THE METAMORPHOSED SEDIMENTS OF THE PRETORIA GROUP AND THE ASSOCIATED ROCKS NORTHWEST OF ZEERUST, WESTERN TRANSVAAL

by

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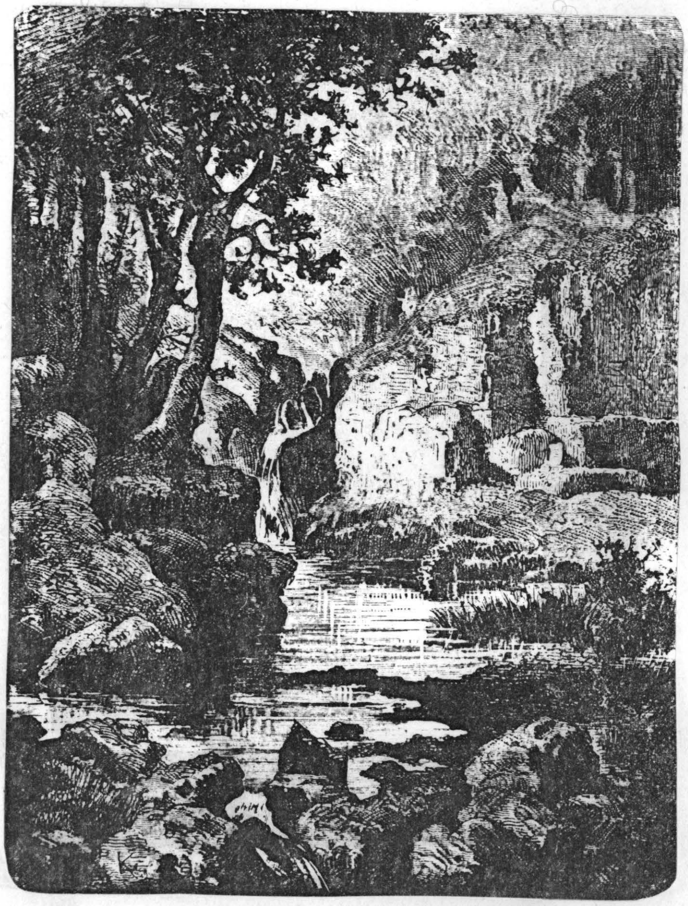
Submitted in partial fulfilment of the requirements for the degree of Magister Scientiae in the Faculty of Science of the University of Pretoria, Pretoria.

May, 1978



Buispoort, rocky cleft in the Bushveldt.

(From the facsimile reproduction of Seven Years in South Africa, Vol. 1, by Emil Holub (1881), published by the Africana Book Society, Johannesburg, 1975.)

Frontispiece

ABSTRACT

Part of the Transvaal Supergroup, viz. the upper formations of the Chuniespoort Group and the Pretoria Group between Zeerust and the border with Botswana, was mapped. The metamorphic aureole of the Bushveld Complex as developed in the Transvaal Supergroup in this area decreases in metamorphic grade both along and across the strike as a result of an apparent reduction in the thickness of the mafic rocks towards the west. The presence of the metamorphic index minerals tremolite, anthophyllite, cummingtonite, cordierite and almandine indicates rocks of the hornblende-hornfels facies in the east. West of long. 25°53'E (which transverses the strata), the metamorphic assemblages are typical of the albite-epidote-hornfels facies and contain minerals such as talc and epidote. Total fluid pressure in the mapped area is unlikely to have exceeded 4 kb. Temperatures are estimated to have been between 300 and 500°C for the albite-epidote-hornfels facies and between 500 and 600°C for the hornblende-hornfels facies.

Few of the complex structures present in adjoining Botswana enter South Africa. A low-angle strike fault zone is an exception, however, and enters South Africa near Skilpadhek to cut out a large part of the Malmani Subgroup. The post-Bushveld linear structures, which are predominant in most of the mapped area as well as in a large part of the Kaapvaal province, viz. the NNW faults and the ENE photo-lineations, were formed under tensional conditions. En echelon NNW faults appear to be a result of crustal adjustments in response to an

isostatic rise of the underlying Gaberone basement granite dome, which is part of the Vryburg arch. ENE and EW photo-lineations appear to be the surface manifestations of diabase dyke systems. EW faults are rare.

Several lateral lithofacies changes in the sedimentary layers of the area indicate a higher energy environment in the west. This, together with an increase in the amount and size of detrital chert near Botswana, suggests a nearby original margin of the Transvaal basin in Botswana.

Uplift and erosion of the Chuniespoort Group after its deposition did not remove the Penge Formation, with the result that the basal layer of the Pretoria Group is a chert conglomerate and not a residual chert breccia as elsewhere in the Transvaal basin. The sequence of the Rooihoogte Formation at Skilpadhek,as indicated by the cores of four boreholes, represents a delta partly destroyed by strong currents and superseded by linear clastic shore deposits. Lava of the Hekpoort Andesite Formation was extruded subaerially and has an upper, metamorphosed, residual paleosoil cover.

