Overturned.
- Fractures, Shears, or Joints.
- Fault.
- Photogeological Trend Directions.
- Axis and Plunge of Syncline.



**PHOTOGEOLOGICAL MAP OF
THE RUSERE SYNCLINE FROM CHIDWARA TO THE MUKWICHE RIVER**

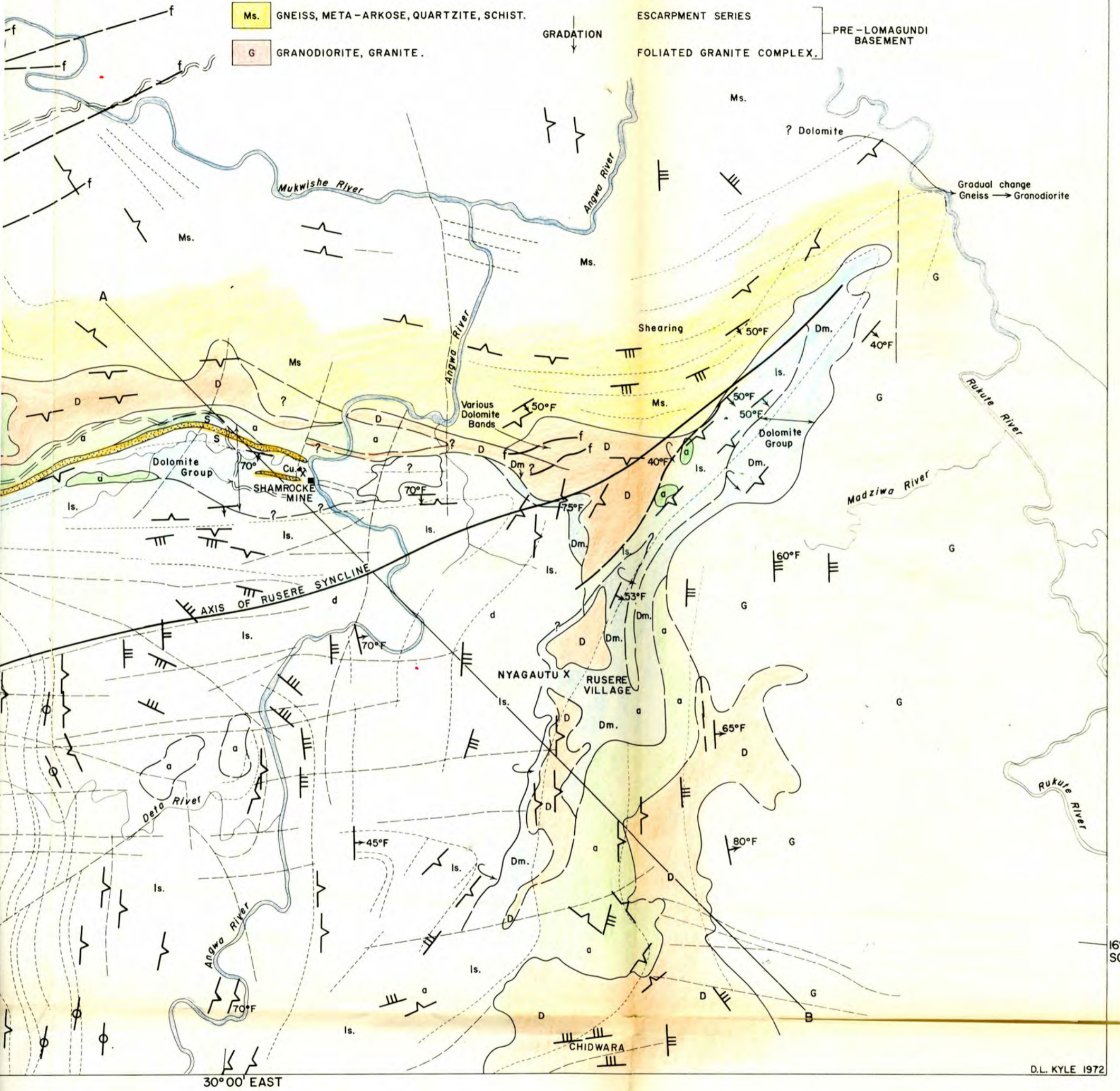
SCALE 1:50 000 (Approx.)

- NOTE: (1) This map is prepared from Photogeological Interpretation and structurally augments the detailed geological maps by Workman east of the Angwa River and by Kyle west of that river.
- (2) The map is compiled using as a base an Air-photo mosaic at the approximate scale of 1:25 000.
- (3) Planimetric detail is skeletal.



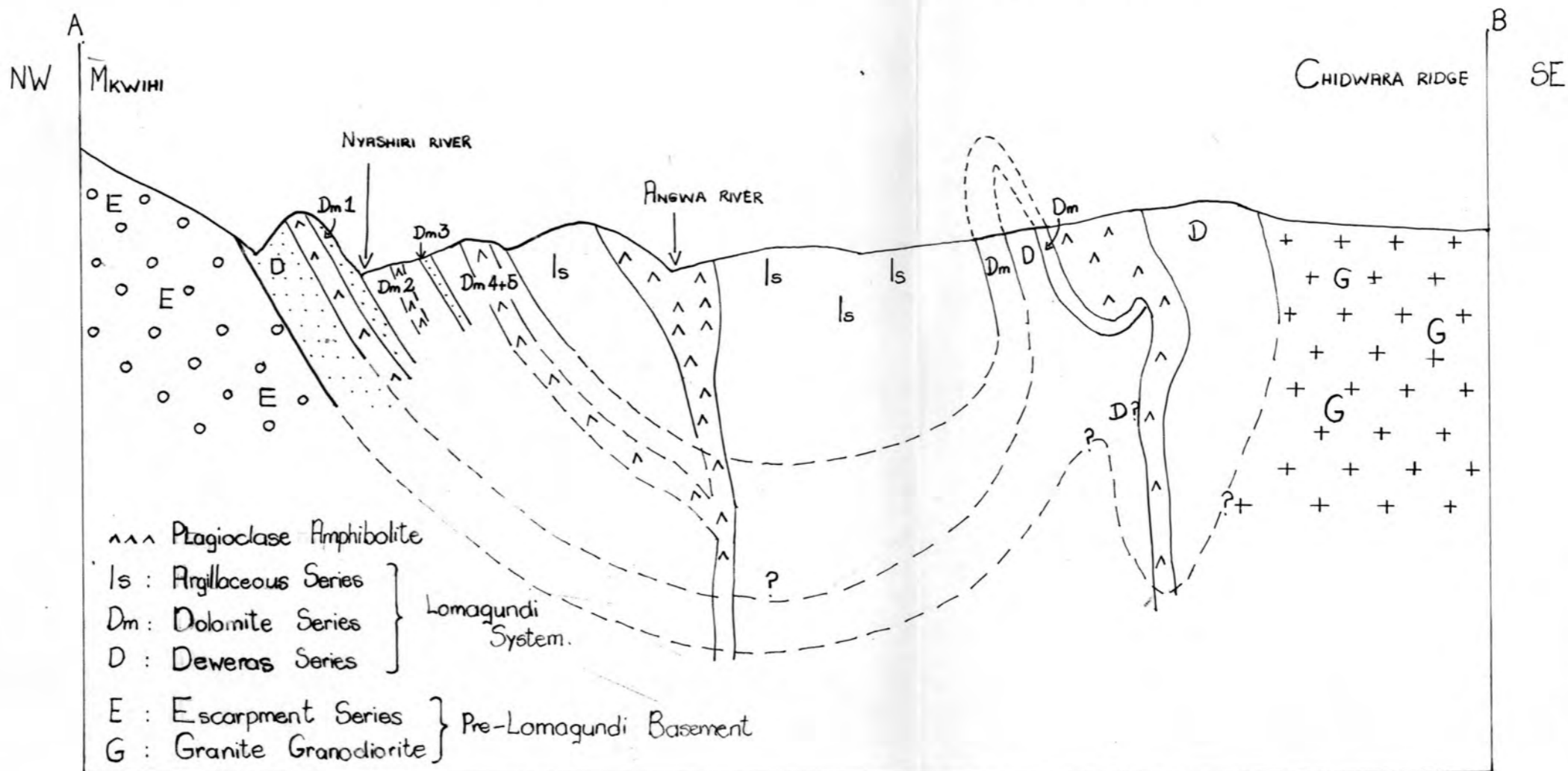
LEGEND

- a PLAGIOCLASE AND GARNET AMPHIBOLITE — ALTERED DIABASIC INTRUSIVE.
 - ls. SHALE, PHYLLITE, SANDSTONE, QUARTZITE
 - Dm. DOLOMITIC LIMESTONE, GRAPHITIC SCHIST, AND PHYLLITES
CALCAREOUS GRITS, GRANULITE.
 - D META-ARKOSE, QUARTZITE SCHIST AND CONGLOMERATE.
 - Ms. GNEISS, META-ARKOSE, QUARTZITE, SCHIST.
 - G GRANODIORITE, GRANITE.
- | | |
|---------------------------|------------------------|
| ARGILLACEOUS SERIES | LOMAGUNDI SYSTEM |
| DOLOMITE SERIES | |
| DEWERAS SERIES | |
| ESCARPMENT SERIES | PRE-LOMAGUNDI BASEMENT |
| FOLIATED GRANITE COMPLEX. | |



GEOLOGICAL SECTION A-B ACROSS THE RUSERE SYNCLINE

(See Figure 4)



^^^ Plagioclase Amphibolite
 Is : Argillaceous Series
 Dm : Dolomite Series
 D : Deweras Series
 } Lomagundi System.

E : Escarpment Series
 G : Granite Granodiorite
 } Pre-Lomagundi Basement

Horizontal Scale : 1:50,000

Vertical Scale : Arbitrary (Elevations not known).

these cross-folds could be due to the controlling influence of an earlier structural trend during the formation of the Lomagundi fold system by pressures parallel to the strike of the earlier trend.

The most prominent of these cross-folds is the very large Rusere Syncline in the northeast of the area. This broad structure commences immediately south of Chidwara, swinging sharply to the northeast and then again more sharply immediately north of Rusere. North of Rusere the northeastern point of the embayment consists of a large narrow prong of the Lomagundi System projecting northeastwards into the "Basement" gneisses.

Workman observed that the central part of this prong is occupied by strongly folded metamorphosed schists, quartzites and limestones of the Dolomite Series, with an incomplete rim of Deweras Series grits and conglomerates. He described this fold complex in the extreme northeast as consisting of two isoclinally folded synclines, the two synclines being separated by a zone of horizontal dislocation parallel to the fold axis. Northwest of this fault considerable southwesterly movement of the northern limb relative to its southern counterpart was affected by strong tear-faulting and internal shearing along the northern limb of the fold. The great width of outcrop of the Dolomite along the southern limb may be due to the squeezing of limestone along the fold limb.

Moving westwards through the Shamrocke Mine area, the dips continue to be steeply to the south and comprise the northern edge of the syncline. To the west of the Shamrocke Mine, the Deweras Series swings northwards and short of the Mukwishe River turns westwards to be truncated by a north-south fault with the rocks thrown on the western side some half a mile southwards. From this point the Deweras Series again swings northwards to cross the Mukwishe River and then swings again sharply westwards. These two minor folds in the western area show axes roughly parallel to the major syncline to the east.

It is important to note that, following the map (Figure 4) northwards from the southern boundary, it is seen that east-west trending fracture or shear planes through the Argillaceous Series occur throughout the area. It is important that at the points of flexure, i.e., at Chidwara, again at the axis and immediately south of the axis of the major Rusere Syncline and, to a lesser extent, in the axes of the two flexures to the west, these east-west fracture or shear planes become

more dense. The east-west trending shears and fractures extend from the Argillaceous Series through the Deweras Series and can at times be seen trending into the pre-Lomagundi rocks. It is for this reason that one may consider the cause of this cross-folding to be due to a reflection of pre-Lomagundi rock trends.

The rocks of the lower part of the Argillaceous Series to the west of the Angwa River are little affected by the large cross-folding of the major Rusere Syncline. These rocks trend north-northwest until the approximate position of the axis of the syncline and then swing sharply westwards to align themselves parallel to the strike of the rocks of the northern flank of the structure. To the immediate southwest of the tight nose of the fold, where the associated horizontal dislocation parallel to the fold axis took place, the lower part of this Argillaceous Series is only slightly dragged in the direction of the fold.

It is pertinent to note the general distribution of plagioclase amphibolite (probably altered diabasic lava) at the top of the Deweras Series. It is only in places that this amphibolite is absent.

The axis of the major Rusere Syncline southwestwards from the horizontal displacement of the Deweras Series in the centre of this isoclinal nose appears to run well north of the Angwa/Deta River junction. The north-northwesterly trend of the strike within the lower portion of the Argillaceous Series is somewhat truncated some 10,000 feet south of the Shamrocke orebody by a series of dislocations trending at right angles to this direction. Dips in this area are difficult to ascertain from photo-interpretation, but a number of southward dips come into contact with very definite, steep, easterly and vertical dips measured on arenaceous bands in the Argillaceous Series. It is therefore concluded that the axis of the Rusere Syncline passes through the meeting point of these two conjugate strike directions.

The Rusere Syncline - description by Workman (1962).

This structure has been carefully mapped in the field by Workman, and all structural aspects discussed in detail by him (1962), that it remains here only to reproduce a portion of Workman's publication "The Rusere Syncline - Cross-Folding in North Lomagundi District, Southern Rhodesia" (1962).

Photogeological analysis has qualified Workman's conclusions and the following extract enlarges and endorses the comment in the previous section.

Workman (1962) describes the Rusere Syncline thus:

"The fold complex consists of two synclinal folds, with parallel northeast-southwest trending axes, each overturned to the northwest and closing to the northeast. No intervening anticline can be detected, the two synclines being separated by a zone of horizontal dislocation parallel to the fold axes. Considerable southwesterly movement of the northern fold relative to its southern counterpart was affected by strong sinistral tear-faulting and internal shearing along the northern limb of the southern fold. The outer limbs of the two folds show evidence of thrusting, of the Lomagundi System over the basement on the northern (normal) limb of the northern fold and vice versa on the southern (overturned) limb of the southern fold.

"The evolution of this composite structure is believed to be as follows:

The first stage was the development of the two folds by horizontal or sub-horizontal movement after the Lomagundi System was folded into sub-vertical attitudes. The drag-folds resulting from the differential movement were in the form of steeply plunging synclines overturned towards the northwest, that is, they possessed a shape and attitude similar to that of the major Rusere Syncline itself. While the differences in yield continued, the two drag-folds developed in slightly different ways, owing to the different structural attitudes of their respective limbs. The normally dipping sequence of Lomagundi beds on the northern limb of the northern fold was thrust over the basement and imbricated into a series of thrust wedges. Conversely on the southern limb of the southern fold, the older gneiss was possibly thrust over the Lomagundi, either this or stratigraphic thinning being the reason for the virtual absence of the Deweras Series along the outcrop of this limb. The great width of outcrop of the dolomite along this southern limb may be due to squeezing and migration of the limestone along the fold limb away from the point of maximum pressure.

"Simultaneously with the development of the two drag-folds, sinistral displacement took place between them, partly by tear-faulting and partly by shearing within the beds on the northern limb of the southern drag-fold. Evidence for tear-faulting is clear. A minimum horizontal displacement of one mile can be measured in the limestone beds on either side. The line of the fault is a

marked linear topographic depression along which streams flowing in various directions are deflected. Along this fault-controlled valley pebbly grits of the Deweras Series (below the limestone) on one side are in juxtaposition with phyllites of the Argillaceous Series (above the limestone) on either side. There is no fresh outcrop in the deep gullies of the valley itself, which instead display an unusual depth of weathering. Thus no supporting evidence of tear-faulting has been gained from the internal structure of the rocks themselves. Along a line extending northeast from (in linear continuity) the tear-fault, the rocks apparently give way not by bodily lateral displacement, but by intense internal shearing and stretching. The limestone and the Deweras Series conglomerate were stretched into narrow discontinuities along the northern flank of the southern drag-fold".

A.3. REGIONAL METAMORPHISM

The Lomagundi System in this northern province gradually increases in metamorphic grade from south to north, from low Greenschist facies at Mangula to low Amphibolite facies at Rusere. Westwards from the overturned nose of the syncline in the region of the Shamrocke Mine, lower Almandine Amphibolite facies rocks are recognised. There is therefore a general increase in metamorphic grade from Mangula north-northwestwards towards the northern contact with the Escarpment Series. Westwards there is a sharp increase in metamorphism from the Angwa River. The increase of metamorphism northwestwards can be correlated with the Zambezi metamorphism, while the metamorphism increases westwards with the Miami metamorphism. During metamorphism the arenaceous sediments were converted to granulite, meta-arkose and meta-quartzite; mudstone and impure dolomitic limestones to graphitic, calcareous and amphibole bearing schists, dolomite and calcite; and dolerite to plagioclase amphibolite. Northwards from the Lomagundi System the Escarpment Series shows retrogressive effects of the post-Lomagundi metamorphism on earlier more advanced metamorphism.

Workman (1966, p.245) has so carefully considered a great deal of evidence in his summation of the regional metamorphism that it remains here only to quote from him: "The existence of gneissic rocks on either side of the Mid-Zambezi Valley has been known for many years, and the idea that they might be metamorphosed members of the Lomagundi/Katanga System has been put forward by Macgregor (2) and others. The main basis for this hypothesis was the apparently gradual increase in metamorphism towards the Zambezi Valley on either side, northwards in the Lomagundi System of Rhodesia and southwards in the Katanga System of Zambia. In Rhodesia, however, this metamorphic increase had been observed only in the Piriwiri Series around Miami (Maufe, 1920; Wiles, 1961). This meant that there was no evidence that the Lomagundi System as currently defined by the Geological Survey had anywhere been metamorphosed beyond low Greenschist facies. The possibility therefore arose that the Zambezi-Miami metamorphism might be pre-Lomagundi in age, and the gneisses of the escarpment high-grade metasomatic derivatives of the Piriwiri Series, as suggested by Worst (1960, p.29). The two alternative sequences of events which thus presented themselves may be summarised as follows:

(i) from Macgregor

2. Zambezi-Miami metamorphism
Piriwiri Series
1. Lomagundi System
Argillaceous Series
Deweras Series

(ii) from Worst

3. Lomagundi System
Argillaceous Series
Deweras Series
2. Zambezi-Miami metamorphism.
1. Piriwiri Series (including the arenaceous, felspathic sediments of the Zambezi Escarpment).

"The present work shows that neither of these two alternatives is complete. The full sequence of events is more probably as follows:-

4. Zambezi II and Miami metamorphism (partly separate in space, may or may not be contemporaneous).
3. Lomagundi System
Argillaceous Series (including the Piriwiri Series)
Deweras Series
2. Zambezi-Miami metamorphism
1. Arenaceous and felspathic sediments of the Zambezi Escarpment.

"In North Lomagundi District, the Deweras Series and the Argillaceous Series of the Lomagundi System can be followed north-northwestwards along strike through a gradual increase in metamorphic grade from low Greenschist facies at Mangula to low amphibolite facies at Rusere village ten miles from the foot of the southern Zambezi escarpment. The country between Rusere and the Zambezi escarpment is occupied by older gneisses which also possess low amphibolite facies mineralogy. Thus there is a general northward increase in metamorphic grade over a distance of more than 30 miles. To the west, there is a merging with a metamorphism whose grade increases sharply towards Miami, northwestwards in the south and southwestwards in the north. This means that, although the two metamorphic fields cannot be distinguished from each other in the south, they face in opposite directions in the north. A metamorphism in the north Lomagundi District not directly related to the metamorphic culmination at Miami is thus

established, and all the Precambrian formations of that area, including the Lomagundi System, are affected.

"The Lomagundi System around Rusere consists of essentially the same succession as it does further south. The basal group of meta-arkose and conglomerate (here comparatively thin) is succeeded by metamorphosed dolomitic limestone, which is in turn overlain by a thick sequence of pelitic schists and phyllites with minor quartzites and meta-limestones. The whole succession is intruded by numerous doleritic sheets and dykes. On being metamorphosed, arenaceous sediments were converted to granulite and psammitic schist, limestone to amphibole-bearing schist and marble, shales to kyanite- and hornblende-bearing phyllite and schist and dolerite to mainly non-epidotic andesine-bearing amphibolite. The mineralogy of the underlying gneisses places them in the same metamorphic facies as the Lomagundi System, in that they contain similar ferromagnesian minerals and the same epidote/plagioclase relationship. Texturally, however, they are in a much more advanced state of reconstitution. They characteristically exhibit such features as true gneissic foliation, pygmatic folding, segregation pegmatites and large feldspar porphyroblasts. Rocks in the Lomagundi System with a similar or comparable mineralogy are invariably compact granulites or psammitic schists with none of these features. Moreover no relict sedimentary or igneous features have survived in the gneisses, whereas these are common in the Lomagundi System and associated intrusives. The present low amphibolite facies mineralogy of the gneisses of the Zambezi Escarpment is attributed to the retrogressive effects of the Post-Lomagundi metamorphism on an earlier, more advanced, metamorphism".

Although Workman identifies the Shamrocke area with the Staurolite-Kyanite Sub-zone on his sketch map "Metamorphic Zones in North Lomagundi Area", (1966), no kyanite has been encountered in the rocks in the immediate vicinity of the Shamrocke Mine. Kyanite is found only in a very limited area in fine-grained dark indurated schist in the Angwa River area and southeast from the river, and may be very locally developed in these indurated schists due to their almost complete enclosure by amphibolite (meta-diorite). This northernmost area about the Shamrocke Mine should rather be ascribed to the Staurolite-Garnet sub-zone of Workman (1966) and the Staurolite Almandine sub-facies of Turner and Verhoogen (1960).

For a more specific discussion on the metamorphism of the rocks in the immediate vicinity of the Shamrocke Mine, the reader is referred to Section B.6 "Metamorphism and Petrogenesis".

A4. REGIONAL CORRELATION

In Central and Southern Africa, it is remarkable how similar the nature of the lithologies are towards the base of the various cover sequences at the edges of cratonic areas, and flanking the major tectonic belts separating the stable cratons. The environmental conditions at the time of deposition must have been very similar and it may be more pertinent some times to consider similar environments as correlation criteria for comparing geological formations than the often dubious reliance on correlation by radiometric age determination.

The correlation of the Lomagundi System with formations elsewhere has always been a subject for considerable discussion. The Lomagundi rocks have been generally correlated with the formations in the copper belt of Zambia and those in Katanga. The lithological succession towards the base of the Lomagundi System and the Katanga System of Zambia is indeed very similar and, moreover, the copper mineralisation usually occurs in both systems immediately above basal conglomerates and quartzites, in quartzites, dolomites, shales, calcareous grits, greywacks, gritty argillites and calcareous argillites which generally occur below thick dolomite horizons. This correlation is shown in Table 3 where the obvious similarity is seen between the lithology of the Deweras Series of the Lomagundi System and the Lower Roan (Lusaka) Group; the Dolomite Series and the Upper Roan (Lusaka) Group; and the Argillaceous Series of the Lomagundi System and the Mwashia Group of the Katanga Series. Another factor supporting such a correlation would be the presence of the Lusaka Series rocks on the northern side of the Zambesi mobile belt across from the Lomagundi System on the southern margin of the belt. This correlation may be valid on the grounds of similar depositional environments, and their presence on either side of the Zambesi Belt.

On the grounds of environmental similarity and the often similar succession (particularly the gradation from conglomerates and coarse clastic sediments through argillaceous material, impure and mixed dolomites, limestones and shales, above which are present the main calcareous horizons), the Lomagundi rocks can be compared with the majority of sedimentary cover sequences with craton edge - mobile belt margin associations. Table 3 compares the Lomagundi System of Rhodesia, the Katanga System of Zambia, the Damaran System and Tsumis/Doornpoort/Ghanzi Formations of South West Africa and Botswana.

The structural continuation of the Lomagundi System southwards through the Wankie area, into northeast Botswana and across that territory into South West Africa, accompanied by lithological similarity, makes the correlation of the Lomagundi System with the Tsumis/Doornpoort/Ghanzi Formations very feasible.

These formations all lie near the edge of a major sedimentary depository, the Damaran Orogenic belt, which occurs as a major north-east-trending belt, extending from South West Africa through Botswana and into Zambia and Rhodesia. The north-eastern extension of this tectonic belt is the Zambesi Mobile Belt. The stratigraphic position of the Tsumis/Doornpoort/Ghanzi formations relative to the Damara System (late Precambrian) has been a source of controversy, although most workers agree that the Tsumis Formation is older than the Damara System. The controversy centres on whether the Tsumis Formation is the basal part of the Damara System or whether it forms part of an older basin development. It is also difficult to establish whether the Lomagundi System is the basal part of the sedimentation within an original Zambesi trough, or whether in fact it forms part of an older sedimentary depository which covered the entire craton as well.

There appears to be sound evidence to correlate the Damara System of South West Africa and the Katanga System of Zambia. Concerning the correlation of the Damara sedimentary cycle with similar sequences elsewhere in Southern Africa, numerous investigators, notably Martin, (1961), and Clifford, (1962, 1963), are inclined to equate the sediments of the Damara System with those of the Katanga System in Zambia. Dating of tectonic events within these two areas provides remarkable similarities. It would appear that in both areas various events may be dated from the major period of folding at 620 my. to the later post-tectonic events which fall into the range 525-450 my. The continuation of the north-east trend of the Damara Belt links directly with the known trends of the western portion of the Katangan-Lufilian-Arc. Cahen and Snelling (1966), support this correlation and go even further to produce evidence which suggests very strongly that a correlation between the Katangan, Damaran, and West Congolian of Northern Angola is by no means unlikely. They propose further that the central portion of this area, surrounded by highly deformed belts comprise portion of a stable craton on which the equivalent sediments were deposited but which have been preserved as a relatively undeformed tabular cover. The sedimentation on the northern edge or margin of the Damaran tectonic belt includes the Outjo facies of the Damara System, which

NOTE: This Table in no way accords correlation of the regions on grounds of age dating. The comparison is relative to similar succession and environmental conditions of deposition.

LOMAGUNDI SYSTEM RHODESIA	KATANGA SERIES ZAMBIA	KATANGA SERIES KATANGA	TSUMIS/DOORNPOORT FORMATION BOTSWANA/SWA	DAMARA SYSTEM NORTHERN S.W.A.
SIJARIRA SYSTEM			NAMA - BUSCHMANNSKLIPPE FORMATION.	
		Unconformity		
<p>Argillaceous Series or Piriwiri System Argillaceous Series</p> <p>Quartzite, phyllite Dolomite & Schist</p> <p>Schist & Phyllite) Granulite Ore Zone Schist & Phyllite)</p> <p>Conglomerate Meta-arkose, quartzite) Deweras Series</p>	<p>Kundelungu Series</p> <p>Shale, Phyllite, Dolomite, Quartzite) Mwashia Group Dolomite & Argillite) Upper Roan Group</p> <p>Hangingwall Formation) Ore Formation) Argillite, Dolomite, Greywacke)</p> <p>Lower Roan Group) Footwall Formation Conglomerate, quartzite)</p> <p style="writing-mode: vertical-rl; transform: rotate(180deg);">MINE SERIES</p>	<p>Kundelungu Series</p> <p>Mwashia Group</p> <p>Mofya Group</p> <p>Dipata Group</p> <p>"Mine Series" (Ore) Group</p> <p>Lower Roan Sandstone</p> <p>Major Unconformity</p>	<p>Calcareous quartzite Dolomite Stage</p> <p>Calcareous Argillite Stage</p> <p>(Mineralised Zone)</p> <p>Lower Quartzite Stage</p> <p>Basal Conglomerate</p> <p>Opdam/Skumok Volcano-Sedimentary Stage,</p>	<p>Mulden Series</p> <p>Tsumis/Doornpoort Formation Tsumeb Stage) Otavi Series) The Mineralised Zone) Abenab Stage) Nosib Series</p>
ESCARPMENT SERIES	BASEMENT COMPLEX			

27a

consists of a sequence of fairly well-sorted clastic sediments, belonging to the Nosib Series and the Abenab stage of the Otavi Series, which are overlain by the predominantly chemical sediments of the Tsumeb stage. The lithology again is practically identical with the sequence of the other formations already discussed and is compared in Table 3.

It is interesting to note that the correlation between the basal Damaran rocks of the northern edge of the Damara System, being correlated with the Katangan System of Zambia, are considered to show an age of approximately 650 my. This age has been constantly quoted in the Zambian copper belt and Katanga. The Lomagundi rocks are considered to be of the order of 1700 - 2000 my. which, when the structural continuity into Botswana and South West Africa on the southern margin of the Damaran tectonic belt is considered, makes the correlation of the Lomagundi System with the Tsumis/Doornpoort/Ghanzi Formations more likely, as these formations are recently considered to be very much older than the Damaran System which has been dated at approximately 650 my.

The above discussion indicates some of the problems inherent to attempting correlation of the Lomagundi System to other sedimentary sequences in Southern Africa. This subject is too wide and complex to discuss further in this study, however, it may be pertinent to note that similar lithologies and environments exist in the Frontier-Gairezi System of eastern Rhodesia, the Umkondo System of south-eastern Rhodesia, the Messina Formation in the central and south marginal zone of the Limpopo Mobile belt in the northern Transvaal and the southern extremity of Rhodesia, and also the rocks at Matsitama in Botswana. All these formations are present at the edge of stable cratons and are generally associated with the sedimentation either within or related to tectono-thermal belts of weakness separating the various cratons.

To sum up then: The Lomagundi System could be correlated, on the grounds of similar depositional ~~and~~ environment, with the rocks of the Katanga System in Zambia and Katanga, the Tsumis/Doornpoort/Ghazi formations of Botswana and South West Africa, the basal Damaran succession of the northern edge of the Damaran organic belt, the West Congolian of Angola, the Frontier-Gairezi System of eastern Rhodesia, the Umkondo System of south-eastern Rhodesia, the Messina Formation of the Transvaal and southern Rhodesia and possibly the Matsitama area of Botswana. Considering the available geochronological evidence the picture becomes most confusing.

B. THE GEOLOGY OF THE SHAMROCKE AREA

B 1. THE STRATIGRAPHIC POSITION OF THE SHAMROCKE MINE
RELATIVE TO OTHER COPPER OCCURRENCES WITHIN THE
LOMAGUNDI SYSTEM

The Lomagundi Province

The Shamrocke orebody occurs in a "granofelsic" feldspar-biotite rock (here termed "granulites") within graphitic schist and phyllite of the Dolomite Series towards the base of the Lomagundi System, some 1250 feet above the upper contact with the Deweras Series. The mineralisation is closely associated with metasomatic calcite, while the "granulite" orezone appears to be a metamorphosed calcareous grit.

The importance of the meta-arkoses and dolomitic rocks of the Deweras Series and Dolomite Series with regard base metal mineralisation in the Lomagundi System cannot be emphasised too strongly.

To the south of the Shamrocke area the mineralisation at the Mangula Mine is concentrated mainly in this lower portion of the Lomagundi System. Here mineralisation is found in dense, fine-grained feldspathic quartzites and arkoses, sericitic quartz-schists and quartzites, and in calcareous quartzites, arkoses and schists. These rocks may be correlated with the Deweras Series as in the Shamrocke sequence. The dolomitic rocks occur to the west of the Mine (W. Jacobsen 1961).

The orebody of the Norah Mine immediately south of Mangula occurs in chloritic quartzite and schist at what would appear to be very near the contact between the equivalent of the Deweras and Dolomite Series of the Shamrocke area. Due east of the Norah Mine the Silverside deposit is a fracture lode (W. Jacobsen, 1961) within grits and chloritic schist of the Deweras Series.

Further southwards at the Alaska Mine immediately south~~west~~ of Sinoia the mineralisation is found in schistose rocks with a certain preference for dolomitic schists, grey dolomites, and greywackes. Here the schists are the main ore carriers (J.B.E. Jacobsen 1964). Arenaceous rocks are also mineralised; again an analogy can be drawn with mineralisation within the Dolomite Series of the north Lomagundi Province and more particularly the Shamrocke area. The arenaceous horizons within the dolomitic rocks closely resemble the "granulite" and calcareous grits of the Shamrocke area. M.E. Jacobsen terms these greywackes, as they differ from the Shamrocke "granulite" by having less than 25% feldspar.

The copper deposits of the Sanyati area, again southeast of Alaska, are thought to be present in the Piriwiri Beds higher in the Lomagundi sequence (Bahnmann 1961). These deposits are found in calcareous rocks in a succession of intensely folded quartzites and micaceous and graphitic schists. Careful study of Bahnmann's publication "The Ores of the 'J-Lines', Sanyati Copper Mine" (1961), together with a brief investigation in the field of that area, and brief study of the cores from drilling, indicate a close similarity to the rocks of the Shamrocke sequence, the mode of occurrence of the Shamrocke ore, and to the base of the Lomagundi System generally. It is suggested that more careful mapping of that area could reveal that the basal sequence is repeated that far to the west by large structures in a region already known to have been subjected to large folding and faulting. As discussed later however, this area may represent an original basement high or ridge in the original Lomagundi basin or depository, giving similar conditions of sedimentation as at the basin edge to the east.

J.B.E. Jacobsen (1965) considers the Sanyati copper deposits to be in a similar metallogenetic zone, the pyrometamorphic zone, as the Shamrocke deposit. The old Copper Queen and Copper King orebodies occur in a very similar manner and the outcropping gossans closely resemble the Shamrocke Main Outcrop gossan, (see Plate 9 A and B).

In the Shamrocke area northwards from Mangula, copper occurrences are known at Chidwara, where the copper occurs as bornite and chalcopyrite in compact gritty arkoses of the Deweras Series. These Chidwara occurrences are located towards the upper contact of a considerable thickness of Deweras Series rocks and also within the Lower Dolomite Series rocks.

Moving northwards from Chidwara, the tight nose of the isoclinal syncline, although mapped by Workman, has until recently been unprospected.

Westward from the Shamrocke Mine, along the northern limb of the Rusere Syncline, copper in the form of chalcocite and chalcopyrite is found in the Deweras arkoses towards its upper contact where the Series swings northwards some 6-7 miles from the Shamrocke deposit. Here the mineralisation occurs as scattered sporadic occurrences of chalcocite and chalcopyrite within meta-arkose.

Further northwards, some four miles along the northerly swing of the Deweras and where it again swings westwards, trenches have been seen on the photographs but most have been excavated subsequent to any field visits by the writer. Further westwards near Karokuruwe are two separate copper occurrences in Deweras meta-arkose. Again the mineralisation is towards the top of this Series and consists of malachite staining in fractures within the arkoses, and in one instance chalcopyrite was found. The two occurrences are approximately $\frac{1}{2}$ mile

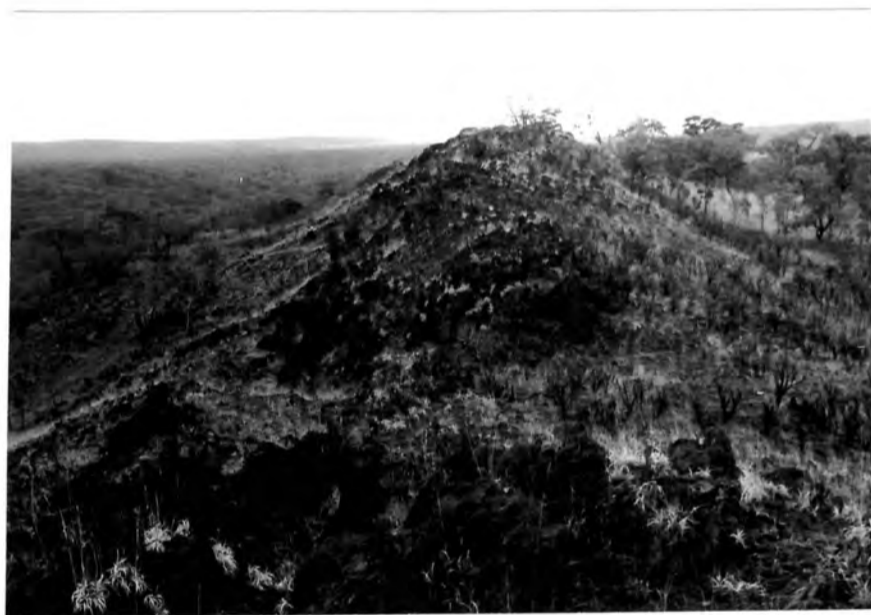
PLATE 9.

9A.



Outcropping Gossan, Copper Queen deposit, Sanyati Area.
- note similarity to Main Outcrop at Shamrocke.

9B.



Outcropping Gossan ridge, Copper King Sanyati Area,
- dipping steeply south west.

apart and immediately southeast of the Mukwishe/Sabi River confluence.

It is therefore obvious that the Deweras Series, particularly towards its upper contact, and the Dolomite Series, together constitute a "positive zone" for potential copper mineralisation at the base of the Lomagundi System.

The Wankie Area.

In an area north of the Gwai River some 50 miles east of Wankie and some 10 miles north of the Gwai River Hotel, is a northeast trending inlier of gneisses, quartzites, schists and granodiorite rocks enclosed by Karroo arenites and argillites. This area was mapped for the Geological Survey of Rhodesia by Watson, 1962 at a scale of 1 : 100,000. Watson named the low-to medium-grade sequence of arenites, schists and magnesian schists within the region "The Malaputse Series" which he regarded as correlates of the Lomagundi System. Recent field investigation and mapping by the present writer indicate many lithological similarities between this area and the Lomagundi sequence in the Shamrocke area, both successions being cover rocks resting upon partly remobilised acidic basement close to the margin of the Rhodesian craton. The controls of mineralisation appear to have much in common.

An amphibolitic group occurs in the axial region of a marked syncline underlain and flanked by rocks of a psammitic group. This amphibolitic group consists of tremolite-hornblende-anthophyllite- and actinolite-bearing oligoclase, andesine and quartz schists with fine-to medium-grained hornblende-plagioclase-quartz schists or typical para-amphibolites. These amphibolitic rocks are most probably metamorphic derivatives of impure magnesian limestones and dolomites and could be correlated with the Dolomite Group in the Lomagundi System. The Psammitic Group underlying these amphibolitic rocks consists of a series of medium-to coarse-grained muscovite-biotite-quartz-felspar schists, hornblende-biotite-plagioclase-quartz schists, granular rocks and amphibolite bands. The oldest rocks flanking this syncline are arenites and quartzites, Watson's (1962) Malaputse Quartzites. These are clean, compact, white, recrystallised quartzites with arkoses and arkosic arenites with conglomeratic bands in variable states of recrystallisation. This Psammitic Group of rocks is very similar to the rocks of the Deweras Series of the Lomagundi System.

Metamorphism is largely upper greenschist facies with locally developed lower almandine-amphibolite facies metamorphism.

Most of the known copper mineralisation is found within the amphibolites, generally within banded quartzites occurring in the amphibolitic succession. The mineralisation always appears selective in gritty bands of host rock. This mineralisation therefore, lying immediately above the Psammitic Group (the equivalent of the Deweras Series), is therefore in the same position stratigraphically as the deposits in the Lomagundi System, i.e. immediately above the Deweras System rocks and very similar to the Shamrocke deposit in that it occurs in gritty arkosic lenses within the amphibolitic group rocks, which were possibly originally impure magnesian limestone.

B 2. DETAILED STRATIGRAPHY

THE ESCARPMENT SERIES

North of the Nyashiri ridge and underlying the basal rocks of the Lomagundi sequence in the Shamrocke area are the rocks of the Escarpment Series, an expanse of meta-sedimentary rocks extending from Mukwishe in the south, northwards and north-westwards along the south Zambezi escarpment. In the north, in the vicinity of the Maura River, these rocks are again overlain by sandstones, red micaceous mudstones and conglomerates of perhaps Karroo age. These Triassic beds are flat lying. The conglomerates are extremely coarse and contain pebbles, cobbles and boulders of arenite, pegmatite, amphibolite and quartz, well cemented in a grey, sometimes red, matrix.

Although a great deal of work was done in this tract of country, no real stratigraphic sequence was forthcoming. This was probably due to the obliteration of the original bedding by the metamorphic effects of the Zambezi Mobile or Tectonic Belt. The various types of gneiss can be broadly separated into two main types, the massive meta-arkose, deficient in mica, and the more gneissic and foliated "paragneisses" with the broad gneissic banding of amphibolitic and narrow quartzo-felspathic layers.

The Escarpment Series comprises largely meta-arkoses, banded amphibole para-gneisses (see Plate 7b), meta-quartzites, mica schists, migmatites and limestones. Quartz veins and small pegmatite veins are often present and appear to increase generally in a north-easterly direction across the area mapped. The meta-quartzite is generally of a compact, fine-grained grey variety, sometimes containing mica. Subordinate rock types encountered in this series are actinolite, tremolite, and anthophyllite schists and amphibolites. Quartz-muscovite schists and quartz-biotite schists are locally developed.

As previously discussed, the rocks of the Escarpment Series appear to grade in an easterly and then southeasterly direction about the nose of the Rusere Syncline into the granodiorites and granitic migmatites east of Rusere and Mangula, generally described as pre-Lomagundi basement rocks.

The contact of the Escarpment Series with the basal beds of the Lomagundi System is not clear-cut, and in places it is difficult to pick up any unconformity between the base of the Deweras Series and the rocks of the Escarpment Series. Much of this contact is obliterated by plagioclase amphibolite, an alteration product of a diabasic intrusive. The whole succession dips southwards at moderate to high

Reconnaissance Geological Map Of

The Country Between

The Mukwishe And Maura Rivers

Scale 1:60 000 (Approx.)

EXPLANATION

LOMAGUNDI SYSTEM Major Unconformity.

- A A Amphibolised meta-arkose.
- G G Amphibole gneiss.
- O O Coarse-grained well sorted gritty meta-arkose often with abundant mafic minerals.
- [Stippled Box] Fine-grained white to buff meta-arkose generally free of mafics, occasionally micaceous.
- [Dotted Box] Hard, fine-grained grey meta-quartzite.
- [White Box] Fine-grained grey mica schist.
- [V-shaped Symbols] Medium to coarse-grained dark amphibolite often showing lineation of amphiboles.
- [Wavy Symbols] Quartz biotite schist.

* * Anthophyllite, tremolite, and actinolite - schist.

M M Red mudstone of unknown age. Triassic ?

C C Coarse conglomerate. Triassic ?

ESCARPMENT SERIES

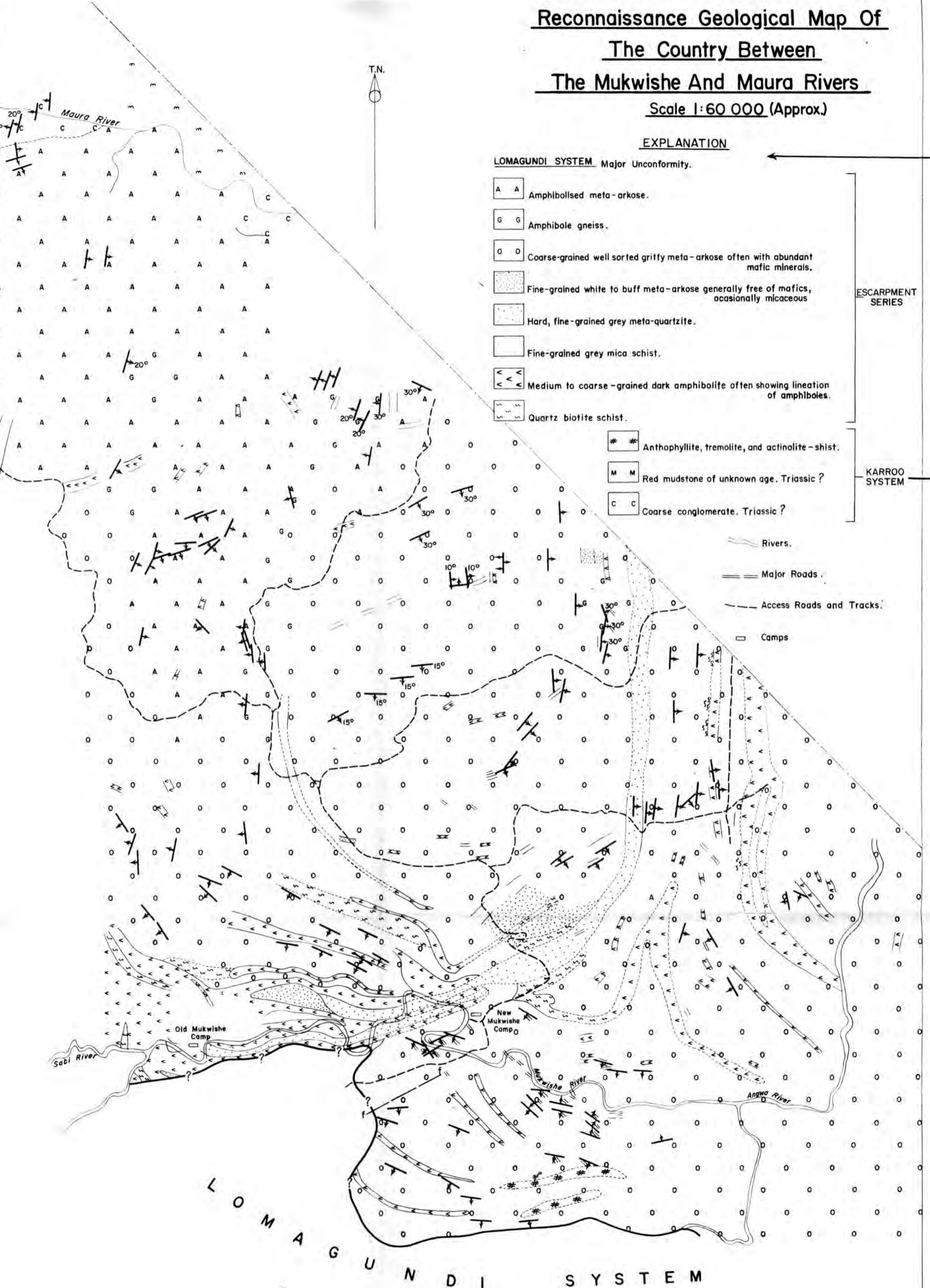
KARROO SYSTEM

Rivers.

Major Roads.

Access Roads and Tracks.

Camps



LOMAGUNDI SYSTEM

angles. The difficulty experienced in establishing the unconformity between the basal Deweras Beds and the Escarpment Series metasedimentary rocks could be due to the persistence across this contact of the post-Lomagundi metamorphism. At the contact both series are granular and quartzo-felspathic, with the rocks of both series having attained similar metamorphic grade. Northwards of this contact, however, although still in the same metamorphic facies as the Lomagundi System, the Escarpment Series rocks become texturally different and show a much more advanced stage of reconstitution. Microscopically, the rocks comprising the two series are easily separable, microcline being an important index mineral in the Escarpment Series rocks.

Southwards of the Mukwishe River the rocks of the Escarpment Series generally dip southwards at between 30° and 70° , the dip increasing towards the upper contact. In the area between Mukwishe Hill and the Mukwishe River a well sorted gritty meta-arkose often with abundant mafic minerals predominates. A finer grained, more compact white to buff coloured meta-arkose, generally free from mafic minerals and occasionally micaceous appears to be the result of a facies change westwards from Mukwishe and north of Bedsa. Narrow concordant intrusive amphibolite and occasional narrow bands of actinolite schist occur in this southern area.

Northwards the monotonous sequence of meta-arkose is interrupted by a very prominent band of hard, fine-grained grey meta-quartzite, regularly 1200 feet thick, extending from the confluence of the Mukwishe and Sabi Rivers along the Mukwishe valley and swinging northwards some $2\frac{1}{2}$ miles west of the Angwa/Mukwishe confluence. Immediately overlying this fine-grained grey meta-quartzite band the arkoses show a distinct lateral facies change from coarse-grained gritty arkosic arenite to a fine-grained compact buff coloured meta-arkose with less mafic minerals. Some $1\frac{1}{2}$ miles north of the old Mukwishe camp a band of coarse quartz-biotite schist, approximately 1000 feet thick, appears to change laterally to a finer-grained schist eastwards and into a meta-arkose to the west.

Narrow amphibolite bands and occasional pegmatite veins a few hundred feet thick occur sporadically within this expanse of meta-arkose and para-gneiss. Towards the Maura River the rocks become more amphibolitic; the contact between the amphibolised meta-arkose and the less mafic arkose has been shown by field mapping to occur some 5 miles north of the Mukwishe River.

Occasional bands of calc-silicate gneisses, quartz-mica schists, amphibolites, migmatites and occasional narrow limestone bands occur.

In summary, the Escarpment Series comprises a sequence of metamorphosed largely clastic sediments, mainly felspathic, in places migmatized and gneissose and very obviously older and different from the Lomagundi sediments overlying them. These rocks are very similar to those found on the northern Zambezi escarpment and can be followed westwards along the southern Zambezi escarpment.

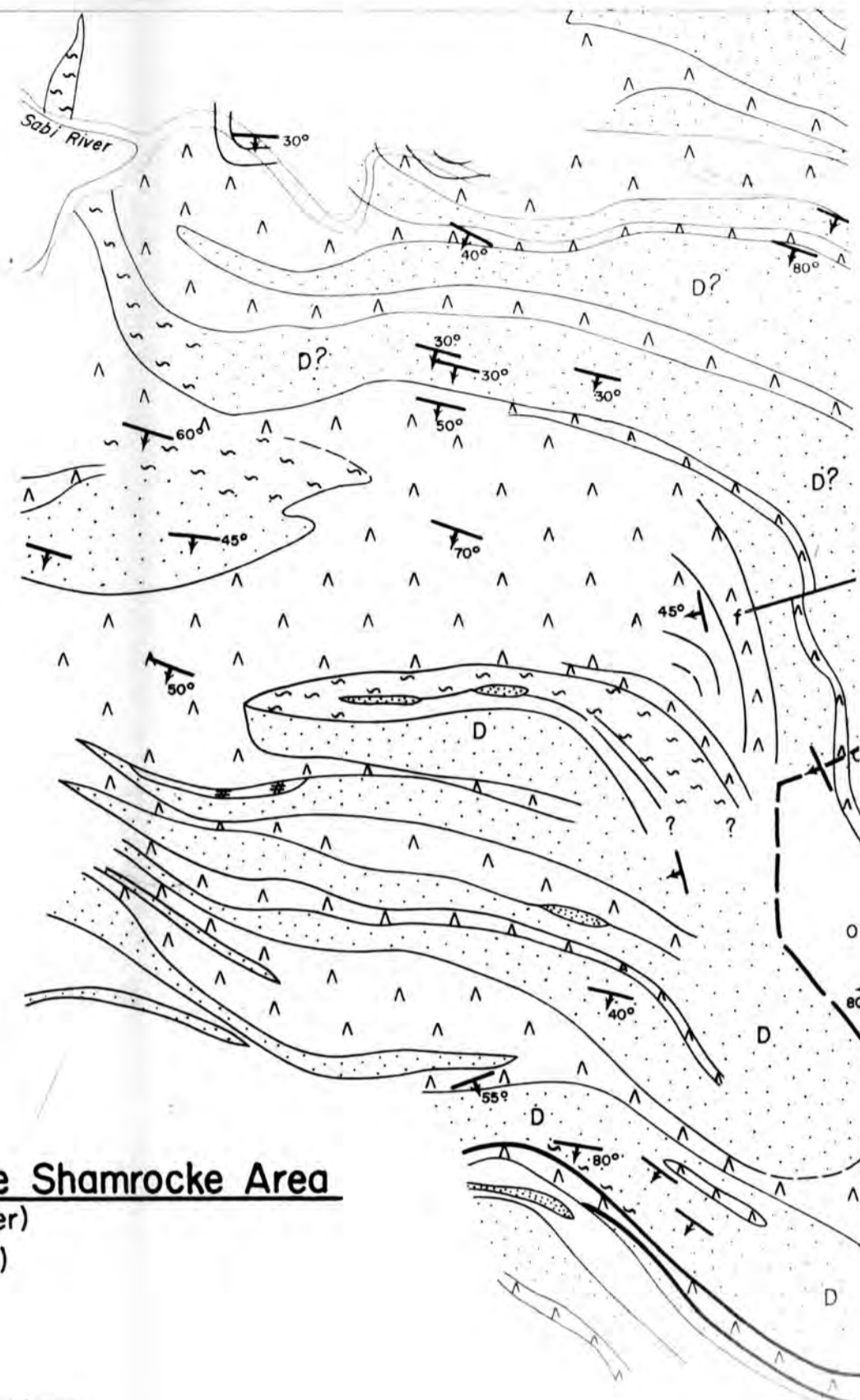
THE LOMAGUNDI SYSTEM

THE DEWERAS SERIES

The Deweras Series, the basal series of the Lomagundi System, overlies the Pre-Lomagundi basement gneisses of the Escarpment Series with an unconformity. This unconformity in the field is not very marked and as a structural unconformity it is unrecognisable both in the field and on the final map. Furthermore, the lithological composition of the base of the Deweras Series and the underlying Escarpment Grits is similar, although photogeologically there are discrete differences in photographic expression. Eastwards of the Angwa River the contact is more easily recognised due to thrusting of the base of the Deweras Series against the Escarpment Series rocks towards the nose of the Rusere Syncline.

Workman (1966) described the Deweras Series thus: "The Deweras Series is composed mainly of felspathic clastics, ranging from siltstones to boulder beds. Basic lavas may be present but no conclusive evidence of volcanic activity has survived the metamorphism to which the rocks have been subjected. Apart from this, the sequence as a whole closely resembles the original description of the Deweras Series by Phaup and Dobell (1938) and there can be little doubt regarding a direct correlation. However, whereas Phaup and Dobell recognised a major unconformity between the Deweras Series and the overlying dolomite in the Hartley district, no such break could be found in north Lomagundi. In north Lomagundi the Deweras Series is made up mainly of metamorphosed arkose and conglomerate. Often rich in mafic minerals, two principal conglomerates were recognised, one near the base and one near the middle of the series. The pebbles of the conglomerates are almost all of felspathic sedimentary or meta-sedimentary rocks similar to those of the Deweras itself. Pebbles of gneiss and granite, similar to the rocks of the underlying basement complex do occur, but are strikingly rare."

In the vicinity of the Shamrocke Mine much of the lithology of the Deweras Series is obscured by plagioclase amphibolite (meta-dabase) intrusion. Conglomerates were not recognised north of the Shamrocke Mine, the first conglomerate recognised being approximately 1 mile east of the Angwa River. The meta-arkose, (see Plate 7a) is generally fine-grained, white to buff coloured, generally free of mafics and occasionally micaceous. Where plagioclase amphibolite does not interfere at the contact, fine compact meta-arkose almost ubiquitously overlies the Escarpment Series rocks. No sign of thrusting is evident north of Shamrocke.



Geological Map Of The Immediate Shamrocke Area
 (West Of The Angwa River)
 Scale 1:30 000 (Approx)

EXPLANATION

- ▲ Plagioclase Amphibolite - Altered Post-Lomagundi Diabasic Intrusives.

- Is Is Phyllite, Schist, Sandstone, Quartzite. — ARGILLACEOUS SERIES

Dm 4 & 5	Dolomite, Schist and Phyllite.	} DOLOMITE SERIES	} LOMAGUNDI SYSTEM
Dm 3	Shamrocke Granulite and Calcareous Grif.		
Dm 2	Dolomitic Limestone, Schist and Phyllite.		
Dm 1	Nyashiri Quartzite.		
Dm 1(a)	Schist and Phyllite.		

D	Actinolite Shist.	} DEWERAS SERIES
D	Quartz Biotite Shist.	
D	Meta-Arkose, Meta-Quartzite and Schist	

O O	} ESCARPMENT SERIES	} PRE - LOMAGUNDI
O Ms O		
O O O		

 - == Roads.
 - ~ Rivers.
 - f Fault.
 - ↙ 80° Dip and Strike.





36a

30° East

The rock types generally associated with the Deweras Series are fine-grained buff coloured compact meta-arkose, narrow bands of hard fine-grained grey meta-quartzite, thin shaly bands, and schistose rocks which may be described as quartz-mica-hornblende schists, arenaceous biotite schists and anthophyllite, tremolite and actinolite schists. Generally the rocks show little sign of disturbance.

Thin mica schists occur intercalated with the meta-arkose, while overlying the main mass of fine grained buff coloured meta-arkose there are narrow bands of both quartz-biotite schist and medium-to coarse-grained dark amphibolite showing a strong lineation of amphiboles and in places tending to be monomineralic.

The upper contact of the Deweras Series rocks against the overlying Dolomite Series north of the Shamrocke Mine is everywhere obliterated by intrusive plagioclase amphibolite which follows the contact from just east of the Angwa River to the limit of the area mapped to the west near the Nyarinde River. This sheet was intruded along the lower contact of the Nyashiri Quartzite very near the base of the Dolomite Group. It is at only one location immediately north of the Nyashiri Ridge that the mica schist underlying the Nyashiri Quartzite and obviously belonging to the Dolomite Group is evident. Eastwards this plagioclase amphibolite lies between the bottom contact of the Nyashiri Quartzite and between it and the schist and arkose of the Deweras Series, and has generally an estimated thickness of between 400 and 1,000 feet, which makes it very difficult to postulate the thickness of the Deweras Series in this area. East of the Angwa River, towards the nose of the Rusere Syncline some two miles due east of the Shamrocke Mine, the Deweras Series attains a larger thickness due mainly to duplication by thrust faulting and a bunching effect in the axis of the syncline. In the Angwa River north of the Shamrocke Mine the Deweras Series is hardly exposed at all due to the intrusive meta-dabase. The only rock type recognised as being of Deweras age in the Angwa section northwards from the mine is a micaceous quartz-biotite schist. Westwards from the Angwa section the Deweras in places attains a thickness at outcrop of 1,500 feet, and if it is accepted that the plagioclase amphibolite preferentially intrudes the Dolomite Group schists, this postulated thickness of 1,500 feet for the Deweras Series can be accepted as a general thickness of that series in the Shamrocke area.

THE DOLOMITE SERIES

Immediately overlying the Deweras Series, amphibole - biotite schist occurs, very similar to the phyllites higher in the succession, which in turn are immediately overlain by the narrow hard compact glassy quartzite of the Nyashiri

ridge. The exact thickness of these basal schists of the Dolomite Group cannot be ascertained in this area as these are intruded by plagioclase amphibolite, and at only one point north of the Nyashiri Ridge do these schists remain exposed at surface. It is therefore not possible to ascertain the thickness of these lower schists.

The Nyashiri Meta-quartzite (Dm 1) (See Plate 7a) is consistently 160 to 180 feet thick and dips at a constant angle of 60° to the south immediately north of the Shamrocke Mine. This hard, grey, fine-grained meta-quartzite is thrown approximately 700 feet northwards on the western side of a north-northeast trending fault just north of the mine, and then continues eastwards across the Angwa River until it appears to be faulted out against Deweras Series rocks some 4,000 feet east of the Angwa River. Westwards this persistent meta-quartzite band is easily discernible on air photographs and easily followed in the field to the limits of the detailed mapping in the west in the vicinity of the Nyarinde River.

The Lower Graphitic Phyllite and Schist (Footwall) (Dm 2)

Overlying the Nyashiri Quartzite are approximately 1250 feet of fine- to medium grained foliated dark-grey to black schists and phyllites, generally very graphitic, which form a monotonous layer of alternating foliated schistose rocks and more finer grained compact dark phyllites. Narrow dolomitic limestone lenses can be seen on the hillslope immediately south of the Mine. Eastwards of the Angwa River these limestone bands become very much wider and more persistent, in places attaining a width of 400 to 500 feet, and dipping steeply to the south.

At surface these rocks dip at an angle of approximately 60° to the south and are manifested at surface by highly foliated, in places fissile, grey to dark-black graphitic schists weathering to a very fine grey-brown soil.

Narrow sill-like bodies of plagioclase amphibolite up to 200 feet wide are ubiquitous and may become irregular and transgressive. Eastwards and westwards of the Mine these bodies thicken and may reach 800 feet in thickness in the west.

The Shamrocke Granulite (Incorporating the Ore Zone) (Dm 3)

Some 1,250 feet above the Nyashiri Quartzite and overlying the Lower Graphitic Phyllite and Schist, and in the immediate Shamrocke section, a narrow band of granulitic rocks extends westwards from the main adit at the Shamrocke Mine for a distance of some 2,250 feet. This granulitic zone is regularly 100 feet wide at outcrop for a distance of 1,500 feet westward from the main adit, and then for a further 750 feet it thins out in places to 20 feet.

Although this granulitic zone is obviously not a planar one, as indicated both at surface outcrop and in underground workings and boreholes by tight lateral folding, it dips regularly to the south at approximately 60° . Westwards from the main outcrop area this dip steepens somewhat to 70° in places. In the main outcrop area the width at surface in trenches is between 120 and 140 feet. Extending down-dip this granulite zone has a fairly regular thickness of between 60 and 100 feet, although the one intersection at 2,500 feet down-dip gave a thickness of 40 feet. Further westwards, where it narrows at surface, this zone narrows sympathetically in depth, averaging regularly 60 to 65 feet.

A narrow band of porphyroblastic feldspar-amphibole rock very often occurs at the contact between the granulite and the underlying schist and phyllite. This is a medium-to coarse-grained, very often calcareous, porphyroblastic feldspar-amphibolite rock with some quartz in the fabric and it occurs at irregular intervals through the granulite zone, varying in thickness from bands of a few inches to several feet in width.

The granulites themselves vary radically in composition from place to place and for this reason correlation is difficult to achieve between boreholes and even in the underground workings. The granulite zone will be discussed in detail under the section "The Shamrocke Orebody". At this stage therefore, it suffices to mention that these granulites occur as medium-grained pink biotite granulite generally free from amphibole, more amphibolised granulite, and a compact grey granulite devoid of biotite. In places the granulite becomes dark and schistose and even mottled in places, and furthermore varies from a non-calcareous to a highly calcareous variety.

Within the granulite zone calcite occurs as stringers from a few centimetres in width to large irregular bands of coarse-grained calcite, generally pure white and occasionally pinkish, together with large "blows" and irregular bodies occasionally up to 30 feet across. These calcite bodies are irregularly distributed through the zone and are difficult to correlate from borehole to borehole, and in the underground workings, both laterally and down-dip. Also, within this granulite zone are scattered remnants of fine-grained dark, generally amphibolised mica schists, from a few inches thick up to bands of 25 feet or more.

In places the granulite appears to be split into an upper and lower zone by a dark calcareous biotite-rich amphibolite, in places resembling a dark schistose granulite; this has locally been termed 'the internal zone' and becomes more evident and of increasing width in depth. This is not ubiquitously the case; the occurrence of

this internal zone being discussed in the section "The Shamrocke Ore Zone".

The structure of this granulite zone will be briefly discussed in the section on structure, however, it is pertinent to mention here that no further granulitic rock, or for that matter arenaceous rock, is found eastwards of the Main Adit and across the Angwa River. This granulite zone in plan indicates a tight lateral fold, possibly a very tight anticline, nosing and plunging to the east, the limbs opening slightly westwards.

In the Shamrocke section granulite bands in the hanging wall of the ore zone are narrow and infrequent, the widest zone being approximately 110 feet thick some 700 feet above the orebody. Westwards from the Mine and towards the Nyashiri River to the west, arenitic bands are frequent and of varying thickness. The majority of these bands are best described as calcareous grit, which in thin section resemble the Shamrocke granulite, but are not as metamorphosed and recrystallised and at surface often form a crumbly, sugary, calcareous grit. Some arenite bands are not calcareous and are more compact and buff coloured. The plagioclase amphibolite obviously intruded into some 1,500 feet of calcareous grit in the vicinity of the Nyashiri River to the west of the Shamrocke Mine; leaving plagioclase amphibolite interlayered with bands of calcareous grit and buff coloured arenite generally 30 to 50 feet thick, and in places up to 2,000 feet thick. These calcareous grits to the west however have never been seen to contain sulphide mineralisation and close spaced geochemical grid soil sampling gave no indication of mineralisation in these rocks.

The Upper Graphitic Schist and Phyllite (Hanging wall) (Dm 4)

Overlying the Shamrocke Granulite is a zone of medium to fine-grained irregularly banded dark grey mica schist and phyllite with alternating bands of grey dolomitic limestone. This zone is approximately 400 feet thick and, although not as homogeneous as the Footwall rocks, show only occasional dolomitic limestone and granulite bands sporadically developed.

The Upper Dolomite (Dm 5.1)

Bands of dolomitic limestone become more numerous towards the top of the Upper Schist and Phyllite and upwards form an alternating sequence approximately 300 feet thick, of medium-grained grey-white dolomitic limestone, medium-grained silicic granulites, grey biotite schist, quartz and calcite. Very often the top 100 to 200 feet of this zone comprises largely banded dolomitic limestones, in places micaceous, siliceous and amphibolised.

Plagioclase Amphibolite Sill (Dm 5.2) (See Plate 7B)

Regularly 700 feet above the granulite zone is a large concordant plagioclase amphibolite sill, between 600 and 1,000 feet thick, found in all the deeper boreholes. This corresponds with the large body mapped on surface some 1,500 to 1,700 feet south of the granulite zone. It appears that this sill intruded and assimilated a dolomitic horizon between the Lower and Upper Dolomite. This sill is now a medium-to coarse-grained calcareous plagioclase amphibolite with a little disseminated pyrite and pyrrhotite. Occasionally garnetiferous bands are evident.

The calcareous nature of the plagioclase amphibolite and its difference in appearance from the other intrusive plagioclase amphibolites of the Shamrocke area indicate this assimilation of dolomitic material. The occurrence of narrow bands of plagioclase amphibolite showing distinct gradation of grain size, becoming finer-grained towards chilled margins, and the presence of a typical idioblastic biotite-garnet contact zone, further indicates intrusion by separate heaves into the sill in various places. Generally the sill is a medium-to coarse-grained calcareous plagioclase amphibolite with ramifying calcite veinlets. It is pitted and brecciated with scattered pyrite in solution cavities. Dolomitic limestone and medium-grained equigranular pinkish amphibolised calcite, when occurring as narrow bands, give a mixed calc-amphibolite and dolomitic limestone sequence. It is evident that the sill has differentially replaced dolomitic material, both down-dip and laterally. In places the dolomitic sequence is only partly intruded by plagioclase amphibolite, with much remnant dolomitic limestone and calcite, whereas elsewhere the plagioclase amphibolite almost entirely takes the place of the dolomitic sequence. Occasional narrow bands of grey compact granulites are found within this amphibolite band, generally some 300 feet above the lower contact. The limestone and calcareous zones are generally either a fine-to medium-grained grey dolomitic limestone, in places silicified, or white to pink equigranular calcite bands.

The Upper Dolomite (Dm 5.3)

Immediately overlying the sill of calcareous plagioclase amphibolite intruded into the dolomitic sequence, is a zone of medium-grained grey dolomitic limestone, often with decussate amphibole lath development. Zones of coarse-grained pink dolomite and calcite with irregular inclusions of crushed green amphibole give a large-scale mottled appearance. Narrow bands of compact crystalline pink

calcite abound. This upper dolomite zone occurs regularly 1,200 to 1,400 feet above the Shamrocke Granulite and is upwards of 600 feet thick; the upper portions are generally intruded by further concordant sills of plagioclase amphibolite. One important feature of this dolomite zone is a fairly persistent and coarse-grained garnet amphibole staurolite schist regularly some 1,500 feet above the Shamrocke Granulite. This is the only place where staurolite is positively identified in the Shamrocke area and is an important index mineral for metamorphic facies identification.

The upper contact of this dolomite is accepted as the upper contact of the Dolomite Series. Although no further boreholes were drilled south of this dolomite, detailed field mapping did not reveal further dolomitic rock to the south. These dolomites have interbedded with them granulitic rocks which vary from a silicified grey granulite to a pink micaceous granulite. These granulites are generally more compact and recrystallised than those of the ore zone and in places are mineralised with pyrite. No copper values are encountered in these hanging-wall granulites.

Occasional bands of quartz-felspar-biotite-garnet schist occur.

THE ARGILLACEOUS SERIES

Overlying the Dolomite Series with no obvious unconformity is the Argillaceous Series, a very thick sequence of micaceous phyllites, schists, sandstones and quartzites. The lower members of this series are found in the area south of the Shamrocke Mine to the Deta/Angwa confluence, thereafter westwards the rocks belong to the Piriwiri System as described by Stagman (1959), or the Upper Shales as described by Workman (1962).

Immediately overlying the Dolomite Series the Argillaceous Series comprises alternating bands of dark mica schist, felspathic sandstone and quartzites, and some limestone bands.

The arenaceous members are of two distinct types; a fine to medium-grained compact grey-white quartzite and a medium-grained grey to brown felspathic sandstone. The schist is predominantly coarse-grained dark-grey to black mica schist (biotite, muscovite and sericite), and shows a silky appearance due to the abundance of the large micas. Dark fine-grained schistose phyllites also occur with a more compact fabric. In the area immediately south of the Dolomite Group in the Shamrocke section the rocks are a series of intercalated metamorphosed argillaceous and arenaceous horizons being intruded by large sills and narrow dykes of plagioclase amphibolite.

At the Deta/Angwa River confluence a prominent ridge of blocky quartzites occur, the Deta Quartzites. Southwards and southwestwards from this quartzite and overlying it is the Deta Schist, in turn overlain by the monotonous series of dark graphitic phyllites, described as Piriwiri Series phyllites by Stagman, and Upper Shales by Workman. The contact between the Deta schists and the Piriwiri phyllites or Upper shales is outside the boundary of the present work and is therefore unrecorded.

B 3. STRUCTURE OF THE ORE ZONE

As previously described, the ore zone granulites are evident at surface by a zone of granulitic rocks approximately 100 feet wide, striking roughly east-west and dipping somewhat uniformly to the south at generally 50° - 70° . The zone appears to be a tight lateral fold closing in the vicinity of the Main Adit and plunging to the east. These granulitic rocks are not seen eastwards of the Angwa River while westwards the zone thins to a width of 20 feet in places and disappears against the edge of a narrow intrusive meta-diabase which may have assimilated the zone. Westwards from this point boreholes did not intersect the zone at the same level but intersected a similar narrow zone of granulite very much deeper and further north; however, detailed surface mapping failed to elucidate the structure due mainly to numerous concordant plagioclase amphibolite sills, and lack of more drilling westwards.

The underground logging showed that the deposit cannot be treated as an uncomplicated planar one. The suggestion of a tight lateral fold nosing out to the east and accompanied by a plunge eastwards is substantiated by minor fold axes and plunges recorded during the underground logging. This would explain the split in the body to the west (as indicated both underground and on surface), the limbs of the fold opening out and thinning in a westerly direction. Subsidiary drag-folding and ingress of folded internal zones within the body can be seen in the workings. Any duplication of beds is obscured by differential local metamorphism.. The narrowness and uniformity of the granulite zone to at least some 2500 feet down-dip, the parallelism of the upper and lower contact and the irregular nature of the "internal zone" indicates the fold, if it is a fold, to be very tight indeed.

Information with regard the width and position of the orebody mineralisation relative to the granulite zone is strictly the specific knowledge of the exploration group under whose auspices the work was carried out and therefore has no place in this discussion. Furthermore, information with regard the details of structure of the deposit must also be considered classified to the exploration group and should not be pursued here.

B 4. PETROGRAPHY

DESCRIPTIVE PETROGRAPHY

THE ESCARPMENT SERIES

The rocks comprising the Escarpment Series northwards from the Mukwishe ridge are largely metamorphosed sediments which form an irregular succession of gneisses, meta-arkose, quartzites, amphibolites, mica schists, migmatites and limestones.

These rocks are described here from observations during field mapping. Thin sections were prepared of representative gneiss, quartzite and meta-arkose specimens only. The following is a description of each rock type of the area:

Meta-Arkose -This meta-arkose is the predominant rock type of the Escarpment Series and grades laterally into both migmatites and gneisses. Three types of arkose are described: (i) a coarse-grained, well sorted, gritty meta-arkose often with abundant mafic minerals (ii) a fine-grained clean buff-coloured meta-arkose, generally free from mafic minerals (iii) meta-arkose subjected to a higher degree of metamorphism and distinctly amphibolitic.

The coarse-grained gritty meta-arkose occurs massively and rarely gives any indication of bedding, whereas the jointing of the fine-grained arkose, presumably along bedding planes, gives an indication of structure.

This meta-arkose in thin section is generally of equigranular texture with fine to coarse-grained varieties. Grain size varies from 0.1 mm to approximately 1 mm and the fabric is generally that of a mosaic of interlocking mineral grains showing early signs of recrystallisation.

The mineral assemblage is generally feldspar, quartz, biotite, chlorite, muscovite, clinozoisite, microcline, epidote, with at times sphene and apatite as accessory minerals.

The meta-arkose does not have a great deal of quartz and is largely felspathic. The typical mineral composition of a leucocratic coarse-grained meta-arkose and that of a medium-grained epidotised meta-arkose with some mafic minerals is as follows:

	<u>Leucocratic Coarse-Grained Meta-Arkose.</u>		<u>Epidotised Meta-Arkose With Mafic Minerals.</u>
Plagioclase Felspar	90%	Felspar	73%
Quartz	5% - 10%	Quartz	5%
Biotite, Epidote, Metallic ore,	Less than 2%	Chlorite	10%
		Clinozoisite	5%
		Epidote	5%
		Muscovite	2%

The epidote content of these arkoses can at times be as high as 30% this mineral occurring as scattered anhedral granules.

The individual minerals generally occur in the following manner:

Quartz - few scattered anhedral grains.

Plagioclase felspar: generally reasonably clear but slightly altered to saussurite in places. Approximately half the plagioclase crystals are twinned and the rest are untwinned. The twinning appears to follow the albite law.

Microcline: commonly occurs in the meta-arkose and with the characteristic lamellae at right angles to one another.

Biotite - light brown to black, pleochroic.

Chlorite - pale to dark-green, pleochroic with a 2V angle of $\pm 45^\circ$.

Clinozoisite - an anomalous blue interference colour with c/Z angle of 0° , biaxial and 2V angle $70^\circ - 90^\circ$.

Amphibole Gneiss - This is a medium-to coarse-grained equigranular hornblende biotite gneiss with the foliation and banding in the form of linear amphibole porphyroblasts and quartzo-felspathic bands. Flow folding is conspicuous. In thin section this is granoblastic equigranular with the mineral assemblage quartz, plagioclase (untwinned), microcline, biotite/chlorite and accessory sphene and apatite. When less mafic and less banded, the rock in thin section closely resembles the meta-arkose.

Quartzite - A fine-grained, compact usually clean quartzite with in places a greenish mica. The fabric is generally one of sutured quartz grains interlocking, with both a siliceous and ferruginous cement. The rock is generally fine-grained within the range 0.1 to 0.3 mm. and the mineral assemblage generally quartz and felspar.

Amphibolites - Amphibolites are ubiquitous throughout the area and appear to be mainly a quartz amphibolite, occasionally with epidote. A lineation of the amphiboles is evident and in places it shows unmistakable signs of flowage. These are both concordant and transgressive and appear to alter with weathering to a quartz biotite schist. An occasional dark-green monomineralic amphibolite occurs, at times tending to be calcareous.

Quartz Mica Schist.

Here there are two distinct types, the quartz-biotite schist which occurs as a weathering product of the amphibolites and a quartz-muscovite schist which occurs as a weathering product of an extremely micaceous and schistose variety of meta-arkose. The quartz is granoblastic and the mafic minerals are generally arranged in a decussate pattern, with very often minute colourless to greenish laths of tremolite and actinolite.

Limestone

This is a clean, white, fine-to medium-grained rock consisting mainly of dolomite and calcite with some tremolite.

THE LOMAGUNDI SYSTEMTHE DEWERAS SERIES

The Deweras Series in this area does not have a conglomerate at the base. The Series lying unconformably upon the Escarpment Series consists largely of quartz mica hornblende schist, arenaceous biotite schist, anthophyllite, tremolite and actinolite schist, hard fine-grained grey meta-quartzite and thin shale bands.

Meta-quartzites.

These are hard fine-grained, grey, glassy meta-quartzites composed mainly of quartz with a little subordinate muscovite and microcline. In places the meta-quartzites can become epidotitic.

Meta-arkose

The meta-arkose of the Deweras Series is generally fine-grained white to buff coloured generally free of mafics, and occasionally micaceous. They are often hard and granular, buff coloured to pink, which on microscopic examination indicate grains of plagioclase ranging in size from 0.1 to 0.5 mm. and a little quartz. The principal mineral assemblage is plagioclase, quartz and microcline with subordinate biotite, tremolite, actinolite, hornblende, muscovite, epidote, chlorite, sphene and apatite. The composition of this arkose is averaged as follows: quartz 12%, plagioclase 71%, microcline 5-10%, hornblende/tremolite/actinolite 2%, chlorite/sphene/apatite/epidote - trace.

Anthophyllite, Tremolite and Actinolite Schist

These schists are quartz mica schists generally with a high percentage of amphiboles. These can be so amphibolised as to be almost monomineralic, generally with a decussate arrangement of actinolite, tremolite and anthophyllite.

THE DOLOMITE SERIES

The Shamrocke deposit occurs within the Dolomite Series and the rocks as described below are from the general vicinity of this deposit. The Series comprises quartzite, graphitic biotite schist and phyllite, granulite, calcareous grit, amphibolite, dolomite and limestone.

Meta-quartzite

Hard fine-grained grey quartzite composed mainly of reconstituted quartz grains with microcline.

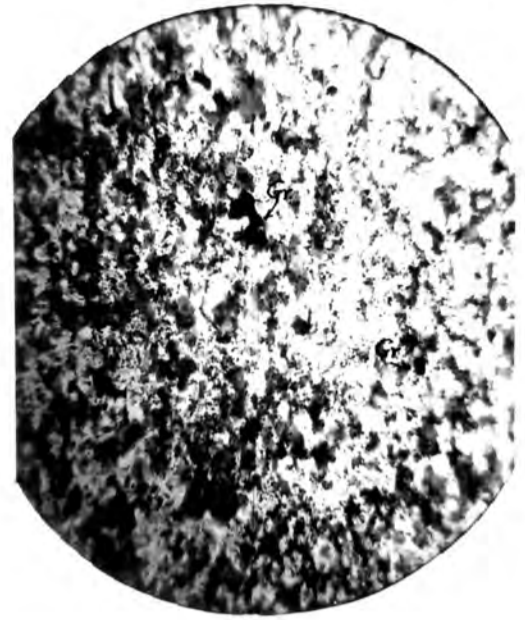
PHYLLITE AND SCHIST

In hand specimen these are fine-to medium-grained foliated dark-grey to black schist and phyllite, in places quite carbonaceous. Macroscopic porphyroblasts are often abundant. In thin section these are predominantly fine-grained, xenoblastic, and sometimes porphyroblastic, biotite phyllite with a ground mass of fine anhedral feldspar and quartz with abundant biotite, in generally exhibiting lineation. Tremolite, anthophyllite, green amphibole and garnet occur as porphyroblasts. Golden brown strongly pleochroic staurolite occurs in porphyroblastic habit in a coarse-grained garnet-staurolite schist. Accessory minerals are calcite, rutile, zircon and opaque ores. Shreds, segregations, lenticles and veins of graphite impart a black colour to the schist. Graphite is also included in the feldspar. Abundant elongated lath-like porphyroblasts, sometimes curved, are found to be granular feldspar and quartz segregations.

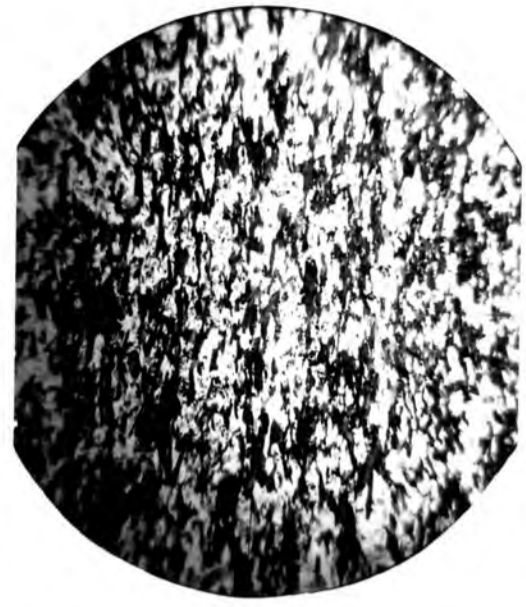
The different types of phyllites and schists as recognised in the immediate vicinity of the Shamrocke Mine are :

- Graphitic Biotite Schist and Phyllite
- Garnetiferous Biotite Schist and Phyllite
- Anthophyllite, Cummingtonite, and Actinolite Schist
- Calcareous Schist and Phyllite
- Garnet Staurolite Schist

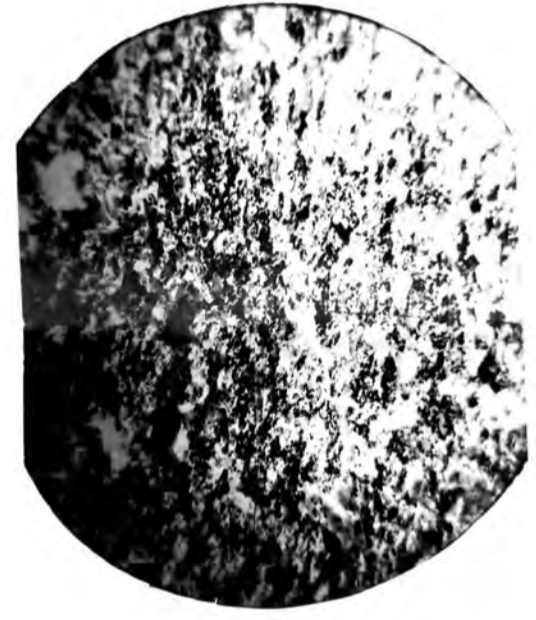
PLATE 10



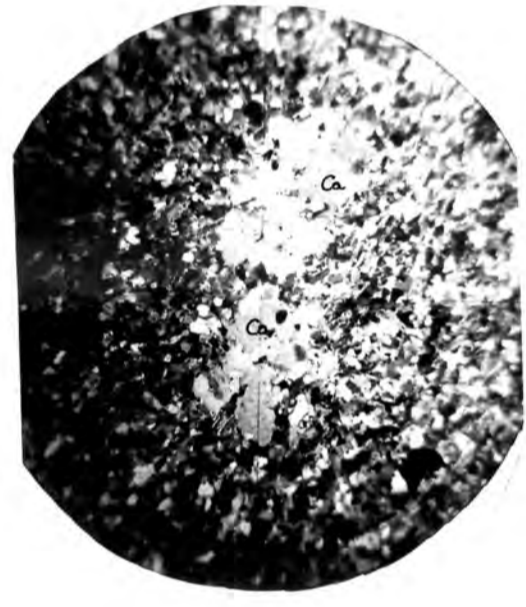
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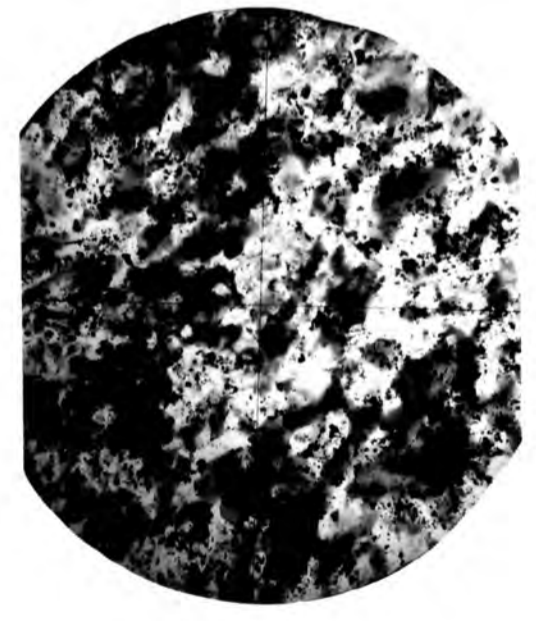
B



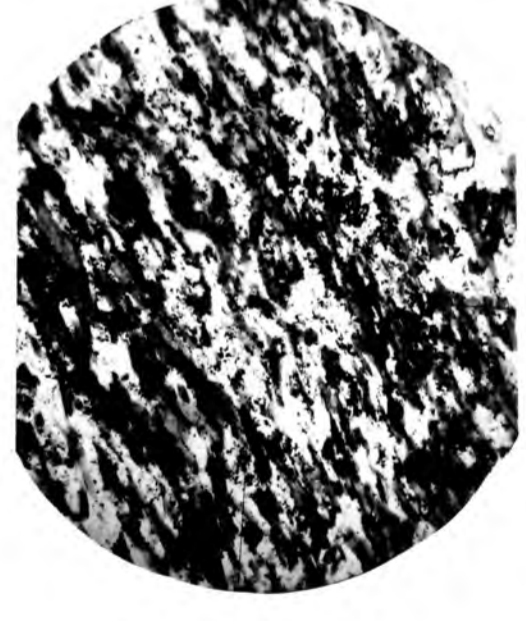
C



D



E

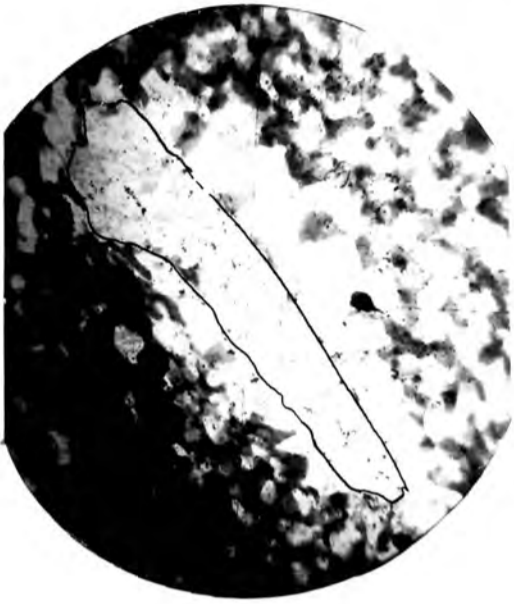


F

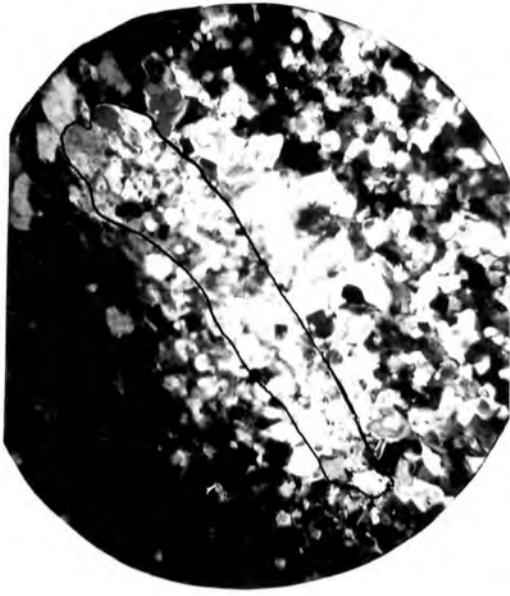
EXPLANATION OF PLATE 10

- A. Fine-grained biotite-schist with minor graphite.
Section cut perpendicular to the schistosity.
Ordinary light X 40.
- B. Fine-grained graphitic biotite schist showing distinct
parallelism of biotite prisms. Section cut parallel to the
schistosity.
Ordinary light X 40.
- C. Fine-grained graphitic biotite schist. Graphite shreds and flakes
in groundmass.
Section cut perpendicular to the schistosity.
Ordinary light X 40.
- D. Fine-grained calcareous biotite schist with calcite as larger
crystals in the groundmass.
Crossed Nicols X 40.
- E. Same section as A. Ordinary light X 100
- F. Same section as B. Ordinary light X 100.

PLATE 11



A



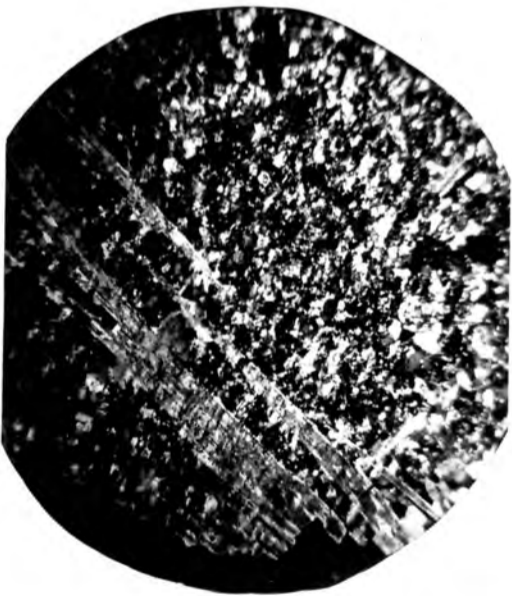
B



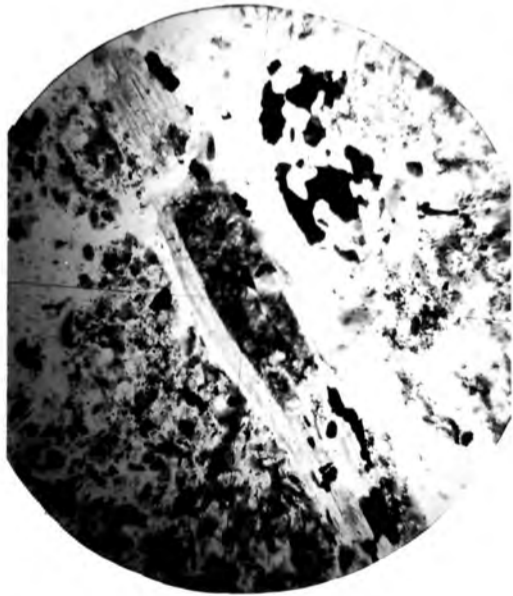
C



D



E



F

EXPLANATION OF PLATE II.

- A. Biotite schist with porphyroblast of granular quartz and felspar. Segregation or pseudomorph after a metamorphic mineral?
Ordinary light X 40
- B. Biotite schist with porphyroblast of granular quartz and felspar.
Crossed Nicols X 40.
- C. Garnetiferous biotite schist - one small anhedral garnet crystal (G) in plagioclase-quartz groundmass and hornblende and biotite shreds.
Ordinary light Low Power.
- D. Highly graphitic amphibole porphyroblast in fine-grained graphitic biotite schist.
Ordinary light X 40.
- E. Narrow anthophyllite crystals in fine-grained graphitic schist.
Crossed Nicols Low Power.
- F. Graphitic anthophyllite porphyroblast in fine-grained graphitic biotite schist. Graphitic impurity only in central portion of anthophyllite crystal.
Ordinary light X 40.

Graphitic Biotite Schist and Phyllite (See Plate 10 A, B, C, and D)

In hand specimen these are generally fine-grained, dark-grey, carbonaceous schist and phyllite, fairly well foliated. In places more slaty types are compact and appear to contain more graphite. In thin section the fabric is generally fine-grained crystalloblastic to xenoblastic with crystals from less than 0.05 mm in size to approximately 0.1 mm.

The biotite is both subhedral and anhedral. In some sections preferred orientation of the biotite causes a very definite lineation whereas in others the lineation is not very distinct, with the biotite showing no preferred orientation. The graphite content is generally as irregular shreds masking much of the crystallinity. Felspar and quartz generally form a fine-grained xenoblastic groundmass, with anhedral crystals of up to 0.1 mm in size.

Generally the schist and phyllite is distinctly porphyroblastic. These porphyroblasts vary in both size and form and vary from .5 mm to 5 mm long, generally elongated along the plane of the foliation, and comprise largely granular aggregates of clear anhedral plagioclase and subordinate quartz. These porphyroblasts are at times zoned and appear to be either segregations of felspar and quartz or granular quartz/felspar pseudomorphs after some metamorphic mineral, possibly kyanite or staurolite (see Plate 25 A and B). At times the outer zone is of clear anhedral quartz and felspar with an inner zone of finer-grained altered plagioclase and murky quartz showing distinctly undulose extinction. Hornblende, actinolite and anthophyllite are also common porphyroblasts (see Plate 10 D, E and F).

The mineral assemblage of the schists and phyllite is : felspar, quartz, biotite, graphite and the accessory minerals garnet, rutile, calcite and opaque ores.

Garnetiferous Schist and Phyllite (See Plate 11).

Large garnet porphyroblasts up to 2 mm across develop in a groundmass which is a fine-grained quartzo-felspathic biotite matrix with the biotite often showing parallelism of laths. The garnet is pale pink, almandine garnet, often showing signs of rotation and very deformed due to stress. Opaque ore inclusions in the garnet are common and these often indicate the rotational development. The garnet is at times a pale brown colour and is isotropic. Amphibole porphyroblasts which develop are generally anthophyllite, actinolite or cummingtonite crystals of up to 2 cm in length. These porphyroblasts tend to be generally large, widely scattered and idioblastic. In contrast to the amphibole of the granulite, these porphyroblasts contain much included graphite as minute specks which tend

to mask the colour. Any wavy texture of the graphite exhibited through the rock fabric passes through the porphyroblasts indicating that the porphyroblast growth did not disturb the groundmass texture.

Garnet Staurolite Schist (See Plate 20 A, B and C)

This is generally medium-to coarse-grained garnet staurolite schist with small porphyroblasts of subhedral pink garnets. Schistosity is generally lacking and a decussate matrix predominates. Biotite sheaths are very prominent in the hand specimen. In thin section these garnet staurolite schists show a coarse-grained crystalloblastic, slightly deformed matrix. Subhedral almandine garnet has a somewhat porphyroblastic habit together with large bladed greenish amphibole crystals. Garnet is pinkish almandine, isotropic and anhedral and deformed by stress. Distinct evidence of rotation of the crystal is given particularly by opaque ore inclusions in the garnet. Staurolite crystals appear fractured by stress, and tend to follow the direction of the amphibole. It is strongly pleochroic, from a deep golden-brown to a light-brown. Quartz inclusions in the staurolite are common and abundant. Occasional subhedral biotite forms a decussate arrangement within a matrix of anhedral quartz and feldspar. Irregular scattered opaque ore crystals are present.

This is one of the few rocks of the Shamrocke area where quartz is a prominent constituent mineral. The quartz is clear and generally anhedral with undulose extinction. Quartz is important as inclusions in the staurolite.

Staurolite occurs as anhedral crystals which appear fractured.

GRANULITE

In hand specimen this is generally a fine-to medium-grained pinkish feldspar biotite rock, sometimes strongly amphibolised. Microscopically the granulite can be described as a fine-to medium-grained granulo-feldspar biotite rock with the predominant fabric a granoblastic mosaic of plagioclase feldspar. The plagioclase is usually in the form of clear pellucid untwinned anhedral crystals. The chief characteristic of the granulite of the ore zone is the very low quartz content, generally less than 6%, and very often with quartz being almost entirely absent.

It is extremely difficult to distinguish between quartz and feldspar in the groundmass of the granulite, and to establish the existence or not of orthoclase, without resorting to Selective Staining. Early in the investigation optical examination indicated that the quartz content was very low, this being subsequently shown to be correct by the staining. Identification by optical means is very difficult on the small crystals and is impossible when applying modal analysis. The Selective Staining showed plagioclase feldspar to predominate, with virtually no orthoclase. The plagioclase stains red with potassium rhodizonate solution after etching with hydrofluoric acid while the quartz is unaffected. The etch effect with HF on the plagioclase is very distinctive while the quartz remains unetched. With cobaltinitrite solution no yellow stain was seen to indicate the presence of orthoclase, except on one crystal in the section.

The two predominant mafic minerals are biotite and amphibole. The former is an important constituent of the granulite and generally occurs in porphyroblastic habit as fairly large, brown non-pleochroic basal flakes and lath shaped pleochroic crystals. These do in some cases show a preferred orientation within the granulite. The amphibole, usually present as subhedral lath porphyroblasts, can be up to 5 mm long. Both aluminous and non-aluminous amphiboles have been determined from the orebody granulites. Though hornblende appears ubiquitously through the rocks of the Shamrock Mine, the non-aluminous amphiboles are generally only found in close proximity to the ore zone. Three distinct non-aluminous amphiboles have been identified, anthophyllite, cummingtonite and tremolite-actinolite.