Nsutite, a battery-active manganese dioxide, is mined between Skilpadhek and Livingstone's Poort. The ore body originated by replacement of a layer of stromatolitic,dolomitic limestone in the Polo Ground Member of the Rooihoogte Formation and has a dip of 15^{o} to the north or northeast, a strike length of 10 km and a thickness of between 0 and 7 m. Ore formation could still be in progress in the oxygen-rich zone of the ground water, which would curtail the extent of the ore to ween 30 and 40 m below ground level.

Lenses of magnetite occur in a thick noritic sill above the Daspoort Quartzite Formation. Many small iron ore bodies exist in the Transvaal Supergroup. Carbonaceous slates are usually rich in sulphides, especially pyrite.

SAMEVATTING

'n Gedeelte van die Transvaalsupergroep nl. the boonste formasies van die Chuniespoortgroep en die Pretoriagroep tussen Zeerust en die Botswanagrens, is gekarteer. Die metamorfe oureool van die Bosveldkompleks wat ontwikkel is in die Transvaalsupergroep, verminder in metamorfe graad langs sowel as dwarsoor die strekking weens 'n blykbare afname in die dikte van die mafiese gesteentes na die weste. Die teenwoordigheid van die metamorfe indeksminerale tremoliet, antofilliet, cummingtoniet, cordieriet en almandien in mineraalassosiasies dui op gesteentes van die horingblende-horingfelsfasies in die ooste. Wes van die lengtegraad 25°53'O wat dwarsoor die gelaagdheid sny, is metamorfe asso-siasies wat tipies is van die albiet-epidoot-horingfelsfasies en minerale soos talk en epidoot bevat. Dit is onwaarskynlik dat die totale vloeistofdruk ooit 4 kb oorskry het. Die tem-peratuur het blykbaar gewissel tussen 300 en 500°C vir die albiet-epidoot-horingfelsfasies en tussen 500 en 600°C vir die horingblende-horingfelsfasies.

Min van die ingewikkelde strukture in die aangrensende gebied in Botswana dring Suid-Afrika baie vêr binne, behalwe vir 'n sone van vlakhoekige strekkingsverskuiwings wat 'n groot gedeelte van die Malmanisubgroep afsny in die Skilpadhek-omgewing. Na-Bosveldse lineêre strukture is dominant in die grootste gedeelte van die gebied asook in 'n groot gedeelte van die Kaapvaalprovinsie. Dié lineamente bestaan uit NNW-verskuiwings en ONO-fotolineasies, wat beide onder tensie-

toestande ontstaan het. Die en echelon, NNW-verskuiwings is skynbaar te wyte aan aanpassings van die aardkors wat genoodsaak is deur 'n isostatiese styging van die onderliggende Gaberone-koepel van Argeïese graniet, wat deel uitmaak van die Vryburgboog. Die ONO- en OW-fotolineasies is waarskynlik oppervlakverskynsels van diabaasgangsisteme. Daar is min OW-verskuiwings.

Etlike laterale litofasiesveranderinge in die sedimentêre lae van die gebied dui op 'n hoër energie omgewing in die weste as in die ooste. Daar is ook 'n styging in die hoeveelheid en grootte van detritale chert naby Botswana. Hierdie verskynsels dui op 'n nabygeleë oorspronklike grens van die Transvaalkom in Botswana.

Opheffing en erosie van die Chuniespoortgroep na afsetting het nie die verwydering van die Pengeformasie tot gevolg gehad nie, met die gevolg dat die basale laag van die Pretoriagroep 'n chertkonglomeraat is en nie 'n residuele chertbreksie nie soos elders voorkom in die Transvaalkom. Die opeenvolging van die Rooihoogteformasie in die Skilpadhek-omgewing soos aangedui deur die kerne van vier boorgate, stel 'n delta-afsetting voor wat gedeeltelik vernietig is deur sterk seestrome. Lineêre klastiese kusafsettings volg bo-op die oorblyfsels van die delta. Lava van die Hekpoort Andesiet Formasie het op land uitgevloei. Die boonste laag lava is verander na 'n gemetamorfoseerde residuele paleogrond.

Nsutiet, 'n battery-aktiewe mangaandioksied word in die Skilpadhek-Livingstone's Poortgebied ontgin. Die ertsliggaam is 'n vervanging van 'n laag stromatolietiese dolomitiese kalksteen wat voorkom in die Polo Groundlid van die Rooihoogteformasie en het 'n helling van 15° noord of noordoos, 'n strekkingslengte van 10 km en 'n dikte van tussen 0 en 7 m. Vorming van die erts kan miskien nog aan die gang wees in die suurstofryke sone van die grondwater, wat die diepte van die erts sou beperk tot tussen 30 en 40 m onder die grondoppervlak.

Magnetietlense kom voor in 'n dik noritiese plaat bokant die Daspoortkwartsietformasie. Baie ander klein ystererts-afsettings is in die studiegebied opgemerk. Koolstofryke skalie bevat gewoonlik heelwat sulfiede, veral piriet.

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I. INTRODUCTION

The main part of the study comprises an investigation of a suite of metamorphosed sedimentary and volcanic rocks of the Pretoria Group of the Transvaal Supergroup, located between Zeerust and the border with Botswana. Most of the terrain is in Bophuthatswana, whereas the eastern portion is part of the Transvaal, Republic of South Africa. The project was initiated in order to provide more information on the metamorphism as well as the structure and conditions of deposition of the rocks of the Pretoria Group in the western part of the Transvaal basin. For this purpose an area of some 860 km^2 was mapped, which included adjacent strips of the Chuniespoort Group and the Bushveld Complex (Folder, Fig. 1).

A first geological report of the district, accompanied by a reconnaissance map, was produced by Hatch in 1904. Seven years later the Geological Survey published a geological map of the Marico area (1:148 700) on which the various units of the "Pretoria Series" were distinguished by Humphrey, who also wrote the accompanying explanation of the sheet (Humphrey, 1911). Crockett mapped the adjacent area in Botswana and interpreted the complex geologic structures there present as being the result of "gravity sliding following a catastrophic collapse of the basin floor in post-Transvaal System times" (Crockett, 1969, p. 2). Terrains to the south and east of the study area were investigated by Kingsley (1961) and Engelbrecht (1973) respectively. Groeneveld and De Wet (1960) reported on the magnetite occurrences and Ortlepp (1964, p.152)