The hornblende varies from colourless to a dark-green and occurs sporadically throughout the ore zone granulite, and never occurs together with non-aluminous amphiboles. It generally occurs as scattered porphyroblasts 1 to 2 mm long showing typical poikiloblastic or "sieve structure" with remnant groundmass plagioclase occurring as small inclusions. These amphiboles are described in detail in the section B5, "Mineralogy". The colour of the hornblende is generally darker green outside the ore zone in both hangingwall and footwall, and shows a strong pleochroism outside the ore zone with a weaker to non-existent pleochroism within the ore zone. The extinction angle c/Z was generally constant for the hornblendes between 14° and 17° . The refractive indices of the hornblendes of the ore zone are distinctly lower than those in the hangingwall.

The non-aluminous amphiboles all have a similar mode of occurrence and appear similar in hand specimen. The anthophyllite is seen to be colourless to straw-coloured, (Plate 16 A and B) the cummingtonite a pale-brown (Plate 16 C) and the tremolite-actinolite a pale to distinct green (Plate 16 A, E and F).

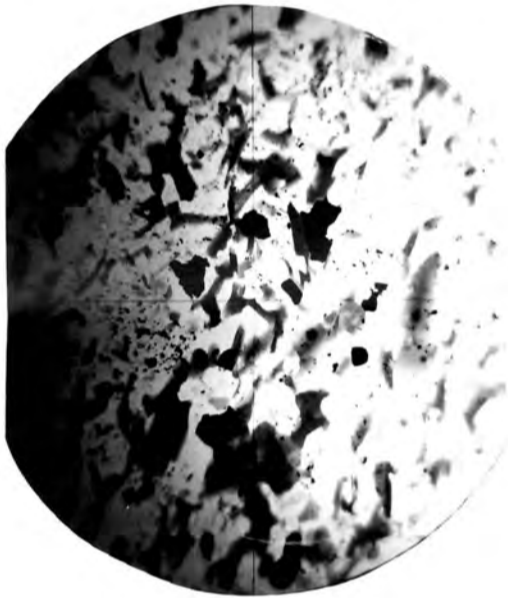
PLATE 12



A



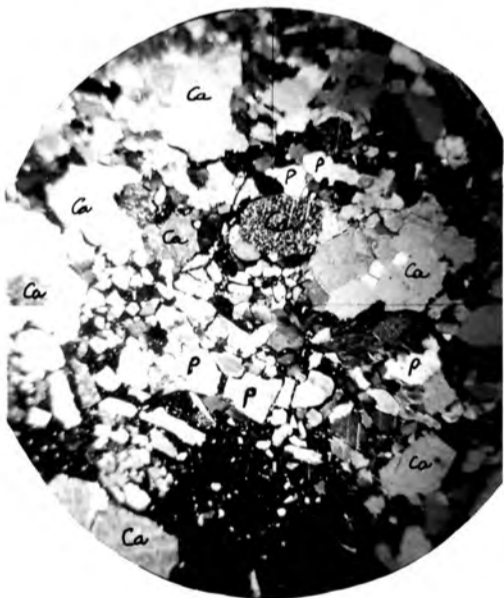
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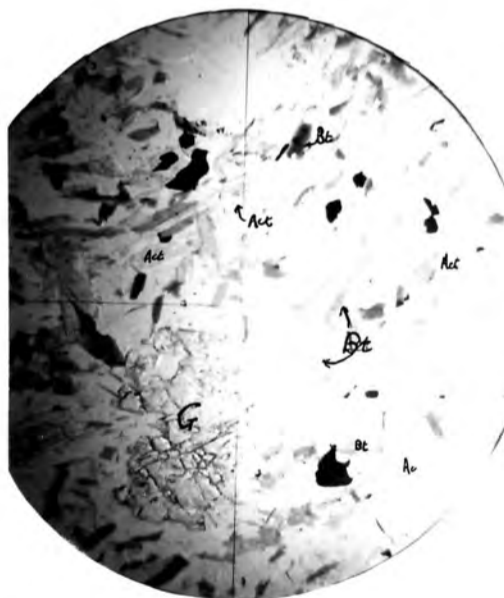
C



D



E



F

EXPLANATION OF PLATE 12.

- A. Medium-grained biotite granulite. Note unaltered clear felsic groundmass with basal and prismatic biotite (Bt). Scattered rutile prisms (e.g. centre of cross hairs).
Ordinary light. Low Power X 40.
- B. Medium-grained biotite granulite. Granoblastic plagioclase groundmass with no twinning.
Crossed Nicols X 40.
- C. Fine-grained biotite granulite with scattered sulphide ore. Groundmass is granoblastic plagioclase with very minor quartz.
Ordinary light. X 40.
- D. Fine-grained biotite granulite with scattered sulphide ore (cf 12C). Groundmass is granoblastic plagioclase with very minor quartz.
Crossed Nicols X 40.
- E. Medium-grained calcareous granulite. Note absence of biotite. Anhedra calcite crystals (Ca) larger than plagioclase groundmass (P).
Crossed Nicols X 40.
- F. Garnet actinolite granulite- anhedra pale-grey to pink garnet (G), very pale actinolite prisms (Act) and pale brown biotite (Bt).



These non-aluminous amphiboles occur either as needle-like crystals or large elongated widely scattered porphyroblasts, often poikiloblastic, the "sieve structure" being more marked in the granulites than in the surrounding schists.

Accessory minerals are rutile, calcite, apatite and the iron and copper sulphides. The rutile occurs as minute yellowish brown crystals showing straight extinction and having an adamantine lustre, the calcite generally as anhedral crystals, and the apatite as rounded, columnar and narrow needle-like crystals.

The granulites show distinct differences one to another and the following types have been identified: Biotite Granulite

Amphibole Biotite Granulite (Hornblende, anthophyllite,
cummingtonite, and
tremolite-actinolite.)

Garnetiferous Biotite Granulite

Calcareous Biotite Granulite

Grey Glassy Granulite.

Biotite Granulite (See Plate 12 A, B, C and D).

The simple biotite granulite of the ore zone is generally a fine-grained, pink to grey felspar biotite rock, with an equigranular fabric consisting largely of plagioclase and biotite. The abundance of biotite often imparts a slight schistosity to the fabric. In places the pale felsic minerals are distinctly glassy. In thin section they are fine-grained and granoblastic with the felsic minerals a mass of plagioclase which is seldom twinned. The plagioclase is generally unaltered and fresh. Biotite occurs as two types, the more abundant anhedral light-brown non-pleochroic groundmass crystals becoming green in places, and the occasional well formed highly pleochroic subhedral prismatic laths. These laths can be up to 0.2 mm long. From both microscopic examination and selective staining it appears that there is little or no quartz in the fabric. The mineral assemblage is plagioclase and biotite with accessory amphibole, calcite, rutile, sphene and opaque ore.

Amphibole Biotite Granulite

As previously discussed the amphiboles in these granulites are hornblende, anthophyllite, cummingtonite, and tremolite-actinolite. The mode of occurrence of these minerals is described in detail under Section B5 "Mineralogy". These amphibolised granulites are generally fine-to medium-grained and pinkish. The amphibole porphyroblasts are generally sub-linear or occur as shreds and scattered porphyroblasts throughout the groundmass fabric. The amphibole crystals can be

from 1 mm to 5 mm. The amphibole in porphyroblastic habit can at times be estimated at 20% of the rock. The groundmass fabric is very similar to the biotite granulite.

Within the amphibole porphyroblasts scattered minute crystals of rutile are present which are either dark red-brown slightly pleochroic and anhedral crystals, or occur as narrow short columnar crystals and as small granules.

Grey Glassy Granulite

There is a variety of medium-grained compact grey granulite showing a mass of glassy feldspar and occasional small colourless fibrous amphiboles, and finely disseminated chalcopyrite and pyrrhotite. The peculiarity of this rock is the limited amount of biotite making its appearance only as occasional flakes.

Garnetiferous Granulite (See Plate 12 F).

Where the granulite is garnetiferous the garnets are almandine, pink to grey in thin section, showing a distinct poikiloblastic texture. Generally where garnets occur apatite is an accessory mineral.

Calcareous Biotite Granulite (See Plate 12 E)

This is a medium-grained compact grey calcareous granulite or a medium-grained pinkish amphibolised granulite with an abundance of scattered anhedral calcite in the groundmass. In thin section the rock comprises a granoblastic fabric with crystals of plagioclase feldspar and calcite of varying size. The calcite are crystals up to 0.1 mm in size, anhedral in habit, showing polysynthetic twinning in two directions. Tremolite-actinolite is generally scattered about the groundmass as small anhedral and subhedral crystals. Occasional biotite occurs within this rock. When the rock type is compared in thin section with the calcareous grit west of the Shamrocke deposit, there is a distinct similarity in texture and mineral composition. Calcite can comprise some 40% to 50% of the rock.

PORPHYROBLASTIC FELSPAR-AMPHIBOLE ROCK (See Plate 15 A and B)

This is a coarse-grained porphyroblastic feldspar-amphibole rock which at the outset of the study was termed from hand specimen evidence " Quartz Amphibole Rock". However, in subsequent thin section work little quartz was found. Again the diagnostic assemblage plagioclase - hornblende occurs with porphyroblasts of

dark green amphibole occurring within a xenoblastic groundmass of plagioclase with minor quartz. The plagioclase feldspar generally is clear and mostly untwinned, with occasional twinning with poorly developed composition planes. Alteration of the feldspar gives shreds of epidote which in some cases become quite abundant.

The dark-green extremely pleochroic amphibole has all the properties of hornblende. In hand specimen the hornblende occurs as large dark-green bladed laths up to 10 mm in length, either orientated sub-parallel or more generally with irregular arrangement. The large poikiloblastic crystals show a distinctive "sieve structure" with interstitial clear untwinned plagioclase. The green colouration of the hornblende of this rock of the ore zone is decidedly paler than the dark green of the hornblendes of the hangingwall feldspar-amphibole rock and has a weaker pleochroism.

Similar to the granulite, the porphyroblastic feldspar-amphibole rock contains some 5% of quartz, occurring as clear anhedral crystals (uniaxial positive) which are unstained by potassium rhodizonate.

These rocks become at times exceptionally calcareous, the calcite occurring as a variable component of the groundmass, with typical calcite relief and birefringence. The calcite occurs either within the groundmass fabric or is associated with the hornblende in the interstices of the poikiloblastic texture.

An average modal analysis was as follows:

plagioclase	55%
hornblende	34%
quartz	5%
opaque ores	2.5%
biotite	1%

and sphene, garnet rutilite and

apatite	1-2%
---------	------

The relative proportion of groundmass to porphyroblasts averaged 70% groundmass and 30% porphyroblasts. The rutilite occurs as clusters of abundant yellow-brown minute laths and tiny occasionally rounded anhedral crystals scattered throughout the fabric (occasional knee-twins). Apatite generally occurs scattered through the rock as small rounded crystals. Occasional large isotropic basal sections of apatite occur.

CARBONATE ROCKS (See Plate 19 B)

The carbonate rocks, other than the calcareous granulite and schist, vary in composition from pure dolomite, through dolomitic limestone to pure limestone.

The dolomite, generally occurring high in the sequence above the ore zone, is a medium-to coarse-grained pinkish crystalline dolomite with much crushed green amphibole, giving a large scale mottled appearance with much finely disseminated pyrite. Occasionally the dolomite is a coarse-grained pink and grey crystallised dolomite with no other mineral present.

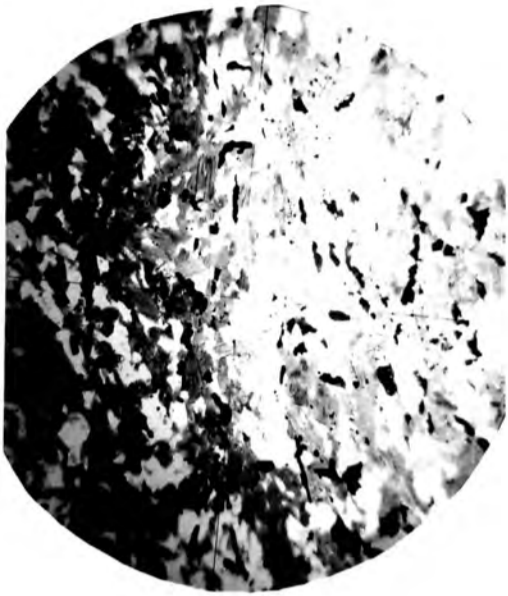
The dolomitic limestone and pure limestone is generally a fine-to medium-grained light-grey to white limestone often with some remnant schist. The fine-grained rock is compact and hard with the coarser-grained varieties appearing to be somewhat granular. Occasionally these become quite silicic in part with granoblastic quartz development. Some biotite and pyrrhotite is at times found, particularly in narrow bands along the bedding.

AMPHIBOLITES

From field evidence the plagioclase amphibolite is often transgressive to the Lomagundi Sequence and obviously often causes the induration of the immediate surrounding rock. The contacts of the plagioclase amphibolite are generally finer-grained, in some cases this gradation to finer-grained towards the contacts being very marked. Within the larger bodies of plagioclase amphibolite there often occur narrow bands of a generally finer-grained plagioclase amphibolite of identical composition, again exhibiting fine-grained margins. This evidence, together with the composition and fabric similar to the plagioclase amphibolite of igneous origin elsewhere in the world, make it obvious that these amphibolites are metamorphic products of a basic igneous rock, an original diabase or dolerite. The "chilled" margins and the presence of an idioblastic biotite-garnet contact zone indicate very often different "heaves" within a large body.

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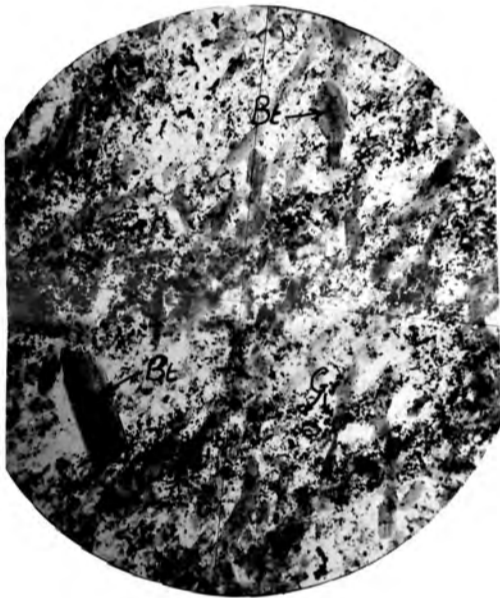
PLATE 13



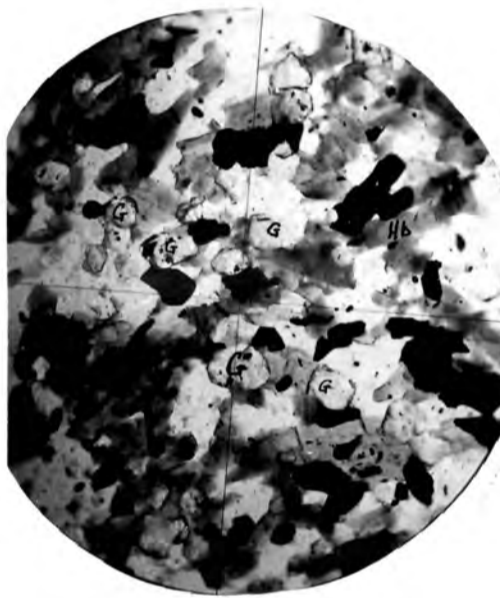
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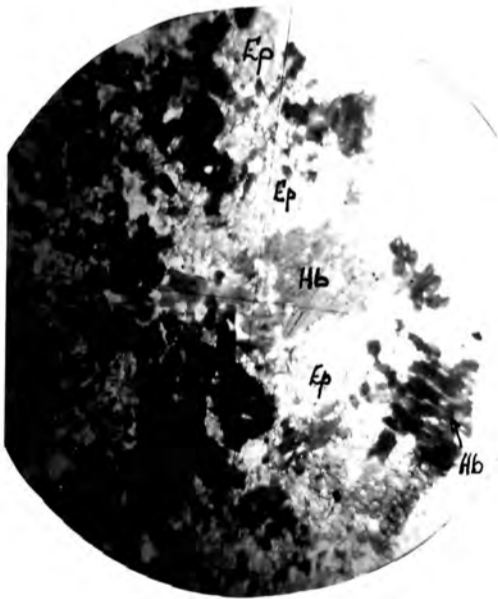
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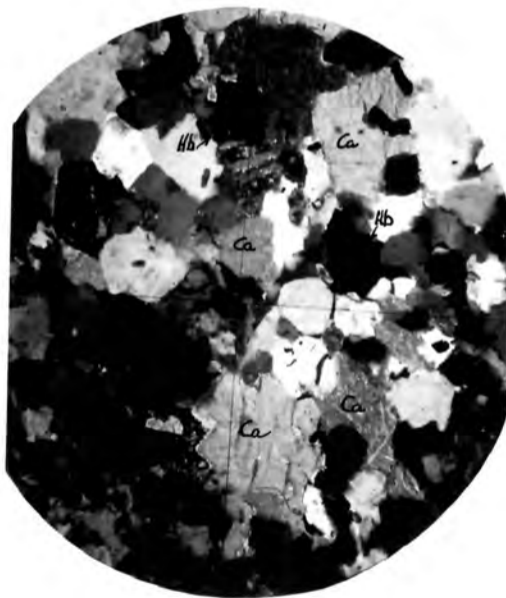
C



D



E



F

EXPLANATION OF PLATE 13.

- A. Fine-grained plagioclase amphibolite, showing both sub-parallel laths and basal sections of hornblende. Opaque ore is scattered throughout.
Ordinary light X 40.
- B. Fine-grained plagioclase amphibolite, with long narrow crystals of ilmenite (ilm) with abundant sphene granules (Sph).
Ordinary light. Medium power X 100.
- C. Fine-grained graphitic plagioclase amphibolite, with minute shreds and aggregates of graphite.
Ordinary light. Medium power X 100.
- D. Highly garnetiferous plagioclase amphibolite. Garnets pale grey, rounded and unshattered (G). All the dark silicates are hornblende (Hb), with no biotite present. Opaque ore minerals include narrow ilmenite crystals.
Ordinary light X 100.
- E. Epidotised plagioclase amphibolite. Epidote as granular masses (Ep). Extremely pleochroic hornblende (Hb) shown in different positions.
Ordinary light X 40.
- F. Calcareous plagioclase amphibolite. Calcite as anhedral crystals in groundmass.
Ordinary light X 100.

It is pertinent to note that some of the more biotitic and schistose amphibolites could well be of sedimentary origin, however, it is perhaps beyond the scope of the present study to identify these with certainty.

The Plagioclase Amphibolite (Meta-dabase) (see Plate 13 A, B, C, D) is a fine-medium and coarse-grained plagioclase amphibolite with macroscopic dark-green amphibole and white feldspar. The fabric, as seen in hand specimen, is either a fine dark compact rock or, with increasing grain size and clustering of the feldspar, a more spotted variety.

Occasional porphyroblasts of varying size occur which appear to be a segregation of white to grey feldspar. As the general grain size of the fabric increases, these segregations increase in size, and often tend to be developed along a foliation. These porphyroblastic segregations vary in size from less than 1 mm up to occasionally 4 cm in length. In places these plagioclase amphibolites are schistose in appearance, where both the hornblende prisms and plagioclase porphyroblasts have a preferred orientation.

The biotite content of the plagioclase amphibolite varies considerably. As the biotite content in the rock increases so it takes on a more schistose appearance, particularly in the fresh broken section.

Occasionally the plagioclase amphibolite becomes highly garnetiferous (see Plate 13E) where discrete garnet crystals are scattered abundantly throughout the rock fabric. These garnets vary in size from microscopic up to 5 mm in size, and are a pale pink, almandine garnet, occurring as rounded crystals with plagioclase, quartz and opaque ore inclusions.

In thin section the plagioclase amphibolite often shows an obvious preferred orientation of hornblende prisms which defines a schistosity, or a lineation, or both. Hornblende and plagioclase are equally abundant, the hornblende occurring as a dark-green pleochroic amphibole in the form of subhedral laths (110) or occasionally basal sections; the plagioclase as equant xenoblastic crystals of clear to slightly turbid feldspar with only occasional twinning. The hornblende varies in grain size from 0.1 mm in the fine-grained variety to 1 mm in the coarse-grained rock. Optical analysis shows the hornblende to be different to the hornblende of the other rock types of the area by exhibiting a slightly larger 2V angle (average 60-78°) and a slight decrease in the refractive index. Biotite in the form of both dark-brown highly pleochroic laths and non-pleochroic anhedral patches, is extremely common in varying proportions, quartz is a minor mineral, and accessory minerals are rutile, apatite and the opaque ores. Epidote has only been seen to occur in a few isolated places (see Plate 13F) the lack of abundant epidote is unusual but may, as is discussed

later, be due to the fact that the epidote often substitutes for the anorthite content of plagioclase, and with the plagioclase of the Shamrocke rocks almost always less than An_{30} , the epidote cannot form from the plagioclase.

Calcareous plagioclase amphibolite (see Plate 13 D), occurs where the calcite causes strong effervescence with dilute HCL. In the more calcareous plagioclase amphibolites, the hornblende content is slightly lower than usual and a greater porportion of the rock is composed of felsic minerals.

Apatite is developed throughout, either as long needles up to 0.2 mm in length, as inclusions in the biotite, or as tiny discrete crystals.

The mineral assemblage of the plagioclase amphibolite is generally plagioclase and hornblende with accessory quartz, garnet, apatite and opaque ore (pyrrhotite and ilmenite).

An average modal analysis as carried out on the CTS point counter is as follows:

plagioclase felspar	21%
hornblende	46%
quartz	8%
biotite	16%
opaque ores	8%
garnet, quartz and apatite	1%

"Chilled" Margins Contact Zone Plagioclase Amphibolite/Schist

In places in the field it is obvious that the large plagioclase amphibolite bodies are obviously transgressive and intrusive in character, showing fine-grained chilled margins. In addition to this the graphitic schists are distinctly indurated for a short distance from the intrusive. This induration produces a hard compact flinty black-to dark-grey schist, very often with scattered minute garnet porphyroblasts. The plagioclase amphibolite is generally fairly coarse-grained, however approaching the margin of the intrusion the fabric becomes finer-grained with an increased development of biotite. Garnets are developed at the margin forming a contact zone of idioblastic biotite and garnet from one inch to a few inches wide. Examination of thin sections cut at intervals across the contact zone show an increase in size of the biotite porphyroblasts towards the contact. This biotite can be up to 1 mm across and shows a very distinct pleochroism from pure yellow in the X direction through dark-brown in the Y direction, to a very dark opaque brown in the Z direction.

THE ARGILLACEOUS SERIES

Southwards from the Shamrocke Mine and overlying the Dolomite Series, the Argillaceous Series is a sequence of intercalated metamorphosed argillaceous and arenaceous horizons, being intruded by large bodies of plagioclase amphibolite, both transgressive and semi-concordant. Micaceous phyllites and schists, and white to buff coloured sandstones and quartzites occur.

This sequence is correlated with Workman's Lower Shale Group, which he describes as predominantly shales with subsidiary bands of quartzite. The quartzite he describes as being usually thin and persistent, except in one place in the Angwa River north of the Deta River. Here he describes a thick formation of flaggy quartzites. In the area of the Deta/Angwa River confluence the quartzites are thick and cover large areas.

Metamorphosed Argillaceous Rocks.

These are represented by various types of mica schist, in some instances graphitic. The more predominant form is a fairly coarse-grained dark-grey to black mica schist, where the mica is predominantly biotite, muscovite and sericite. These mica schists often show a silky appearance due to the abundance of large micas.

Dark fine-grained phyllites also occur with a more compact fabric. Adjacent to amphibolitic intrusions these phyllites have become indurated and amphibolised to dark compact aphanitic rocks with occasional large porphyroblasts of hornblende.

Metamorphosed Arenaceous Rocks.

These are represented by two distinct types, a fine-to medium-grained compact grey-white meta-quartzite and a medium-grained grey to brown felspathic sandstone. These outcrop as blocky ridges giving little indication of strike and dip.

SELECTIVE STAINING

The granoblastic fabric of the granulite and felspar-amphibole rock, and the anhedral, relatively clear, and untwinned nature of the silic minerals makes it virtually impossible to distinguish between quartz-orthoclase-plagioclase, without resorting to the selective staining of the rock. Furthermore the application of a staining technique assisted materially in distinguishing calcite from dolomite.

The Quartz-Orthoclase-Plagioclase Problem (see Plate 14, A, B, C, D, and E).

The clear, pellucid and untwinned anhedral crystals in thin section were examined optically without being able to readily identify each crystal. Apart from the identification of each individual crystal, the difficulty of ready recognition of the minerals made modal analysis of the rock impossible.

Extensive examination of the interference figures gave early indication that quartz was subordinate to felspar in the majority of the felsic rocks and that in some of the granulites quartz was all but absent. Very few uniaxial interference figures were obtained, and, allowing for a degree of strain in the quartz crystals, it was obvious that the rock comprised largely felspar, orthoclase or plagioclase. As is typical of metamorphic rocks the plagioclase is generally untwinned and therefore to distinguish between orthoclase and plagioclase in the granulite and felspar-amphibole rock of the Shamrocke was difficult without selective staining.

The staining was not highly successful but did allow sufficient reaction to distinguish between the minerals and to facilitate modal analysis.

The selective staining method chosen was as described by Edgar H. Bailey and Rollin E. Stephens (1960) "Selective Staining of K-Feldspar and Plagioclase on Rock Slabs and Thin Sections". They describe a method where plagioclase is etched by hydrofluoric acid, the etched surface treated with a solution of barium chloride, and then stained red by the reaction with potassium rhodizonate. The procedure is combined with the cobaltinitrite staining of K-feldspar to a bright yellow. The staining of K-feldspar with cobaltinitrite was described by Gabriel and Cox (1929) and developed by Rosenblum, (1956). The method caused the residual potassium in the K-feldspar to react with the sodium cobaltinitrite to form yellow potassium cobaltinitrite. The staining of the plagioclase is achieved by the calcium ion in the etched surface being replaced by the barium which in turn reacts with the rhodizonate reagent to form red insoluble barium rhodizonate.

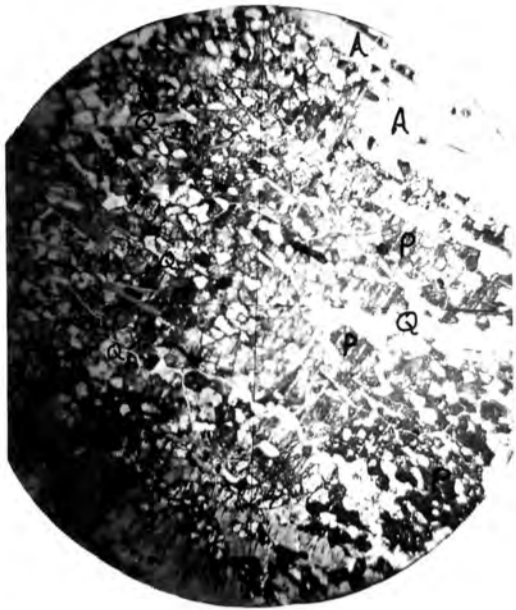
Due to the fine-grained nature of the rocks, the staining of thick sections was not successful and all the staining was done on thin sections. Again due to the fine-grained fabric of the rocks the staining was not highly successful but was sufficient to identify the minerals.

The staining method was attempted, varying all the parameters of length of time of etch, etching by immersion in the HF or using the vapour only, thickness of section etc. The best results were obtained with thin sections and an etch time of 45 seconds in the HF vapour.

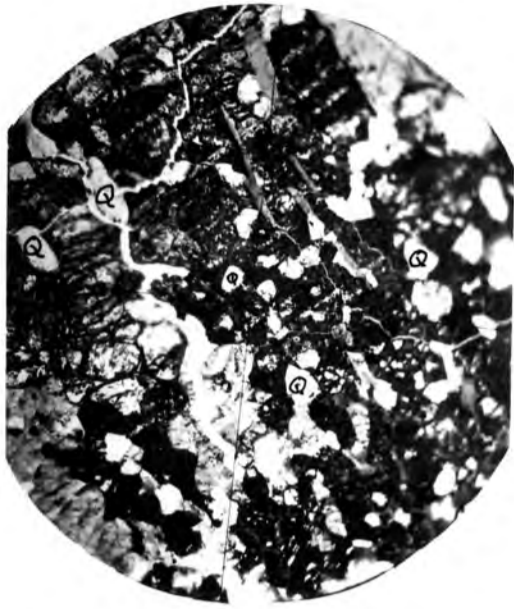
The results of the selective staining with rhodizonate and cobaltinitrite were as follows:

1. The cobaltinitrite stained some of the biotite differentially yellow and only in one section did one salic crystal stain yellow. It must therefore, be assumed that the method was successful and that orthoclase is virtually absent from the rocks.
2. The rhodizonate reaction stained the plagioclase differentially red. The red stain is quite marked on the section under the binocular microscope in transmitted light but loses distinction in transmitted light. The red staining clearly indicates that plagioclase is the predominant mineral. This is substantiated by the modal analyses.
3. The most successful aspect of the technique was the etching of the plagioclase with the hydrofluoric acid, the quartz being unaffected. The enhanced relief of the plagioclase crystals in thin section by the HF etching was the most useful identification criterion during the modal analysis of thin sections.
4. The quartz did not etch with the HF and did not stain, making it readily identified after staining.
5. The stain colours are not intense enough for thin section colour photography, while the differences in relief between the plagioclase and quartz is readily visible in treated thin section and are recorded by black and white photographs (Plate 14 A, B, C, D and E).
6. Some of the biotite coloured differentially pink.

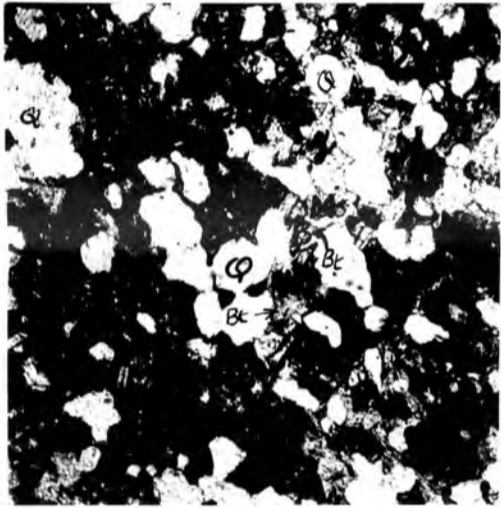
PLATE 14



A



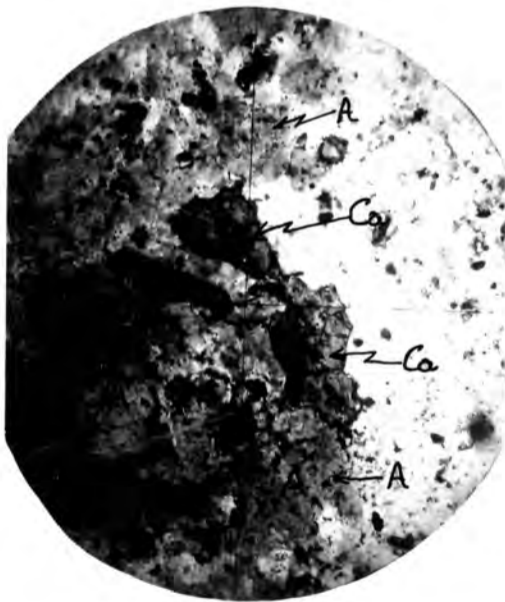
B



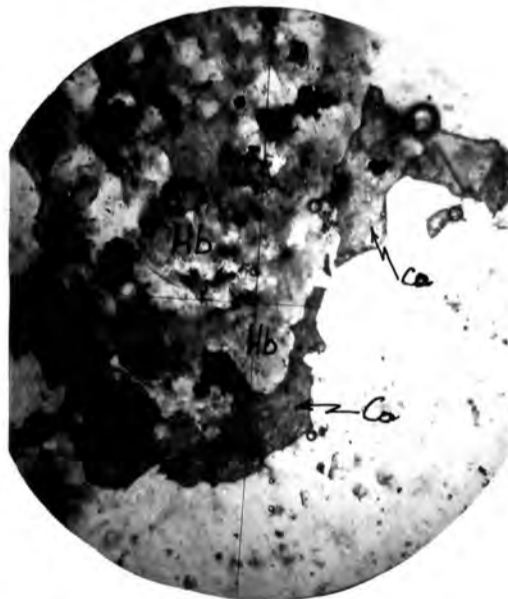
C



D



E



F

EXPLANATION OF PLATE 14.

A. Porphyroblastic felspar-amphibole rock stained with potassium rhodizonate. The plagioclase felspar is stained red, while the quartz remains unstained. The coarser grain of the rock facilitates staining, more than the finer-grained granulite.
Ordinary light X 40.

B. Porphyroblastic felspar amphibole rock stained with potassium rhodizonate. The plagioclase felspar is stained red, while the quartz remains unstained. The coarser grain of the rock facilitates staining more than the finer-grained granulite.
Ordinary light X 100.

C. Fine-grained biotite granulite after etching and staining with HF and rhodizonate. Q and similar grains are quartz, unaffected by etching and staining. P and similar grains are plagioclase etched and differentially stained red. Dark elongate grains are biotite.
Ordinary light X 50.

D. Fine-grained biotite granulite with all plagioclase grains well stained red by rhodizonate; the quartz remains unstained. The plagioclase are the dark semi-opaque crystals due to deep stain.
Ordinary light X 50.

E. Calcite crystals (Ca) stained deep red-purple with haematoxylin solution in amphibolised (A) calcareous granulite.
Ordinary light X 40.

F. Calcite crystals (Ca) stained red-purple with haematoxylin solution with hornblende (Hb) in calcareous granulite.
Ordinary light X 40.

The Calcite-Dolomite Problem

Without resorting to selective staining of the calcite and dolomite, it was originally very difficult to distinguish between calcite and dolomite by either macroscopic or microscopic examination. However after staining, which in this instance was extremely successful, the results were examined in the light of optical properties and appearance, and it then appeared reasonable to identify the carbonate with some degree of confidence.

Having checked various parameters against the result of staining, the following observations became apparent:

- (i) The calcite generally occurs as anhedral irregular crystals when constituted within the rock fabric, whereas the dolomite generally tends to have crystals with straight sides and display often a more anhedral rhombohedral habit. In thin section this is obvious, whereas in the hand specimen the criterion appears to be evidence of a greater crystallinity of the dolomite within the rock fabric. The crystallised white calcite as secondary veining and "blows" within the ore zone is of course an exception to this.
- (ii) The calcite crystals generally appear to be slightly turbid and show a slightly less distinct cleavage in ordinary light, and less distinct twin composition planes in crossed polarised light. Dolomite on the other hand is completely colourless and the cleavage traces are very sharp in ordinary light, whereas the twin planes are very distinct in crossed polarised light.
- (iii) The slight turbidity or murkiness of the calcite crystals appear to exhibit an anomalously high relief relative to the colourless and completely clear dolomite.

As stated above the selective staining of the calcite was very successful. The staining technique as described by Fairbanks (1925), was used where calcite is rapidly stained dark red and then deep purple, and the dolomite is unaffected, by treatment with a solution of haematoxylin and aluminium chloride.

The solution was applied to the surface of rock fragments and polished thick and thin sections. The calcite stained rapidly deep red and then purple while the dolomite was unaffected. (See Plate 14 E and F).

The only precaution taken was to apply only a thin film of the haematoxylin solution, as too much tended to allow the colour to run over the specimen. Furthermore the stain was liable to spread to surrounding crystals on standing and all observations were made and photographs taken almost immediately after staining. Even the application of glycerine tended to cause the colour to run.

In hand specimens the calcite stained very easily rendering that contact of the rock easily visible.

In thick and thin sections the staining was as successful and allowed, particularly from thin section, the detailed observation of the textural relationships involving the calcite. Staining of the thin sections allowed for recording this staining by photography in transmitted light (see Plate 14 E and F).

This method of staining is both rapid, easy to apply and diagnostic.

MODAL DATA

Modal proportions were determined for the various types of granulite, the felspar-amphibole rock and the plagioclase amphibolite. The schist and phyllite proved too fine-grained for modal composition determination. The modal analysis was undertaken using a Swift Point Counter to examine only thin sections that had been treated by the cobaltinitrite and rhodizonate staining techniques.

Subsequent to the staining the minerals were readily recognisable in thin section, both the red stain to the plagioclase and its greater relief after etching with HF making identification of plagioclase from quartz during linear traversing of the thin sections satisfactory.

Results of the Modal Analyses1. GranulitesFine-grained pink Schistose Biotite Granulites(Sample M3)
Orebody Sample.

	<u>Volume %</u>
Plagioclase	34.9
Biotite	37.3
Carbonate	12.5
Ore Minerals	9.4
Hornblende	5.4
Quartz	0.6

Medium-grained pink Schistose Biotite Granulite(non amphibolitic)
(Sample M 25)
1000' above Orebody.

	<u>Volume %</u>
Plagioclase	36.5
Biotite	30.6
Quartz	28.3
Ore Minerals	4.6
K-Felspar	Trace.

Fine-grained pale-grey Anthophyllite Granulite (Sample M 14)
Orebody Sample.

	<u>Volume %</u>
Plagioclase	85.0
Amphibole	7.2
Biotite	2.2
Ore Minerals	3.5
Quartz	2.2

Fine-grained pale white-grey Biotite Granulite (Sample M 24)
Orebody Sample.

	<u>Volume %</u>
Plagioclase	78.1
Biotite	11.6
Quartz	5.2'
Ore Minerals	3.5
Amphibole	1.5

Fine-grained pale-grey Silicic (Cherty) Granulite (Sample No. 83)
232' above Ore Zone.

	<u>Volume %</u>
Plagioclase	43.9
Quartz	39.1
Muscovite-biotite	12.8
Ore Minerals	4.2

2. Felspar-Amphibole Rock

(Sample B/427 at 2050'0")
Ore Zone Sample

	<u>Volume %</u>
Plagioclase	55.1
Hornblende	33.5
Quartz	5.9
Ore Minerals	2.65
Biotite	1.1
Sphene, Garnet, Apatite	1.8

3. Plagioclase Amphibolite

	<u>Volume %</u>
Hornblende	46.9
Plagioclase	20.8
Quartz	8.1
Biotite	15.5
Ore Minerals	7.5
Sphene, Garnet	1.2

It is interesting to note the very low quartz content of the granulite and felspar-amphibole rock of the ore zone (less than 6% and in one instance 0.6%). The two modes determined for granulite 232 feet and 1000 feet above the ore zone showed the quartz to be 28.3% and 39.1% of the rock. This result was expected after optical examination of the rocks of the ore zone and those of the hangingwall and it would appear that the rocks of the ore zone are quartz deficient. Further staining and modal analysis would be imperative to prove this.

B5 MINERALOGY

NON OPAQUE MINERALS

PLAGIOCLASE FELSPAR

The principal minerals of the Shamrocke rocks are plagioclase feldspar, biotite and amphibole. The plagioclase has been studied in detail, in the hope that the results may lead to a better understanding of the nature of the original rock types and the metamorphic and metasomatic changes these rocks have undergone to produce the well mineralised orebody granulite of the Shamrocke deposit, and their associated hangingwall and footwall rocks.

Plagioclase feldspar occurs as the dominant felsic mineral in all the rocks of the Mine. Modal analyses, following the staining of sections, show that nowhere in the vicinity of the Shamrocke orebody does the plagioclase constitute less than 90% of the felsic constituents of the rock.

Suitable plagioclase crystals within some 50 thin sections were examined with the universal stage and their average composition, zonal variation in composition, twin characteristics and optic orientation determined. The results of these determinations are discussed below.

Appearance in Thin Section

The plagioclase crystals are typical of the plagioclase feldspar of metamorphic rocks. They are granular, xenoblastic and generally clear and untwinned. Although these xenoblastic crystals, as a general rule, show no distinct morphology, there are instances where one or two cleavage traces are visible, and in more isolated cases, twinning. The general lack of twinning and/or visible cleavage traces makes composition determination and study of the feldspars tedious and difficult.

Where twinning does occur there is an absence of fine polysynthetic lamellae. The more abundant twinning takes place on the Albite and Al₁A twin laws with lamellae being very rare. Visible cleavage traces correspond to (010) and (001).

The crystals are extremely uniform in size, the normal size of the groundmass plagioclase being 0.1 to 0.2 mm., while scattered larger crystals up to 0.4 mm. occur. The crystal dimensions in the mica schists, however, are of the order of 0.1 mm. or less.

These crystals are usually clear and unaltered, inclusions are not abundant (apart from graphite which is heavily included in the plagioclase of the mica schist).

Twinning and Cleavage

The twin characteristics of these plagioclase feldspars are similar for all the Shamrocke rock types and show dominant twinning on the Albite Law, where the composition plane is (010) and the twin axis is perpendicular to (010); and the Al₂A Law where the composition plane is (001) and the twin axis is (100). Subordinate twinning on the Albite-Carlsbad, Pericline and Manebach laws were encountered, and, although of limited occurrence, these were important for composition determinations.

The results obtained from the examination of upwards of 125 crystals on the universal stage indicated that there does not seem to be any relationship between chemical composition of the plagioclase and the commoner twin laws.

In isolated crystals, there is well developed cleavage, where either one or two cleavage traces are visible. These are the (001) basal and (010) brachypinacoidal cleavages.

Where Pericline twinning was observed, it is as extremely fine lamellae which are easily confused with the basal cleavage. Due to the fineness of twinning, if only one direction occurs within a plagioclase feldspar crystal, it is at times difficult to distinguish twin lamella from the trace of the basal cleavage. However, where in isolated cases both exist within the same crystal, it is possible to measure the angle between the plane (001) and the composition plane. This angle is generally very small, of the order of 5° .

Optic Orientation

There appears to be a tendency towards a preferred orientation within the plagioclase. In a single thin section the orientation of the indicatrix is practically the same for all crystals.

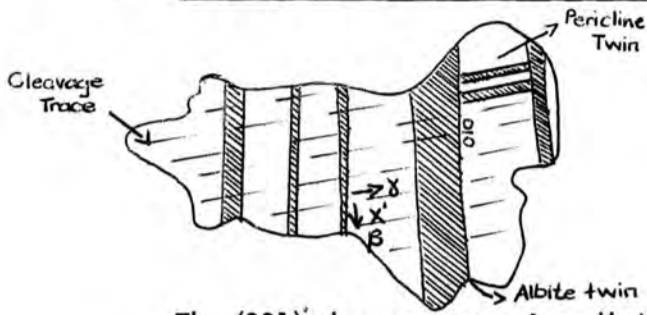
The rock sectioning was not done with specific orientation relative to minor structural features, or to the attitude of the orebody. Hence any statement relating the optical orientation of the feldspar to local structures and stress conditions cannot be made with confidence. However, it does appear that the principal section ("A plane which includes the optic axes is called a Principal Section", Wahlstrom (1949), containing the vectors β and γ , consistently lies in a plane with the schistosity, and where schistosity or bedding is lacking, e.g. within the orebody granulite, this principal section appears to lie in a plane parallel to the general dip of the orebody. As the composition of the plagioclase is relatively low in the anorthite molecule, the crystallographic axis Z, of the plagioclase lies within the plane of the schistosity. (In the Albite-Oligoclase portion of the plagioclase series the principal plane containing the vectors β and γ is practically parallel to the macropinacoid (100) and hence the crystallographic axis Z.)

In most plagioclase crystals examined, the β vector could be brought parallel to the control axis of the Universal Stage (i.e. in sections cut parallel to the schistosity), and at least one optic axis brought parallel to the microscope axis. With the large $2V$ angle of plagioclase the cases where both optic axes could be brought into this position are restricted to crystals where both the crystallographic planes 001 and 010 can be orientated vertically, i.e. where the X axis can be orientated vertically. This is in accordance with the optical orientation of the oligoclase member of the plagioclase series, where the X axis is virtually parallel to the intersection of planes (001) and (010), and this axis is the acute bisectrix. Oligoclase is shown to be the dominant plagioclase of the Shamrocke rocks. It follows that any plagioclase crystal in these rocks showing two crystallographic directions in the form of twin composition planes, or cleavages parallel to (001) and 010), has a very good chance of showing both optic axes, provided that the anorthite content is not at a maximum or minimum within the range found in the Shamrocke rocks. This would place the plagioclase outside the oligoclase range of composition and hence make the crystals positive, with Z as the acute bisectrix and X no longer parallel to (001) and (010).

Since most crystals are optically negative, and with Y and Z generally in the plane of the section (most sections were cut parallel to the schistosity), the probability of being able to rotate from one optic axis to another is great.

Typical Examples

1. Where the dominant twin is the Albite twin, with the Twin Plane (010)

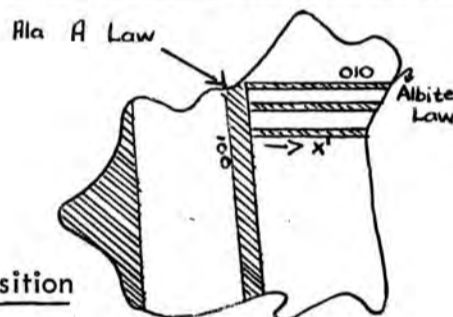


Albite twinning with Subordinate Pericline twinning. The albite twin has a twin plane (010).

The (001) cleavage trace is well developed and the angle between this cleavage plane and the composition plane of the Pericline twin can be determined where both occur in the same crystal. Where they do not occur together in the section of the crystal examined, it is often difficult to distinguish between fine pericline twinning and the (001) cleavage; in this case, a number of parallel traces were accepted as cleavage and any lamella transmitting light and showing an extinction was accepted as pericline twinning.

The faster vibration direction α always lies within a few degrees of the (010) trace, with the slow vibration direction tending to be parallel to the trace of (001).

2. Where the dominant twin is the Ala twin with the Twin Plane (001)



Ala twins on (001) and subordinate albite twinning on (010).

All composition determinations were carried out using the Leitz 4 Axis Universal Stage and the measurements taken were according to the zonal method of Rittmann (Chudoba & Kennedy, 1933). The distinct lack of well developed twin lamellae, the relatively small size of the feldspar crystals and the existence of a certain degree of zoning, makes the Fedorov Method of feldspar determination unsuited to this study. The Zonal method of Rittmann is particularly well suited to measurements on small, poorly twinned feldspar and for the rapid determination of progressive compositional changes within zone crystals.

The accuracy of this method is quite adequate and where conjugate results were constantly being obtained with the Rittmann Method for plagioclase

containing less than 15% of the anorthite molecule, this difficulty was overcome by careful determination of the sign of the extinction angle measured from the faster ray (X) to the trace of (010). (In the Rittmann method of plagioclase determination where the extinction angles in the zone perpendicular to (001) were measured from X to the trace of (001), conjugate positions on the graph were obtained for plagioclase more sodic than An_{25} where the extinction angles are plotted against composition). Where this is the case, the decision as to the correct composition value was made by the accurate determination of the optic axial angle.

The Zonal Method of Felspar (Plagioclase) Determination of Rittmann (Chudoba & Kennedy, 1933), uses the universal stage as a means of orientating the section under study into the most appropriate position for the determination of actual extinction angles. This method is applicable to the determination of the optical properties of the plagioclase of the Shamrocke rocks, due to the comparative lack of twinning, and the number of determinations necessary for the investigation of zonal differences in one crystal. The rapidity of composition determination using this method was essential to the study and depended upon the nature of the cleavage and composition planes in a twinned crystal being determined instantly, and the direct measurement of actual extinction angles after the orientation of the cleavage planes vertically. The procedure adopted using the Zonal Method of Rittmann is described adequately by Carl Chudoba (translated by Kennedy)(1933).

CHARACTERISTICS OF COMPOSITION VARIATION

A great deal of attention was given to felspar determination in an effort to establish a relationship between plagioclase composition and proximity to the orebody. Upward of 50 thin sections were examined and composition determination of more than 125 plagioclase crystals carried out. As a result, some generalisations may be drawn:-

- (i) There is a distinct compositional difference between the plagioclase of the ore zone granulites and that of the country rock.
- (ii) This difference is not created by a serial variation outwards from the ore zone, but depicts a sudden change in composition outside the limits of the ore zone.

- (iii) Zoning was detected in all sections other than the orebody granulite where zoning is apparently absent. The compositional variation within a single crystal is always from an acid core to a calcic margin.
- (iv) Although there is variation in composition within each rock type from place to place, there does not appear to be any variation within any one thin section.