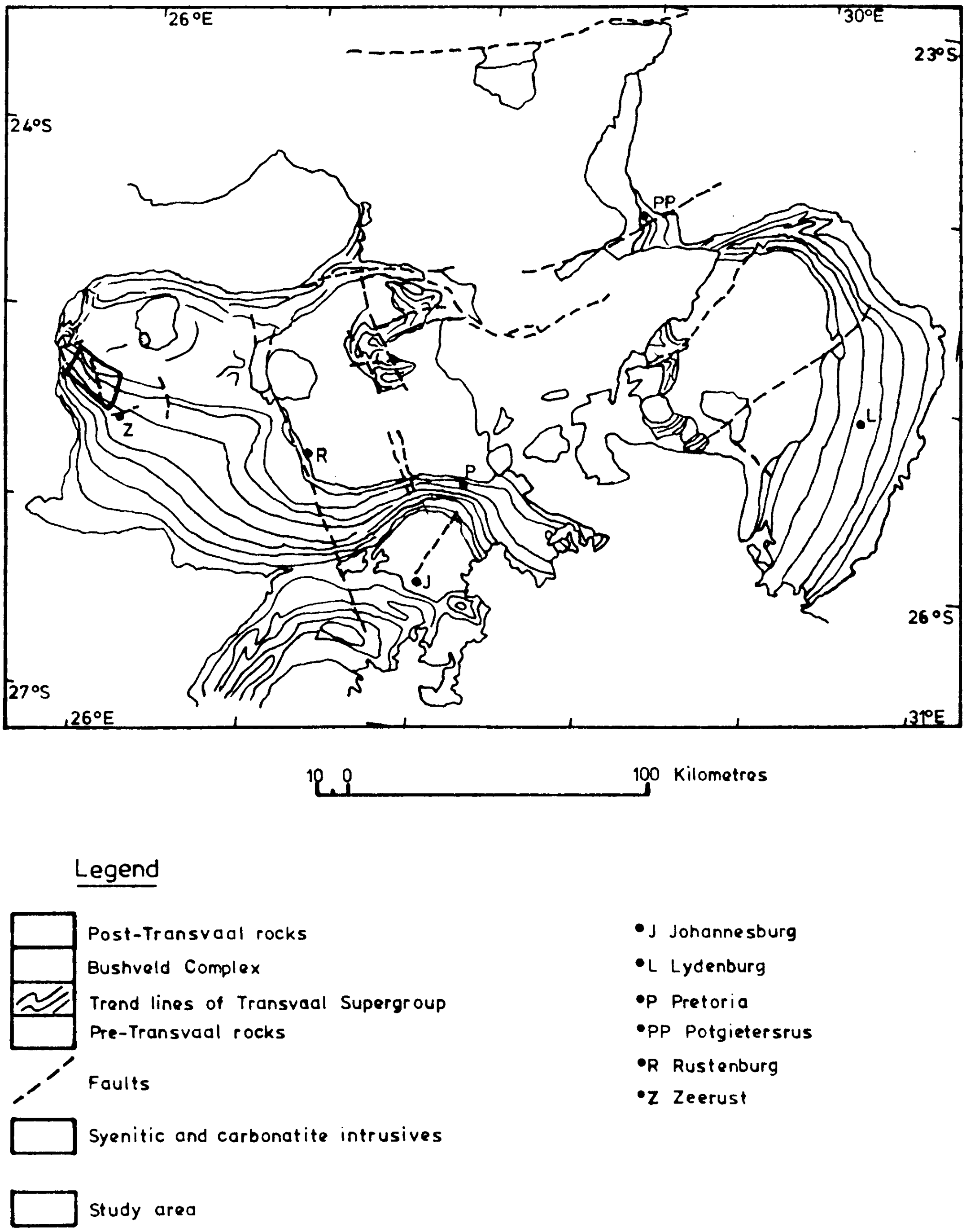


FIGURE 1: Locality map (after Hunter, 1975, Fig. 3) of the study area in the Transvaal basin.

noted the nsutite (gamma-manganese dioxide) deposits in the investigated area.

Present investigation started in May, 1975, with the stereoscopic interpretation of aerial photographs at a scale of 1:30 000. Most of the fieldwork was completed by November, 1975, although the area was revisited in September, 1976, to remap parts of the Chuniespoort Group.

Laboratory work relied mainly on the microscopic identification of minerals and description of textures. Rocks that contained minerals which still needed identification or which still required determination of physical properties were crushed by mortar and pestle , sieved and separated by heavy liquids or by a Frantz Isodynamic Separator. Refractive indices were determined with the aid of immersion liquids in polychromatic light at room temperatures. X-ray analyses of minerals were done with a 114,6 mm Guinier double camera as developed by Jagodzinski or with a Seifert diffractometer. Minerals such as feldspars and cordierite were identified in uncovered thin sections by staining with organic dyes.

Thicknesses of beds (Table 1) must only be considered as approximations because of the general dearth of exposures amenable to dip and strike measurements, as well as the paucity of exposures of contacts between beds.

Clastic sedimentary rocks were classified according to Wentworth's grain size scale (1922) as modified by Griffiths (1967, p.76). However, metamorphosed siltstones are referred to in the text as coarse-grained slates and metamorphosed grit simply as grit.

II. GENERAL GEOLOGY

A. INTRODUCTION

Subdivision of the Transvaal Supergroup into formations in the study area (Fig. 2, Table 1) is according to the scheme proposed by the South African Committee for Stratigraphy (1977). However, a number of beds indicated in the stratigraphic column for the Western Transvaal (SACS, 1977) were not located in the mapped area and vice versa. In addition, the Rooihoogte, Timeball Hill and Strubenkop Shale Formations do not comply with the definition of a formation as set out by the International Subcommittee on Stratigraphic Classification (SACS, 1971) and each of these formations could be divided into two or three separate formations.

It should be noted that Table 1 contains the description of most of the mapped beds in the study area, and that subsections B and C of this chapter serve to amplify only some of the features and also to mention beds or zones of limited extent not indicated in Table 1.

B. PRETORIA GROUP

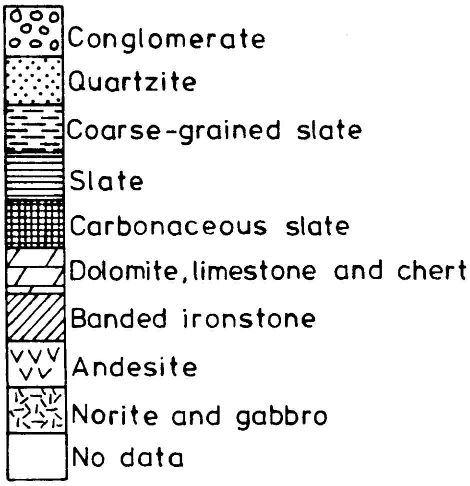
1. Rooihoogte Formation

a. Bevet's Conglomerate Member (RC)

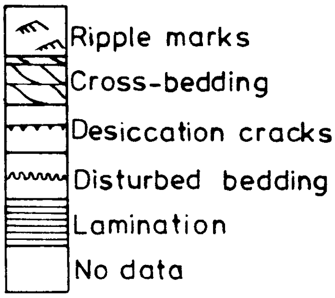
Southeast of Dinokana the chert-pebble conglomerate of the Bevet's Conglomerate Member has a matrix of hornblende (n_x = 1,652, n_y = 1,670, n_z = 1,681, $Z\hat{}c$ = 23^o, AK322), which partly or completely replaces the chert pebbles (Fig. 4). Near Dinokana is a small area of ferruginized conglomerate.

FIGURE 2 : Measured sections of the Transvaal Supergroup in the eastern (long. 26°00'E) and western (South Africa/Botswana border) sectors of the study area, indicating the lithology and sedimentary structures of the formations.