Plagioclase Composition within the Ore Zone Granulite

Within the ore zone granulite the plagioclase was found to be considerably more sodic than that of the hangingwall and footwall rocks. From the examination of suitable granulite thin sections, the plagioclase was always found to contain less than 15% of the anorthite molecule. The composition varies within these granulites from An_{04} to An_{15} , a range of 11% An. Each individual section showed a completely consistent anorthite content of the plagioclase throughout the section, within the range of error of the method.

The composition variation from section to section proves interesting. It was found that no serial variation exists relative to the distance from the hangingwall and footwall contacts with the schist. The plagioclase composition proved irregular throughout the orebody, within the range 4% to 15% anorthite. Due to the continual change of granulite appearance from place to place within the ore zone, it is difficult to relate composition to granulite character; however, it does appear that the more sodic plagioclase occurs adjacent to calcite veins and bodies, in fact the innermost zones of the reaction banding about these calcite masses show the most acidic composition.

Plagioclase Composition within the Porphyroblastic Felspar-Amphibole Rock.

A radical difference in composition was found within the plagioclase felspar of the felspar-amphibole rocks, which often form an intermediate rock type between the ore zone granulite and the surrounding schists; however, they are not restricted to the ore zone and occur at varying intervals within the hangingwall and footwall, and have been found as

far distant as 1000 feet from the ore zone. Suitable sections were examined of this felspar amphibole rock, from both the ore zone, ore zone contacts with the schists, and that found in the hangingwall schists.

In the region of the ore zone and always in close proximity with or sometimes enclosed within the orebody granulite, the plagioclase was never found to be more sodic than An_{33} .

The variation in composition throughout these felspar-amphibole rocks is from An_{23} to An_{28} and, unlike the granulite, shows a variation within a single rock slice. This latter variation can be explained in terms of zoning, with each zoned felspar being intersected at different places by the plane of the rock section. The composition variation due to the effects of zoning will be discussed under that topic.

No distinct compositional relationship was found within the felspar-amphibole rock relative to the distance from the ore zone. However, it does appear that the amphibolites within the ore zone have an average composition of $An_{23} - An_{25}$, that the felspar 300-500 feet from this zone tends not to show an anorthite molecule content of more than 30%, and that those at 1000 feet and more show examples giving a composition of up to An_{38} . The effects of zoning tend to obliterate evidence for a gradational change.

Plagioclase Composition within the Plagioclase Amphibolite

The plagioclase amphibolite occurring throughout the area as the possible alteration product of an originally basic igneous rock gives a constant range in plagioclase composition of An_{23} to An_{33} . This is within the range of the zoning.

Plagioclase Composition within the Mica Schists

The plagioclase felspar of the hangingwall and footwall mica schists is not suitable for optical determination as very few crystals showing twinning or visible cleavage are found. Only 7 crystals in 50 thin sections of the schists gave definite results. These determinations gave compositions which were consistently between An_{30} and An_{35} .

Zoning

The character of the zoning in the feldspars was studied in detail in the hope that the results would shed some light on the difference in composition between the plagioclase of the ore zone granulite and the other rock types of the area.

The ore zone granulite shows an almost complete lack of zoning of the plagioclase. Effects of zoning are found in most of the other rocks of the Shamrocke area, reaching maximum development in the amphibolites. The plagioclase of the mica schists is relatively free of zoning, with exceptions in the high grade garnet amphibole schist.

The degree of this zoning is limited, the range in composition within a single crystal never exceeding 10% of anorthite. The variation of composition within the zoned crystals is in every case from an acid core, becoming increasingly calcic away from this core. The variation is either symmetrical or asymmetrical relative to crystal outline. Phemister, terms a progressive variation of this sort "reverse zoning", and although his nomenclature was applied to crystalline igneous rocks, the literature on zoned plagioclase of metamorphic rocks is so scarce that this term is adopted here.

General Character of the Zoning

- (i) The zonal variation on composition is always from an acid core becoming progressively more basic towards the margins. This is here referred to as reverse zoning.
- (ii) The compositional range within these crystals does not ever exceed 10% of anorthite.
- (iii) The composition of the acid core is relatively constant within a particular rock type.
- (iv) This reverse zoning (see (i)) occurs either symmetrically or asymmetrically relative to the crystal outline. This is illustrated when contour lines of equal composition are drawn within the crystal (see Figure 9). However asymmetrically the core may be situated in relation to the crystal edge, the

zones of progressive composition change generally occur concentrically outwards from this core. The effect of an asymmetrically situated core, is for the opposite margins of the crystal to differ in composition due to the unequal distance from the core, the extreme case being where the core is situated marginally in the crystal, giving rise to a composition difference between opposite marginal areas equal to the zonal range in composition.

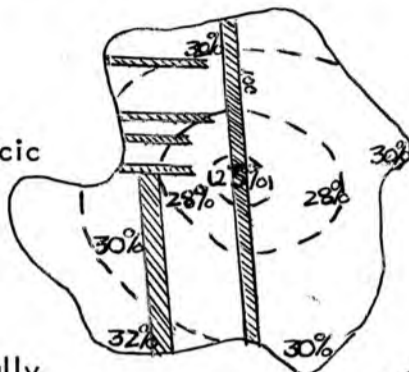
- (v) The progressive variation in composition outwards, as depicted by the composition contours, is more a continuous enrichment in the anorthite content rather than sharply demarcated boundaries between zones of varying composition. The zonal variation of composition within a crystal assumes various characteristics; the most general form being where a reasonably small acid core is surrounded by zones with a constant rate of increase outwards in the percentage of anorthite. However, there are forms showing a departure from this generalisation. These forms are explained in the drawings in Figure 9.
- (vi) While the zoning is predominantly reverse zoning (see (i)); there are isolated examples showing Oscillatory Reverse Zoning (Phemister) but these are very rare (see Figure 9). In these crystals the acid core is generally surrounded by a narrow zone of more albitic composition, with the outer portions of the crystal reverting to reverse zoning.
- (vii) No direction of maximum variation was found relative to any crystallographic direction. The isolated cases where zone contours tend to straighten out, giving a unidirectional change across the crystal, can be explained by the plane of the thin section cutting a zoned crystal well away from the core. The unidirectional variation within narrow twin lamellae is self-explanatory due to the narrowness of the lamellae; zone contours are truncated by a well developed twin composition plane, giving the effect of the one side of such a composition plane, showing zonal characteristics, which do not persist across the twin plane. These cases are relatively rare.
- (viii) Not all the plagioclase crystals show zonal characteristics. No relation between zoning and twinned crystals was found.

(ix) The gradational change is generally more rapid in the immediate vicinity of a small acid core, than further outwards.

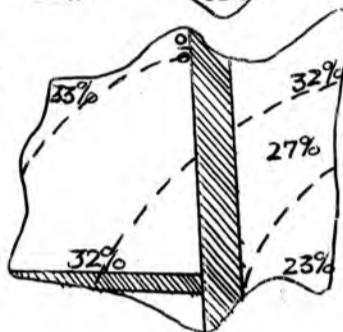
FIGURE 9.

TYPES OF ZONING IN PLAGIOCLASE CRYSTALS

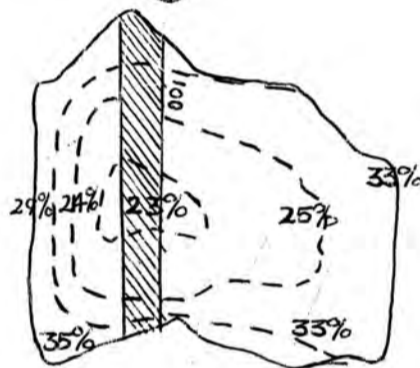
No. 1. Progressive Reverse Zoning with a centrally situated acid core and calcic margins. Type abundant.



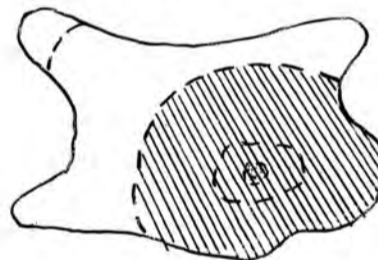
No. 2. Type where the acid core is marginally situated, with the opposite margins of the crystal of vastly different composition. Type fairly common.



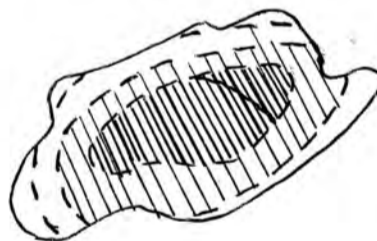
No. 3. Crystal where the acid core is asymmetrically situated, resulting in a greater contour density on one side. Type abundant.



No. 4. Type showing slight asymmetric zoning about a small acid core. Note rapid gradation of composition near the core, with wider spaced contours towards the margin. Type abundant.

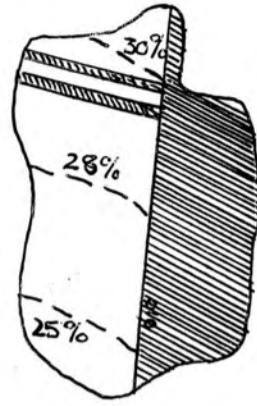


No. 5. A large acid core surrounded by a narrower basic mantle where composition- al change is rapid. Type rare.

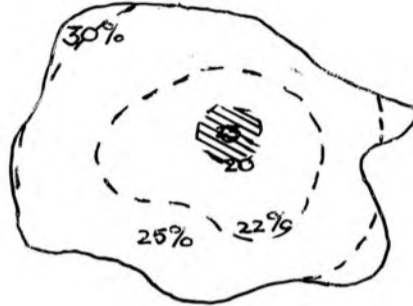


75 b

- No. 6. A crystal showing variation along the length of one twin lamellae, with conjugate lamellae showing no zoning at all.



- No. 7. Rare type of Oscillatory Reverse Zoning, where the more calcic core is surrounded by a narrow zone of more acid composition, with reverse zoning again outwards.



The percentage composition shown in the drawings represents the percentage of the anorthite molecule in the plagioclase.

AMPHIBOLES

Introduction

Amphibole minerals occur throughout the area and provide a rewarding study. They were examined with special reference to specific optical properties, most measurements being carried out on the universal stage, while the indices of refraction were determined by immersion methods. An extensive examination of these properties was carried out with a view to identification in the case of the colourless minerals, to determine as accurately as possible molecular composition, and to establish whether their composition and properties are related in any way to the mineralisation.

The amphiboles can be divided into two main groups: the aluminous amphiboles, falling within the hornblende series, and the non-aluminous amphiboles belonging to the anthophyllite, cummingtonite and tremolite-actinolite series. The aluminous hornblendes are abundant in all the rock types both as constituents of the groundmass and as larger porphyroblasts, whereas the non-aluminous amphiboles are generally found in carbonaceous schist and granulite in the immediate vicinity of the ore zone.

Optical Examination

Measurements of the optic axial angle $2V$, extinction angle c/Z , and the indices of refraction were made for a great many crystals. The value for the optic axial angle was obtained by direct rotation on the universal stage from one optic axis to the other about the optic normal. Crystals with the Y vector in the plane of the section are abundant and these can be quickly picked out and tested with the optic plane vertical and perpendicular to the control axis K.

A lack of twinning on the orthopinacoid makes the accurate determination of the extinction angle c/Z difficult. A method was devised, accepting that the sections on the clinopinacoid had amongst the many cross fractures, traces of a basal parting, these being indicated by parallel arrangement with one another. With this parting vertical, and one of the (110) cleavage planes brought vertical, the crystal is then tilted through 28° bringing the (010) plane horizontal. In this position, again with the basal parting vertical, the angle is measured from the extinction to the trace of the (110) cleavage. If, on tilting the crystal and rotating to extinction, it does not remain extinguished for all rotations about K, the tilt must be effected in the opposite direction. Where the basal parting is

definite this method is considered accurate to within two degrees. Where the parting is not definite numerous measurements were taken on unorientated crystals and the maximum value accepted.

The Y index of refraction was generally used for comparative results and for attempts at composition determination. The method described for pyroxenes by Hess (1949) was adopted, parting fragments on (100) and (110) being used. Measurements were taken only on crystals showing an optic axis near the field of view of the microscope. The Y vector was aligned parallel to the north-south cross wire and brought horizontal by obtaining an isogyre lying horizontal and splitting the field almost exactly. Results obtained on (100) fragments showing straight extinction gave a true value for Y, while fragments on (110) showing an extinction angle gave in fact a component of Y, and a correction of 0.003 was applied to give a value for Y. Where it was difficult to measure the Y index due to the tendency for most fragments to be cleavage fragments on (110), the value for Y was calculated from the known 2V, and the values for X and Z using the formula

$$\tan^2 V_x = \frac{Z - Y}{Y - X}$$

The accuracy of the result obtained for Y from this calculation was found to be surprisingly high, as the value of 2V can vary considerably without affecting the result overmuch.

Composition Determination

The composition of the amphiboles is shown in the following pages by plotting various optical properties against molecular composition for the different amphibole series. The diagrams used are from Winchell, Third Edition, 1933; Winchell, Fourth Edition, 1959; and Deer, Howie and Zussman, Volume 2, 1963. The results of plotting the optical parameters on these diagrams are remarkably consistent.

Ronald B. Parker (1961), published diagrams designed for the rapid determination of the approximate composition of amphiboles and pyroxenes. These diagrams, however, make use of the refractive index determination n_1 and n_2 measured on (110) cleavage flakes, for the rapid and approximate study of variation in chemical composition in which a very large number of samples are to be studied. As in the present study the refractive indices X, Y and Z (α , β and γ) were measured accurately, the diagrams of Parker were not used.

THE ALUMINOUS AMPHIBOLE - HORNBLENDE SERIES

The members of this series in the vicinity of the Shamrocke orebody show a great diversity of character, the difference in appearance and optical properties in relation to this orebody being discussed below.

The hornblende occurs in a variety of ways. The hornblende of the ore zone occurs in three distinct parageneses intimately associated with the sulphide mineralisation and coarse equigranular calcite, as incipient crystals scattered sporadically through the granulite and as large porphyroblasts in the porphyroblastic felspar-amphibole rock.

In the rocks surrounding the ore zone the hornblende occurs as large porphyroblasts in the rocks of sedimentary origin, and as an important constituent in the critical assemblage hornblende-plagioclase of the plagioclase amphibolite of igneous origin.

Some observations made from thin section study (See Plate 15 A, B, C, D, E, and F)

- (i) The colour of the hornblende of the ore zone is of a distinctly paler green contrasted with the dark-green strongly pleochroic hornblende prevalent in all rocks of the hangingwall and footwall. The hornblende is sometimes almost completely colourless, showing correspondingly weak pleochroism to a light green.
- (ii) The refractive indices of this hornblende of the ore zone are decidedly lower than that of the surrounding rocks.
- (iii) The optical properties of the hornblende scattered throughout granulite of the ore zone are identical to that associated with the sulphide mineralisation, these being constant throughout the deposit.
- (iv) The hornblende of the porphyroblastic felspar-amphibole rock of the ore zone shows similar properties to the hornblende of the granulite (refractive index sometimes slightly higher), while apparently identical rock types occurring as bands in the hanging-wall, give hornblendes showing differing optical properties i.e. darker colour and higher refractive index.

- (v) Poikiloblastic "sieve" structure characterises the hornblendes of the altered sediments, the crystallisation being more complete in some cases than in others.
- (vi) The hornblende of the originally igneous plagioclase amphibolite differs in character from the other hornblende of the deposit, an interesting feature being the apparent increase in $2V$ and slight decrease in refractive index towards the finer-grained chilled margin of the altered intrusions.
- (vii) Twinning and zoning are extremely rare. Very occasional, poorly developed twins on (100) were encountered and only one large crystal of hornblende showed a suggestion of zonal variation in composition.

Composition Determination

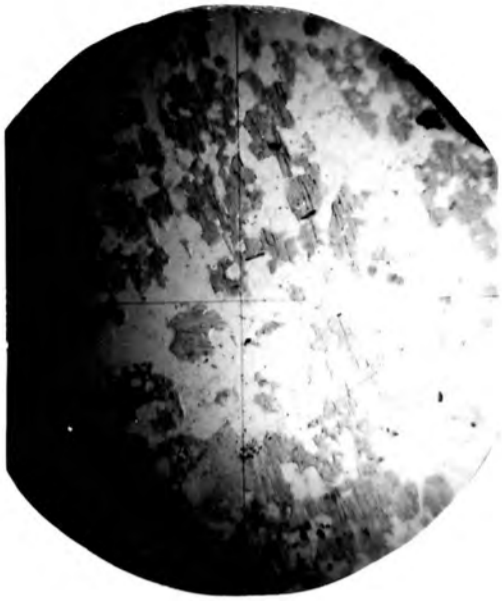
Composition determination from optical properties within the hornblende series is both difficult and inaccurate. The amphiboles do not lend themselves to classification in the same way as do the pyroxenes, with the result that texts on descriptive mineralogy are not able to give satisfactory charts relating optical properties to composition. Winchell (Third Edition, 1933) states,

"There are so many molecules present in varying amounts in hornblende and paragasite that the relations between optical properties and composition cannot be accurately shown in any diagram".

Winchell does, however, in the Third Edition give a chart showing approximate relations between the inferred refractive index Y and the chief constituent molecules (see Figure 10). Use has been made of a diagram (Figure 11) devised by the same author (Third Edition, 1933) showing variations in composition and optic properties of the paragasite-hornblende system. However, in this diagram water is disregarded, constant tenor of 10 - 15% Al_2O_3 is assumed and $NaFeSi_2O_6$ and Fe_2O_3 are combined. This diagram is considered by Winchell to be very approximate due to the disregarding of water, variable components not shown also causing variation in this diagram (Figure 11). The Y index was used as the main pointer to the constituent molecules in Figure 10, whereas the value of $2V$ and c/Z were used to fix the position in Figure 11.

79a

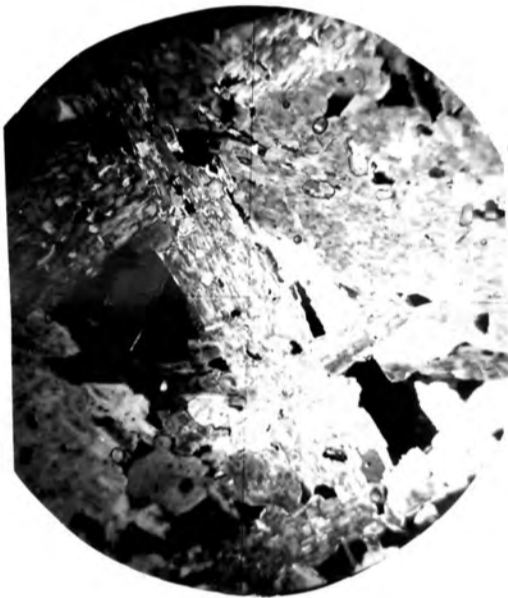
PLATE 15(A)



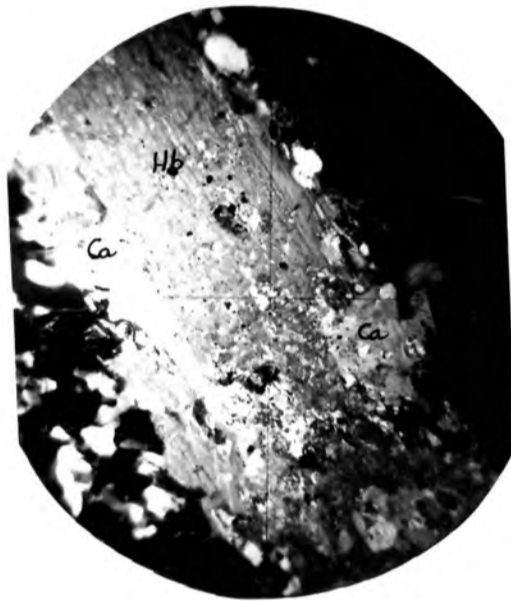
A



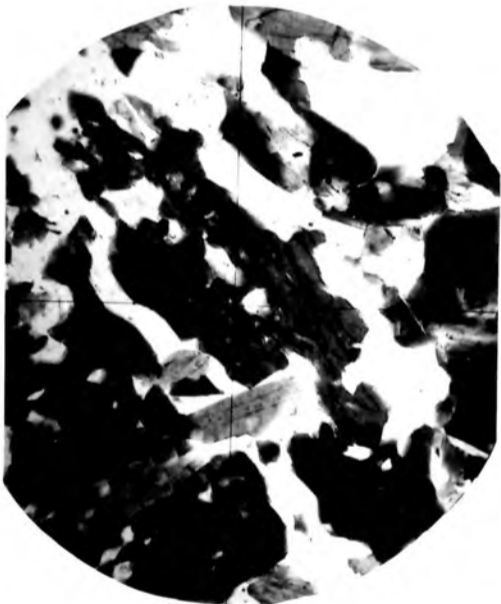
B



C



D



E



F

EXPLANATION OF PLATE 15A.

- A. Early incipient hornblende crystallisation in granoblastic quartz-plagioclase fabric.
Ordinary light X 40.
- B. Sieve structure in poikiloblastic hornblende porphyroblast. Quartz and plagioclase in interstices are remnant fabric after increased incipient crystal growth.
Ordinary light X 40.
- C. Bladed hornblende crystals. Crystal growth almost complete.
Crossed Nicols X 40.
- D. Hornblende porphyroblast (Hb) crystallising with calcite (Ca).
Crossed Nicols X 40.
- E. Basal section of hornblende.
Ordinary light X 100.
- F. Basal section of hornblende, 0.4 mm. across showing cleavage traces. The section is of felspar-amphibole rock.
Ordinary light X 100.

Deer Howie and Zussman, 1963, shows a diagram (Figure 12) giving the relation between chemical composition and the optical properties and density of common hornblendes.

Although the general habit and character of these amphiboles suggested that they belong to the hornblende series, the pale-green colour in thin section and their optical properties gave rise to doubt as to whether these were not in fact members of the non-aluminous tremolite-actinolite series. The optical data could suggest an actinolite with 38% of the ferrotremolite molecule. However, a chemical analysis carried out qualitatively on a pure specimen from the orebody calcite, yielded a relatively uncontaminated alumina precipitate, proving these amphiboles to be members of the aluminous hornblende series.

The only pure specimens of this amphibole uncontaminated by silicates in poikiloblastic texture are the green amphiboles found within the orebody calcite. These are, however, intergrown with much sulphide. A brief description of the analytical procedure follows, (Wahlstrom 1955):

The specimen was crushed and hand sorted to obtain amphibole with a minimum of sulphide intergrowth. This was ground extremely fine in an agate mortar and the sulphides dissolved out by heating with aqua regia, filtered off and washed with hot, dilute hydrochloric acid to dissolve as much of the iron as possible. A small amount of the remaining amphibole was fused with potassium hydroxide and dissolved in 1 : 1 hydrochloric acid and evaporated to dryness on a water bath, rendering the silica insoluble. A second evaporation was carried out and the residue dissolved in 1 : 1 hydrochloric acid. The silica was filtered off. A small amount of ammonium persulphate was added and the iron and aluminium precipitated as hydroxides with a slight excess of ammonium hydroxide. These were filtered off and washed with hot water. The aluminium hydroxide was separated by dissolving in a solution of sodium hydroxide and filtering. The filtrate was acidified with hydrochloric acid and the aluminium hydroxide precipitated with a slight excess of ammonium hydroxide. A clear grey-white gelatinous precipitate of aluminium hydroxide was obtained.

HORNBLLENDE ASSOCIATED WITH THE CALCITE OF THE OREBODY. (See Plate 15 D).

This occurs concentrated as irregular patches, veins and stringers within the equigranular white calcite typical of the orebody. It forms a coarsely crystalline mass of dark-green amphibole always closely associated with sulphide mineralisation, the hornblende occurring as large elongated crystals showing a very well developed cleavage. The sulphide minerals pyrrhotite and chalcopyrite

are intimately intergrown with these, giving a coarsely crystalline mixture of hornblende and sulphide, with individual hornblende crystals enclosing finely divided sulphide, generally concentrated along cleavage planes.

The constant association of hornblende with the mineralisation and the mode of occurrence in irregular veins, stringers and concentrations along contacts of the calcite and granulite, point to a hydrothermal origin for this hornblende, crystallising together with the sulphides from the same migrant solution.

Due to the friable nature of this amphibole-sulphide assemblage, thin section preparation proved impossible. However, crushed fragments immersed in oil show a paler coloration than suggested by the hand specimen. Pleochroism is moderate to weak with absorption $X < Y < Z$ where the colour along the X vibration direction is pale yellow-green, that along Y pale blue-green and along Z a darkish-green. The refractive indices and extinction angles were determined as :

X	1.637		
Y	1.646	$X - Z = 0.016$	$c/Z = 15^\circ - 17^\circ$
Z	1.653		

These measurements were identical to those obtained for the hornblende of the granulites and were completely constant on specimens collected from various parts of the orebody.

HORNBLLENDE OF THE GRANULITES

The hornblende crystals occur sporadically throughout the ore zone granulite, but never together with the non-aluminous amphiboles. In thin section these appear as scattered porphyroblasts, 1 - 2 mm long, showing varying degrees of crystallisation within the granoblastic groundmass. (See Plate 15A (A) and (B)). At the outset of crystallisation, hornblende shows portions of the eventual crystals scattered through the groundmass. With advancing crystallisation these portions have grown together until large crystals are formed showing typical poikiloblastic or "sieve structure", remnant plagioclase occurring as small inclusions. Although tending to clear themselves of these plagioclase relicts the hornblende of the granulites is never free of inclusions. Large porphyroblastic amphiboles showing sieve structure have been described in the Grenville Series, Ontario, as "feather-amphibolites" (Adams and Barlow, 1910).

In thin section, clinopinacoidal sections show a fairly well developed parting on the base. They are elongated along the C axis and show ragged terminations. The sections on (100) occur both as broad tablets and as crystals with an irregular outline. These are distinguished by straight extinction and low

birefringence having the Y and Z vibration directions in the plane of the thin section. Where basal sections occur, these are generally xenoblastic, showing the prismatic cleavages at 56° .

As stated above, these hornblendes are of a paler colour and of weaker pleochroism than those of the hangingwall rock types. There is a variation of colour within these hornblendes from almost colourless with a greenish tinge to a distinct green. The pleochroism is generally weak with the absorption $X < Y < Z$.

Typical Examples

X	Y	Z
Colourless	-	pale-green
light yellow-green	blue-green	darkish-green

Optic Axial Angle

Measurements of 2V angles on the Universal Stage were carried out on a large number of crystals throughout the granulite. Of 24 crystals examined, 16 showed 2V angles of $81^\circ - 82^\circ$, while the remaining 8 measurements gave values between 78° and 88° . Measurements made within a single section were found to be constant to within 3° . This average value $81^\circ - 82^\circ$ for the optic angle is decidedly lower than values determined on amphiboles of the hangingwall. Crystals showing values greater than the average 2V angle were noted to be of a slightly darker colour but with no appreciable difference in refractive index.

Extinction Angles

The value of c/Z was constant for this hornblende between $14^\circ - 17^\circ$ for determinations carried out on clinopinacoidal sections.

Refractive Indices and Composition

Eight determinations were carried out on specimens of known 2V angle. The following represent an average of values recorded :

X	1.635	
Y	1.646	X - Z = 0.018
Z	1.653	

These values are distinctly lower than refractive indices of the hornblende of the hangingwall. The value for Y was constant to within 0.004 and a mean value accepted.

HORNBLLENDE OF THE PORPHYROBLASTIC FELSPAR-AMPHIBOLE ROCK (see Plate 15 A.B. and C)

In hand specimen these crystals occur as large dark-green porphyroblasts up to 10 mm. in length, set in a granoblastic plagioclase and quartz groundmass. These are bladed laths set either in subparallel orientation or more generally with irregular arrangement.

In thin section these appear in similar manner to the hornblende just discussed in the granulites, but showing a slightly higher degree of crystallisation. Poikiloblastic "sieve structure" is still a dominant feature, although compared to the occurrence in the granulite, there are fewer inclusions. Although examples of poikiloblastic texture show different stages reached in the advancement of crystallisation, there are crystals which show little or no inclusions, having cleared themselves of these. The habit of these hornblendes is identical to those of the granulite already discussed and occur generally as prismatic sections on (010) and (100), the former being elongated crystal laths with ragged termination and high birefringence, while the latter tend to have a more irregular outline and show lower birefringence and straight extinction. The cleavage trace (110) is well developed, as is the trace of the basal parting.

The green coloration of the hornblendes of the felspar-amphibole rocks of the ore zone resembles the darker examples found within the granulites, but is decidedly paler than the dark-green of the hornblendes of the hangingwall rocks. The pleochroism is moderate but again weaker than the hangingwall types. Absorption is $X < Y < Z$.

Typical Examples

X	Y	Z
pale yellow-green	grass green	bluish-green
yellow-green	bluish-green	dark-greenish-blue

Optic Axial Angle

19 thin sections were examined, 8 from the felspar-amphibole rock of the ore zone and the rest from various occurrences of this rock in the hangingwall. Of these, only 7 had crystals which were suitable for 2V determination (i.e. where measurement between both optic axes was possible), 4 of these were from within the ore zone and 3 in para-amphibolites of the hangingwall. The measurements of the 2V

angle obtained were constant between -85° and -89° . Values within each individual slide were constant with a variation within the range -85° to -89° from section to section; the range is not extreme and the number of observations not sufficiently widespread to postulate differences of $2V$ relative to the orebody.

Extinction Angles

Measurements were taken on all 19 thin sections mentioned above. c/Z angles varying between $12\frac{1}{2}^{\circ}$ and 16° were obtained which are slightly lower than extinction angles obtained anywhere else in the deposit.

Refractive Indices and Composition

Refractive index determinations were carried out on 9 specimens of known $2V$ angle, 5 from within the ore zone and 4 from hangingwall felspar-amphibole rocks. The values found within the ore zone were fairly consistent, showing slightly higher indices than those of the granulite hornblende, the Y index here being 1.653 as compared with 1.646 in the granulite. The 4 determinations made in specimens outside the ore zone give the following values for the Y index : 1.650, 1.650, 1.668, 1.670 with increasing distance from the orebody.

The following are average values for the felspar-amphibole rock of the ore zone:

X	1.643	
Y	1.653	X - Y = 0.014
Z	1.657	

HORNBLLENDE OF THE PLAGIOCLASE AMPHIBOLITE

The hornblende of these amphibolites of igneous origin is strongly coloured, with strong pleochroism from yellow-green to dark-blue-green. The absorption is $X < Y < Z$ with a typical example :

X	yellow-green
Y	olive-green
Z	dark-blue-green

This hornblende occurs mainly as prisms bounded by the well developed (110) cleavage and showing irregular terminal boundaries. Abundant inclusions of opaque ore are present. Basal sections are seen especially where sections are cut perpendicular to the lineation. The variation in grain size is generally from 0.1 mm. in the fine-grained to 1 mm. in the coarse-grained plagioclase amphibolites. The hornblende never occurs in porphyroblastic form.

The optical properties show a difference between those of the fine-grained variety and those of the coarse-grained amphibolite.

Optic Axial Angle.

Sixty-five determinations were made on crystals in 20 slides examined from various parts of the deposit, representing the complete variation in grain size. The maximum values for the 2V angles were obtained in the fine-grained compact plagioclase amphibolite of narrow vein-like intrusions and the fine-grained contact type of large intrusive bodies. A complete gradation appears to exist with an increase of grain size until a minimum value was reached in the coarse-grained amphibolite from the central portions of the intrusions. The following are values obtained from plagioclase amphibolites of varying grain size:

0.1 to 0.3 mm.	75° - 78°
0.3 to 0.5 mm.	70° - 74°
0.5 mm. & greater	60° - 68°

The above generalisation is considered only approximate.

Extinction Angles

Measurements of the c/Z angle gave constant results between 17° and 20°.

Refractive Indices

Eight determinations were carried out on specimens of known 2V angle, 4 from fine-grained and 4 from coarse-grained varieties, in an effort to establish upper and lower limits to the refractive indices of the hornblendes of the plagioclase amphibolites. The value for the Y index in the hornblende of the fine-grained amphibolite was found to be constant at 1.673 while the values in the coarse-grained variety gave values ranging between 1.674 and 1.680. The following are average values :

Fine-grained Plagioclase Amphibolite

X	1.656	
Y	1.673	Z - X = 0.026
Z	1.682	

Coarse-grained Plagioclase Amphibolite

X	1.659 - 1.661	
Y	1.674 - 1.680	Z - X = 0.029
Z	1.686 - 1.690	

SUMMARY OF THE OPTICAL PROPERTIES OF THE HORNBLLENDE
RELATIVE TO ROCK TYPE

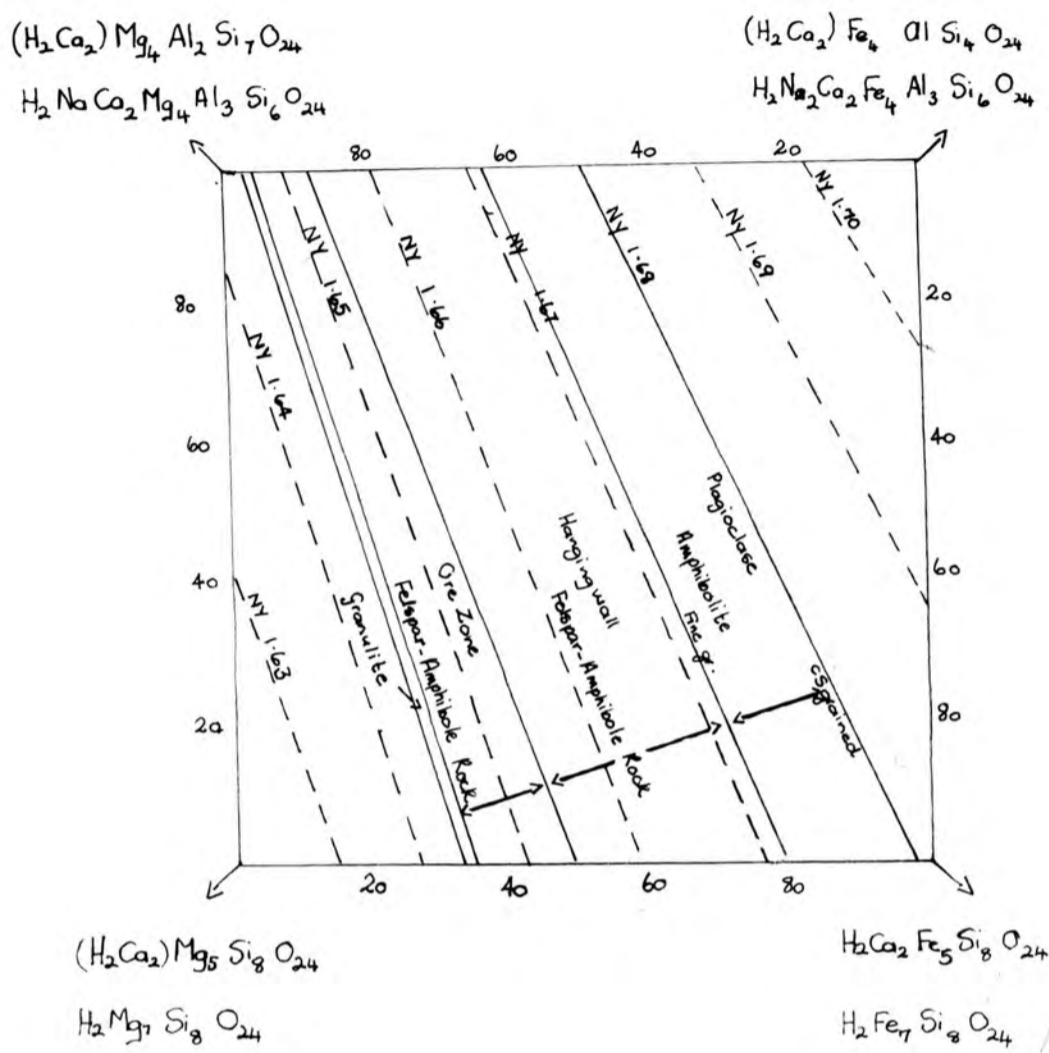
	<u>2V</u>	<u>c/Z</u>	<u>Index X</u>	<u>Index Y</u>	<u>Index Z</u>	<u>(Z-X)</u>
<u>Ore Zone Granulites :</u>	-81° to -82°	14° -17°	1.635	1.646	1.653	0.018
<u>Ore Zone Calcite:</u>	-82°	-17°	1.637	1.646	1.653	0.016
<u>Ore Zone Felspar- Amphibole Rock :</u>	-87° to -89°	13° -16°	1.643	1.653	1.657	0.014
<u>Hangingwall Felspar- Amphibole Rock.</u>	-86° to -87°	10° -15° -20°		1.650-1.670		0.020
<u>Plagioclase Amphi- bolite:</u>	-66° to 78°	15° -20°	1.656- 1.661	1.672- 1.682	1.682- 1.690	0.026- 0.029

Composition

The Hornblende Series is both complex and does not lend itself to classification. However an attempt has been made to show diagrammatically the position of the amphiboles of the various Shamrocke rock types in composition diagrams relative to special properties i.e. Figures 10, 11 and 12.

FIGURE 10

869



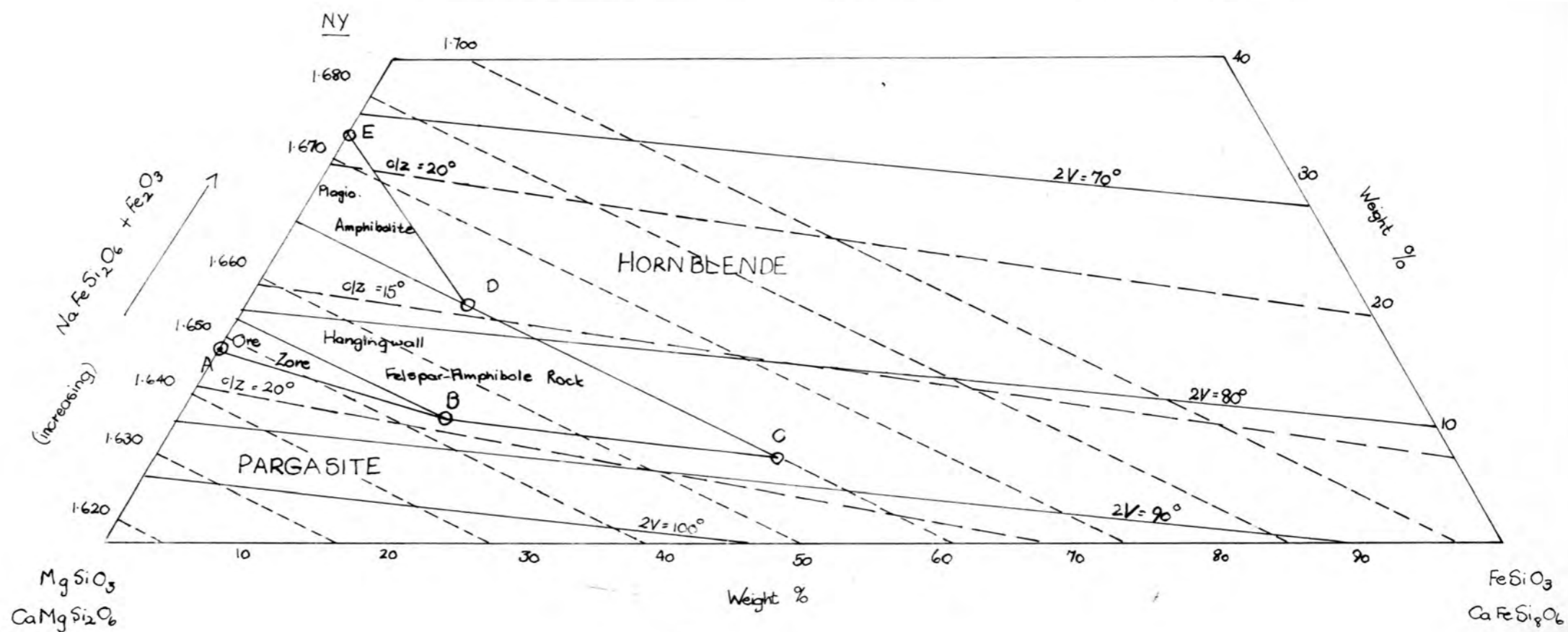
VARIATIONS IN COMPOSITION WITH MEAN REFRACTIVE INDEX Y IN PART OF THE PARGASITE-HORNBLLENDE SERIES (APPROXIMATE - AFTER WINCHELL THIRD EDITION PART 11, 1933)

The range in composition of hornblende within the Shamrocke rock types is shown

FIGURE 11.

VARIATION IN COMPOSITION AND OPTIC PROPERTIES IN PART OF THE PARGASITE-HORNBLende SYSTEM (Approximate after Winchell, Third Edition, Part 11, 1933)

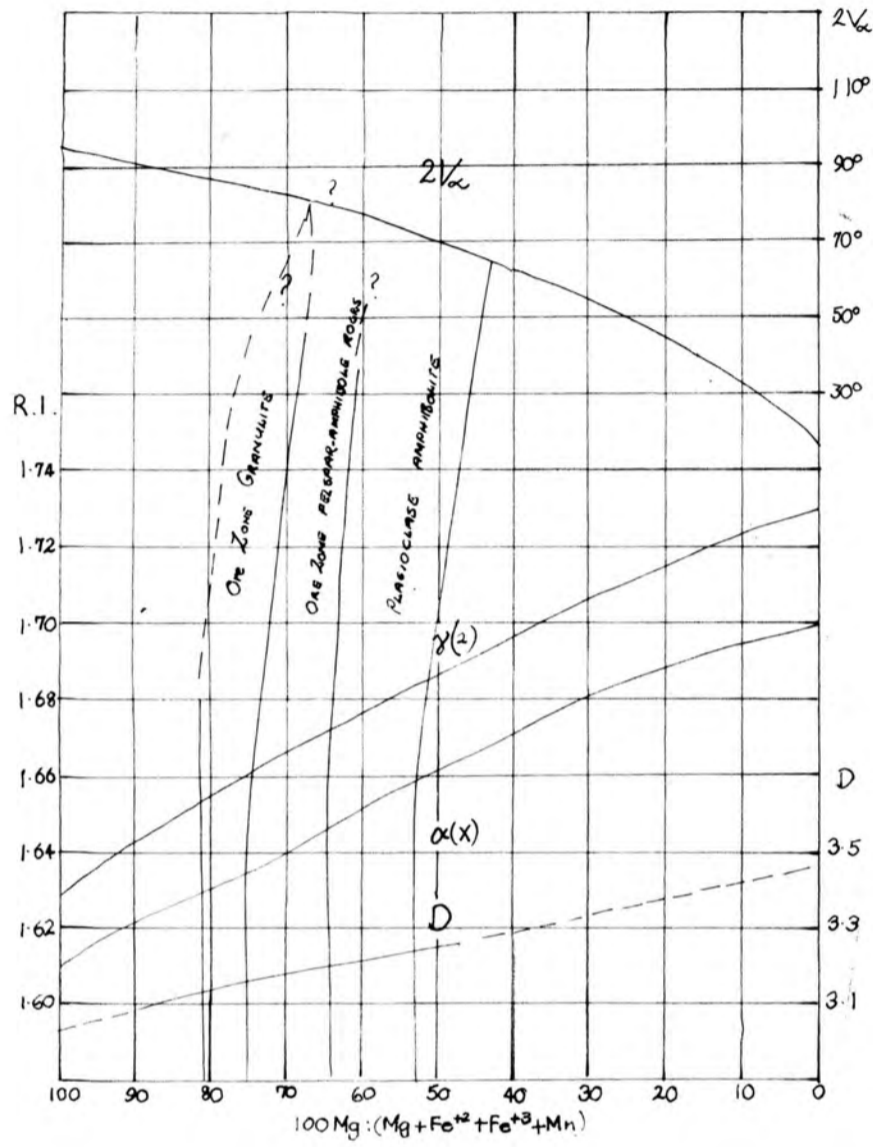
The range in composition of the hornblende within the Shamrocke rock is shown.



998

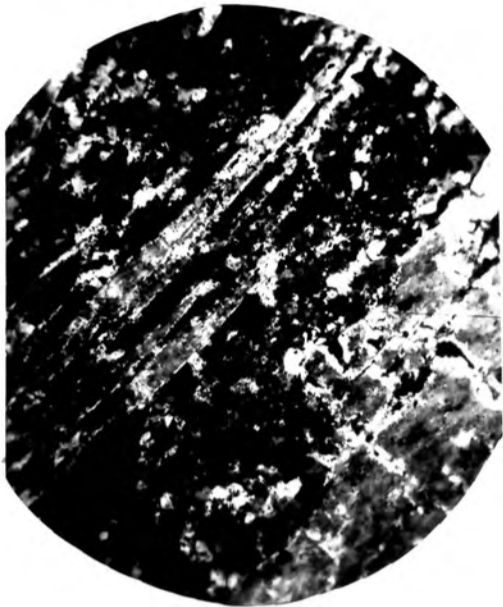
FIGURE 12.

86c

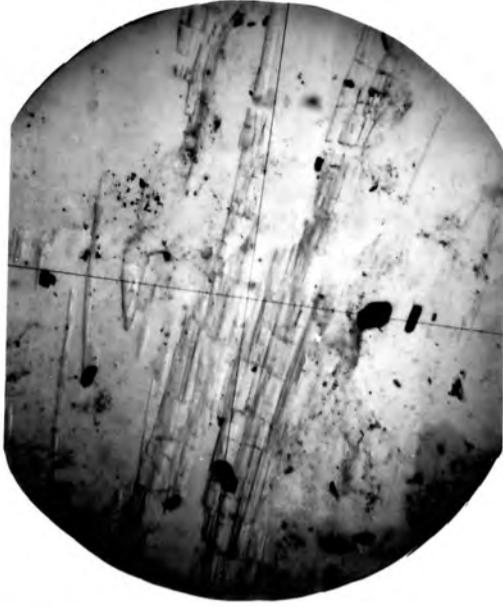


THE RELATION BETWEEN CHEMICAL COMPOSITION AND THE OPTICAL PROPERTIES AND DENSITY OF COMMON HORNBLENDES (AFTER DEER, HOWIE AND ZUSSMAN, VOL. 2, 1963)

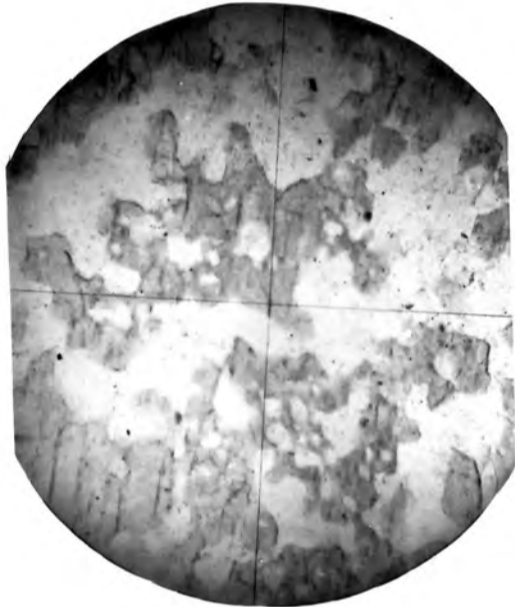
PLATE 15 (B)



A



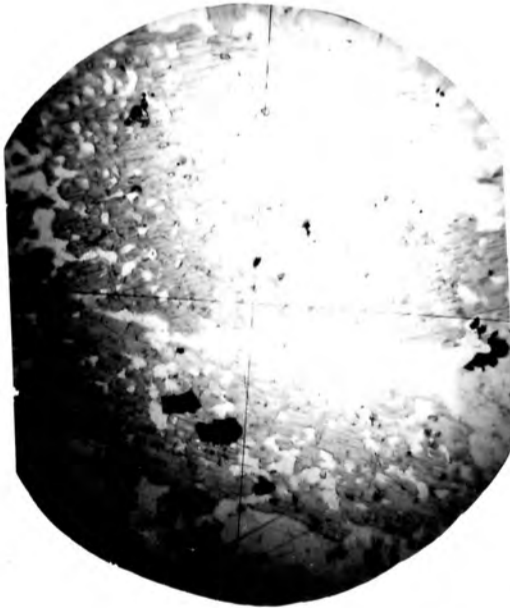
B



C



D



E

EXPLANATION OF PLATE 15(B)

A. Anthophyllite crystals in anthophyllite granulite.

Crossed Nicols X 100.