LITHOLOGY :



SEDIMENTARY STRUCTURES:



Symbols used to identify the beds, e.g. IS, are the same as those on the geological map in the folder.

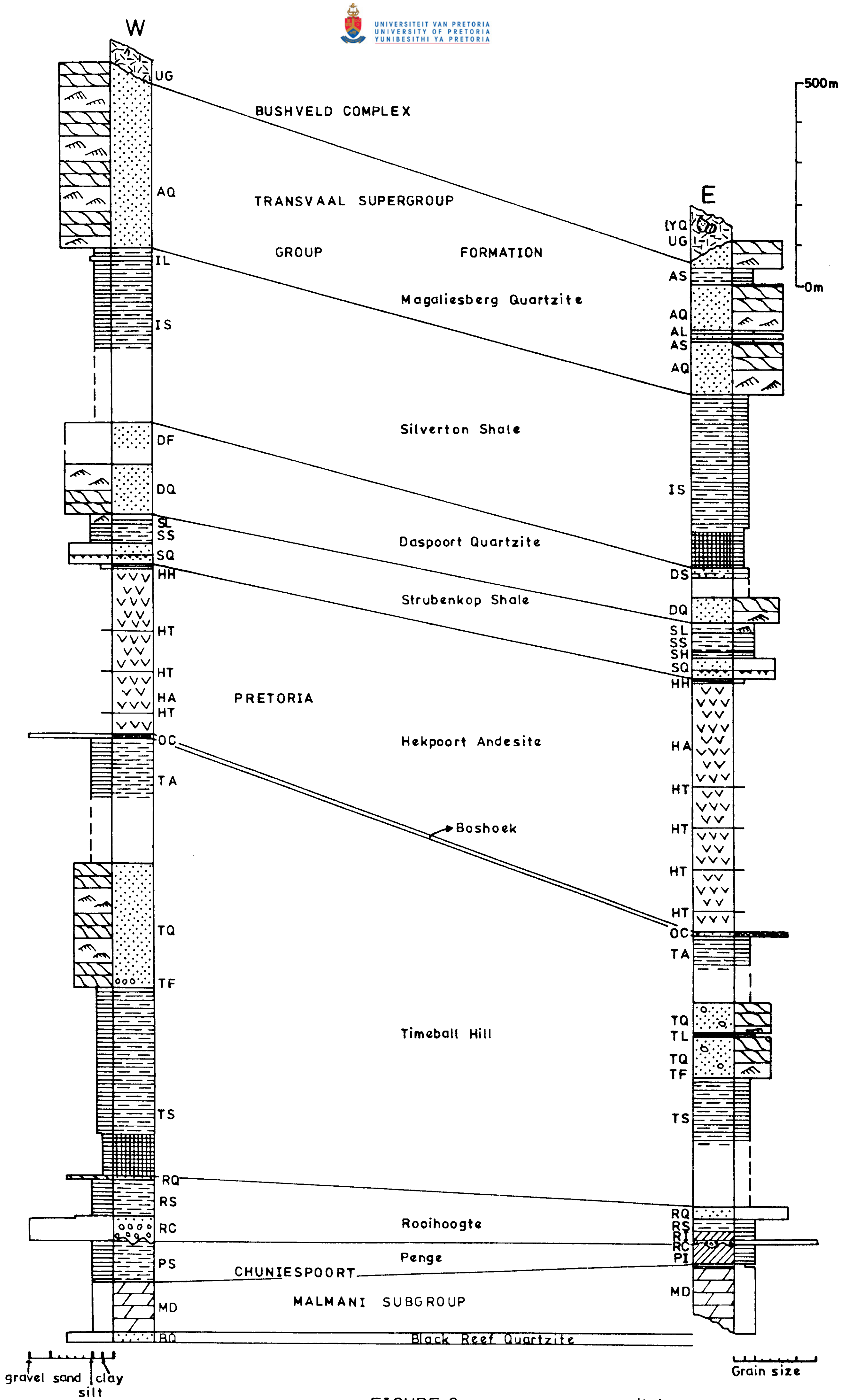


FIGURE 2 (For legend see opposite)

Table 1 : Subdivision of the Transvaal Supergroup on Moilwaslokasie and adjacent farms

Formation	Map symbol	Thickness (m) E(26°E)	Thickness (m) W(25°45'E)	General description
Pretoria Group:				
Rayton	YQ	-	-	Xenoliths of quartzite and hornfels (AK208[1]) in norite (AK403) and gabbro (AK404) of Bushveld Complex.
Magaliesberg Quartzite	AQ	370	450	Medium- to coarse-grained, well sorted quartzite (AK104) with monocrystalline quartz grains, though chert grains plentiful in west (AK388). Hornfels beds (AS, Table 2) and stromatolitic limestone bed (AL, 5-10 m, AK133) in east; thin conglomerate beds in west.
Silverton Shale	IS	420		East of 25°53'E: Hornfels (Table 2), often with rhythmic, graded bedding; some cross-bedding and mud cracks. Cherty hornfels beds (IC, AK147) associated with diabase sill. Carbonaceous slate (AK230) at base (in valley floor) with black, quartzose "gossan" (AK150).
			420	West: Sericitic and chloritic slates (AK386) with dolomite bed (IL, 5-10 m, AK387) near Botswana. Only upper slates exposed.
Daspoort Quartzite	DQ	130	220	Cross-bedded and ripple marked, medium-grained quartzite in east (AK86); decrease in maturity and sorting and increase in amount of chert grains towards west; grit

W

				laminae in west (AK377). Beds of tourmaline-bearing, carbonaceous, sericite slate (AK264) and quartzite in east (DS). Magnetite-rich, chloritic quartzite bed (DF, 50 m, AK361) at 25°15'S.
Strubenkop Shale	SL	25	25	East: Coarse-grained, sericitic slate; magnetite- and biotite-bearing on Rietgat 91JP (AK84). West: Purple sericite slate with laminae of green, coarse-grained, sericitic slate (AK357).
	SS	45	45	East: Biotite-andalusite hornfels (AK101) West of 25°17'S: Chloritoid slate (AK369) Whole exposure (SS) often displays rhythmic, graded bedding.
	SH	15	-	Rietgat 91JP: Cherty garnet hornfels with laminae and lenses rich in xenoblastic garnet (AK94).
	SQ	50	50	Magnetite-rich quartzite with laminae and lenses of hornfels.
Hekpoort Andesite	HH	5	5	Andalusite-muscovite hornfels.
	HA	600	400	Lava, metamorphosed to hornblende-plagioclase hornfels (AK48) with tuffaceous beds (HT) up to 5 m thick.
Boshoek	OQ and OC	5	1-10	Quartzite and hornfels with thin conglomerate beds in east (OQ), grading west of 25°59'E

		E	W	
				into chert-pebble conglomerate (OC) with sporadic quartzite beds.
Timeball Hill	TA	160	300	East: Carbonaceous, biotite-chiastolite slate (AK45). West: Micaceous slate (AK324).
	TQ	180	300	East: Quartzite with hornfels bed (TL) as well as slate bed. Ferruginous quartzite (TF) at base. West: Quartzite with basal ferruginous zone (TF) in which conglomerate is sporadically developed.
	TS	310	450	East: Andalusite slate (AK20) with laminae and beds of coarse-grained, micaceous slate (AK38) and a garnet hornfels bed at top (AK242). West: Carbonaceous slate at base (Fig. 3) overlain by sericite slate (AK278), often coarse-grained.
Rooihoogte	RQ	2-30	10	Polo Ground Member: East: Quartzite (AK316). West: Quartzite, slate and dolomitic limestone (Fig. 3).
	RS	10	90	Coarse-grained, sericite-chlorite slate.
	RI	10	0-10	East: Grunerite-rich banded ironstone (AK318) with chert beds and ferruginous slate beds. West: Banded ironstone with coarse-grained, chloritic slate beds (AK315). RI wedges out near Botswana.

E W

	RC	5-10	50	Bevet's Conglomerate Member: Chert-pebble conglomerate. In east, it is partially amphibolized or ferruginized and contains beds of tourmaline-bearing, hornblende slate.
Chuniespoort Group:				
Penge	PI	50	 100	East: Banded ironstone with chert beds and intra-formational breccia beds. West: Banded ironstone grading laterally into coarse-grained, muscovite slate (PS, AK307) with ferruginous slate bed (AK309) at base and sporadically developed micaceous quartzite bed at top.
Malmani Sub-group[2]	MD	1700	 120	East: Five dolomite and chert formations (AK525) with bed of carbonaceous, talcose slate (AK526) at top and residual pockets of Giant Chert. West: Largely cut out by Schilpadshek slide.
Black Reef Quartzite[2]	BQ	25	25	Quartzite with grit bed at base and black slate beds.

Note: 1. Specimen numbers, e.g. AK242, are indicated on the map (Folder).

2. Only a reconnaissance geological survey was conducted on the Malmani Subgroup and the Black Reef Quartzite Formation.

In the Skilpadhek and Livingstone's Poort areas near the Botswana border, the chert clasts are more varied in size and more densely packed than in the Dinokana area. Clasts range in size from medium sand grains to large pebbles (long axis up to 70 mm), set in a matrix which is usually ferruginized (AK304). The pebbles are generally bladed, well rounded and often orientated parallel to the bedding. In the west, the conglomerate grades upwards into fine-grained, chloritic quartzite (AK303) about 5 m thick, with abundant clinozoisite crystals.