B. Anthophyllite crystals in anthophyllite granulite.

(note two cleavage directions).

Ordinary light X 100.

C. } Progressive crystallisation of hornblende in the
D. } groundmass fabric from incipient growth in C
E. } through the poikiloblastic texture in D to a more
complete crystallisation in E.

Ordinary light X 100.

THE NON-ALUMINOUS AMPHIBOLES

These amphiboles are found in the immediate vicinity of the ore zone, generally in a fine-to medium-grained light-coloured granulite and in the dark fine-grained carbonaceous mica schist in close proximity to the ore zone and in narrow bands within the ore zone.

Three distinct minerals were identified. These are anthophyllite, cummingtonite and tremolite-actinolite. All three of these have a very similar mode of occurrence and in hand specimen their appearance is very similar. However, on careful examination, the anthophyllite is seen to be colourless to straw coloured, the cummingtonite a pale brown and the actinolite a pale to distinct green. In thin section these generally tend to appear colourless with identification dependent on optical properties.

Non-aluminous amphiboles in 20 thin sections cut from granulites and carbonaceous mica schists were examined on the universal stage and refractive index determinations carried out on the amphibole of the corresponding hand specimens.

Some Observations made from Optical Study. (See Plate 16 A, B, C, D, E and F).

1. Of the 20 thin sections examined, 8 were found to contain anthophyllite, 6 cummingtonite and 6 actinolite.
2. No two of these non-aluminous amphiboles occur in the same rock.
3. Numerous crystals were examined within the same section and the optical properties were found to be constant throughout the slice.
4. The optical properties of each amphibole type are practically identical, irrespective of position in relation to the ore zone or the type of host rock.
5. The habit and mode of occurrence of all three of these non-aluminous amphiboles are distinctly similar. This is discussed below.

6. Twinning occurs only in cummingtonite; polysynthetic twins on (100).

Identification

With these three minerals being invariably colourless or pale coloured in thin section, and showing distinctly similar habit, specific optical data were used to establish their identity. Although the actinolite is pale or distinctly green, it does in many cases appear practically colourless.

Anthophyllite is immediately distinguished from the other two by its parallel extinction, while cummingtonite can easily be distinguished from actinolite by virtue of its optically positive nature and considerably higher indices of refraction.

SUMMARY OF OPTICAL DATA

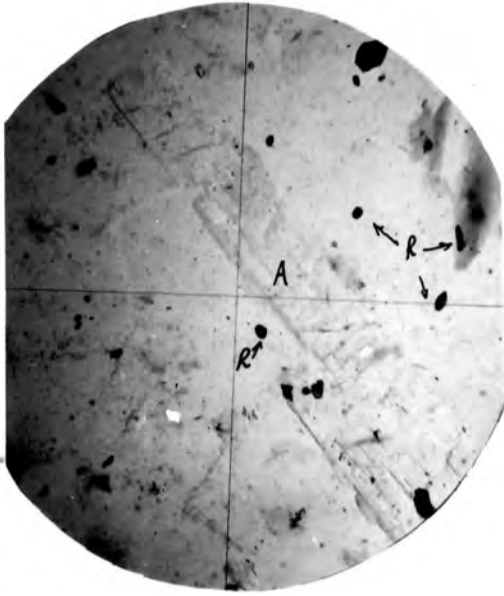
	<u>2V</u>	<u>c/Z</u>	<u>Refractive Index Y</u>	<u>Z-X</u>
Anthophyllite	+79½°	0°	1.638	0.029
Cummingtonite	+80°	15°-20°	1.646	
Actinolite	-80° to -88°	16°-20°	1.633	0.028

Composition Determination - The Anthophyllite Series, the Grunerite-Cummingtonite-Kupfferite Series and the Tremolite-Actinolite - Ferrotremolite Series.

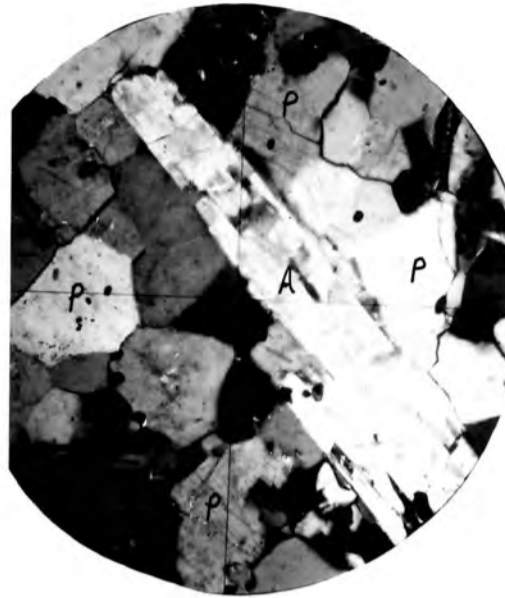
Winchell, (Third Edition 1933 Part 11) gives three diagrams (see Figures 13, 15 and 18) showing the variation in composition and optical and physical properties within the Anthophyllite Series, the Grunerite-Cummingtonite-Kupfferite Series and the Tremolite-Actinolite-Ferrotremolite Series. As with the hornblendes the Y index was used for the deduction of molecular composition from these diagrams while the other optical properties were used merely as a guide or as confirmative values. In the majority of cases these other optical properties give a similar molecular composition. However, where one or other of these do not give corresponding results this is not an error of measurement of that property but is a fact. We must accept that the diagrams were drawn up from the analyses available to that author and could be only approximate for all naturally occurring minerals.

88 a

PLATE 16



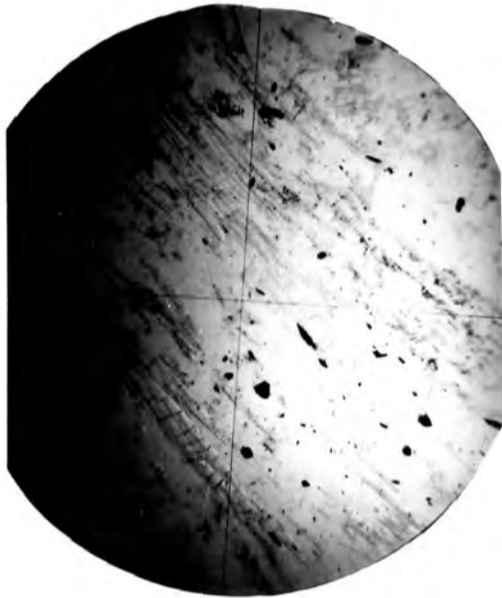
A



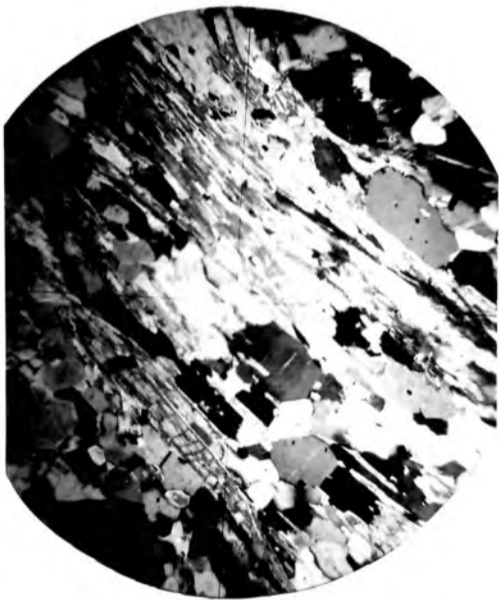
B



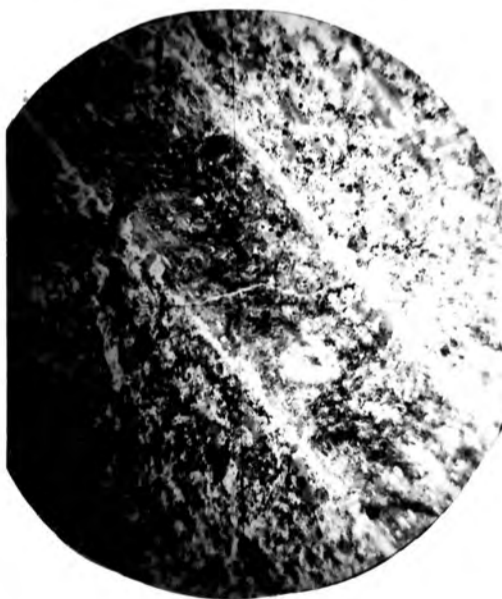
C



D



E



F

EXPLANATION OF PLATE 16.

- A. Colourless porphyroblastic anthophyllite (A) crystal in anthophyllite granulite. Scattered small rutile crystals (R).
Ordinary light. X 100.
- B Anthophyllite porphyroblast between straight extinction positions in granoblastic fabric of the granulite (cf 16A). Note one plagioclase polysynthetic twin. Untwinned clear plagioclase (P).
Crossed Nicols X 100.
- C. Cummingtonite laths showing polysynthetic twinning on (100). Rock is granulite with predominantly plagioclase groundmass, and biotite.
Crossed Nicols X 40.
- D. Prismatic sections of very pale green actinolite. Two cleavage traces clearly visible. The rock is a granulite.
Ordinary light X 100.
- E. Prismatic sections of porphyroblastic actinolite in granoblastic plagioclase groundmass of granulite (cf 16D).
Crossed Nicols X 40.
- F. Pale green actinolite porphyroblast with much graphitic inclusion. Rock is graphitic biotite granulite.
Ordinary light X 40.

In Figure 3, where the only optical properties plotted against molecular composition are the 3 indices of refraction, the agreement is excellent. In Figure 5, this agreement prevails, facilitated by the wide composition range for a single optical value; while in Figure 4, the value for the $2V$ angle points to a lower molecular percentage of the kupfferite molecule.

Winchell again in his Fourth Edition Part 11, 1959 gives two diagrams (Figures 16 and 19) which, when the optical data is plotted give similar results to that in Figures 15 and 18 of his Third Edition.

Deer, Howie and Zussmann Vol. 2 1963 give similar diagrams (Figures 14, 16 and 19) to depict the optical properties of these amphibole series against chemical composition. The results obtained from plotting the optical data in these diagrams again indicate similar results from those obtained from the diagrams of Winchell.

The use of these diagrams in conjunction with accurately determined optical data is the best available method for composition determination outside of tedious chemical analysis.

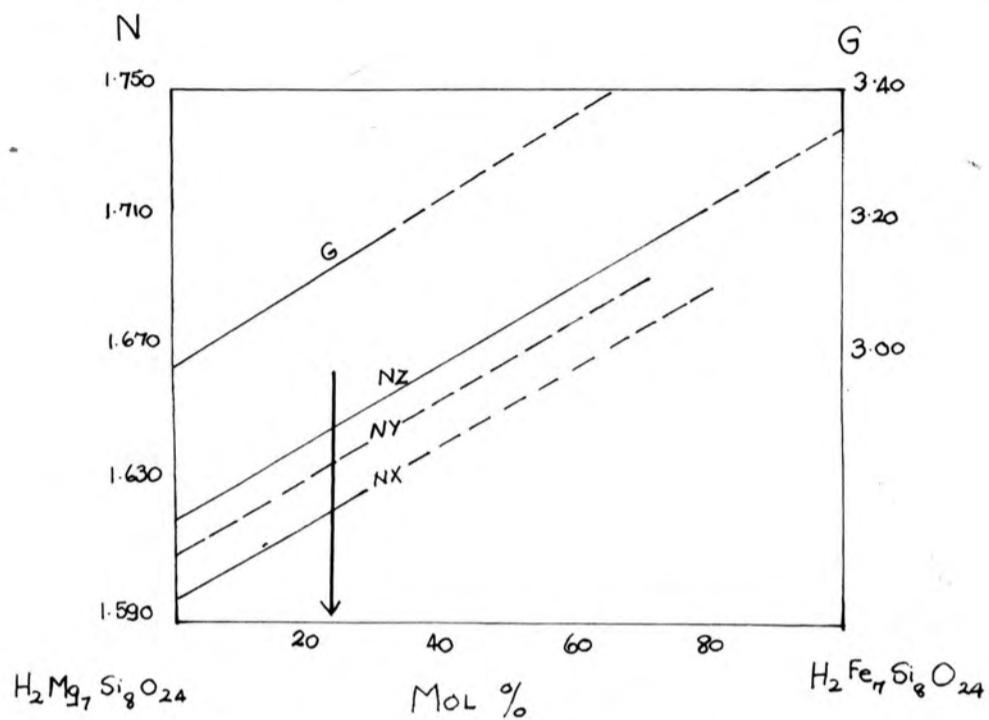
ANTHOPHYLLITE (See Plate 16 A and B)

In hand specimen the anthophyllite occurs as fibrous bundles and acicular crystals from colourless to straw coloured.

These occur as both narrow, needle-like prisms on (010) showing prominent cross fractures, and broad columnar crystals on (100), also with cross fracturing. In places these also become quite fibrous. The (110) cleavage trace is well developed and occasionally, where basal sections occur, the traces intersect at 56° . The habit is generally porphyroblastic with crystals of up to 2 cm. in length scattered throughout the groundmass. The crystals are generally completely colourless but where alteration effects are visible a greenish tinge is noticed, even sometimes showing extremely weak pleochroism. A poikiloblastic texture often occurs where isolated feldspar relicts and opaque ore are scattered about within the amphibolite; this texture is not generally well developed.

Alteration of the anthophyllite to highly birefringent talc is fairly common. With this alteration a greenish tinge becomes noticeable which in extreme cases shows weak pleochroism. Sometimes large irregular patches of what appears to be a totally altered anthophyllite occur, presumably a greenish to greenish-brown talc.

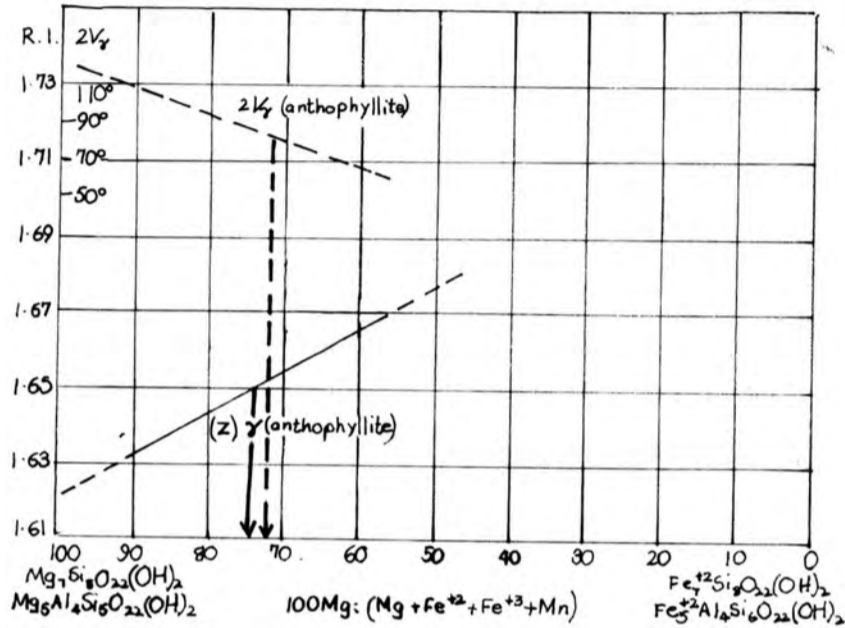
FIGURE 13



VARIATION IN COMPOSITION AND INDICES OF REFRACTION IN THE ANTHOPHYLLITE SERIES. (AFTER WINCHELL THIRD EDITION PART 11, 1933)

The arrow indicates the position in the series occupied by the anthophyllite of the Shamrocke Mine.

FIGURE 14



RELATION BETWEEN THE OPTICAL PROPERTIES AND CHEMICAL COMPOSITION FOR ANTHOPHYLLITE (AFTER DEER, HOWIE AND ZUSSMAN, VOL. 2, 1963)

The solid arrow is the position in the Series as indicated by R.I.Z. occupied by the anthophyllite of the Shamrocke Mine.

The bottom arrow is the position in the Series indicated by the value of 2V_z, occupied by the anthophyllite of the Shamrocke Mine.

Extinction Angle.

The anthophyllite shows parallel extinction which renders it easily distinguishable from the other amphiboles.

Optic Axial Angle.

The value for the 2V angle is regularly $79\frac{1}{2}^{\circ}$ measured about the slow vibration direction.

Refractive Indices and Composition

The following are the values consistently obtained for the anthophyllite.

X 1.621

Y 1.638 X - Z = 0.029

Z 1.650

These values are constant irrespective of the nature of the host rock.

From Figure 13 all three of the refractive indices indicate a composition with approximately 25% of the ferroanthophyllite molecule. From Figure 14 the value of the refractive index Z again indicates a composition with approximately 25% of the ferroanthophyllite molecule, which expressed roughly in terms of atomic proportions is approximately $\underline{H_2 Mg_5 Fe_2 Si_8 O_{24}}$.

CUMMINGTONITE (See Plate 16 D)

In hand specimen the cummingtonite is seen as fibrous, almost silky, brownish coloured crystals scattered about the groundmass. It occurs as narrow acicular prisms on the clinopinacoid, tabular prisms on the orthopinacoid and small idoblastic basal sections. The traces of the (110) cleavage are always well developed; these can be seen intersecting at 56° in the basal sections. These crystals are porphyroblastic in habit, scattered about in the xenoblastic plagioclase groundmass.

These cummingtonites do not show "sieve structure" as do the other non-aluminous amphiboles of the deposit. Occasional crystals have a few inclusions but these are the exception. The cummingtonite of the carbonaceous mica schist is riddled with extremely minute graphite specks in contrast to the clear amphibole of the granulites. This graphite does not in any way alter the properties or mode of occurrence of the cummingtonite and is due to the extremely carbonaceous nature of the mica schist.

Twinning

Twinning on (100) is extremely common and characteristic of the narrow acicular prisms. The twin-lamellae are well developed and usually narrow (see Plate 16 C)

Optic Axial Angle.

The optically positive nature immediately distinguishes the cummingtonite from negative actinolite. The $2V$ angle is constant at 80° , as measured by rotation between the optic axes about Z.

Extinction Angle.

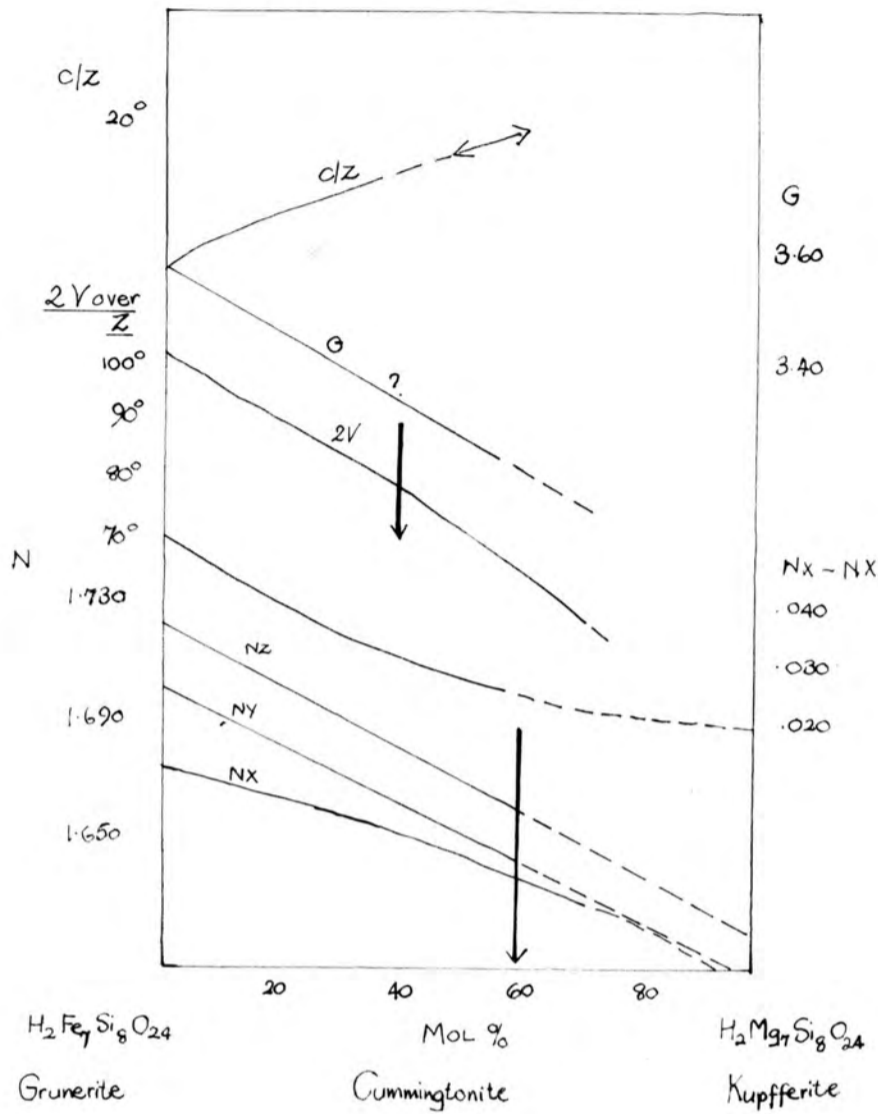
The value for the c/Z angle was found to vary between 15° and 20° . However, the majority of measurements gave values of 19° and 20°

Refractive Indices and Composition

The refractive indices were found to be constant whether the sample is from the granulites or whether it is full of graphitic inclusions as in the carbonaceous mica schists.

FIGURE 15

91a



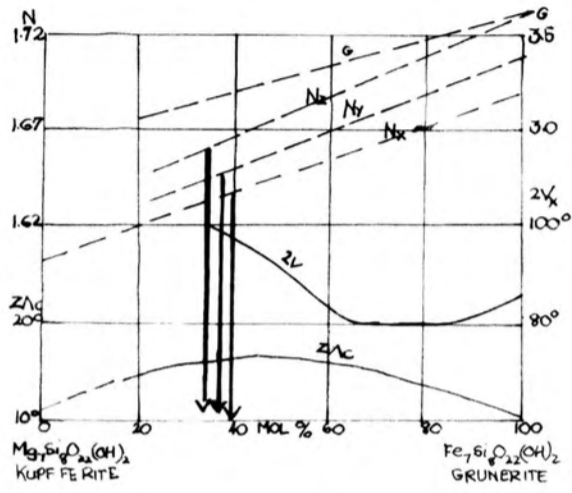
VARIATIONS IN COMPOSITION AND OPTIC PROPERTIES IN THE GRUNERITE - CUMMINGTONITE - KUPFFERITE SERIES.

(After Winchell Third Edition Part 11, 1933.)

The arrows indicate the position occupied by the cummingtonite of the Shamrocke Mine.

91b

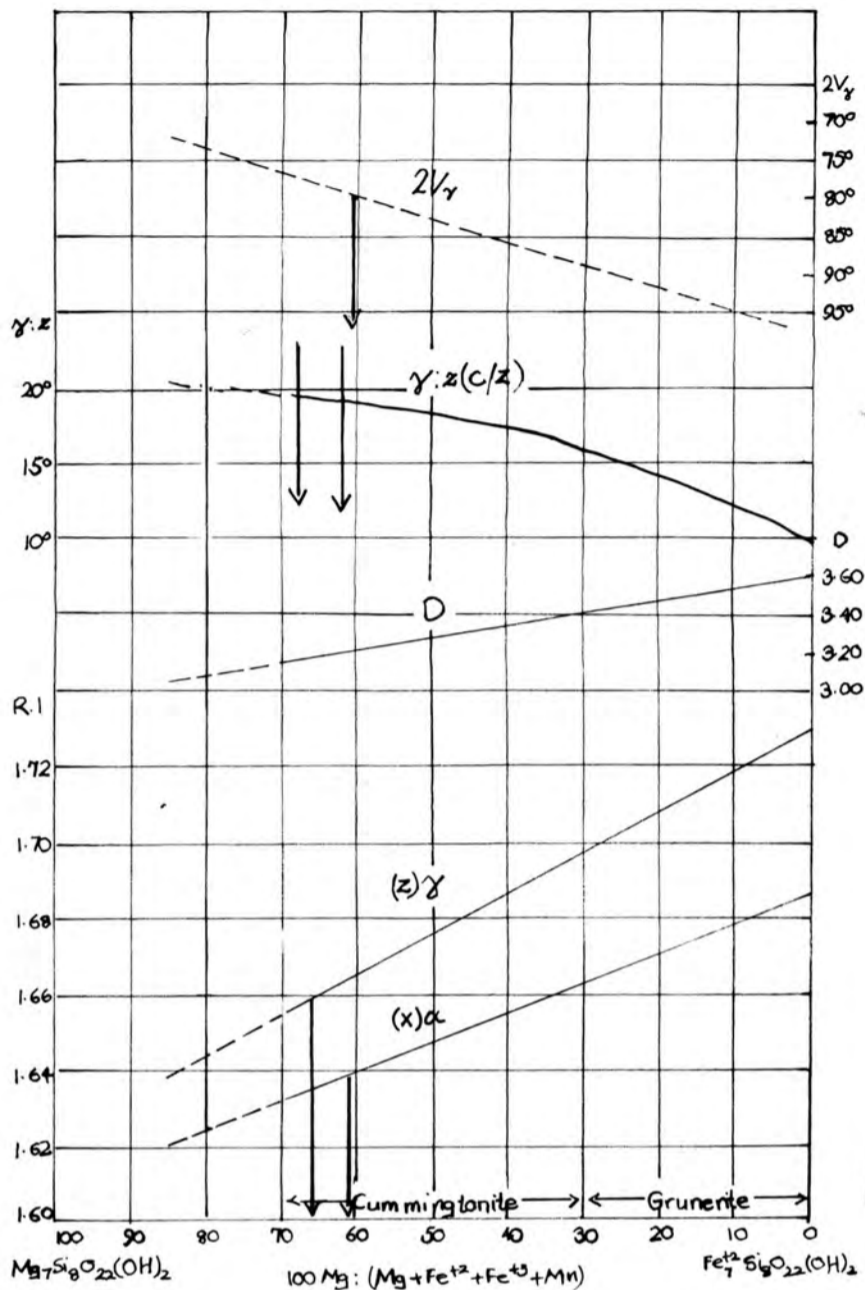
FIGURE 16



^M
PROPERTIES OF THE CUMINGTONITE SERIES (After Winchell
 Fourth Edition Part 11, 1959).

The arrows indicate the position in the Series occupied by the Cumingtonite of the Shamrocke Mine.

FIGURE 17



THE VARIATION OF THE OPTICAL PROPERTIES AND DENSITY WITH COMPOSITION IN THE CUMMINGTONITE - GRUNERITE MINERALS. (After Deer, Howie and Zussmann Vol. 2, 1963).

The arrows indicate the position in the Series occupied by the Cummingtonite of the Shamrocke Mine.

These values are :

X 1.639

Y 1.646 X - Z = 0.020

Z 1.659

From Figure 15 (after Winchell Third Edition) the Y index value 1.646 suggests a molecular composition of 60% of the kupfferite molecule.

From Figure 16 (Winchell Fourth Edition 1933) the value of the X, Y and Z indices further indicates a composition of 60% - 65% of the kupfferite molecule. The c/Z angle however falls slightly outside the curve while the $2V_x$ value was not measured.

From Figure 17 the values of the X and Y indices, c/Z angle and the value of $2V_Z$ combines the result from Figures 15 and 16 and indicates a composition of 60% - 65% of the kupfferite molecule.

All three diagrams therefore indicate a molecular composition of approximately 60% of the kupfferite molecule which in terms of atomic proportions is approximately $H_2 Mg_4 Fe_3 Si_8 O_{24}$.

TREMOLITE - ACTINOLITE (See Plate 16 C, D and E.)

In hand specimen the tremolite-actinolite occurs in numerous forms : as small needle-like crystals, as larger broader distinctly green crystals scattered abundantly through the groundmass and as large elongated widely scattered green porphyroblasts generally found in the carbonaceous mica schist.

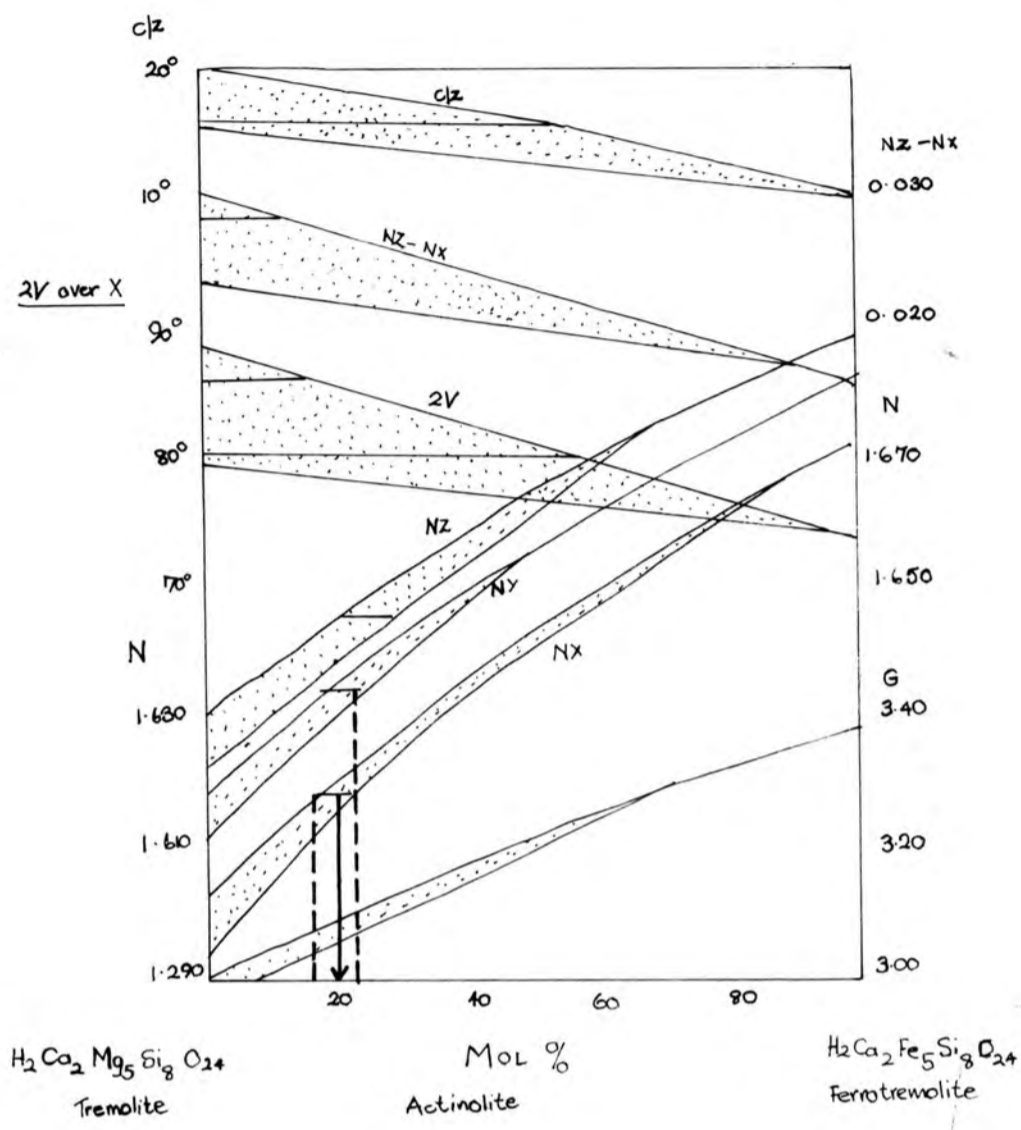
In thin section these vary from colourless through a very pale-green to crystals with a distinct green colour. The green variety shows weak to moderate pleochroism with $X < Y < Z$. From a large number of slides examined it is clear that the actinolite of the schists is generally the deeper green with stronger pleochroism.

The habit of the tremolite-actinolite varies from section to section. It occurs in the granulites scattered abundantly through the groundmass as narrow elongated prisms on the clinopinacoid, these showing the trace of the (110) cleavage sometimes well developed and in other cases poorly developed. It also occurs as prismatic sections on the orthopinacoid, both as subhedral broad tabular crystals or crystals with irregular boundaries, both of these having Y and Z in the plane of the section. In the mica schists, although the tremolite-actinolite does in some cases occur in the same manner as the granulites, it tends generally to be in the form of large, widely scattered, green porphyroblasts, showing a tendency to idioblastic outline. Basal sections are distinctly eight-sided.

In the majority of crystals poikiloblastic texture or "sieve structure" occurs. Where the groundmass is granoblastic and fairly fine-grained, this groundmass texture prevails within the actinolite crystals. This "sieve structure" is more prominent and of a coarser nature within the granulites than in the mica schists. The interior of these crystals has a marked poikiloblastic texture with the marginal regions being cleared of inclusions, giving the crystal an unbroken outline.

The tremolite-actinolite of the mica schists is packed with dark graphite inclusions and although not affecting the optical properties these do tend to mask the colour and general characteristics. Only about the extreme edges are these actinolites free from graphite. Where the graphite of the schist shows minor wavy or ripple-like textures, this is often seen to persist through an actinolite porphyroblast, suggesting that the crystal of tremolite-actinolite grew in the carbonaceous groundmass without much affecting the distribution or character of the stable graphite.

FIGURE 18



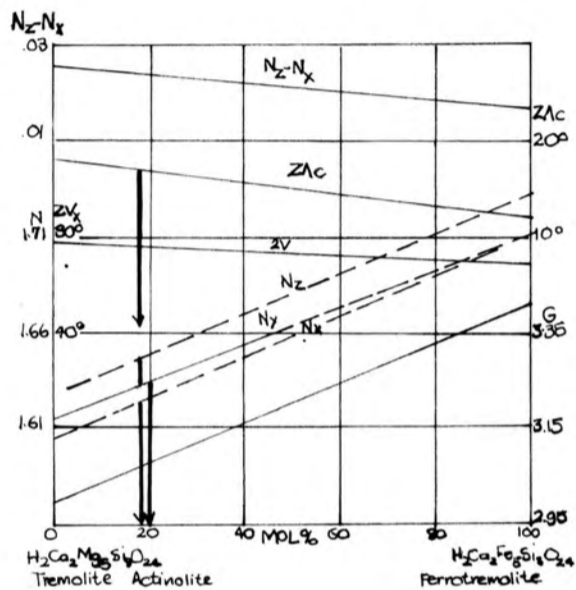
VARIATIONS IN COMPOSITION AND OPTIC PROPERTIES IN THE TREMOLITE-ACTINOLITE - FERROTREMOLITE SERIES.

(After Winchell Third Edition, Part 11, 1933).

The thick horizontal lines indicate the range of properties, and the arrow, the approximate composition of the Tremolite-Actinolite of the Shamrocke Mine.

FIGURE 19

93b

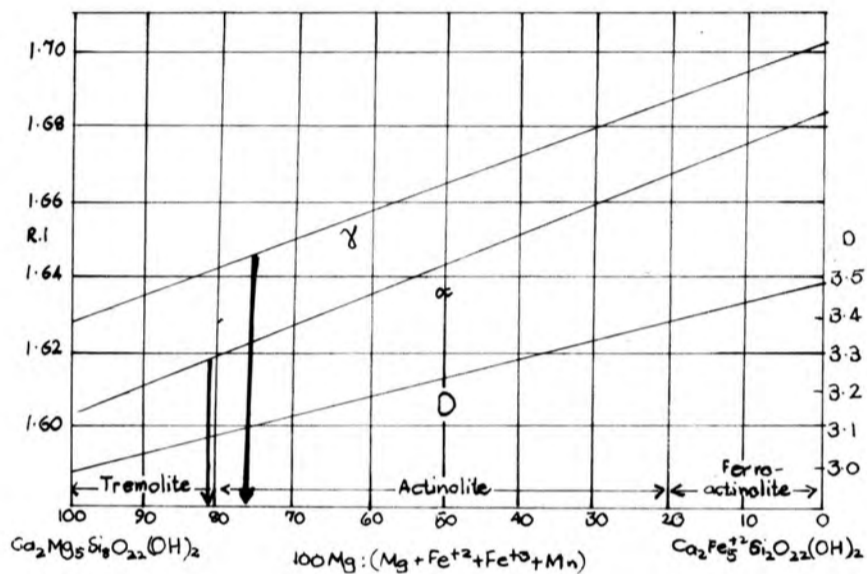


PROPERTIES OF THE TREMOLITE-FERROTREMOLITE SERIES.

(After Winchell Fourth Edition Part 11, 1959).

The arrows indicate the position in the Series occupied by the Tremolite - Actinolite of the Shamrocke Mine.

FIGURE 20



THE RELATION BETWEEN CHEMICAL COMPOSITION AND REFRACTIVE INDICES AND DENSITY OF THE TREMOLITE-FERROACTINOLITE SERIES.

(After Deer, Howie and Zussmann Vol. 2, 1963).

The arrows indicate the position in the Series occupied by the Tremolite-Actinolite of the Shamrocke Mine.

The tremolite-actinolite is not highly altered, although occasional minor alteration to calcite and talc is encountered.

Extinction Angle.

The value for the c/Z angle varies between 16° and 20° with the majority of measurements being in the region of $17\frac{1}{2}^\circ$.

Optic Axial Angle

This value for the optic angle gives varying measurements between -80° and -88° . However, the tremolite-actinolite was found to be always negative, i.e. the acute bisectrix is X.

Refractive Indices and Composition

The refractive index measurements were found to be fairly constant throughout, the average values being :

X	1.618	
Y	1.633	X - Z = 0.028
Z	1.646	

From all three Figures 18, 19 and 20, a suggested composition would be approximately 20% of the ferro-tremolite molecule which is approximately $H_2 Ca_2 Mg_4 Fe Si_8 O_{24}$ in terms of atomic proportions.

BIOTITE (See Plate 17 A and B)

Introduction.

Biotite is one of the predominant minerals of the rocks of the Shamrocke Mine, and is the sole representative member of the mica group.

Biotite mica is the only mafic mineral present in the groundmass assemblage of the typical mica schist of the hanging-wall and footwall, the marked schistosity of these rocks being brought about by the parallel alignment of these biotite crystals. In the granulite, biotite is the main ferromagnesian mineral of the normal pinkish biotite granulite. However, in the granulite, rather than being an intricate member of the groundmass, it occurs as slightly larger crystals sometimes in porphyroblastic habit. Where these granulites become amphibolised in varying degrees, the abundance of the biotite decreases and where amphibole occurs abundantly as scattered porphyroblasts, the biotite is very minor to absent. In the felspar amphibole rocks and the plagioclase amphibolite, biotite is a minor constituent, and where it occurs it is generally as fairly large, dark, strongly pleochroic semi-idioblastic crystals. An important occurrence of biotite is as idioblastic porphyroblasts giving a distinctive appearance to the narrow contacts between altered intrusive rocks and the surrounding schists.

The character of this biotite is very similar throughout the area differing only in the intensity of colour and pleochroism.

Orientation.

In the mica schists, thin sections cut perpendicular to the schistosity show the biotite consistently as basal or near basal sections with the Y vibration direction approximately corresponding to the plane of the thin section. In all these sections the interference figures show the optic axes in the field of the microscope; the majority giving these optic axes fairly centrally situated. In sections cut parallel to the schistosity these generally show a definite parallel arrangement of elongated biotite laths which are strongly pleochroic, indicating a preferred direction parallel to the schistosity. In the schists these biotites are generally 0.1 mm. in size and make up a large part of the groundmass.

The biotites of the granulite do not show a preferred orientation to the same extent as the mica schists. It is general to find the biotites in the granulite

scattered about the groundmass both as elongated prisms and irregular basal sections, these varying in size from crystals almost identical in size to the granoblastic groundmass feldspar to large crystals of idioblastic habit up to 0.5 mm. across.

Colour and Optic Properties

The deep colour and strong pleochroism tend to make measurements of optic properties difficult. In certain orientations and tilts of the universal stage the dark brown, almost opaque character of the mineral somewhat obscures the optic properties.

The biotite is generally deeply coloured with marked pleochroism as follows:

X	Y	Z
pale-yellow	reddish-brown	dark-reddish-brown
pale-yellow	dark-brown	dark-opaque brown

The absorption appears $X < Y < Z$. The pleochroism in yellows and deep browns is general throughout the Shamrocke rock types, differing only in intensity. Green varieties of biotite are rare. In the biotite amphibolite forming an internal zone between the upper and lower granulite zones in some of the deeper boreholes, a deep brown biotite is possibly altering to a blue-green hornblende with occasional intermediate crystals of deep green biotite.

The optical properties of the biotite are similar throughout the area. The extinction is parallel to the cleavage traces while interference figures show the crystals to be pseudo-uniaxial or having an extremely small $2V$ angle. Measurement of the $2V$ angle was attempted on the universal stage. With the optic axial plane both vertical and at right angles to the control axis K of the stage, a rotation about K gave only one position of extinction in the 40° position over a wide range of tilt. However, this extinction persisted through a maximum rotation of 5° and it must be accepted that the two optic axes are close together and due to dispersion, cause a continuous extinction rather than two definite positions a few degrees apart. We must therefore conclude that the average $2V$ angle must be between 0° and 5° .

The indices of refraction were measured on one specimen from each

rock type using the immersion method and the average value for γ obtained was

$$\gamma = 1.606$$

Pleochroic haloes are extremely common in the biotite; (see Plate 17B) these are themselves surprisingly weakly pleochroic, and sometimes show no detectable pleochroism. The minute crystals causing these haloes are invariably cut away by the section through the crystal, showing however evidence of their presence in the form of the halo.

Inclusions found in the biotite are feldspar, iron ore, apatite and rutile. These inclusions, generally minute stumpy laths of apatite up to 0.01 mm., are found in the biotite of the idioblastic feldspar-biotite contact rock between the plagioclase amphibolite and the mica schist. These apatite inclusions do not produce pleochroic haloes.

97 a



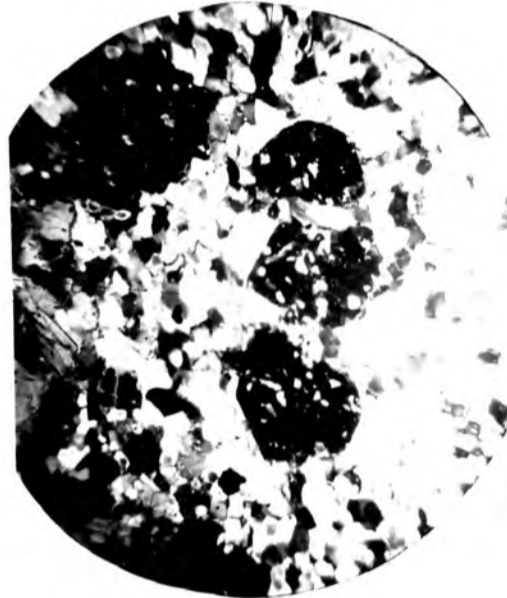
A



B



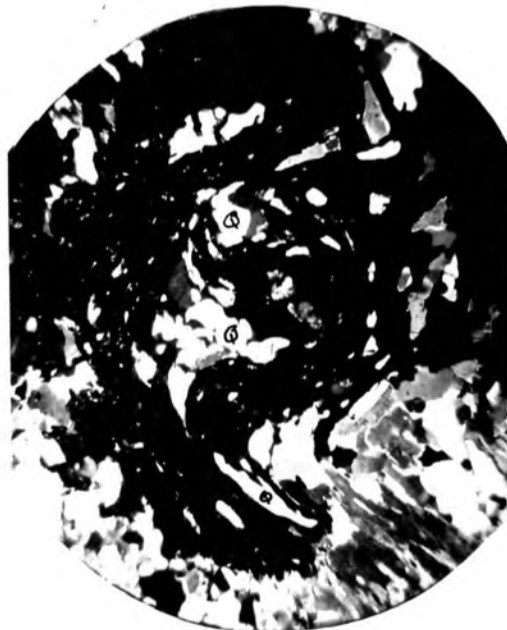
C



D



E



F

97 b

EXPLANATION OF PLATE 17.

- A. Poikiloblastic biotite crystal forming in granoblastic plagioclase groundmass.
Ordinary light X 40.
- B. Pleochroic haloes in biotite crystal.
Ordinary light X 40.
- C. Garnet crystals (0.5 mm.) in granoblastic plagioclase groundmass.
Ordinary light X 40.
- D. Garnet crystals (G) showing included remnant plagioclase.
Crossed Nicols X 40.
- E. Spiral garnet crystal (3 mm. across) showing included opaque ore (Fe) and remnant quartz (Q). The inclusions enhance the effect of rotation during growth.
Ordinary light X 40.
- F. Spiral garnet crystal (3 mm. across) showing included opaque ore and remnant quartz. The inclusions enhance the effect of rotation during growth.
Crossed Nicols X 40.

QUARTZ.

Although the quartz content of the rocks of the ore zone is very low (less than 6%), quartz is an important constituent of the country rock.

It occurs either as a constituent of the granoblastic groundmass, as larger scattered crystals, or as minor and very narrow veinlets very occasionally cutting the rock.

The quartz crystals as previously discussed, are difficult to distinguish from the plagioclase feldspar without resorting to etching and staining.

On etching with hydrofluoric acid, the quartz resists attack whereas the plagioclase is easily etched. Treatment with cobaltinitrite and rhodizonate does not stain the quartz and where the plagioclase is stained red by rhodizonate the quartz can be easily distinguished.

When interference figures are produced from crystals unstained by reagent, they often give uniaxial positive figures with distortion by strain, often causing a biaxial effect. Due to the lower quartz content in the rocks and hence fewer crystals, and also due to the effect on the interference figure by strain, the optical method was not satisfactory for quartz identification for modal analysis.

The quartz crystals are always anhedral and clear, unaltered and free from inclusions.

MINOR CONSTITUENTSAPATITE (See Plate 18A)

Apatite is an accessory mineral in all the rocks of the Shamrocke Mine other than the simple mica schists. In thin section it occurs generally as minute, rounded and columnar crystals of the order of size of approximately 0.01 mm. In some granulites and porphyroblastic felspar amphibole rocks, these occasionally increase in size to 0.1 mm., while in one exceptional case in a thin section cut from felspar amphibole rock from borehole 19 at 73'9", basal sections of up to 0.4 mm. were grouped together. Narrow acicular crystals of apatite are rare but are occasionally found in the plagioclase amphibolites and garnet amphibole schists. The maximum length measured of these needle-like crystals was in a thin section of plagioclase amphibolite from borehole 20 at 232'0", where these needles are up to 0.2 mm. long.

In ordinary light, these crystals are colourless with a relatively high relief. Between crossed nicols they show very weak birefringence, the interference colours being greys and blues of the first order, basal sections being isotropic. They show straight extinction except where small crystals overlie crystals of the groundmass and the extinction position is obscured by the interference colours of the underlying minerals.

Short columnar crystals of apatite are sometimes found included in biotite porphyroblasts. These do not cause pleochroic haloes in the biotite host.

RUTILE. (See Plate 18B and Plate 26A)

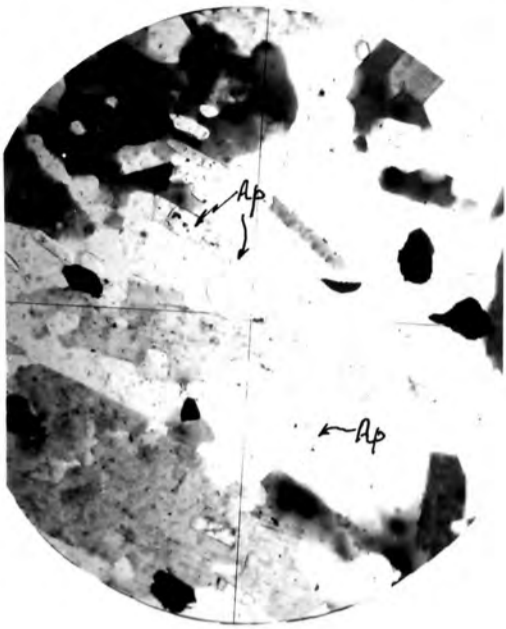
Rutile is found only in the granulite and porphyroblastic felspar amphibole rocks. It is an abundant accessory within the ore zone; where these rocks occur outside this zone it is relatively rare.