A small, isolated outcrop of large, rounded boulders southeast of Dinokana, contains large clasts of chert and dolomite as well as sulphide mineralization (AK531) and resembles an agglomerate.

b. Sericite-chlorite slate (RS)

In the Dinokana area, the dark green sericite-chlorite slate can contain chloritoid (AK397). Wad occurs in the alluvium on the slate at two localities southeast of Dinokana, and this evidence as well as fragments of carbonaceous, talcose limestone (AK402) found nearby, may indicate the presence of an intercalated calcareous bed.

Borehole cores of the slate (AK519, Fig. 3) from the Skilpadhek area reveal rhythmic, graded bedding with laminae 0,2-5 mm thick which coarsen upwards.

c. Polo Ground Member (RQ)

Cores from four boreholes which intersect the Polo Ground

Member in the Skilpadhek area near Botswana, show that the Member consists of beds of quartzite, slate and dolomitic limestone in contrast to the eastern sector where it consists only of a bed of quartzite. A typical stratigraphic section of this Member and the adjoining beds in the Gopane area is presented in Figure 3.

The clastic beds, as revealed by the borehole cores, have a groundmass of chlorite, sericite and calcite as well as varying amounts of carbonaceous material and sulphides. The quartzite has medium-sized, well rounded grains of quartz and chert. Near the border with Botswana, exposures of this quartzite (AK300) contain intercalated lenses, stringers and beds of chert.

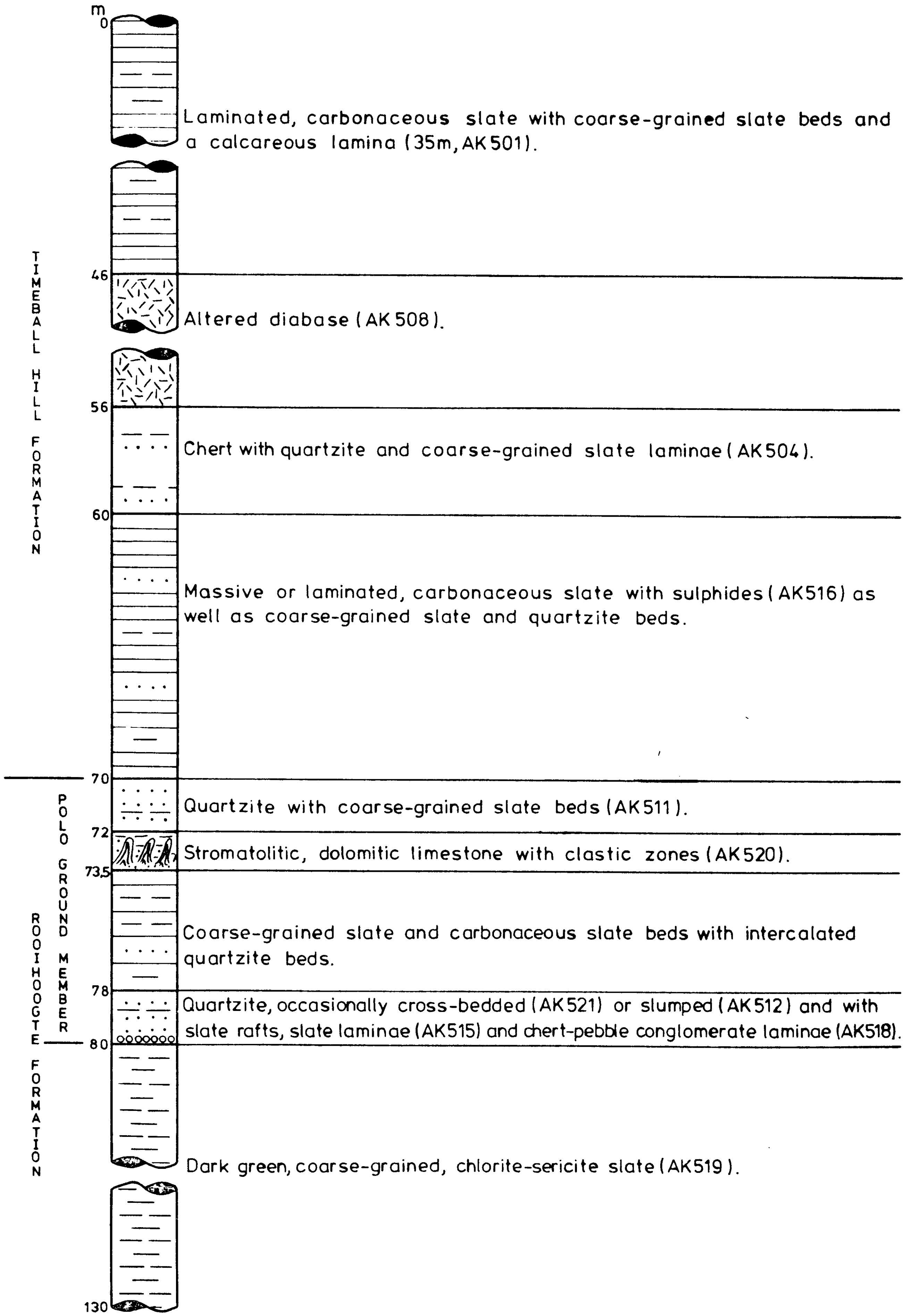
A dolomitic limestone with small columnar stromatolites (Fig. 23) is the important unit of the Member in the west, as it is responsible for the manganese mineralization in the Skilpadhek-Livingstone's Poort area. The deposition of carbonates in this bed took place in competition with clastic sedimentation as is shown by the presence of laminae consisting of well rounded silt and sand grains and granules of quartz, chert and calcite as well as sericite and chlorite, all of which also fill the voids between the stromatolites (AK520).