In thin section, the rutile occurs as minute prisms and rounded grains 0.05 mm. to 0.1 mm. in size. These are both pale and deep coloured generally showing pleochroism as follows:

X	Z
pale-yellow-green	yellow-brown
yellow-brown	deep-coppery-red-brown

99a

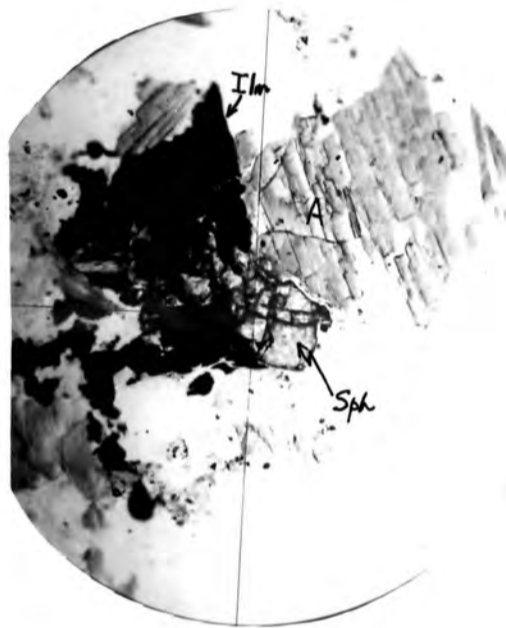
PLATE 18



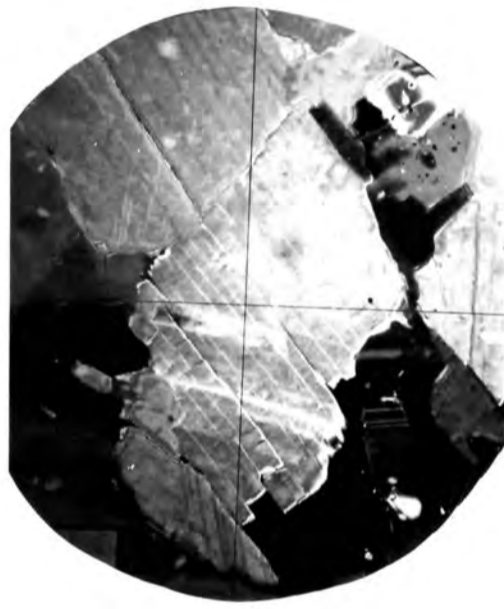
A



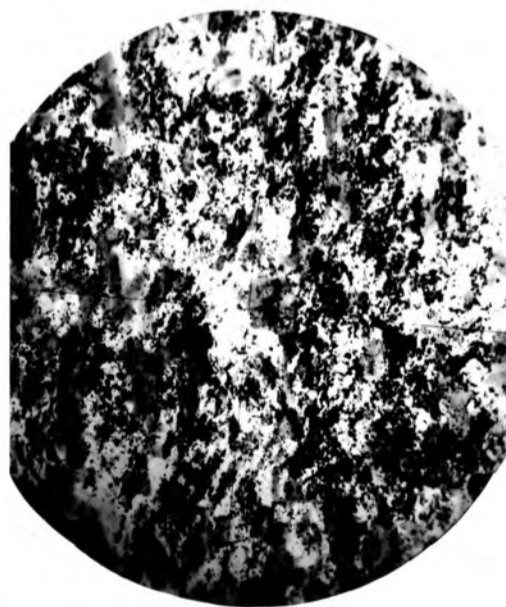
B



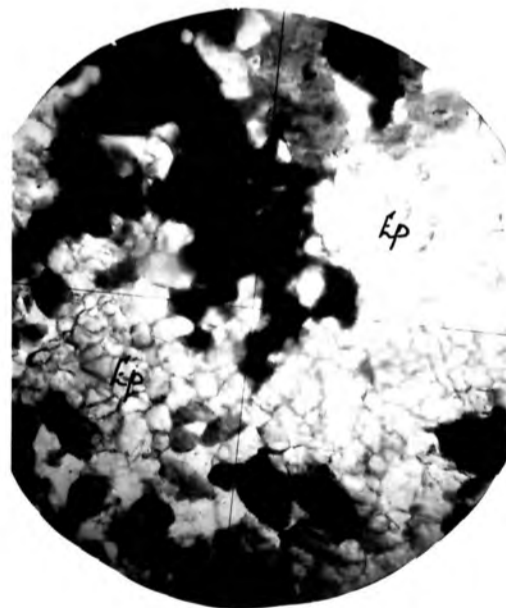
C



D



E



F

99b

EXPLANATION OF PLATE 18.

- A. Stubby apatite crystals included in biotite.
Ordinary light X 100.
- B. Genuiculate twin of rutile of deep red-brown colour.
Ordinary light X 400.
- C. Sphene associated with ilmenite.
Ordinary light X 100.
- D. Subhedral dolomite crystals showing
both cleavage and faint twinning in two directions.
- E. Shreds of graphite (black) in groundmass of biotite schist.
Ordinary light X 100.
- F. Epidote (Ep) granules in plagioclase amphibolite.
Ordinary light X 100.

The absorption is greater when the lengths of the prisms are parallel to the trace of the lower nicol, distinguishing it quite definitely from tourmaline where absorption is greatest across the length. Where the colour is extremely deep, it appears almost opaque and is often confused with finely disseminated opaque minerals. Occasionally geniculate twins are seen (see Plate 18B).

SPHENE (See Plate 18C)

Sphene is a constant accessory mineral of the plagioclase amphibolite, occurring only sporadically in the other rock types. In the granulite it is rare while in the porphyroblastic felspar amphibole rock it is occasionally found as an accessory, particularly in this rock type occurring outside the ore zone. It is also occasionally found in the inner zones of reaction banding in the granulite around calcite bodies.

It occurs both associated with a sulphide mineral, presumably ilmenite, and as scattered crystals within the rock mass. In thin section the sphene appears as irregular anhedral crystals generally between 0.01 and 0.1 mm. across and as small drop-like granules. It generally has the characteristic sphene brown colour while between crossed nicols the larger crystals show extreme birefringence.

Where the sphene is associated with the oxide it appears either as granules surrounding it or appears to be an alteration product of a larger oxide crystal - in this case ilmenite. In extreme cases such as may sometimes be found in the garnet amphibole schists, sphene pseudomorphs after ilmenite occur with minute remnant ilmenite throughout.

STAUROLITE (See Plate 18D, E and F).

Staurolite is an important index mineral in metamorphism. The implications of the presence of the mineral are discussed under the metamorphism.

Staurolite is rare in the Shamrocke rocks and has only been isolated in thin section in two places - in a typical carbonaceous-biotite-mica schist from borehole C at 217'0" and in a coarse dark-green garnet-amphibole schist

from borehole 28 at 114'8". However, the mere existence of this mineral is important when considering the metamorphic facies relative to the area.

It occurs as irregular porphyroblasts up to 0.5 mm. long which appear to have been drawn out along the direction of schistosity. It is conspicuous by virtue of its golden-yellow colour and strong pleochroism from a pale yellow brown to a deep golden-yellow along the length.

A large number of sections cut from identical garnet-amphibole schist throughout the sequence failed to give further occurrences of staurolite.

Williams, Turner and Gilbert,(1958) state : "The presence of staurolite (like that of chloritoid at lower grades of metamorphism) indicates deficiency in potash combined with a rather high content of iron". It is always associated with garnet and micas.

EPIDOTE (See Plate 19A)

Epidote is generally absent in the immediate area of the Shamrocke Mine; it is found occasionally in the plagioclase amphibolite, and as minute crystals in the saussuritisation of plagioclase feldspar. In isolated cases it can be seen within secondary veining in the plagioclase amphibolite and impregnating the surrounding rock with minute granules of highly birefringent epidote. An example of this is seen in borehole 27, (Plate 19A). Epidote occurs as columnar aggregates in the felsic groundmass of a very characteristic coarse para-amphibolite with decussate hornblende porphyroblasts, as found in borehole 28 at 156'0" and 146'0".

CALCITE AND DOLOMITE

As discussed under the section on Selective Staining, the various properties of the two minerals were studied relative to the result obtained from the staining, and certain criteria were observed which apparently distinguishes the calcite from the dolomite in specimens from the Shamrocke Mine. These diagnostic criteria are discussed in that section, together with the observations made from the staining.

Calcite (See Plate 19D and E).

In thin section the calcite occurs generally as anhedral irregular crystals, usually turbid or murky and, due to the turbidity it appears to have a higher relief than the dolomite. Very few, if any, straight edges to the crystals are found. The cleavage traces are visible but not distinct, two traces are often visible, but cannot be identified relative to any crystal edge. Some of the traces observed could be due to parting. Interference colours are generally of high order and twinning along two directions is visible. The twin planes are not always as distinct as in the dolomite.

Macroscopically, the calcite is usually white and, within the rock fabric, appears granular. Only the calcite from veins and "blows" of secondary origin appears crystalline.

The calcite stains a deep purple with haematoxylin solution.

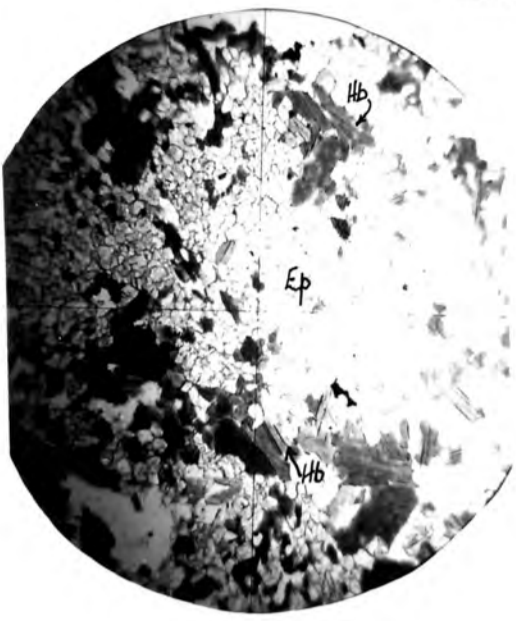
Dolomite (See Plate 18D and 19 F)

In thin section the dolomite crystals are completely colourless and transparent in ordinary light. The cleavage traces are easily seen and are very sharp; two sets of cleavages can be seen, intersecting at oblique angles. The crystals are often anhedral but always show some straight crystal edges. At times subhedral to anhedral crystals abound, showing rhombohedral habit. The interference colours can be moderately low to very high.

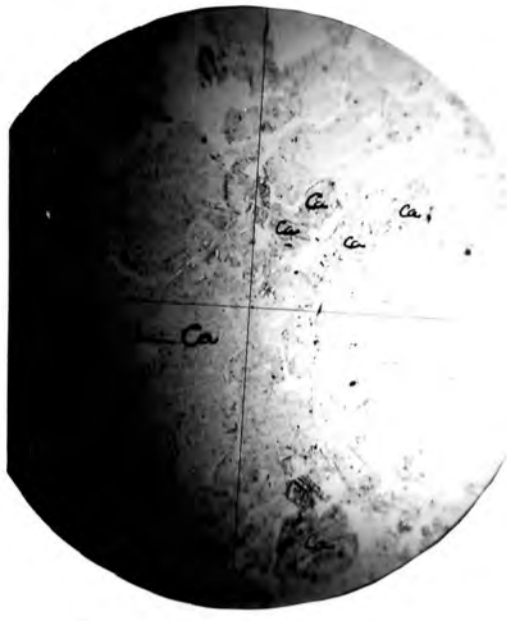
Macroscopically the dolomite is generally obviously crystalline and often a pinkish colour.

The dolomite is unreactive to the haematoxylin solution.

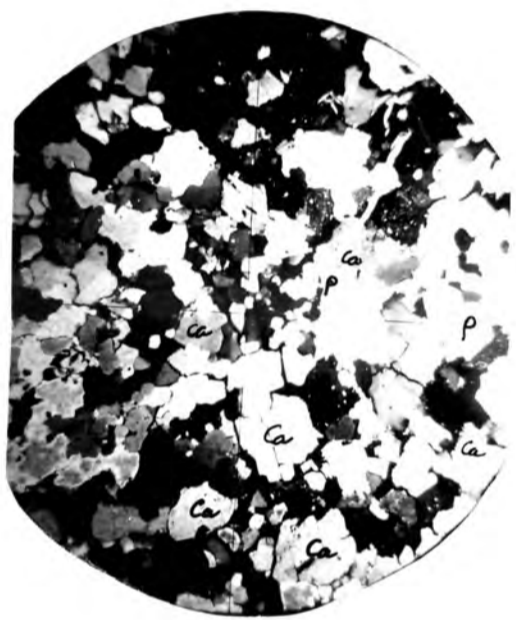
PLATE 19



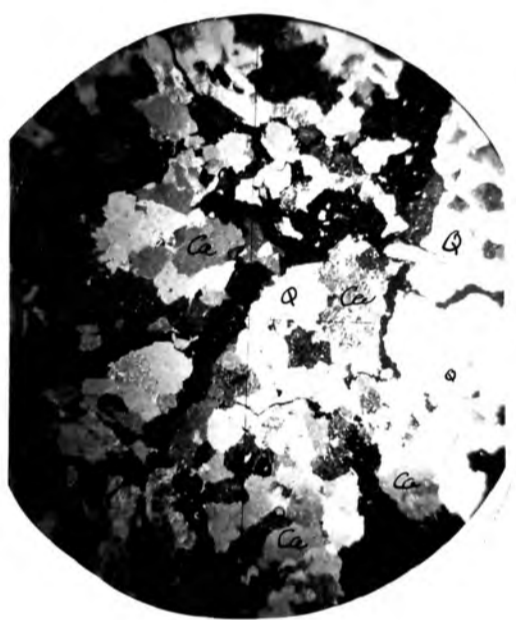
A



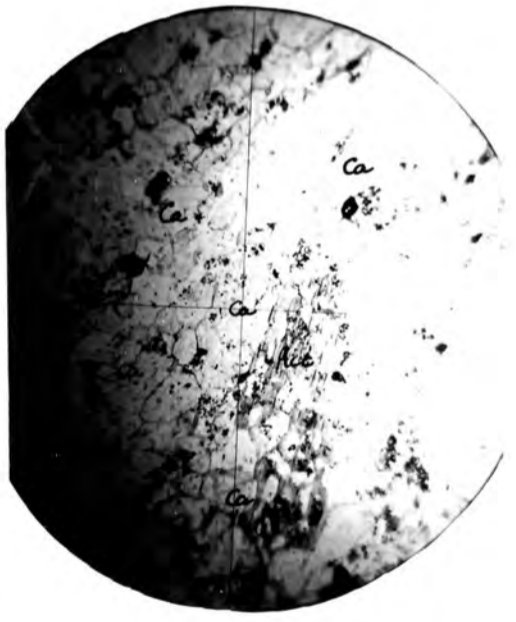
B



C



D



E



F

102 b

EXPLANATION OF PLATE 19.

- A. Highly epidotised plagioclase amphibolite. Epidote granules (Ep) showing high relief. The amphibole is hornblende (Hb).
Ordinary light X 40.

- B. Calcareous grit from well west of the Mine. Anhedral calcite crystals abound in felspar rich groundmass.

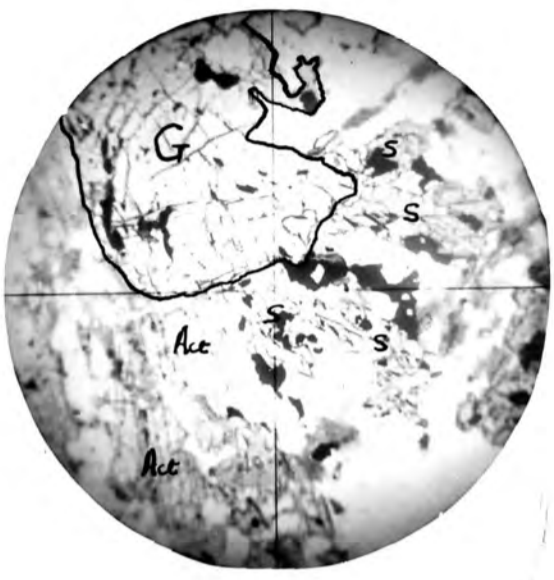
- C. Calcareous grit from well west of the Mine. Anhedral calcite crystals abound in felspar rich groundmass.

- D. Impure limestone. From north of ore body. Predominantly calcite (Ca).
Amphibole, biotite, graphite, opaque ores, quartz and felspar are impurities. Note anhedral habit of calcite crystals.
Ordinary light X 40.

- E. Amphibolised limestone. Anhedral calcite grains (Ca) with poikiloblastic actinolite crystal.
Ordinary light X 40.

- F. Pure dolomite. Largely subhedral dolomite crystals showing twinning in two directions.
Crossed Nicols X 40.

PLATE 20



A



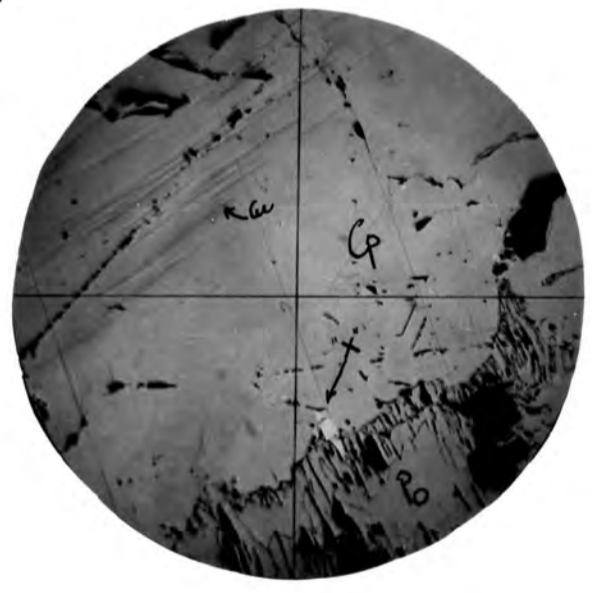
B



C



D



E

EXPLANATION OF PLATE 20

A. Garnet-Staurolite Schist.

G = garnet

S = schist

Act = actinolite.

B. Garnet Staurolite Schist. -

The staurolite (S) is a golden colour and highly pleochroic.

The groundmass is predominantly quartz (Q). The garnet (G) occurs as anhedral crystals.

Ordinary light X 40.

C. Garnet Staurolite Schist -

The staurolite (S) is a golden colour and highly pleochroic.

The groundmass is predominantly quartz (Q). The garnet (G) occurs as anhedral crystals.

Crossed Nicols X 40.

D. Polished section showing a basal section of hornblende in chalcopyrite. Note the interstitial chalcopyrite within the incipient hornblende crystal.

E. Unstained polished section with cubanite lamellae just visible in the chalcopyrite with unidentified mineral "X" at the grain boundary between chalcopyrite and pyrrhotite.

GARNET

The garnet of the Shamrocke rocks is a pale-pink to grey colour in hand specimen and occurs as rounded crystals scattered through the fabric of some of the rocks, to a greater or lesser extent. Garnets are found in some of the granulites, schist and phyllite, and plagioclase amphibolite. Some rocks are entirely free of garnet; its distribution through the area is not known.

In thin section, the garnet is generally rounded and varies in grain size from minute crystals up to 2 mm. across. They are isotropic and a colourless to pale-grey colour in the thin section.

Rotational effects are well evidenced by the spiral distribution of inclusion.

Refractive index measurements were attempted using solid melt media, but the results were entirely unreliable.

The garnet is assumed to be of the Almandine subspecies from its appearance, colour and the grade of metamorphism of the enclosing rock.

GRAPHITE

Graphite is a common constituent of some of the schist, phyllite and granulite of the study area. It occurs as black shreds and flakes scattered throughout the rock fabric and often shows a lineation, enhancing the foliation caused by aligned biotite prisms.

OPAQUE MINERALS

SAMPLING

The Shamrocke orebody was sampled systematically so as to give specimens at regular intervals across the body, and with increasing depth below the surface.

In all, 41 samples were taken, from which 23 polished sections were prepared, 12 of these from specimens taken at varying depths and 11 from specimens at regular intervals across the body. By this systematic sampling, it was hoped that differences in the mineralogy with position, within the orebody would shed some light on the mode of deposition of the ore.

Sample Positions (from the specimens underlined, polished sections for microscopic study were prepared).

Depth Sampling

B/H	1	at	<u>180'0"</u>	188'0"	165'0"
B/H	6	at	144'0"	144'0"	
B/H	7	at	<u>372'0"</u>	353'0"	<u>398'0"</u>
B/H	17	at	886'0"	926'0"	489'0"
B/H	19	at	<u>1479'0"</u>	<u>1482'0"</u>	1516'0"
B/H	27	at	<u>2380'0"</u>	2128'0"	<u>2382'0"</u>
B/H	28	at	<u>2269'0"</u>	2719'0"	2692'0"

Lateral Sampling

Sampling at regular 5 feet intervals across the orebody was done from Borehole 6, allowing for gaps due to the absence of sulphide mineralisation. 21 samples were taken, while 11 were polished. Those samples polished were from the following depths down Borehole 6:

34', 54', 74', 94', 104', 114', 124', 134', 144', 154' and 164'.

DESCRIPTION OF THE ORE MINERALS

The Shamrocke ore minerals form a simple suite with simple textures.

The individual minerals are described below by way of their physical and optical properties under the microscope, while their textural relationships are discussed in the next section.

The Shamrocke ore mineral suite is as follows, listed in the approximate order of importance:

Chalcopyrite
 Cubanite
 Pyrrhotite
 Arsenopyrite
 Pyrite
 Ilmenite
 Haematite (specular)
 Molybdenite
 Unidentified mineral "X"

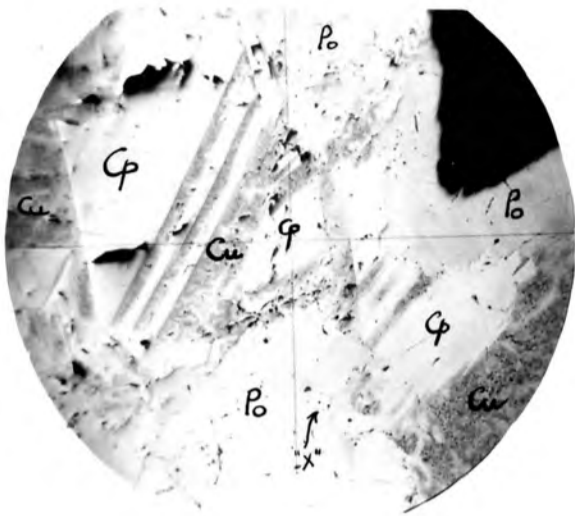
Chalcopyrite

Chalcopyrite occurs as anhedral crystals ranging from 0.01 to 0.1 mm. in size, disseminated through the groundmass, to large irregular masses of varying size. It generally shows a "mutual boundaries" texture with the pyrrhotite and has cubanite crystallised within it, generally as broad and narrow lamellae crystallographically controlled, or less generally with irregular boundaries. When adjacent to calcite gangue, the boundaries are sometimes crenulated along the rhombic edges of the calcite.

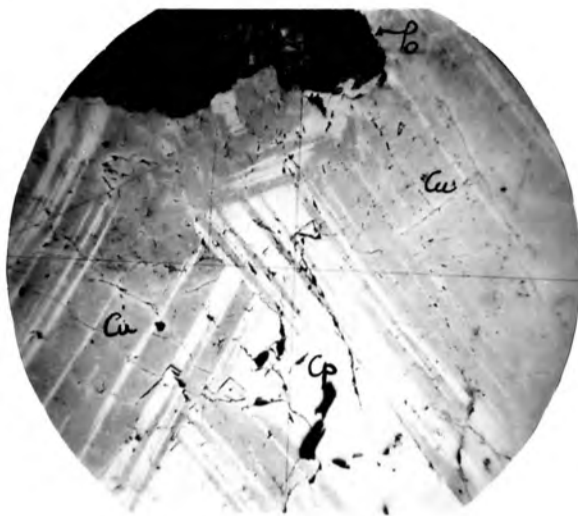
The colour of the chalcopyrite is generally a brassy yellow, but very often exhibits a pinkish sheen, which at times makes it difficult to distinguish from the cubanite, and sometimes from the pyrrhotite. This pinkish sheen is most probably tarnishing which may arise from high speed and dryness of the polishing lap. Hallimond (1956) describes a similar effect which he terms "The Beilby Layer". The highly polished chalcopyrite tarnishes a deep yellow with age and it is in that form more easily distinguished from the exsolved cubanite.

The chalcopyrite is sometimes very weakly anisotropic, polarising colours vary from a yellow to a grey-blue, with some crystals showing no anisotropism.

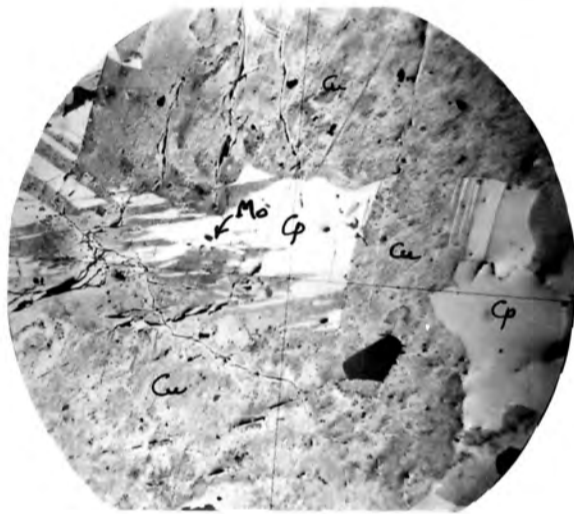
PLATE 21.



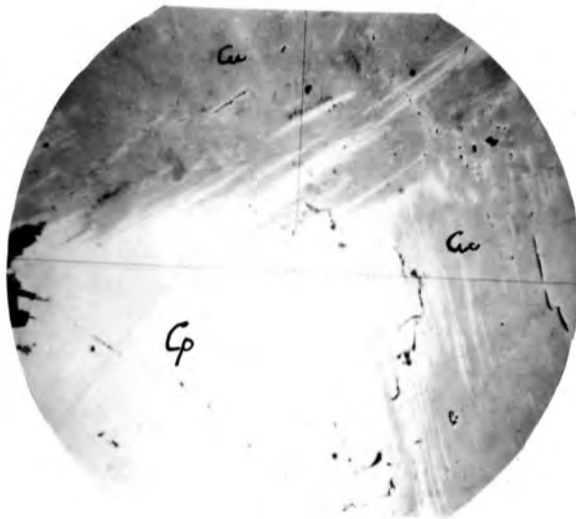
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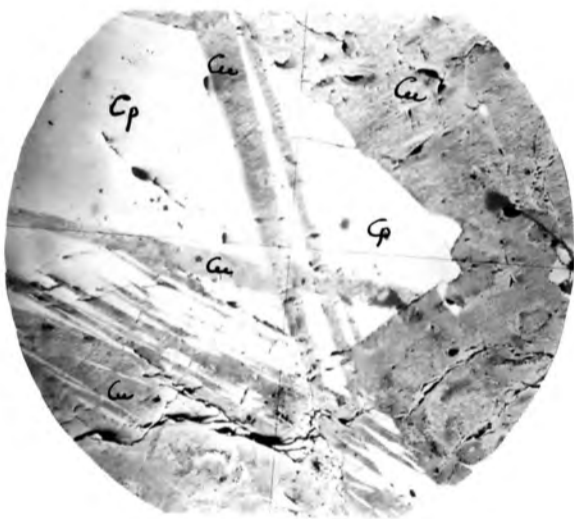
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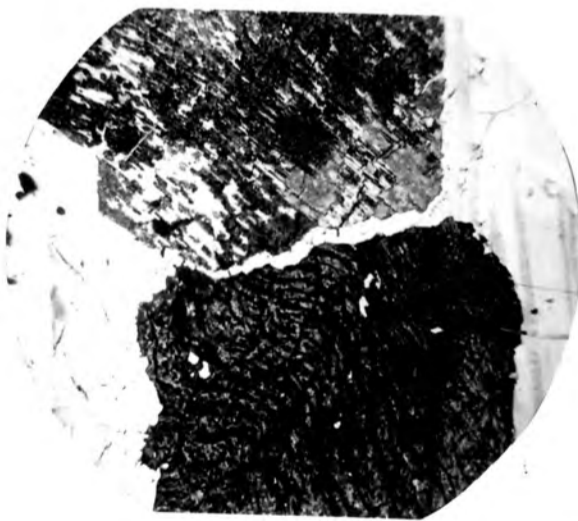
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E



F

EXPLANATION OF PLATE 21.

- A. Cubanite (Cu) lamellae in chalcopyrite (Cp) with pyrrhotite(Po) showing mutual boundaries texture relative to the chalcopyrite. The cubanite shows the natural tarnish with time. The pyrrhotite can be seen distinct from the chalcopyrite and exhibiting a pinkish sheen similar to the "Beilby" layer referred to in the text. The unidentified mineral "X" is indicated.
X 60
- B. Tarnished cubanite crystallizing in three crystallographic directions (111) of the chalcopyrite. The dark mineral is pyrrhotite stained deeply iridescent with Cr_2O_3 solution.
X 60
- C. Tarnished cubanite (Cu) predominating with chalcopyrite (Cp). Small curved molybdenite prism is shown (Mo). The cubanite is both as large masses and exsolution lamellae in chalcopyrite.
X 60
- D. Cubanite (Cu) natural tarnish in chalcopyrite (Cp). Cubanite lamellae pinching out.
X 60
- E. Tarnished cubanite showing exsolution lamellae crossing, with no thickening at intersection.
X 60
- F. Pyrrhotite crystals with natural cleavage and pitting due to parting.

The reflectivity is slightly higher than the pyrrhotite, showing regularly a greater value from relative readings on a C.T.S. microphotometer.

The hardness of the chalcopyrite is less than the pyrrhotite and approximately that of the cubanite. It is readily scratched by a needle.

The chalcopyrite tarnishes differentially light-brown with aqua regia and in places stains light-brown. With HNO_3 it occasionally tarnishes differentially iridescent. It shows a negative reaction with HCl , KCN , FeCl_3 , HgCl_2 and KOH .

Pyrrhotite

The pyrrhotite occurs both as large crystals of varying size down to small "blebs" 0.01 to 0.1 mm. across, and occasional minute stringers at the grain boundaries of the chalcopyrite. It has generally a "mutual boundary" relationship with the chalcopyrite and cubanite and is often seen with chalcopyrite both within it and filling cracks in the pyrrhotite crystals. It is generally a pinkish cream colour and is strongly anisotropic, with polarisation colours grey-white to red-brown.

At times the pyrrhotite is difficult to distinguish from the cubanite as the colour is often similar, and the polarisation colours also similar; however, the pyrrhotite shows a deeper brown polarisation colour even where the cubanite is tarnished. The pyrrhotite is however notably harder, and the Becke Line at the interface between the pyrrhotite and the cubanite is seen clearly to move from the pyrrhotite into the cubanite when the microscope is raised.

At times, the pyrrhotite shows a strong trace of the basal parting, which may be in the form of parallel straight lines, or at times wavy and irregularly deformed by stress. Coarse pitting at times takes place along this parting and enhances the effect.

The reflectivity is moderately high, but less than chalcopyrite. The polish obtained is generally good except when the parting cracks are evident.

A resistance to staining by chromium oxide (CrO_3) further distinguishes it from cubanite, although a certain iridescence is obvious. Both HCl and HNO_3 tarnish differentially and KOH stains brown in patches. It is negative to

KCN, FeCl_2 and HgCl_2 . A natural tarnish with time brings up the parting cracks and causes iridescence.

Cubanite

The cubanite occurs as both narrow and broad parallel lamellar exsolution intergrowths along the (111) planes of the chalcopyrite, and in addition exhibits mutual boundaries texture with the pyrrhotite. The boundary between the cubanite and the chalcopyrite is generally recognisable under the microscope, except where the pinkish sheen is present on the chalcopyrite. It is, however, easily distinguishable from the chalcopyrite by its strong anisotropism and its staining by chromic oxide. The textural relationship between the cubanite, chalcopyrite and pyrrhotite is described at length in the section on Textural Relationships. The colour of the cubanite is a pinkish cream which is perhaps yellower than the pyrrhotite. At times, it shows little or no anisotropism, but generally shows a fairly strong anisotropism with polarisation colours from a grey-yellow to a grey-blue. Where the cubanite is tarnished, these colours are grey-blue to a pale-reddish-brown. The hardness of the cubanite is approximately that of the chalcopyrite and distinctly softer than the pyrrhotite. It is easily scratched by a needle.

An important aspect of the cubanite is that it exhibits a natural tarnish with time. It tarnishes both to a pale partly iridescent brownish colour and to a dark brown and in this form is easily distinguishable from both the chalcopyrite and pyrrhotite. With aqua regia it stains deep red-brown drying with an iridescent tarnish. It shows a negative reaction with HCl, HNO_3 , FeCl_3 and Hg_2Cl_3 . As previously mentioned, it stains a deep brown with chromic oxide (this test is the diagnostic test for cubanite) and this distinguishes it easily from the other minerals.

Arsenopyrite

Macroscopically in polished section, the arsenopyrite is a shiny, hard, silvery-grey mineral and cannot be mistaken amongst the other minerals. Microscopically, it is a grey-white colour with weakly developed anisotropism, showing polarisation colours from a greenish-yellow to a pale blue-grey.

An unusual aspect of the anisotropism is that some parts of a crystal may appear isotropic with very small granular sections showing anisotropism. It is extremely hard and cannot be scratched by a needle even with considerable pressure. It has a high reflectivity. It is not an easy mineral to polish and is inclined to retain minute pits, possibly due to its brittleness.

With HNO_3 the arsenopyrite stains differentially iridescent but it shows a negative reaction with the other standard reagents. Aqua regia also stains differentially iridescent. It is distinguished from the pyrite by its white colour and its anisotropism. It occurs as both minute grains and large grains upwards of 2 mm. in length. It shows a "mutual boundaries" texture with the other minerals.

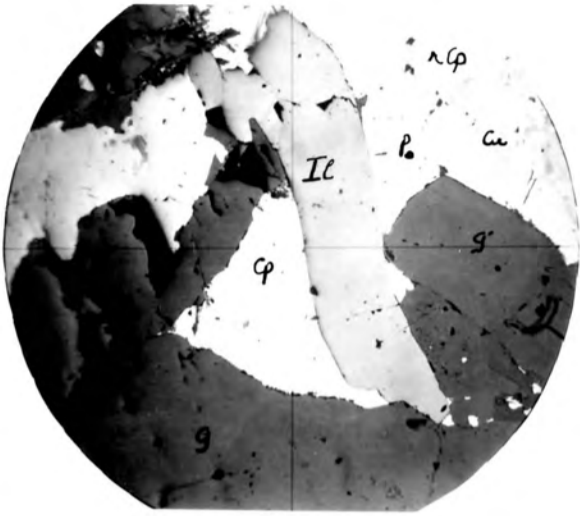
A semi-quantitative spectrographic scan was carried out over a number of ores containing arsenopyrite. The results of this analysis are shown under the section on Chemical Data and it will be noted that the arsenic is generally upwards of 50,000 ppm. in such rocks.

The arsenopyrite is not a very common mineral in the ore zone but does form particularly within the highly graphitic granulites. In the first 14 polished sections taken from various parts of the orebody, no arsenopyrite was found and it was first encountered during the sampling of underground Borehole 6. Previous to the selection of samples for polishing, however, numerous samples containing arsenopyrite were selected for the spectrographic work.

Pyrite

The occurrence of pyrite in the orebody is perhaps similar to that of arsenopyrite, in that it is not a common constituent of the ores of the Shamrocke Mine. Again, it was first encountered in the sampling of Borehole 6 and only three specimens out of 23 polished sections showed the presence of pyrite. In hand specimen it is virtually never identified. In Borehole 6 at 54 feet, the grains are fairly large, upwards of 0.5 mm., and show generally a regular smooth boundary.

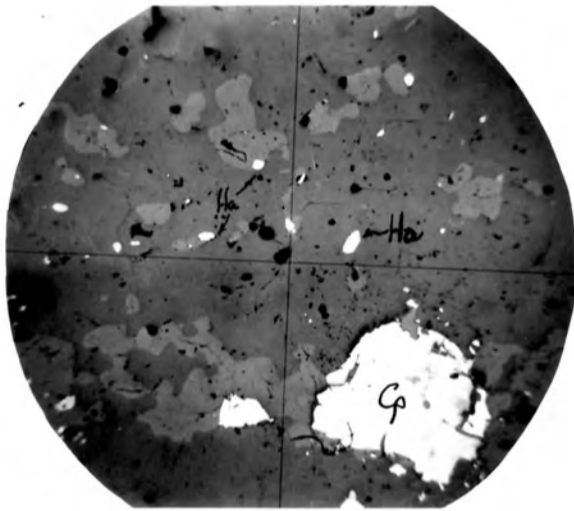
The diagnostic characteristic of the pyrite is that it is isotropic and never shows differing polarisation colours on rotation of the stage. It is a pale-yellow colour in hand specimen and is cream under the microscope. It is extremely hard



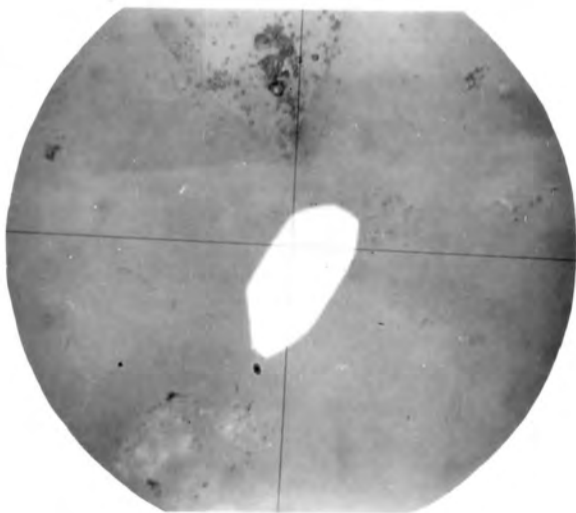
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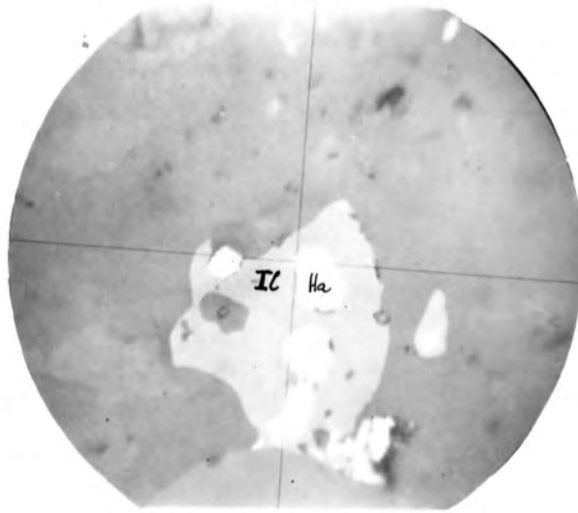
B



C



D



E

EXPLANATION OF PLATE 22.

A. Prismatic ilmenite crystal with chalcopyrite (Cp), pyrrhotite (Po) and cubanite (Cu).

X 60.

B. Highly polished pyrite crystal (Py) alongside pyrrhotite crystal (Po) in gangue. Scratch marks on the pyrrhotite are made by a needle which did not scratch, with considerable pressure, the pyrite.

X 60.

C. Small crystals of specular haematite scattered through the gangue. Large anhedral chalcopyrite crystal indicated (Cp).

D. Small specular haematite crystal under high magnification.

X 400.

E. Anhedral ilmenite crystal with included specular haematite.

High magnification

X 400

and cannot be scratched by a needle. Nitric acid imparts a brownish tarnish to the pyrite which is negative to all other standard etch reagents.

Ilmenite

The larger ilmenite crystals occur both as broad prismatic crystals up to 1 mm. in length and also as irregularly bounded grains 0.1 mm. to 0.5 mm. in size. The most common form of the ilmenite, however, is as minute rounded grains from 0.01 mm. to 0.5 mm. in size, scattered about within the felspar gangue. It is very often, and particularly in the smaller rounded grains, intergrown with even smaller rounded grains of specular haematite. It is very seldom found in a calcite gangue. It is a brown-grey colour, extremely pale in the very small grains and of a more distinctive "ilmenite colour" in the larger grains. It is anisotropic with polarisation colours from a blue-grey to a brown. It is extremely hard and cannot be scratched with a needle, even with considerable pressure. The ilmenite shows no signs of a cleavage and polishes very well. Chemically, it shows a negative result with all standard reagents.

Occasionally, very narrow and minute pale-grey prismatic crystals are seen with a similar hardness, and two extinction positions. A strong internal reflection is suggestive of rutile but the lack of four separate extinction directions rules this out. The hardness of some of these grains distinguished it from the molybdenite.

Haematite (Specular)

The specular haematite occurs almost ubiquitously scattered throughout the fine granular felspar gangue as minute rounded crystals from 0.01 mm. to 0.05 mm. The haematite is a white-grey colour and is very hard, not being scratched by needle with considerable pressure. It is anisotropic from a light-grey to a pale-brown. It is seldom encountered within calcite gangue and also occurs as small rounded grains within the pyrrhotite and chalcopyrite. It has a much higher reflectivity than ilmenite and very often occurs intergrown and included within small ilmenite grains. It is negative to all the standard etch reagents. It is very often seen crystallising along the boundary between the gangue and the pyrrhotite and chalcopyrite.

Molybdenite

The molybdenite always occurs as minute narrow prismatic sections, which are very often curved. The narrow minute laths are generally less than 0.01 mm. long, and show very nearly straight extinction. An important diagnostic property of the molybdenite laths is that they exhibit four distinct extinction directions in a complete rotation of the stage. The crystals show a strong anisotropism, with polarisation colours from a light grey to a dark grey-blue. They are extremely soft and are scratched by a needle drawn gently across them, and a Becke Line moves strongly outwards from the crystals on lowering the microscope tube. Occasionally, they are very long needle-like crystals up to 0.1 mm. in length.

They are negative to the standard etch reagents.

Unidentified Mineral "X"

This mineral is always small and never exceeds 0.02 mm. It is always found within the pyrrhotite or at the boundary between cubanite and pyrrhotite. It is paler than both the pyrrhotite and the cubanite and is a pinkish-white colour.

QUANTITATIVE MINERALOGICAL ANALYSIS OF THE ORE

The standard techniques of the modal analysis of ores, involve serious sources of error. Cameron⁽¹⁹⁶¹⁾ discusses these errors in detail. A summary of his observations here suffices to suggest that the accepted simple methods of modal analysis cannot provide accurate results for the Shamrocke ore, and that should a quantitative analysis be undertaken on this ore, the ore should be crushed, split accurately, and measured after the crush is mounted in a suitable medium. Cameron observes that the modal analysis of ores can throw much light on the origin of the ore, stages of mineral deposition, the chemistry of ore solutions, and other aspects of the origin of particular constituents. Although an accurate quantitative analysis of the Shamrocke ore would be advantageous, especially to establish the relative proportions of chalcopyrite and cubanite, it was decided that the scope of this work did not warrant the advanced techniques indicated. Should a detailed study of the ore for the purposes of deciding on the most suitable ore dressing methods be required, modal analysis would be essential.

Cameron believes that the sampling error is one of the serious errors involved in the modal analysis of ores. The Shamrocke ore is far from being homogeneous and, without a great number of samples systematically taken, the results could not give an accurate and representative result. Even within single specimens of an inhomogeneous ore this sampling error arises, where many sections should be cut for representative results. The Shamrocke ores are too inhomogeneous and in places of too coarse a grain to give representative results. The area which would have to be traversed in each polished section of the coarse-grained ore to obtain accurate results would be impractical.

TEXTURES AND PARAGENESIS

The textural relationships between the ore minerals of the Shamrocke Mine are very simple. This simplicity of texture does not, however, provide much guide as to the paragenetic order of the sulphides and gangue minerals.

The three main sulphide minerals, pyrrhotite, chalcopyrite and cubanite give little evidence through their textural relationships with one another as to exactly which of them was the first to crystallise. There is little doubt that

the relationship between the chalcopyrite and the cubanite is the result of the unmixing of a solid solution between these two sulphides. The cubanite occurs as both narrow and broad parallel laths and bands within the (111) directions of the chalcopyrite, and larger masses which exhibit irregular mutual boundaries towards the chalcopyrite. The fact that not all the cubanite occurs as parallel laths within the chalcopyrite may possibly be attributed to a high concentration of cubanite and chalcopyrite and a slow enough rate of cooling to cause partial unmixing, to segregate masses. The relationship of the pyrrhotite with both the chalcopyrite and the cubanite is not easily understood. Generally, the pyrrhotite shows a "mutual boundary" relationship with both the chalcopyrite and cubanite, suggesting simultaneous crystallisation from the original mineralising solutions. Edwards (1947), however, points out that a "mutual boundaries" feature, while suggesting a contemporaneous formation, can as well indicate the unmixing from a solid solution under sufficiently slow conditions of cooling, or even replacement. Generally the paragenesis of hydrothermal ores shows pyrrhotite to be deposited earlier than chalcopyrite, and in at least two polished sections of the Shamrocke ore, both taken at a shallow depth, minute but fairly reliable indications of initial pyrrhotite deposition followed by replacement by chalcopyrite and cubanite are found. It must be assumed that the pyrrhotite was the first to be deposited, followed very closely by chalcopyrite-cubanite giving overlapping crystallisation.

The presence of both ilmenite and molybdenite as lath shaped crystals within the other sulphide minerals indicates their initial crystallisation and subsequent inclusion within later sulphides.

Among the main constituents, pyrrhotite is thought to have crystallised first, closely followed by chalcopyrite with a certain amount of overlapping of crystallisation on further cooling.

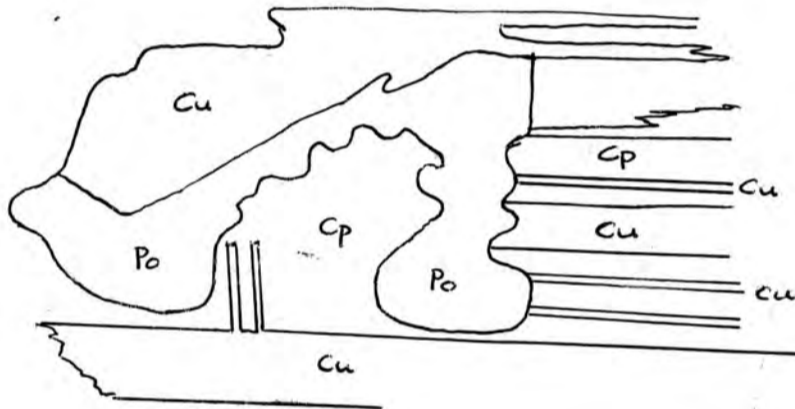
TEXTURAL RELATIONSHIPS BETWEEN THE ASSEMBLAGE
PYRRHOTITE - CHALCOPYRITE - CUBANITE - GANGUE

Some observations of these textural relationships with a few examples are given below.

Pyrrhotite - Chalcopyrite/Cubanite

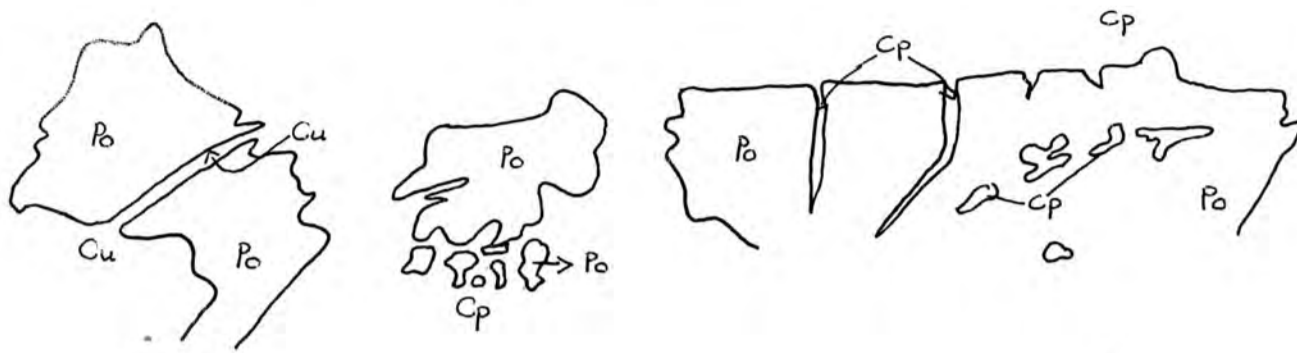
Pyrrhotite in the Shamrocke ore generally has a "mutual boundary" relationship with chalcopyrite/cubanite. These mutual boundaries are generally irregular with no sign of selective replacement on either side of this mutual grain boundary, nor do they show the presence of crystal outline in any form. These mutual boundaries occur irrespective of grain size.

e.g. Borehole 27 at 2382 feet



In two polished sections, small but definite examples of the replacement of pyrrhotite by chalcopyrite/cubanite are seen. Here pyrrhotite is seen to have chalcopyrite and cubanite protruding along cracks into it, as well as the filling of interstices within the pyrrhotite by chalcopyrite. Chalcopyrite replacing pyrrhotite in Borehole 7 at 372'5" has caused numerous crystals of pyrrhotite to show "shredding" at their edges as remnant pyrrhotite to the replacement by chalcopyrite. Occasionally, several wedge shaped grains of chalcopyrite are found within the pyrrhotite.

e.g. Borehole 1 at 180 feet and
Borehole 7 at 372 feet



Pyrrhotite often occurs as blebs up to 0.1 mm. across and minute stringers at the grain boundary between the chalcopyrite and calcite gangue. These do not appear to be pyrrhotite being deposited within cracks in the chalcopyrite, but rather replacement veins and blebs. This texture is very difficult to explain in the suggested paragenetic sequence of the ore. Pyrrhotite is also found as small, narrow, irregular laths or veins within the chalcopyrite; again this is difficult to explain.

e.g. Borehole 19 at 1479 feet



Generally, with a little practice, the pyrrhotite can be distinguished from the cubanite. The pyrrhotite regularly shows the trace of the basal cleavage, but where this cleavage is absent, it is generally seen to be a deeper pink colour and shows a bright "Becke Line" moving into the chalcopyrite or cubanite on raising the microscope tube, indicating a greater polishing hardness than both chalcopyrite and cubanite. The resistance to staining by a solution of Cr_2O_3 instantly distinguishes it from cubanite which is easily stained.

Chalcopyrite - Cubanite

Cubanite occurs both as narrow and broad parallel lamellae in the (111) planes of the chalcopyrite, and exhibits irregular and smooth mutual

boundaries with the chalcopyrite.

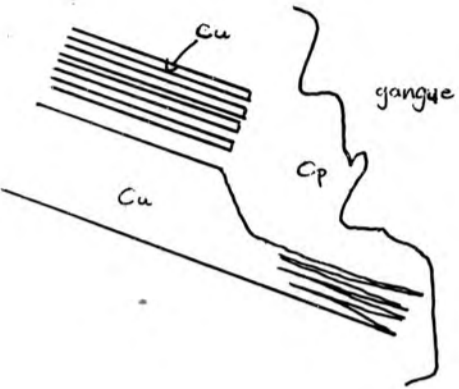
The cubanite is accepted as being the product of the unmixing of a solid solution of chalcopyrite and cubanite. The occurrence of cubanite as both laths and bands along the crystallographic planes of the chalcopyrite, and irregular masses showing mutual boundary texture with the chalcopyrite will be discussed under 'Paragenesis' and is attributed to high concentration of cubanite in the chalcopyrite and to the rate of cooling during deposition.

The boundaries between the chalcopyrite and the cubanite are generally readily recognisable under the microscope, except where the chalcopyrite attains the pinkish sheen associated with the "Beilby Layer" of Hallimond (1956). However, with practice, even this sheen does not make recognition too difficult. Where difficulty is experienced, the staining of the cubanite with a solution of Cr_2O_3 successfully brings out the textural relationship between these two minerals, and at the same time serves to distinguish between cubanite and pyrrhotite. A natural tarnish of the cubanite with time, further serves to distinguish it from the chalcopyrite and pyrrhotite.

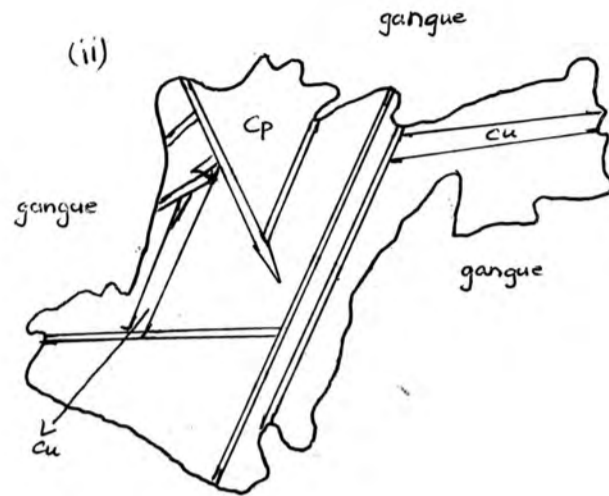
The cubanite laths and bands along the (111) crystallographic directions in the chalcopyrite occur as lamellae ranging from single narrow laths in the chalcopyrite to very broad and numerous bands leaving little chalcopyrite between. These lamellae are parallel to one another in each (111) direction. Where the lamellae cross, forming a connected lattice-work, no thickening takes place. Generally, these lamellae are straight, but occasionally they become wavy and pinch out. A broad cubanite band often splits up into numerous thin laths. A very interesting feature of these parallel cubanite laths, is that they sometimes come to an abrupt end along an invisible plane in the chalcopyrite. Even where the chalcopyrite grains are very small these cubanite laths occur, sometimes quite microscopic in themselves.

Some examples

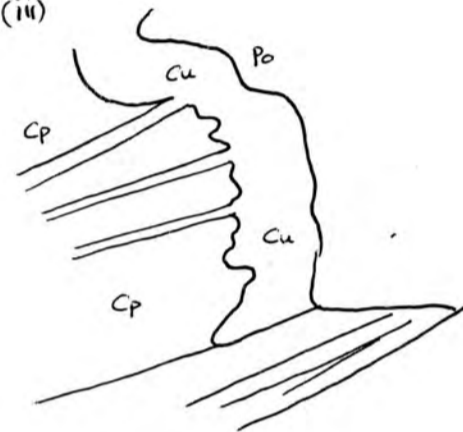
(i)



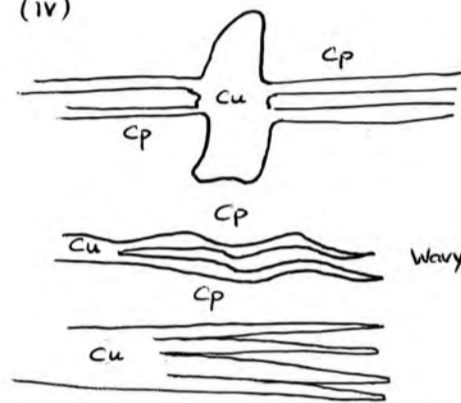
(ii)



(iii)



(iv)



Where chalcopyrite and cubanite show mutual boundaries with one another, these boundaries are smooth and irregular and must be attributed to a sufficiently slow cooling rate during unmixing to segregate the two minerals, as cubanite is, of necessity, an unmixing product from a disordered chalcopyrite.

Sulphide - Gangue

The main gangue minerals are calcite, feldspar and amphibole (hornblende), and again these show simple grain boundary relationships with one another.

The calcite gives an indication of having crystallised both simultaneously with, and before the sulphide minerals. There are examples where irregular and smooth intergrain boundaries and incipient crystallisation of sulphide in gangue, suggest simultaneous deposition. Very occasionally small grains of calcite are found enclosed in the sulphide. Where the calcite shows straight crystal edges against the sulphide, and where the sulphide crystallisation appears to have taken place within the irregularities of the calcite edge or within interstices in the calcite, it is assumed that the calcite was in fact deposited ahead of the sulphides. Here also a certain amount of replacement of calcite by sulphides is seen, the more common indications being a distinctly crenulated calcite boundary where the sulphide is replacing the calcite grain at the edges. It is rather difficult to establish whether the ragged edges shown by some sulphide crystals are due to replacement of the calcite or simultaneous incipient crystallisation from a common solution. Here it is quite feasible that where the calcite appears older than the sulphide, it is a primary calcite from the original calcareous grit, and where simultaneous crystallisation is indicated, that this is in fact calcite that has crystallised alongside the sulphide from metasomatising solution.

The felspar of the gangue is the felspar groundmass of the original rock. The grain-boundary relationship of this felspar with the sulphide is one of irregular and smooth contacts where the sulphide minerals have been deposited against the granular groundmass felspar, within irregularities of these boundaries, and in interstices and cracks between the grains.

Where the gangue mineral is hornblende, this hornblende is of metasomatic origin and crystallised simultaneously with the sulphide minerals. This hornblende is seen as irregular anhedral grains, lath-shaped crystals or basal sections in and about which the sulphide minerals have been formed. The laths are arranged decussately. Occasionally within openings in the chalcopyrite small laths of hornblende are found, ruling out replacement and again indicating simultaneous deposition.

In places, it appears that narrow hornblende laths within the chalcopyrite have been replaced by pyrrhotite. As with the pyrrhotite apparently replacing the chalcopyrite, this second stage pyrrhotite is

difficult to explain. One lath of pyrrhotite appears to have remnant hornblende along the one side. However, these pyrrhotite laths may simply be replacement or exsolution laths in the chalcopyrite.

OTHER TEXTURES

The only other textures of any consequence are those concerning the smaller and unidentified mineral.

- Mineral X occurs almost always enclosed within the pyrrhotite or within the pyrrhotite at the contact with chalcopyrite or cubanite. Only one example of this mineral X a short distance from the pyrrhotite within the chalcopyrite and cubanite was found. These are always anhedral grains.

The molybdenite crystals are always found as laths, sometimes bent, within the chalcopyrite.

TEXTURES RELATIVE TO POSITION WITHIN ORE-BODY

Although sections were polished from specimens taken at regular depth intervals and also at regular intervals away from the hangingwall contact across the width of the body, no textural differences whatever could be found with both depth and distance from the sidewall within the orebody.

PARAGENESIS

Paragenetic Order.

As previously described, the texture of the minerals of the ore of the Shamrocke Mine is relatively simple. This simplicity does not yield very much information as to the sequence of mineral deposition.

Bastin, Gratton et al (1931) p.561, state:

"The precipitation of minerals from any complex solution is governed by composition, concentration, temperature, pressure and time. Changes in any of these factors may result in precipitation. The composition and concentration of this system will change by continued precipitation; they will also be changed by introduction of new materials. Thus, even in a single period of primary mineralisation changing conditions may result in age diversity among the ore minerals.

Simultaneous deposition is where substances being considered to be simultaneous only if their precipitation from solution begins and ends at the same time. Simultaneous deposition may be effected by the unmixing of solid solutions."

In many mineral deposits, replacement is common, resulting in an abundance of replacement textures by which the observer can, with fair confidence, place the minerals in their order of deposition. In the Shamrocke ore, replacement textures are not general, and where replacement has indeed taken place, the degree of replacement has been slight. Bastin, Gratton (1931) discuss replacement thus:

"Where no appreciable open spaces are available which ores may occupy, deposition may be accomplished through replacement. Replacement may be defined as the dissolving of one mineral or group of minerals and the simultaneous deposition of another mineral or group of minerals in their place."

The two dominant textures of the Shamrocke ore are, irregular "mutual boundaries" texture, and laths and parallel sulphide lamellae found within other mineral grains. The isolated small, sometimes microscopic, lath of ilmenite and molybdenite found within larger sulphides are no doubt original crystals of these minerals caught up in the crystallising solutions of the other minerals. The parallel lamellae of cubanite in the (111) direction of chalcopyrite indicates the exsolution from a solid solution of chalcopyrite and cubanite. According to Edwards (1947), "mutual boundaries" can be the result of the unmixing of solid solution, a very high concentration of the solute mineral also resulting in this segregation, simultaneous crystallisation not in solid solution, and "can as readily develop from replacement".

In hydrothermal mineral deposits it is generally accepted that pyrrhotite crystallises ahead of chalcopyrite and cubanite. In the Shamrocke ore, some of the pyrrhotite appears to have been deposited ahead of the chalcopyrite-cubanite where crystals of pyrrhotite show chalcopyrite and cubanite in cracks and interstices in the pyrrhotite. However, much of the pyrrhotite shows a "mutual boundary" texture with chalcopyrite, cubanite and gangue; suggesting simultaneous crystallisation. Isolated cases have been encountered where pyrrhotite apparently replaces chalcopyrite-cubanite as small blebs and stringers generally along the grain boundaries of the chalcopyrite-cubanite and in some instances replaces the laths of hornblende gangue within the chalcopyrite. Possibly overlapping

deposition has taken place to give a general "mutual boundary" texture indicating simultaneous crystallisation outside solid solution, or that solid solution has in fact taken place between pyrrhotite and chalcopyrite and, with slow cooling, unmixing to segregate grains of pyrrhotite and chalcopyrite. However, the presence of even limited replacement textures, and the fact that it would require very slow cooling not to produce at least a few pyrrhotite lamellae in chalcopyrite, does not indicate solid solution and a process of simultaneous crystallisation for the pyrrhotite and chalcopyrite appears more acceptable.

The cubanite ex-solution lamellae in the chalcopyrite are formed by the unmixing on cooling of cubanite from a chalcopyrite-cubanite solid solution, forming an orientated ex-solution texture of parallel laths and blades in the (111) plane of the chalcopyrite. Edwards, Werner and Lombard have shown by thermal and X-ray studies that at the temperature of solid solution, $+140^{\circ}\text{C}$, the chalcopyrite exists as a "high chalcopyrite" modification, which has a disordered structure, and that on cooling, it reverts to the ordered "low chalcopyrite" form. The reversion to order, causing the precipitation of all atoms present in excess of the simple rational proportions of chalcopyrite as blades of cubanite or chalcopyrrhotite. Cubanite is found, in addition to parallel laths within the chalcopyrite, with a "mutual boundaries" texture with chalcopyrite. This "mutual boundaries" texture is no doubt also the result of ex-solution from a solid solution of chalcopyrite and cubanite as described above. At times, a sufficiently slow cooling process allows the complete unmixing and segregation of minerals precipitated in solid solution. Edwards (1947) also states that "where the concentration of the solute mineral is high, such segregation results in more or less granular allotriomorphic texture, in which the two minerals show relatively regular contacts, without very decided projections of the one mineral into the other.

It is difficult to establish the position in the paragenetic order for the pyrite and arsenopyrite. It has been suggested that they should be placed before the pyrrhotite in the sequence although textural evidence does not assist in this choice. However, Schwartz (1927) suggests that pyrite and arsenopyrite normally crystallise ahead of pyrrhotite and Gilbert (1924) states:

"In most ores, the harder minerals appear to have crystallised earlier than the softer ones". Furthermore, the pyrite and arsenopyrite appear to have definite crystal edges against the pyrrhotite which, according to Edwards (1947) make the pyrite and arsenopyrite older than the pyrrhotite.

The textural relationships between the gangue and the sulphide minerals, indicate that a great majority of the gangue minerals were in fact primary minerals of the original rock and that the sulphide mineralisation was subsequent, crystallising against and between the original groundmass. Where this felspar groundmass has sulphide deposited in cracks and interstices between grains and where original calcite shows crystal edges against the sulphide, and in a few instances replaced by the sulphide, the crystallisation of sulphides within the rock fabric is indicated. The calcite is, however, also found as a secondary metasomatic variety which crystallised from hydrothermal solutions and gases along with the sulphides.

From these observations, it is assumed that the paragenetic order cannot have been much different to that suggested below, from oldest to youngest:

ilmenite
 molybdenite
 arsenopyrite
 pyrite
 pyrrhotite
 chalcopyrite/cubanite
 specular haematite
 minor minerals

To sum up then, it appears that, among the main ore mineral constituents some pyrrhotite was the first to crystallise, being closely followed by arsenopyrite, pyrite and the ex-solution of chalcopyrite and cubanite. Some overlapping of deposition is suggested with some late crystallisation of pyrrhotite replacing chalcopyrite/cubanite.

TEMPERATURE OF DEPOSITION

Although not sufficient is known of the Shamrocke ore minerals to discuss the temperature of deposition with any certainty, the following discussion is pertinent.

Edwards (1947) states that temperature determinations are based on the temperature at which some change of form takes place, such as melting, re-crystallisation, inversion, solid solution, etc. According to Edwards (1947)

the presence of pyrrhotite in abundance is evidence that deposition began at approximately 600°C and that the mineral molybdenite is deposited above 500°C . Schwartz (1927) experimentally proved the temperature above which the cubanite-chalcopyrite solid solution is homogenous was 450°C . and he concluded that the ore deposits in which this intergrowth is found were formed above 450°C .

We can therefore reasonably assume that the temperature of deposition of the ore was definitely above 500°C . and probably above 600°C .

B6 PETROLOGYCHEMICAL DATASILICATE ANALYSES

Three full silicate analyses were carried out by wet methods.

The rocks analysed were:

- a fine-grained pink biotite granulite with a minimum of ferromagnesian and sulphide minerals, typical of the ore zone from the Adit drive.
- a coarse porphyroblastic felspar-amphibole rock from the contact of the ore zone with the schist from the Adit drive.
- a typical medium-grained plagioclase amphibolite (meta-dabase) from Borehole 27 at 2050 feet.

Analytical ProcedurePulverisation of the Rock

The rock specimen was pulverised in a hardened steel mortar specially designed to offset the possibility of loss of material during crushing. The pulverised rock was passed through a 100-mesh sieve.

Fusion

Exactly one gram of the rock powder was sampled on careful mixing and quartering and fused with 5 grams of sodium carbonate. The fused cake was thoroughly washed and dissolved in 20 cc. of concentrated hydrochloric acid.

Analysis

The analyses were undertaken following the method as described in the "Manual of the Chemical Analysis of Rocks" by Henry S. Washington, 1919.

The Results of the AnalysesI. Biotite Granulite - Analyst D.L. Kyle 1961

		<u>Norm</u>	
SiO ₂	67.70		
Al ₂ O ₃	18.70	Q	18.42)
Fe ₂ O ₃	0.25	or	18.15)
FeO	1.45	ab	46.01)
MgO	2.19	an	2.78)
MnO	Trace		
CaO	0.56	hyp	7.88)
Na ₂ O	5.45	mt	0.46)
K ₂ O	3.08	cor	5.30)
TiO ₂	0.22	ap	0.36)
P ₂ O ₅	0.12	il	0.45)
H ₂ O +	0.26		
CO ₂ + H ₂ S	0.18	H ₂ O	0.26
H ₂ O -	Nil		
	<hr/>		
	99.96		
			<hr/>
			100.07
			<hr/>

Salic 85.66%

Femic 14.11%

2. Porphyroblastic Felspar - Amphibole Rock - Analyst R. Jacob 1961

SiO ₂	62.09		
Al ₂ O ₃	12.05		
Fe ₂ O ₃	0.24		
FeO	5.62	<u>Norm</u>	
CaO	6.03	Q	3.66)
MgO	5.20	or	2.22)
MnO	Trace	ab	57.64 Salic 65.71%
Na ₂ O	6.76	an	1.39)
K ₂ O	0.39	hyp	11.09)
H ₂ O +	0.22	diop	20.62)
H ₂ O -	Nil	mt	0.23) Femic 34.56%
TiO ₂	0.95	il	1.98)
P ₂ O ₅	0.14	ap	0.34)
CO ₂ + H ₂ S	0.35	H ₂ O	0.22
	<u>100.04</u>		<u>100.27</u>

The granulite and felspar-amphibole rocks of the Shamrocke Mine have an unusual mineral assemblage; with little quartz and predominant plagioclase. An extensive literature search has failed to find any rocks of an identical nature, and, therefore, the following chemical analyses are recorded to afford some comparison of the granulite and porphyroblastic felspar-amphibole rocks of the Shamrocke Mine with other rocks of similar mineral composition.

Some Analyses of Calc-Silicate Rocks

	1	2	A	B	3	Shamrocke Granulite	Shamrocke Felspar-Amphi- bole Rocks.
SiO ₂	62.73	62.55	59.25	71.87	73.51	67.70	62.09
Al ₂ O ₃	16.69	15.75	13.30	12.75	12.21	18.70	12.05
Fe ₂ O ₃	0.42	1.56	0.84	0.29	0.44	0.25	0.24
FeO	3.02	3.26	4.71	4.25	2.05	1.45	5.62
MgO	1.09	2.88	4.20	1.07	0.59	2.19	6.03
CaO	8.86	9.39	11.37	7.08	9.52	0.56	5.20
Na ₂ O	2.88	0.93	1.73	0.33	0.21	5.45	6.67
K ₂ O	0.90	1.54	2.42	0.06	0.05	3.08	0.39
H ₂ O +	0.94	0.64	0.73	0.55	0.27	0.26	0.22
H ₂ O -	0.10	0.15	0.09	0.05	0.06	Nil	-
TiO ₂	0.67	0.79	0.75	1.31	0.54	0.22	0.95
P ₂ O ₅	0.31	0.30	0.18	0.05	0.11	0.12	0.14
MnO	0.29	0.28	0.08	0.43	0.44	Tr	Tr
CO ₂	0.98	Tr	0.13	n.d.	0.06	0.18(+H ₂ S)	0.35
Rest	-	0.09	0.14	-	0.02	-	-
Total	99.90	100.11	99.92	100.10	100.08	99.96	100.04

1. Calc-zoisite-biotite-garnet granulite; (calc-silicate band) in Upper Striped Group of Moine Series, Shore, N.E. side of Mallaig Harbour, Invernesshire. C.O. Harvey, analyst. Average analysis of twenty individual bands. Quoted from W.Q. Kennedy, *The Geological Magazine*, Vol. XXXVI, Jan-Dec. 1949, p.47.
2. Zoisite-hornblende granulite in Moine Series, 3/4-mi. S.W. of Glen Calvie Lodge, Rosshire. W. Pollard, analyst, quoted from the "Geology of Ben Wyvis, etc." (Sheet 93), *Mem. Geol. Survey*, 1912, p.45.
- A. Calc-silicate gneiss, Almaaskroken, Norway. A.Roer, analyst. Quoted from V.M. Goldschmidt, "Die Kalksilikatgneise und Kalksilikatglimmerschiefer des Trondhjem-Gebiets", *Vidensk. Skr., Mat - Naturv.Klasse*, 1915, No. 10, p.15.

- B. Lime-silicate schist (hornblende-anorthite-garnet), Dutchess County, New York. E. Kluver, analyst. Quoted from T. Barth, *Structural and Petrological Studies in Dutchess County, New York II. Petrology and Metamorphism of the Palaeozoic Rocks*. *Bul. Geol. Soc. Am.* Vol.47, 1936, p.813.
3. Pyroxene-anorthite granulites; calc-silicate band in Moine Series, Moidart district, 100 yards S. 20°W of Dalilea Mica Prospect and 1,630 yards E. 10°S of General Ross's Cairn. G.A. Sergeant, analyst. Quoted from W.Q. Kennedy, *The Geological Magazine*, Vol. XXXVI, Jan-Dec. 1949, p.47.

In comparing the analyses as recorded above, the following comment is perhaps pertinent :

- (i) The higher silica percentage of the granulite compared with the felspar-amphibole rock, is due to the higher silic mineral content, i.e. more plagioclase.
- (ii) The magnesium content of the felspar-amphibole rock is higher than in the granulites due to the larger component of ferrous or ferromagnesian minerals. The ferrous iron content is also higher for this reason.
- (iii) The calcium content of the felspar-amphibole rock is tenfold greater than the granulites, where it appears that the granulites have had the calcium extracted during metasomatism, giving rise to the abundant calcite veining and irregular bodies of calcite throughout the ore zone, often associated with the mineralisation. This is sympathetic with the apparent albitisation of the plagioclase by calcium extraction.
- (iv) The higher potassium content of the granulites is no doubt due to the abundance of biotite.

3. Plagioclase Amphibolite - Analyst : N. Wainwright 1961

SiO ₂	46.14
Al ₂ O ₃	15.23
Fe ₂ O ₃	2.15
FeO	14.37
MgO	5.50
CaO	9.26
MnO	-
Na ₂ O	1.93
K ₂ O	0.95
H ₂ O +	0.58
H ₂ O -	-
TiO ₂	4.04
P ₂ O ₅	0.62
	<hr/>
	100.77
	<hr/>

As the above analysis was considered suspect the following checks were carried out:

The composition of plagioclase An₃₀ was calculated as follows:

SiO ₂	61.05%
Al ₂ O ₃	24.66%
Na ₂ O	8.26%
CaO	6.03%

using the modal analysis of the plagioclase amphibolite which indicated 28.9% plagioclase, 46.9% hornblende, 15.5% biotite and 8.7% iron ore; the percentage silica and alumina of the rock was calculated as follows:

<u>% Silica</u>	<u>%Al₂O₃</u>
Felspar 17.04%	Felspar 7.2%
Hornblende 22.09%	Hornblende 4.0%
Biotite 5.89%	Biotite 3.05%
<hr/>	<hr/>
45.62%	14.25%
<hr/>	<hr/>

The fair agreement of these two computed values with the analysis goes some way to validating the analysis result for SiO_2 and Al_2O_3 .

The K_2O and Na_2O were re-determined using flame photometer methods and as the original results were obviously incorrect, the new values were incorporated in the analysis result.

The following are some analyses of plagioclase amphibolites from Scotland, compared with a quartz dolerite, a diabase and the present analysis:

	1	2	3	4	5
SiO_2	51.25	49.57	49.85	48.50	46.14
Al_2O_3	13.57	13.57	16.90	16.17	15.23
Fe_2O_3	1.75	2.47	1.74	4.65	2.15
FeO	13.72	12.78	11.16	11.38	14.37
MgO	3.11	4.26	3.93	4.24	5.50
CaO	8.10	8.51	8.72	7.28	9.26
Na_2O	1.94	2.44	3.45	3.07	1.93
K_2O	1.20	1.42	0.31	1.67	0.95
$\text{H}_2\text{O} +$	0.70	0.55	1.00	1.94	0.58
$\text{H}_2\text{O} -$	0.10	0.22	-	-	-
TiO_2	3.50	2.13	2.32	0.80	4.04
P_2O_5	0.63	1.23	0.27	0.67	0.62
CO_2		0.10			-
S	-	-	tr	-	-
MnO	0.35	0.50	0.30	tr.	-
Remainder	-	0.24	-	-	-
	99.92	99.69	99.95	100.37	100.77

1. Garnet - Biotite - Diorozoisite - Albite - Amphibolite (67/4)

0.2 mile N51°E from north of Loch-na-Craig near Achalaish, South Kuapoak.

Analyst : W.H. Herdsman. J.H.D. Wiseman, Q.J. of Geol. Soc., London, 1934.

Vol. XC, part 3.

2. Quartz Dolerite

Bull. Geol. Sur. of Tasmania No. 43, 1912, p.49.

3. Biotite - Epidote - Albite - Amphibolite

J.H.D. Wiseman Q.J. of Geol. Soc., London, 1934, Vol. XC, part 3.

4. Diabase

Lunds Unversiteit, Austria (xxxiii) (2) 1897. p.24.

5. The Present Analysis: Plagioclase Amphibolite, N. Wainwright, 1961.

These results are sufficiently in agreement to suggest that the plagioclase amphibolite was probably of igneous origin and is a metamorphic product of a diabase or dolerite.

No quantitative analysis was carried out on the hornblende of the Shamrocke rocks. However, as the plagioclase amphibolite of the Shamrocke area appears to have a composition similar to the rocks as detailed above, it may be pertinent to quote an analysis of hornblende from Specimen 1 above.

Hornblende

SiO ₂	47.35
Al ₂ O ₃	8.47
TiO ₂	0.70
Fe ₂ O ₃	2.83
MgO	8.83
FeO	17.16
MnO	0.25
Na ₂ O	0.65
CaO	10.16
K ₂ O	1.34
H ₂ O +	2.05
H ₂ O -	-
	<hr/>
	99.79
	<hr/>

Note: The amount of Hb available was insufficient for the determination of H₂O -

0.2 mile N51°E from the northern end of Loch-na-Craig, near Achalaish, South Kuapok.

Analyst : Maima Jahlkom.

J.D.H. Wiseman, Q.J. of Geol. Soc., London, 1934, Vol. XC, part 3.

SPECTROGRAPHIC ANALYSIS

The only spectrographic scan of the Shamrocke ore was kindly undertaken by the then Rhodesian Selection Trust Laboratories at Mangula Mine in 1960. Only four analyses were done on ore containing arsenopyrite, to check for possible gold content.

Semi-quantitative scan of the 4 samples 1,2,3 and 4 of granulite with arsenopyrite.

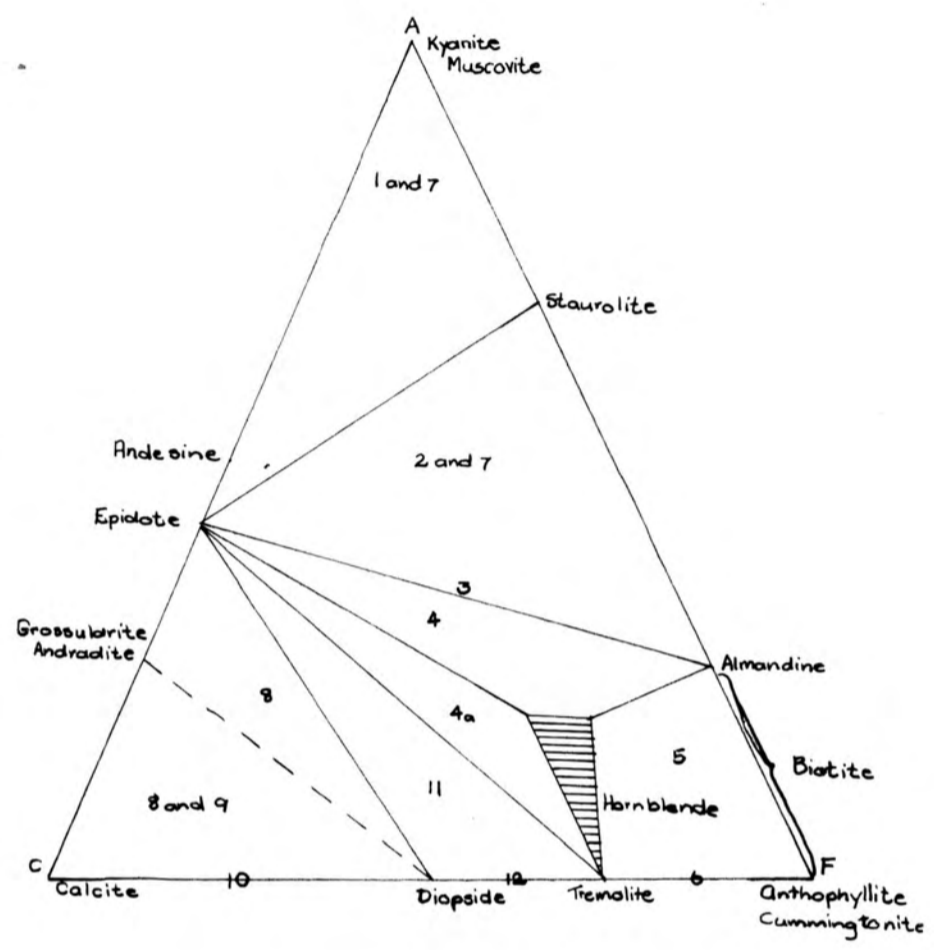
Sample	Cu	Pb	Zn	V	Co	Ni	Sn	Mo	Ag	Li	Ge	Ta Cd Au W Pt			Mn	Cr
												Nb	Be	Sb		
1	50	5	30	5	800	100	5	30	-	-	2	-----	500	100		
2	800	2	-	-	200	80	-	-	-	-	-	-----	500	100		
3	200	2	10	30	1000	800	15	15	-	-	-	-----	500	100		
4	10000	2	2000	-	30	30	-	-	4.5	-	-	-----	500	-		

	<u>As</u>	<u>Bi</u>
1	50000	5
2	50000	-
3	50000	-
4	1000	5

Values are in parts per million. Dash
indicates not detected.

An interesting feature is the sympathetic increase in the zinc value with the high copper value in Sample 4 and the antipathetic cobalt-to-copper value in all four samples. Although the evidence of one sample is not significant, it would appear that arsenic is low with high copper content which agrees with the very small proportion of arsenopyrite visible in the polished sections of the copper ore.

FIGURE 21.



ALMANDINE-AMPHIBOLITE FACIES STAUROLITE-AL MANDINE SUBFACIES; ACF diagram for rocks with excess SiO₂.

METAMORPHISM AND PETROGENESIS

The Regional metamorphic setting of the area is discussed in Section A above.

The metamorphism of the rocks in the immediate vicinity of the Shamrocke Mine is discussed briefly below relative to classification within the facies principle and as an indicator of metamorphic processes.

Facies Classification

Winkler (1967) adequately summarised the previous work by various workers in their attempt to classify metamorphism and metamorphic products. He particularly compares the metamorphic facies series as referred to by Barrow (1893 and 1912), Turner, Fyfe and Verhoogen (1958), Turner and Verhoogen (1960) and Miyashiro (1961).

The rocks of the Shamrocke Mine appear to fall directly into the Almandine Amphibolite facies of Regional Metamorphism of Turner, Fyfe and Verhoogen (1958) and Turner and Verhoogen (1960). These authors state that in the Almandine Amphibolite facies, derivatives of basic igneous rock consist essentially of hornblende and calcium-bearing plagioclase, with or without epidote; contrasted with the assemblage albite-epidote-amphibolite or rocks of lower metamorphic grade (Greenschist facies). The former assemblage is that of the plagioclase amphibolite of the Shamrocke area, which in addition occasionally contains almandine garnet. As discussed below the relationship plagioclase-epidote is critical. In the Shamrocke Mine the plagioclase is oligoclase-andesine (except in the ore zone granulite which comprise plagioclase as sodic as An_{04} due to albitisation by carbonate metasomatism). Epidote is not abundant and the grade of metamorphism appears to be higher than the Quartz-Albite-Epidote-Biotite subfacies of the Greenschist facies (Turner, Fyfe and Verhoogen 1958). The abundance of almandine and staurolite, and the absence of cordierite and andalusite, distinguished the Almandine Amphibolite facies of the schist from the Hornblende-Hornfels facies of contact metamorphism.

The Shamrocke rocks can be further classified into the Staurolite-Almandine subfacies of Turner and Verhoogen (1960) or the Staurolite-Quartz subfacies of Turner, and Verhoogen (1960).

Figure 21 is the ACF diagram for rocks in the Almandine-Amphibolite facies, Staurolite-Almandine subfacies (after Turner and Verhoogen 1960), with the shaded area the position within the subfacies occupied by the Shamrocke rocks. Derivatives

of pelitic rocks in this facies and subfacies have staurolite, almandine and (rarely) kyanite in association with micas, but do not contain potash feldspar. The Shamrocke rocks do not contain orthoclase, nor do they contain kyanite, probably due to their higher alkali content.

Staurolite is generally present in rocks of high alumina and iron content, and which are deficient in potash. The geochemistry of the Shamrocke rocks supports these conditions and staurolite is occasionally found in the hangingwall schist. Almandine and staurolite are not ubiquitous through the rocks of the Mine, with the assemblage hornblende-plagioclase predominant. The typical assemblage of the originally pelitic rocks, now schist and phyllites, is quartz-plagioclase-almandine-biotite (cf. Figure 21). Muscovite is conspicuous by its absence.

Quartzo-felspathic rocks of the Almandine Amphibolite facies generally contain the assemblage quartz-microcline-plagioclase-biotite (Turner and Verhoogen 1960). The Shamrocke granulite however contains amphibole, but not microcline. Amphibole and calcite are found due to the calcareous nature of the original grit. The rocks of the mine are furthermore rich in magnesia and contain cummingtonite and anthophyllite, with a common assemblage cummingtonite - (or anthophyllite, but never both) - hornblende-plagioclase-almandine, thus satisfying the ACF diagram Figure 21.

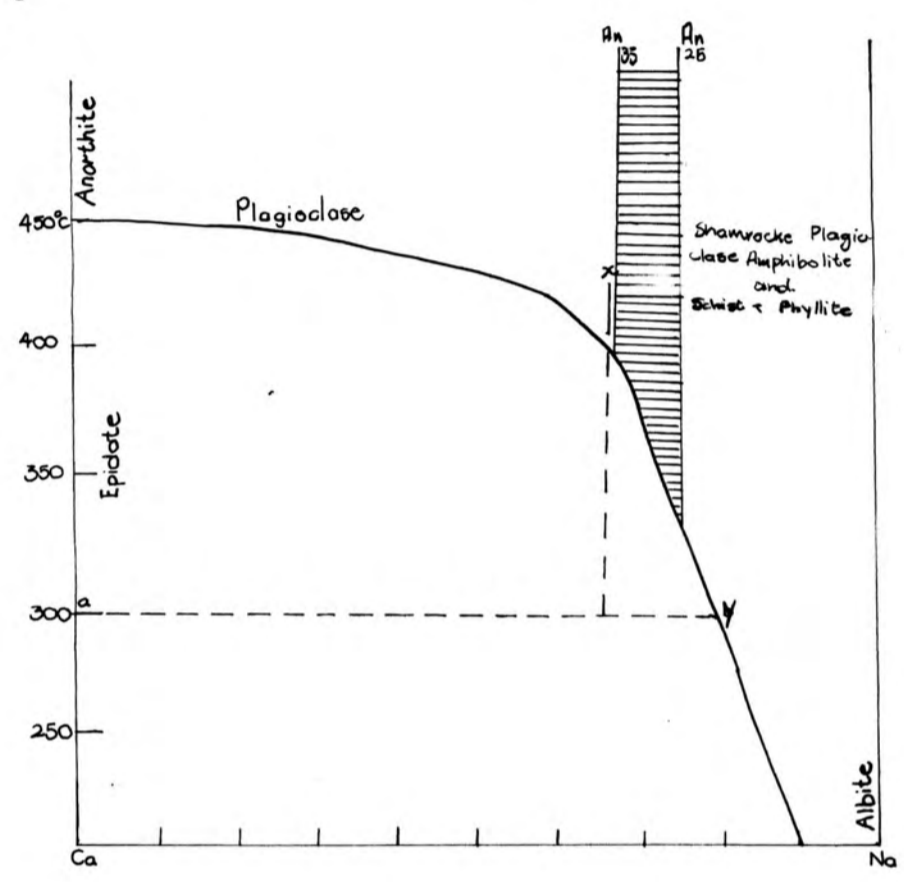
Turner and Verhoogen (1960) conclude from experimental observations that the Almandine-Amphibolite facies covers a temperature range of 550°C to 750°C, with pressures normally between 4,000 and 8,000 bars. These conditions could easily have occurred during the Lomagundi orogeny during complex folding and subsequent deep burial.

The Relationship Epidote-Plagioclase

Many workers have recognised that the anorthite content of the plagioclase of metamorphic rocks increases with increasing metamorphic grade. Ramberg (1952) explains that calcium is an element common to many minerals, whereas sodium is generally only found in the albite molecule of plagioclase. Interaction between the calcium of various minerals with the plagioclase, with increasing temperature, increases the anorthite percentage.

The interaction between plagioclase and epidote is important for classification purposes, and also at times as a geological thermometer. Mason (1958) gives an

FIGURE 22.



EQUILIBRIUM DIAGRAM OF EPIDOTE AND PLAGIOCLASE.
The shaded area shows the plagioclase composition of the Shamrocke rocks other than the ore zone. Plagioclase of this composition will occur with epidote at the temperature X to Y.

oversimplified reaction where zoisite (epidote) is converted to anorthite. He observed, that as the degree of metamorphism increases, the plagioclase becomes more calcic and the amount of zoisite (epidote) decreases.

The rocks of the Shamrocke Mine contain little or no epidote near the orebody. The plagioclase amphibolite does at times contain epidote well into the hangingwall, but this is not generally the case. Southwards from the Mine epidote occurs more frequently in the plagioclase amphibolite, for example exposures in the Angwa River (Plate 10).

With the rocks of the Shamrocke Mine falling into the lower part of the Almandine-Amphibolite facies, temperatures of the order of 550° to 600°C , the lack of epidote can be explained when the anorthite content of the plagioclase is plotted relative to the equilibrium diagram of epidote and plagioclase after Bath (1952, p.285). (Figure 22). Considering the average composition of the plagioclase of the schist and plagioclase amphibolite as ranging between An_{25} and An_{35} , and when plotted on the diagram (Figure 22) it appears that epidote can only occur with plagioclase of this composition range when the temperature drops below 400°C .

The Relationship Staurolite-Kyanite

The rocks in close proximity to the Mine do not contain kyanite, whereas staurolite is found in the hangingwall schist. The absence of kyanite indicates that the rocks are of lower grade than the Kyanite-Almandine-Muscovite subfacies of Turner and Verhoogen (1960), and the Staurolite-Garnet sub-zone used by Workman (1966) as described earlier. Kyanite is, however, found in schist in the Angwa River well south of the Mine and is found in the river gravels of the Angwa at the Shamrocke Mine.

Winkler (1967) quotes Hoschek (1967) who states that staurolite is most commonly formed by the reaction chlorite + muscovite = staurolite + biotite + quartz + H_2O and that this reaction has been realised experimentally with the equilibrium curve at between $540 \pm 15^{\circ}\text{C}/4,000$ bars and $560 \pm 15^{\circ}\text{C}/7,000$ bars water pressure. Ramberg (1952) suggests that staurolite may originate by the reaction garnet-a + kyanite = staurolite + garnet-b, where garnet-a is richer in Fe than garnet-b. This may therefore suggest some degree of retrogression in the degree of metamorphism in the schist.

The narrow elongate white-grey porphyroblasts in hand specimens of the schist and phyllite of the hangingwall and footwall comprise microscopic granular

quartz and felspar. These porphyroblasts are either segregations of quartz and felspar or are pseudomorphs after a metamorphic mineral such as staurolite, kyanite or andalusite. Andalusite is found in the Angwa River gravels, sometimes as well formed chiastolite crosses.

The Cummingtonite-Anthophyllite Relationship

Layton and Philips (1960) examined the available chemical analyses of cummingtonite and anthophyllite and concluded that the two series are not isodimorphous. They consider anthophyllite as a truly lime-free amphibole, while a small amount of calcium is necessary to stabilise the monoclinic lattice of lime-poor cummingtonite.

These minerals are normally found in rocks that are rich in magnesia and, although the carbonate of the ore zone appears to be almost entirely calcite with very little dolomite, the rocks have a fair degree of MgO (between 2.5% and 5%).

The two minerals were not found occurring together in any one thin section.

EXPLANATION OF PLATE 23.

A.



Massive sulphide ore (pyrrhotite, chalcopyrite, cubanite) with green bladed hydrothermal hornblende from Main Adit Drive.

B.



Typical coarse crystalline calcite ore - containing associated massive sulphide.

PLATE 24.

A.



East sidewall, No. 6 cross-cut south, showing the type of reaction banding in the granulites about calcite veining. The banding is probably caused by the carbonate metasomatism - overlay details this banding.

ca	=	coarse white crystalline calcite
p.g.	=	pink granulite
d.b.g.	=	dark biotite granulite.

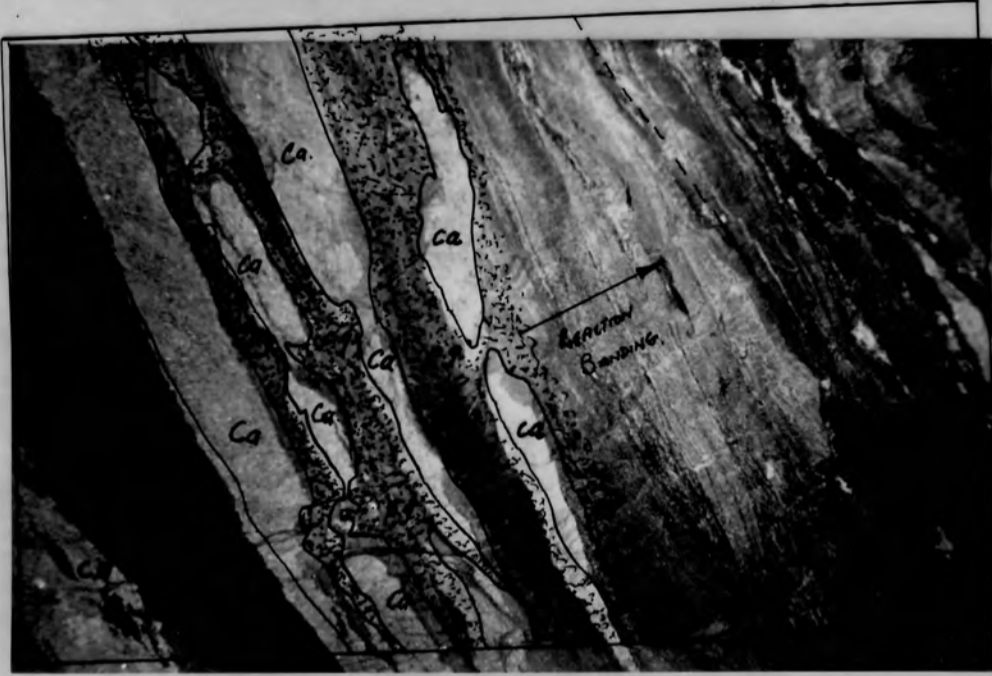
B.



Again showing reaction banding about highly mineralised calcite "blow", the granulite bands becoming progressively darker away from the calcite.

PLATE 24.

EAST WALL 6 X-CUT SOUTH.



East sidewall, No. 6 cross-cut south, showing the type of reaction banding in the granulites about calcite veining. The banding is probably caused by the carbonate metasomatism - overlay details this banding.

- ca = coarse white crystalline calcite
- p.g. = pink granulite
- d.b.g. = dark biotite granulite.

B.

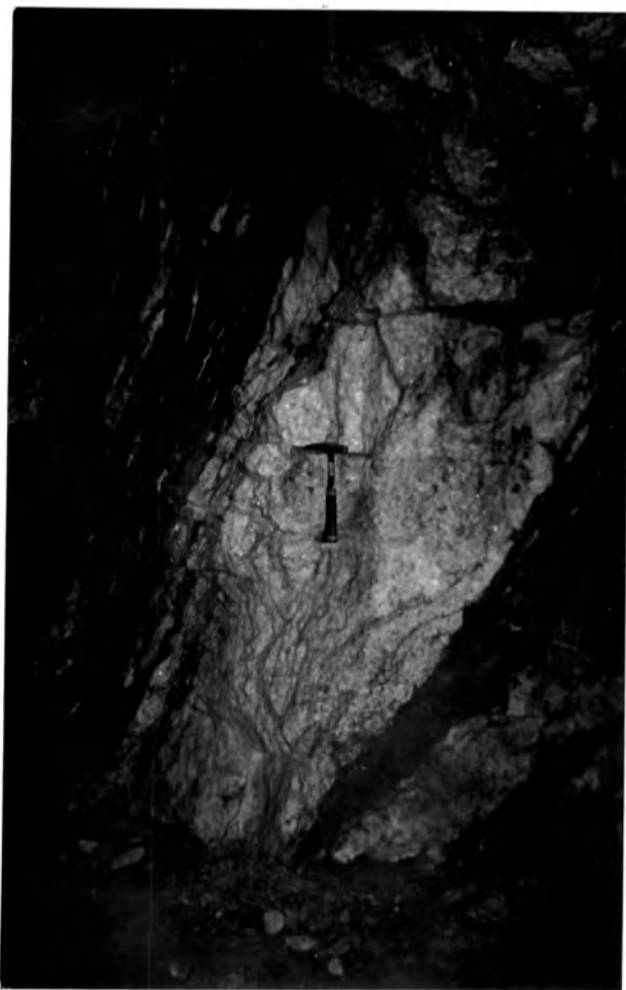


Again showing reaction banding about highly mineralised calcite "blow", the granulite bands becoming progressively darker away from the calcite.

135 e

PLATE 25

A.



Face of Main Adit Drive - highly mineralised coarse white calcite "blow" with massive sulphide and pink biotite granulite.

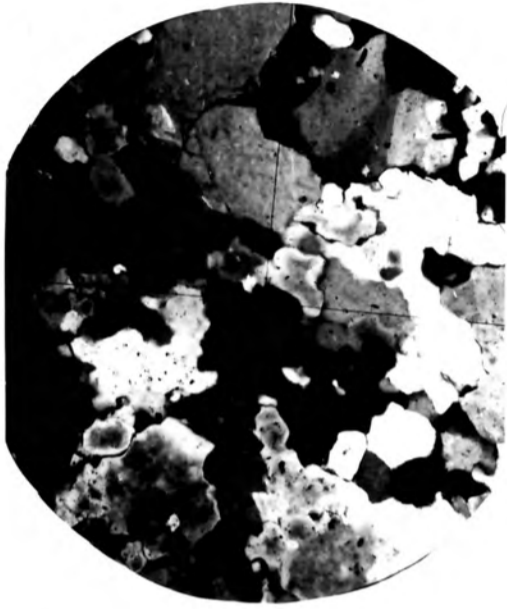
B.



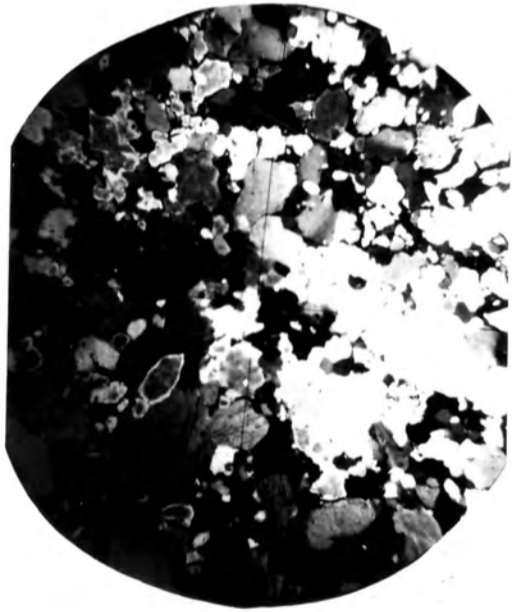
Face of Main Adit Drive - again showing mineralised calcite with dark-pink granulite.

135 d

PLATE 26.



A



B

185 e

EXPLANATION OF PLATE 26

- A. Calcareous grit from well west of the orebody. Again, note similarity in appearance in thin section to B below. Calcite (Ca) and plagioclase (P).
Crossed Nicols X 100.
- B. Calcareous granulite showing close similarity in appearance in thin section to A above. Calcite (Ca) and plagioclase (P).
Crossed Nicols X 100.

METASOMATISM

Metasomatism has been defined by many authors. In this study metasomatism as is described by Goldschmidt (1922, pp 105-123) is accepted i.e. metamorphism involving the introduction and removal of certain substances, with corresponding change, not only in the mineralogy, but in the chemical composition of the rocks affected.

Turner and Verhoogen (1960) state "Metasomatism of silicate rocks is effected by reaction between the constituent minerals and chemically active solutions or gases streaming through the rock pores under the influence of a pressure gradient".

The metasomatic action in the Shamrocke ore zone could certainly have involved a similar process as that described above, where metamorphism, particularly the effects of pressure and heat from folding, caused carbonate rocks to be affected. Under this metamorphism these carbonate rocks possibly caused an abundance of carbon dioxide and sulphide in solution to migrate into the granulite zone from without (probably from below); or was reworked and relocated entirely within the ore zone.

This carbonate metasomatism apparently caused the albitisation of the plagioclase in the ore zone, where calcium was extracted from the plagioclase by the metasomatising solutions. Calcite and sulphide (with "Hydrothermal" amphibole) replaced the granulite to a greater and lesser extent. The metasomatism of the ore zone is discussed at length when describing the possible genesis of the orebody (Section B. 7).

Very many ore deposits represent the metasomatic replacement of the rock by the mineralising agents, where there is little, if any, change in volume, but where the chemical composition and mineralogy is altered to a lesser or greater degree. The solutions and gases responsible for this metasomatism are either from some extraneous source e.g. a granitic or basic intrusion, or are mobilised from the surrounding rocks (usually sediments), or from within the ore horizon itself. The metasomatising fluids and gases are thought by the present writer to originate from the rocks in the vicinity of, or including the Shamrocke Mine, mobilised by the metamorphic effects during deformation.

PETROGENESIS

The petrogenesis of the rocks of the Shamrocke area is perhaps a little obscure without a great deal more chemical work. However, in the light of the mineralogical study the following suggestions can be made.

In the vicinity of the Mine itself:

- (i) The ore zone granulite (or granofels, or felspar-biotite rock) is probably metasomatised felspathic calcareous grits. The granulite has an almost identical composition and a similar texture, although more compact and recrystallised, to the felspathic calcareous grit which appears to be its extension to the west. There is however a possibility that these granulites are in fact metamorphosed acid tuffs from volcanic activity along the edge of the Lomagundi basin. . This latter suggestion is prompted by its appearance in borehole cores, its chemical and mineralogical composition, and its proximity to the edge of the Lomagundi depository.
- (ii) The graphitic schist and phyllite is probably a metamorphosed original calcareous mudstone or marl.
- (iii) Some amphibole schists of the hangingwall, although generally accorded sedimentary origin, have sometimes the appearance of a metamorphosed rhyolite or impure tuff. Insufficient chemical work has been done to assist in the recognition of the origin of these rocks.
- (iv) The plagioclase amphibolite is undoubtedly metamorphosed original diabasic material.

B.7 THE SHAMROCK OREBODY

Mode of Occurrence of Orebody

The Shamrocke orebody occurs in granulite and calcareous granulite within graphitic schist and phyllite of the Dolomite Series. It is thought that the granulite is a calcareous grit which has been altered by calcite metasomatism. The mineralisation occurs as disseminations of predominantly chalcopyrite and pyrrhotite within the granulite, and in places as massive chalcopyrite and pyrrhotite which is present mainly in pure white calcite "blows" within the granulite. There is a close association between the mineralisation and metasomatic amphibole. The granulites dip at 60° to the south and there appears to be tight folding and plunging which limits the orebody on surface in the east. The sulphide mineralisation is best developed in the more calcareous portions of the body.

The granulite is essentially a granulose albite-biotite rock, often amphibolised. Associated with the granulites are:-

1. Lenticular bands of porphyroblastic feldspar-amphibole rock often at the granulite/schist contact and consisting of hornblende, oligoclase-andesine plagioclase and minor amount of quartz.
2. Bands and lenses of coarsely crystalline white calcite, often amphibolised.

The beds have been fairly strongly metamorphosed and, whilst typical grade minerals are absent, staurolite is present some 500 feet above the granulite, thus suggesting a moderate grade of metamorphism (upper amphibolite facies). Evidence of tight folding is present, but has been obliterated by the metamorphism.

The Composition of the Ore Zone

The rocks of the Shamrocke ore zone comprise largely a granulose albite-oligoclase biotite rock, conveniently termed a granulite. Other rock types included in the zone are a porphyroblastic feldspar-amphibole rock; some fine graphitic schist and phyllite; coarse-grained calcite as veins, stringers and blows; and a dark

calcareous amphibolite which appears to be the result of the assimilation of the calcareous ore zone by an intrusive rock. The detailed petrography of these rocks of the Shamrocke ore zone has been described previously.

Where trenched at surface the weathered ore zone shows the different rock types discernible, and this correlates well with the underground workings immediately below. Due to metamorphic effects and the random distribution of calcite through the ore zone, this zone is not a simple sequence of rocks, but different rock types, in places grading one into the other.

The relative proportions of the different rock types making up the ore zone are regularly granulite 70%, porphyroblastic felspar-amphibole rock 5 - 10%, included graphitic schist and phyllite 10-15% and calcite 10-15%.

The relative association of rock types is both complex and irregular. The granulite is generally a fine-grained biotite granulite, in places rather schistose. Porphyroblastic felspar-amphibole rock is very often prevalent at the contact between the granulites and the hanging and footwall schists. Near surface in the underground workings the porphyroblastic felspar-amphibole rock occurs generally at the footwall contact (often attaining a thickness of 40 feet) and occurs as bands, of from less than a foot to 25 feet in width throughout the ore zone.

The granulites vary from a dense sheared schistose granulite, through a fine-grained pinkish biotite granulite, to a light grey granulite. Occasionally where more schistose and highly graphitic, the granulite appears similar to the graphitic phyllites of the hanging and footwall.

Dark fine-grained graphitic schist and phyllite occur irregularly throughout the zone. Generally these schists and phyllites resemble those of the hanging and footwall, but occasionally become dark and actinolitic. These graphitic schists very often contain coarse chalcopyrite.

The calcite of the orebody is generally a coarse-grained white crystalline equigranular calcite with scattered coarse chalcopyrite and pyrrhotite. In places this calcite is barren of sulphides, but very often massive pyrrhotite and chalcopyrite is closely associated with the masses of green bladed "hydrothermal" hornblende. In the underground workings the calcite occurs as both large some-what

irregular bodies (generally lenticular) and bands and veinlets from 10 feet across down to a few inches. In the main adit drive some 80 feet past the winze intersection, a calcite body 70 feet long and some 10 feet wide occurs. These calcite veinlets, bands and irregular bodies occur scattered throughout the ore zone and do not adhere to any particular level.

In a number of boreholes the ore zone appears to be split into an upper zone and a lower zone by a medium-grained biotite-rich calcareous plagioclase amphibolite, which in appearance is similar to the dark schistose biotite granulite but has an abundance of amphibole. This rock has been termed the "Internal Zone" and it is difficult to ascertain whether this is a highly calcified and amphibolised phyllite in the core of a tightly folded sequence or whether it is in fact an intrusive amphibolite assimilating the highly calcareous and felspathic granulite. In places coarse chalcopyrite and pyrrhotite is scattered within the first few feet of the contact. It is pertinent to note that this zone has within it narrow bands of fine-grained plagioclase amphibolite, obviously of later intrusive origin.

Mineralisation of the Orebody

Underground development has shown that mineralisation is best developed in the more calcareous portions of the body and is particularly associated with calcite, which occurs both as large irregular equigranular bodies, up to 20 feet wide, and as thin stringers. This calcite can be accepted as representing the remobilisation and metasomatism of original carbonate in the rock, once a calcareous felspathic grit, and its redistribution and accumulation into stringers and bodies which typify its occurrence. In areas of minor dragfolding it appears to have been squeezed into the crests of the folds. The mineralogical evidence for this remobilisation and metasomatism is strong, an important aspect being the relative decrease in anorthite (and therefore Ca content of the plagioclase) with proximity to calcite bodies and veins. In the immediate vicinity of the calcite, particularly surrounding the larger bodies, distinct bands of hard, pink, very albitic granulite form, with general increase in anorthite content outwards; thus suggesting extraction of calcium from the plagioclase of the original calcareous felspathic

grit into the calcite bodies.

The calcite and sulphide mineralisation are very closely associated. The inter-relationship between occurrences of calcite and copper values can be seen when a value plan is superimposed on a geological log plan. Within these calcite bodies the sulphide minerals are both coarsely scattered and in stringers, generally closely associated with a green "hydrothermal" hornblende. The sulphide mineralisation apparently followed closely on the crystallisation of the calcite, the larger bodies having generally a barren core but being highly mineralised along the amphibolised contacts and being often transgressed by highly mineralised amphibole stringers. Where coarse crystalline sulphide occurs scattered throughout the calcite unaccompanied by green hornblende the crystallisation must have been simultaneous. Mineralisation also occurs finely disseminated within the granulite, both in the vicinity of the calcite bodies and widely separated from these. This disseminated sulphide is often associated with scattered fine calcite, presumably having permeated through the granulite along with the mineralising solutions, either from carbonate solution introduced from without the orebody or more likely original carbonate of the groundmass having been mobilised and redistributed by metasomatic action along with the sulphide. Another type of mineralisation occurs in definite stringer form both in the granulite and the schists, running mainly parallel to the schistosity but often in crosscut veins. Most minor fissures and fracture planes are mineralised. All these features of mineralisation strongly suggest a hydrothermal-metasomatic deposit. Localisation of this mineralisation is undoubtedly influenced by structure.

A study of the ore shows a relatively simple suite of sulphide minerals with simple textural relationships. The three main sulphide minerals present are chalcopyrite, pyrrhotite and cubanite, with subordinate specular haematite, pyrite, arsenopyrite, ilmenite and molybdenite. The textural inter-relationships of these minerals suggest the initial crystallisation of the pyrrhotite, with replacement by chalcopyrite, and subsequent temperature elevation and cooling to produce the chalcopyrite-pyrrhotite intergrowth, cubanite, which occurs as both broad and narrow lamellae within the chalcopyrite and as larger irregular masses at times representing the dominant form of copper mineralisation.

Spectrographic semi-quantitative analysis of the arsenopyrite showed up to 0.1% cobalt and 0.8% nickel and no trace of gold.

The chalcopyrite of the deposit occurs as massive crystalline masses associated with the calcite "blows", disseminated throughout the granulite with varying crystal size, and in calcite stringers within the granulite.

The grade of copper in the deposit is not discussed here as this is obviously information classified within those exploration groups who have investigated the deposit.

During the calcium metasomatism the effect of the streaming of the calcium-rich solutions has resulted in distinct "blow" development of pure white calcite and narrow zones of calcite within the ore-zone granulites. The metasomatic effect on the original host rock was to produce at places a reaction banding within the granulites, manifested by a banded development of granulite varying in colour and more specifically the composition of the feldspars. As discussed above the feldspar of the granulite is distinctly albitic in the vicinity of the calcite bodies, becoming progressively more calcic in composition away from the calcite. Furthermore, the plagioclase feldspar of the ore zone shows little or no zoning and shows a composition of $An_4 - An_{15}$. This albitisation of the feldspar of the ore zone is no doubt due to the extraction of calcium from the feldspar during the calcium metasomatism within the ore zone. This extraction of the calcium from the feldspar has reached a stage where the whole plagioclase crystal shows a similar composition throughout, while adjacent to, and away from the ore zone, this extraction has only been partial, causing zoning in the plagioclase where a calcic core is surrounded by a more acid margin. Examples of this reaction banding within the granulite about the calcite can be seen in Plates 14 and 15.

Difficulty of Correlation

Intersections of the orebody by surface drilling, prospect mining and underground drilling were all logged geologically. From the underground logging it can be seen that correlation of beds over distances of 50 feet is anything but clearcut and it becomes apparent that, with differing local conditions of metamorphism,

the various rock types may grade one into the other. Underground, it becomes apparent that:-

Anthophyllite-bearing schist grades into anthophyllite granulite.

Porphyroblastic felspar-amphibole rock grades into highly amphibolised schists.

Differing types of granulite are capable of rapid interchange.

Attempts at correlating the granulite types by colour differences proved to be unsuccessful.

This grading of one rock type into another means that correlation is made extremely difficult and is further complicated by later metasomatism responsible for the mineralisation. When correlation is attempted between boreholes 500 feet apart, any conclusions drawn are liable to be very suspect. In the underground workings where cross sections of the beds are available at 50 feet intervals, correlation becomes more reasonable but still retains a degree of uncertainty.

THE GENESIS OF THE OREBODY

A comparison Between the Shamrocke Orebody and other Copper Deposits of the Lomagundi System.

The Shamrocke orebody appears to be a metasomatically emplaced deposit of uncertain origin.

The mineralisation is generally closely associated with coarsely crystalline calcite, which occurs both as secondary veins and irregular masses and as anhedral crystals forming part of the fabric of the rocks of the ore zone. Carbonate metasomatism must have to a great extent controlled the distribution of the sulphide mineralisation, the calcite veins and "blows" generally contain a much coarser, massive sulphide, particularly towards the edges of the larger crystalline calcite bodies, and very often closely associated with a deep-green "hydrothermal" hornblende. Sulphide further occurs finely and coarsely disseminated throughout much of the granulite and felspar-amphibolite rock of the ore zone, irrespective of its calcite content.

Without detailed X-Ray analysis of the ore minerals it is not possible to postulate with any certainty the temperature of deposition of the ore. However, from the ore minerals present, their apparent paragenetic order, and certain exsolution textures, it would appear that deposition commenced at very approximately 600°C, and that most of the ore minerals crystallised between 500° and 600°C. From this assumption, and from its obviously metasomatic nature, the orebody could be termed pyrometasomatic or hypothermal metasomatic.

J.B.E. Jacobsen (1965), described regional zoning of the various ore-mineral occurrences in the Lomagundi and Urungwe Districts, and the relationship between the metallogenic zones and zones of regional metamorphism. These zones he considered as being concentric about the Miami and Karoi granites, each zone being characterised by a dominant ore-mineral or ore-mineral suite. He further considers the ores of the Sanyati area to be possibly grouped with the Shamrocke ore into his pyrometasomatic zone. Jacobsen (1965) states: "Both deposits appear to be pyrometasomatic sulphide replacements in carbonate rocks, with associated tremolite, actinolite and other calc silicate minerals, as well as occasional large garnet crystals. The mineralisation at the Sanyati Mine appears to be synorogenic to late-orogenic

(Bahnmann 1961), at the Shamrocke Mine the mineralisation may have been earlier". As is discussed below, the final distribution and emplacement of the ore-minerals of the Shamrocke orebody may well have been synorogenic and/or late-orogenic.

Where the Shamrocke ore-deposit differs from the Sanyati occurrences is in its ore-mineral content, its grade of regional metamorphism, the suggested position of the Sanyati deposit in the Lomagundi sequence and the absence of outcropping post- and late-kinematic granites in the immediate vicinity of the Shamrocke Mine. In the Sanyati ore chalcopyrite, pyrrhotite, arsenopyrite, pyrite, sphalerite and galena are dominant minerals (Bahnmann 1961); the Shamrocke ore suite is similar but does not include sphalerite and galena. Molybdenite is found in the Shamrocke ore and not at Sanyati. The grade of regional metamorphism in the Shamrocke Mine is the Almandine Amphibolite facies (Turner, Fyfe and Verhoogen, 1960) whereas that of the Sanyati area is Upper Greenschist facies. The Sanyati occurrences have been described by Jacobsen (1965) as being in the Piriwiri beds, high in the Lomagundi sequence; it is, however, possible that further structural work may suggest these rocks to the basal portion of the Lomagundi succession, as they closely resemble the rocks of the Shamrocke area. The Sanyati mineralisation is described by Jacobsen (1965) as being associated with the oval-shaped stock of granodiorite in the area, and he suggests that the ore-forming emanations were from the paligenetic centres, with concentration in the calcareous meta-sediments. In the Shamrocke area no post- to late-kinematic granites or granodiorites occur. The nearest younger granite is the Miami Granite. These differences however do not materially detract from the observation that the Shamrocke and Sanyati deposits are indeed similar.

Jacobsen (1965) describes the metallogenic zones concentrically away from the Miami and Karoi granites, as a pegmatitic zone and an intermittent pyrometasomatic zone closest to the granite, characterised by copper, lead, zinc replacement deposits; a broad hypothermal-pyrometasomatic zone trending north-northeast westwards from Alaska and Mangula containing copper, gold, pyrite replacement mineralisation; a narrower hypothermal zone which include the high temperature molybdenite-specularite-chalcopyrite-bornite-chalcocite association of the Alaska and Mangula deposits; and again eastwards, a probable mesothermal zone of lower temperature chalcocite, tetrahedrite, native silver and galena occurrences.

The Shamrocke orebody is similar to the Mangula deposit only in that they both occur towards the base of the Lomagundi sequence, although the Shamrocke ore is found higher in the succession, within the Dolomite Series. The grade of metamorphism at Mangula is Greenschist facies and considerably lower in grade than the Almandine Amphibolite facies of the Shamrocke area. Stagman (1959), W. Jacobsen (1961) and Viljoen (1961) consider the mineralisation at the Mangula Mine to be epigenetic-hypothermal. According to W. Jacobsen (1961) the bulk of the copper mineralisation occurs in the hard arkoses and felspathic quartzites immediately above the basal conglomerate of his Lower Lomagundi (Deweras Series). In these hard arkosic rocks the mineralisation is finely disseminated bornite and chalcocite, whereas immediately above this in the succession these minerals occur in a more "stringy" form in more schistose rocks (W. Jacobsen 1961). Jacobsen further describes a coarser mineralisation of bornite, chalcocite and chalcopyrite in shears, fractures and joints, which appear to be independent of the disseminated mineralisation. W. Jacobsen (1961) and J.B.E. Jacobsen (1965) consider the mineralisation at Mangula to be genetically associated with the intrusive Mangula granite. Jacobsen (1965) describes a close association between microcline and both the mineralisation and the rocks close to the intrusive granite; he describes the K_2O metasomatism within both the ore zone and the granitised zone. Jacobsen (1965) again relates the Mangula mineralisation to hydrothermal activity due to the frequency of Fe-chloride in the mineralised and granitised areas, whereas the chlorite of the mineralised rocks are Mg-chlorite. The Mangula deposit does not exhibit the carbonate metasomatism of the Shamrocke ore, and the latter ore does not contain bornite and chalcocite, nor does it have vein and fracture deposits as at Mangula. The Mangula area is structurally very complex.

The Silverside Mine, 11 miles southeast of Mangula appears to be hydrothermal with obviously invading copper-bearing solutions causing the mineralisation (W. Jacobsen, 1961).

As previously described the Alaska mineralisation is in highly folded rocks of the Dolomite Series and contains a high temperature primary pyrite-chalcopyrite-gold association (J.B.E. Jacobsen 1965), which is apparently different to the hypothermal molybdenite-chalcopyrite, bornite-chalcocite-silver association as at Mangula.

The association between the mineralisation, thrusting and thrust breccias is discussed by J.B.E. Jacobsen (1961 and 1965). Supergene enrichment provided much high grade ore.

The Ell Mine on the Gwai River in the Wankie area has a similar geological setting and position within a sedimentary succession possibly correlated with the Lomagundi System. This is discussed in Section B1.

The Genesis of the Shamrocke Orebody

It is difficult to postulate the origin and genesis of the Shamrocke ore with any certainty. The following points are pertinent to the discussion:

- (i) The orebody is probably a metasomatic deposit. The ore-mineral assemblage, the postulated high temperature of formation, and the obvious association between the sulphide mineralisation and carbonate metasomatism, suggests the ore to be pyrometasomatic or hypothermal metasomatic.
- (ii) The replacement of the ore zone granulite by calcite appears to be both concentrated streaming of carbonate and by permeation throughout the ore zone to produce anhedral calcite in the granulite, scattered through the rock fabric as crystals slightly larger than the granoblastic groundmass. This calcite in the granulite fabric closely resembles that in the calcareous grits found to the west of the ore zone and thought to be similar to the ore zone. This calcite in both instances is either primary to the original sediment or represents metasomatic replacement by carbonate from surrounding calcareous sediments. The sulphide mineralisation is associated with both the crystalline masses of calcite, and is finely to coarsely disseminated through the ore zone in both calcareous and non-calcareous granulite. The sulphide has obviously metasomatically replaced the ore zone rocks (in the final stages of deposition at least), but whether or not the sulphide was introduced from without the ore zone,

or originally had its origin as a primary mineral of the original sediment which was subsequently reworked and redistributed metasomatically, is difficult to ascertain.

- (iii) The copper sulphide was therefore either introduced into the sequence from an extraneous source (having been mobilised together with the carbonate in the surrounding sediments), or was an original primary constituent of the ore zone rock which has been reworked and redistributed metasomatically.
- (iv) The present writer considers it unlikely that a hidden or unrecorded intrusive granite or granodiorite is present in the immediate vicinity of the orebody due to the lack of granitisation effects. The possibility of a hidden boss of Miami granite at depth is unlikely, and would in any event probably not be the source of copper mineralisation. Late and post-kinematic granitic intrusions are not definitely proven to be the source of copper elsewhere in the Lomagundi, although they are in places possibly the cause of the mobilisation of elements.
- (v) The origin of the copper is more probably as primary sulphide in the basal sediments of the Lomagundi System. The fact that the mineralisation is generally towards the base of the Lomagundi succession is sympathetic with the observed criteria for the precipitation and deposition of sulphide ore. This deposition is generally in a transition zone between arenaceous/rudaceous and argillaceous/calcareous sediments, i.e. transitional between the basal coarse clastics and the chemical sedimentary suite towards the edge of the sedimentary depository. Numerous investigators have examined the problem of the syngenetic deposition of copper sulphides in order to establish the most favourable type of geological environment for the development of strata bound copper deposits. The work of amongst others, Baas Becking and Moore (1961), Mendelsohn et al (1961), Davidson (1962), and Dunham (1964), appears to indicate that the most

suitable environment of deposition is a moderately shallow to moderately deep offshore one, where conditions would be able to support simple organisms. These conditions seem to be ideal for the precipitation of sulphides, especially where the sediments consist of fine-grained clastics, shales and dolomitic shales. These are conditions which appear to have prevailed at the edge of the Lomagundi depository. The occurrence of copper mineralisation at such regular intervals along the Deweras-Dolomite Series contact, and close to the base of each series, would support this interpretation.

The presence of copper mineralisation appears in no way dependent on the presence of intrusive granites or granodiorites along the length of the exposed edge of the basin. It is however pertinent to note that very often the mineralisation appears related to cross-folding of the basal Lomagundi beds. It is not for a moment suggested that this cross-folding, most often gentle, is the cause of the mineralisation, but that the cross-folding is the reflection of both pre-Lomagundi basement structures and basement highs and ge-anticlinal ridges, formed during a pre-Lomagundi orogenesis. Basement highs would have provided the moderately shallow water conditions at the steep edge of a deep basin suitable for copper deposition. Furthermore these cross-folds in the cover sequence, if reflections of sub-cover basement weakness, would be areas of maximum disturbance and hence greater possibility of sulphide mobilisation and concentration from a primary origin by the regional physico-chemical effects of deep burial and stress due to large scale faulting and folding. Referring again to the similarity of rock type and mineralisation of the Sanyati occurrences to the Shamrocke deposit, the Sanyati rocks may be from deposition within the Lomagundi depository over a basement high or ridge simulating the depositional environment at the basin edge. One further point with regard the influence of the pre-Lomagundi basement structure and its reflection in cross-folding and structural disturbance in the Lomagundi cover-sequence, is that these sites would be the most favourable for younger granite and/or granodiorite intrusions and their subsequent effect on the mobilisation of sulphide in that area, already a

favourable area for sedimentary copper deposition, (c.f. the granodiorite boss at Sanyati.)

- (vi) The distribution of the copper content within the Deweras and Dolomite Series rocks generally along the length of the regional outcrop has not been studied in detail. Much geochemical work has been done along this narrow tract of country underlain by Deweras and Dolomite Series rocks, but the data has not been sufficiently analysed statistically to establish the general copper content of these rocks. It may yet be established that copper is widespread through these rocks in very small proportions which have been concentrated in places and are then detected by the normal methods of geochemical interpretation. It is perhaps certain that many more copper occurrences will be located in these rocks, obviously of varying grade. Rock chemistry is perhaps an important way of studying the copper content of this portion of the Lomagundi Succession.
- (vii) The detailed examination of the orebody in the underground working shows minor tight folding, and the overall attitude of the orebody at times suggests a very tight and deep lateral fold plunging to the east. This possible tight folding along the northern limb of the Rusere Syncline may in fact have caused heat and pressure conditions sufficient to cause the movement of both the carbonate and the sulphide.
- (xii) Being at the edge of a sedimentary depository against basement rocks, it could be expected that volcanic activity in the form of lava flows and volcanic intrusive centres would be present. The green basal lavas of the Silverside area and southwards would satisfy this expected vulcanicity; however, northwards to the western margin of the present project area there is no sign of obvious Lomagundi-age lavas. At this point however, the earlier

discussion with regard terminology and petrogenesis is referred to when it was suggested that the possibility exists that the Shamrocke granulite and other horizons within the schist could be original acid tuffs, now metamorphosed to their present state. If this is the case, the mineralisation could be associated with acid igneous activity.

- (xi) Just east of the Alaska Mine bedded disseminated deposits occur in arkose on the farms Shackleton and Avondale, and on the Muchi claims some 12 miles south of the Alaska Mine (J.B.E. Jacobsen 1965). On both the Muchi Claims and in the Cedric Mine fine grains of chalcocite, tennantite, bornite and galena are disseminated through silicified dolomite within an asymmetrical anticline. These apparently bedded deposits are again indications of a possibly syngenetic origin of the copper of the Lomagundi System.
- (x) The mechanism of mobilisation of the metasomatising fluids and gases could have been caused by either the heat and pressure from magmatic intrusion or by regional metamorphism, including the effects of structural disturbances. The present writer would prefer to consider the latter process as being the responsible agent.
- (xi) Garlick (1953) and Davis (1964) consider that the mineralisation of the Zambian copper belt was probably deposited from reworked syngenetic copper in the sediments.
- (xii) The possibility exists that the original mineralisation was syngenetic to the surrounding rocks e.g. the Deweras rocks, and that mobilisation took place under conditions of tight and deep folding, with the metasomatic replacement and accumulation occurring within the ore zone rocks within a tight lateral plunging fold. If folding was this intense and tight, the Deweras rocks would be interfolded beneath the Shamrocke ore zone.

- (xiii) The interested reader is referred to a paper presented at the I.A.G.O.D. (International Association of the Genesis of Ore Deposits) meeting in Japan in 1970, by Allen L. Clarke of the U.S. Geological Survey (Clark 1970). In his paper Clark describes strata bound copper sulphide deposits in the Precambrian Belt Supergroup of northern Idaho and western Montana, which were deposited at about 1100 my and 1300 my. The mineralisation occurs as copper sulphides (bornite, chalcopyrite and chalcocite) occurring as discreet blebs, bedding plane concentrations and fracture filling veinlets, in generally carbonate rich coarse-grained clastic phases of a quartzite. Clark gives sufficient evidence to show that the mineralisation features are a modification of a pre-existing sulphide deposit formed originally, essentially contemporaneous with the enclosing sediments. From both his paper and from personal communication during the meeting, it is clear that the Belt Supergroup mineralisation is one of the most recent examples of strata-bound primary copper mineralisation which could be compared with the possible origin of the Lomagundi mineralisation.
- (xiv) V.D. Fleischer (1967) describes how the copper mineralisation in the Mufulira Mine in Zambia is closely related to the irregular sub-Katangan land surface and how over or close to pronounced highs in the basement, there occur lenses of low grade chalcopyrite-pyrite disseminated in quartzite within the limits of the orebodies. Further, he does not genetically relate the orebodies to the folding in the mine.

SUMMARY AND CONCLUSIONS

The opportunity to carry out the thesis study was made possible by the collection of material during the writer's period of duty with Rand Mines Limited, who kindly gave permission for the publication of this thesis.

The field work for the thesis was carried out over a period of 20 months; approximately 6 months were spent at Rhodes University, where petrographical and mineralogical study of the rocks of the Shamrocke Mine was undertaken and the consideration of the results and the preparation of the thesis undertaken subsequently.

The writer personally mapped the greater part of the study area and was closely concerned with the drilling and underground development programmes, logging the majority of the boreholes and some of the underground workings.

The petrographical and mineralogical study included the preparation and examination of upwards of 250 thin sections and 23 polished sections. Microscopic study included extensive use of the universal stage and measurements of refracted indices by oil immersion methods. Selective staining techniques were applied and three silicate analyses were undertaken.

The mineralisation of the Shamrocke ore is described in detail, and the possible genesis and source of the copper mineralisation is discussed.

The position of the Shamrocke Mine in the Lomagundi succession and the nature of the mineralisation is compared with the other copper occurrences of the Lomagundi System.

The physiography is briefly described and the nomenclature of the rocks is defined.

The work of previous writers is summarised and compared with the suggested stratigraphic succession in the immediate vicinity of the Shamrocke Mine.

The structure of the project area is discussed relative to the excellent description of the Rusere syncline by D.R. Workman (1962), and from a photogeological study by the writer.

Some of the more important conclusions from the thesis study are as follows:

1. The thesis area is situated on the South Zambezi Escarpment of Rhodesia, some 35 miles northeast of Karoi, and lies at the fringe of the Rhodesian craton and against the southern margin of the Zambezi Mobile Belt.
2. The Zambezi Mobile Belt is an east-northeast trending zone of metamorphic tectonites extending from Botswana in the southwest across the northern part of Rhodesia and southern Zambia, into Mocambique.
3. The Lomagundi System is a probable cover sequence to the Zambezi Belt tectonites along the northeastern edge of the Rhodesian craton. The Lomagundi Sequence appears to be a cover sequence to the older mobile belt terrain, now exposed against the craton edge. The deeper water facies of the Lomagundi sequence appear to dip below Karroo sediments further into the Zambezi trough.
4. The geology described includes the basal succession of the Lomagundi System and the pre-Lomagundi Escarpment Series.
5. The basal succession of the Lomagundi System pass below Karroo rocks southwestwards, to reappear in the Wankie area, or even further southwest in Botswana.
6. The Lomagundi stratigraphic succession is compared with similar rocks in other regions. A comparison is drawn between the Lomagundi System and the Tsumis/Doornpoort/Ghanzi formations of Botswana and South West Africa, the Damaran System of northern South West Africa, and the Katanga Series of both Zambia and Katanga.

7. The Shamrocke copper orebody is associated with a "granulite" or "granofels" zone within the Dolomite Series of the Lomagundi System. This ore zone granulite appears to be a metasomatised calcareous grit, some 1000 feet above the upper contact with the Deweras Series (basal Lomagundi) and within graphitic schist and phyllite, below a dolomitic horizon, in the Dolomite Series.
8. The base of the Lomagundi System in the thesis area is the Deweras Series, (largely meta-arkose, meta-quartzite and conglomerate) which unconformably overlie the older gneiss and meta-arkose of the Escarpment Series to the north of the Mine.
9. Overlying the Deweras Series is the Dolomite Series, comprising graphitic biotite schist and phyllite, granulite and calcareous grit, dolomite and amphibolite. The Argillaceous Series conformably overlies the Dolomite Series and comprises muscovite, biotite and graphitic phyllites, schists and slates; with subsidiary arenaceous beds.
10. Conglomerates have been recognised within the Deweras Series east and southeast from the Shamrocke Mine, one near the base and one near the middle of the Series. The meta-arkoses are generally compact and granular and occur with arenaceous mica schists, hard compact meta-quartzites and coarse quartz schists. The meta-volcanics found at the base of the Deweras Series east of Mangula and in the southern areas west of Hartley are apparently absent in the thesis area.
11. In the thesis area, the contact between the Deweras and Dolomite Series is generally obliterated by plagioclase amphibolite or altered original intrusive meta-diabase.
12. The Dolomite Series ascends from the basal schist and Nyashiri meta-quartzite through graphitic and calcareous schist and phyllite into a zone of calcareous grit and "granulite" some 1000 feet above the base of the Series. It is in this "granulite" that the Shamrocke orebody is situated. Above the granulite ore zone is a further sequence of graphitic and calcareous schists and phyllites which underlie a thick dolomitic horizon which is in part intruded by a large sill of plagioclase-amphibolite, (altered meta-diabase).

13. The Argillaceous Series extends south and southwest from the Mine and makes up the greater part of the Lomagundi System. The Argillaceous Series comprises micaceous and graphitic schists and phyllites, with sporadic development of white to buff-coloured sandstone and quartzite.
14. The regional structure as described by D.R. Workman (1962) and as evidenced by the photogeological study by the present writer, indicates that the base of the Lomagundi succession north of Mangula strikes north-north-west, the succession ascending westwards. The beds almost always dip steeply to the east and are obviously overturned, this overturn affecting the basal beds for a considerable distance away from the edge of the original depository into the higher parts of the succession.
15. Occasional broad cross-folds and tight lateral folds occur in places along the base of the Lomagundi System at the edge of the original depository.
16. The large Rusere Syncline causes the basal Lomagundi beds to form an embayment towards the northeast into the pre-Lomagundi rocks of the Escarpment Series and the granodiorites east of Chidwara. The axis of this large syncline runs northeastwards south of the Shamrocke Mine and the whole structure is overturned on the eastern and southeastern limb.
17. It is important to note that east-west fracture or shear planes become very dense at the points of flexure of the cross-folds deforming the basal Lomagundi succession.
18. The occurrence of copper mineralisation is in every case associated with a cross-fold structure within basal Lomagundi rocks.
19. The structure of the Shamrocke Mine itself is a little obscure, but it appears that the ore zone granulite is within a tight lateral fold plunging to the east.
20. A comparison of the stratigraphic position of the Shamrocke Mine relative to the other copper occurrences within the Lomagundi System shows that in almost every case the copper ore is associated with either the Upper Deweras Series rocks, or towards the lower part of the Dolomite Series.

Petrographic study shows that the meta-arkoses of the Escarpment Series are predominantly coarse-grained gritty meta-arkoses with abundant mafic minerals, or a fine-grained clean buff-coloured meta-arkose generally free of mafic minerals. In thin section these generally have an equigranular texture. The mineral assemblage is generally feldspar, quartz, biotite, chlorite, muscovite, clinzoisite, microcline, epidote, sphene and apatite.

21. The petrography of the rocks of the Shamrocke area is described in detail; these descriptions having little importance in this summary.
22. Selective staining techniques enabled the distinction between plagioclase, orthoclase and quartz; and between calcite and dolomite.
23. Modal data assisted by the selective staining indicates a very low quartz content of the granulite and feldspar-amphibole rock of the ore zone (less than 6% and in one instance 0.6%). Modes determined for granulite in the hangingwall of the ore zone showed the quartz to comprise between 28% and 39% of the rock.
24. The plagioclase-feldspars were examined using the universal stage. The plagioclase is typical of the plagioclase-feldspar of metamorphic rocks, being granular, xenoblastic and generally clear and untwinned.
25. The general lack of twinning and/or visible cleavage traces made composition determination and study of the feldspars tedious and difficult. Application of the 'Zonal Method' of Feldspar determination of Rittmann (as described by Chudoba and Kennedy, 1933) was found to be extremely rapid and accurate. This technique applied to zoned plagioclase crystals, enabled rapid determination of composition at various points in the same crystal.

Upwards of 50 thin sections were examined and composition determinations on more than 125 plagioclase crystals were carried out. The results of these analyses indicated that (i) there is a distinct compositional difference between the plagioclase of the ore zone granulites and that of the country rock (ii) this difference is not created by a serial variation outwards from the ore zone, but depicts a sudden change in composition outside the limits of the ore zone (iii) zoning was detected in all sections other than the orebody granulite where zoning is apparently absent. The compositional variation within a single crystal is always from an acid core to a calcic margin. (iv) although there is

variation in the composition within each rock type from place to place there does not appear to be any variation within any one thin section.

26. The plagioclase composition of the granulites vary from An_{04} to An_{15} . The plagioclase of the felspar-amphibole rock varies between An_{23} and An_{25} , with an increase in the anorthite molecule content away from the orebody into the hanging wall. The plagioclase composition within the plagioclase-amphibolite (altered meta-dabase) was within the range An_{23} to An_{33} . Plagioclase composition within the mica schists indicated An_{30} to An_{35} .
27. Zoning in the plagioclase crystals is common outside the ore zone, whereas the ore zone granulite showed an almost complete lack of zoning of the plagioclase. It is thought that this was caused by the extraction of calcium from the plagioclase molecule by the effects of carbonate metasomatism in the immediate vicinity of the ore zone, with this effect becoming less obvious away from the ore zone into the hangingwall. Zoned crystals in the hangingwall show a distinctly acid core and a calcic margin.
28. Detailed mineralogical examination of the amphiboles indicated the presence of both aluminous and non-aluminous amphiboles.
29. The aluminous amphiboles are represented by the hornblende series. The hornblende of the ore zone is a paler green contrasted with a dark-green, strongly pleochroic hornblende in the rocks of the hangingwall and footwall. The refractive indices of the hornblendes of the ore zone are decidedly lower than that of the surrounding rocks. Accurate measurement of the $2V$ angle of the hornblende was possible, and measurement of the refractive indices was undertaken.
30. The non-aluminous amphiboles are represented by anthophyllite-cummingtonite and tremolite-actinolite. Non-aluminous amphiboles in 20 thin sections cut from granulites and carbonaceous mica schists were examined on the universal stage and refractive index determinations were carried out. No two of these non-aluminous amphiboles occur in the same rock and the optical properties of each amphibole was found to be constant throughout each section. The optical properties of these amphiboles do not vary in relation to the ore zone or the type of host rock.

31. Composition determination of the non-aluminous amphiboles was attempted by plotting the optical properties as determined against composition in Figures 13 to 20. The composition of each of the non-aluminous amphiboles are suggested in terms of atomic proportions.
32. The properties of the biotite are similar throughout the area, differing only in the intensity of colour and pleochroism. The colour is generally deep and the crystals are generally strongly pleochroic. Measurement of optical properties is difficult as they are somewhat obscured by the deep colour.
33. The quartz of the Shamrocke rocks occurs either as a constituent of the granoblastic groundmass or as larger scattered crystals. Quartz crystals are difficult to distinguish from the plagioclase feldspar without resorting to etching and staining. Although the quartz content of the rock of the ore zone is very low (less than 6%), it is an important constituent of the country rock.
34. The minor constituents of the rocks are apatite, rutile, sphene, staurolite, epidote, calcite and dolomite, garnet and graphite. Each of these accessory minerals are described individually.
35. The suite of ore minerals in the Shamrocke ore are simple and show simple textures.
36. The pyrrhotite, chalcopyrite and cubanite give very little evidence through their textural relationships as to which of them was the first to crystallise. The various textural relationships between the assemblage pyrrhotite, chalcopyrite, cubanite and gangue are described in detail. The paragenesis of the ore is discussed and from the observations from the study of the polished sections it was assumed that the paragenetic order could not have been much different than from oldest to youngest - ilmenite, molybdenite, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, cubanite, haematite, and minor minerals.

37. No X-ray analyses were undertaken, and the study of the ore mineralogy did not give much indication of the temperature of deposition of the orebody. However, in comparing the Shamrocke ore with ores and textures recorded by other writers, it is perhaps reasonable to assume that the temperature of deposition of the ore was definitely above 500°C, and probably above 600°C.
38. The chalcopyrite is a deep-brassy-yellow colour often exhibiting a pinkish sheen which at times make it difficult to distinguish it from the pyrrhotite. Cubanite generally crystallises as both broad and narrow lamellae along the crystallographic directions of the chalcopyrite. The pyrrhotite has generally a mutual boundary relationship with the chalcopyrite and cubanite. Arsenopyrite and pyrite occur very sporadically through the deposit. Ilmenite, haematite, molybdenite and an unidentified mineral X are present in most sections prepared.
39. It was considered that the standard techniques of modal analysis of ores would not provide accurate results for the Shamrocke ore without crushing, splitting and the measurement of the crush mounted in a suitable medium. For this reason quantitative mineralogical analysis of the ore was not undertaken.
40. The chemical data from three silicate analyses undertaken (1 by the writer) indicate that the granulite has a higher silica percentage than the other rocks, probably due to the higher silic mineral content, (i.e. more plagioclase). The magnesium content of the felspar-amphibole rock is higher than in the granulites due to the larger component of ferro-magnesium minerals. The calcium content of the rocks other than the ore zone granulite is higher than the ore zone granulite and it appears that the calcium has been extracted from the granulite during metasomatism. The higher potassium content of the granulite is no doubt due to the abundance of biotite.
41. The metamorphism of the Shamrocke rocks is discussed relative to their position in the facies classification of various writers.
42. The relationships epidote/plagioclase and staurolite/kyanite are criticised. The mineralisation of the Shamrocke ore occurs as dissemination of predominantly chalcopyrite and pyrrhotite within the ore zone granulite, and in places as massive chalcopyrite and pyrrhotite which is present mainly in pure white calcite "blows" within the granulite.

43. Underground development has shown that the mineralisation is best developed in the more calcareous portions of the body.
44. The calcite veins and blows contain much coarse massive sulphide, particularly towards the edges of the larger crystalline calcite bodies, and very often closely associated with the deep green hydrothermal hornblende.
45. Sulphide further occurs finely and coarsely disseminated throughout much of the granulite and felspar-amphibole rock of the ore zone, irrespective of its calcite content.
46. In areas of minor dragfolding the calcite and sulphide appears to have been squeezed into the crests of the folds.
47. During carbonate metasomatism the effect of the streaming of the calcium-rich solutions has resulted in distinct "blows" of pure white calcite and narrow zones of calcite within the ore zone granulites.
48. The metasomatic effect on the original host rock is to produce at places a reaction banding with the granulites.
49. Without detailed X-ray analysis of the ore minerals it is not possible to postulate with any certainty the temperature of deposition of the ore. From the apparent paragenetic order and certain exsolution textures it would appear that deposition commenced at very approximately 600°C, and that most of the ore minerals crystallised between 500° and 600°C.
50. The Shamrocke orebody appears to be a metasomatically emplaced deposit of uncertain origin and can be termed pyrometasomatic or hypothermal-metasomatic.
51. J.B.E. Jacobsen (1965) compared the Shamrocke ore with the ore of the Sanyati occurrences. Although similar, the Shamrocke ore differs from the Sanyati occurrences in its ore mineral content, its grade of regional metamorphism, the position of the Sanyati deposit in the Lomagundi sequence and the absence of outcropping post- and late-kinematic granites in the immediate vicinity of the Shamrocke Mine.

52. Jacobsen (1965) describes metallogenic zoning concentrically away from the Miami and Karoi granites. It appears that the Shamrocke orebody may fall into his pyrometasomatic zone.
53. The Mangula deposit falls in a narrower hypothermal zone which includes the high temperature molybdenite-specularite-chalcopyrite-bornite-chalcocite association of the Alaska and Mangula deposits.
54. The Shamrocke orebody is similar to the Mangula deposit only in that they both occur towards the base of the Lomagundi sequence. The Shamrocke ore is found higher in the succession within the Dolomite Series. The bulk of the copper mineralisation at Mangula is disseminated in hard arkoses and felspathic quartzites immediately above the basal conglomerate of the Deweras Series. The rich ore is a coarser mineralisation of bornite, chalcocite and chalcopyrite in shears, fractures and joints. W. Jacobsen (1961) and J.B.E. Jacobsen (1965) consider the mineralisation at Mangula to be genetically associated with intrusive Mangula granite. The present writer does not feel that this Mangula granite was the source of the mineralisation, although it may, and probably did, have a strong effect in the mobilisation of the original syngenetic copper in the basal rocks of the Lomagundi sequence. The mineralisation is different to that of the Shamrocke Mine, the Mangula deposit being obviously hypothermal compared with the distinctly metasomatic Shamrocke ore.
55. The copper mineralisation at the Alaska Mine is in highly folded rocks of the Dolomite Series and again is a high temperature suite of primary pyrite, chalcopyrite, gold association, obviously hypothermal, and similar to the association at Mangula.
56. The Ell Mine on the Gwai River in the Wankie area occurs in a sedimentary succession similar to the basal sequence of the Lomagundi System in the Shamrocke area. The ore is in lenses of grit within what was possibly original impure dolomites (cf the Shamrocke ore).

57. The possible genesis of the Shamrocke orebody is discussed in detail. It is reiterated that the Shamrocke orebody is probably a metasomatic deposit, with an ore mineral assemblage postulating a high temperature of deposition and an obvious association between the sulphide mineralisation and carbonate metasomatism. It is suggested that the ore is of pyrometasomatic or hypothermal-metasomatic origin.
58. During metamorphism it is thought that the carbonate and the sulphide was mobilised from an original primary constituent of the ore zone rock, or from the surrounding rock; re-worked and redistributed metasomatically.
59. It is unlikely that a hidden or unrecorded intrusive granite is present in the immediate vicinity of the orebody, and the present writer considers that there is no evidence that post- and late-Kinematic granites were the origin of the orebody.
60. It is thought that the origin of the copper is very probably primary sulphide in the sediments, and that the basin edge condition of the original Lomagundi depository would have supported conditions ideal for the deposition of sedimentary syngenetic copper sulphides. It is thought that this original syngenetic copper mineralisation was mobilised and redistributed metasomatically, possibly by the effects of regional metamorphism caused by the deformation of the Lomagundi sequence, by Lomagundi or post-Lomagundi orogeny.
- Disseminated copper occurrences occur east of the Alaska Mine on Shackleton, Avondale and on the Muchi claims and the Cedric Mine further to the south.
61. The interested reader is referred to a paper by Alan L. Clarke (1971) of the U.S. Geological Survey where he describes strata-bound copper sulphide deposits in quartzite in Idaho and Montana, U.S.A.. V.D. Fleischer describes copper mineralisation in the Mufulira Mine as being syngenetic with disseminated copper in quartzite over basement highs in the original basement.

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ADDENDUM

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