2. Timeball Hill Formation

a. Slate (TS)

The basal carbonaceous slate is exposed only in the Skilpadhek area, where it was also intersected by a number of bore-

FIGURE 3: Typical stratigraphic section of parts of the Timeball Hill and Rooihoogte Formations as intersected by four boreholes in the Skilpadhek area, Moilwaslokasie.



holes (Fig. 3). Calcite and sulphides are plentiful in the slate, the bedding of which is often compressed around pyrite nodules.

A curious small structure in the slate (AK505) was encountered in a borehole core 5 m above the Polo Ground Member. It has a central part that resembles a hot air balloon, 3 cm high and 3 cm broad near the bulbous top and 2 cm across at the base. This central part is filled mainly with lenticular calcite veins, as well as some quartz veins and fragmented slate. Sedimentary layers are bent around the breccia "balloon", which causes a degree of overfolding but not fracturing at the base. This "ballooning" is probably due to the bubble-like rise of gas or water through the primordial mud. It can not be considered to be a true mud volcano (Reineck and Singh, 1975, p.48) as it never reached the surface.

A layer, 3 cm thick, of chert as well as calcite and magnetite crystals, is intercalated in the carbonaceous slate. The chert contains many round or elliptical structures about 0,1 mm in length that may be the shards of a tuff (AK501, Fig. 5).

b. Quartzite (TQ)

The quartzite is generally a fine-grained rock in which rounded, monocrystalline quartz grains predominate. Chlorite usually forms the matrix and gives the rock a dark olive green colour, though the quartzite has a spotted appearance (AK287) at Livingstone's Poort, apparently because of the

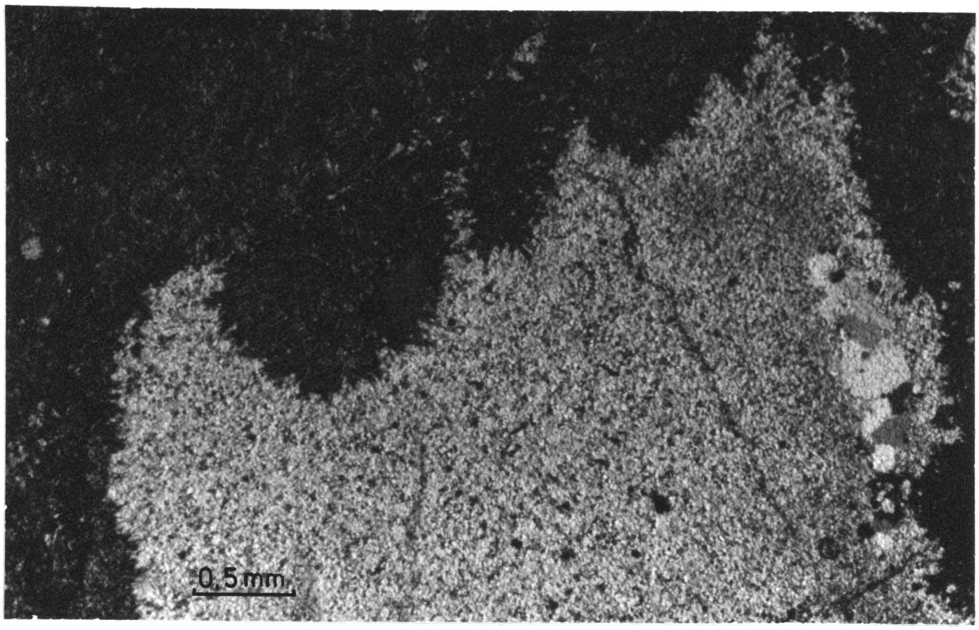


Figure 4: Hornblende (dark) matrix partly replacing a chert pebble (light) in a conglomerate (AK319, RC, Bevet's Conglomerate Member, southeast of Dinokana, polarized light).

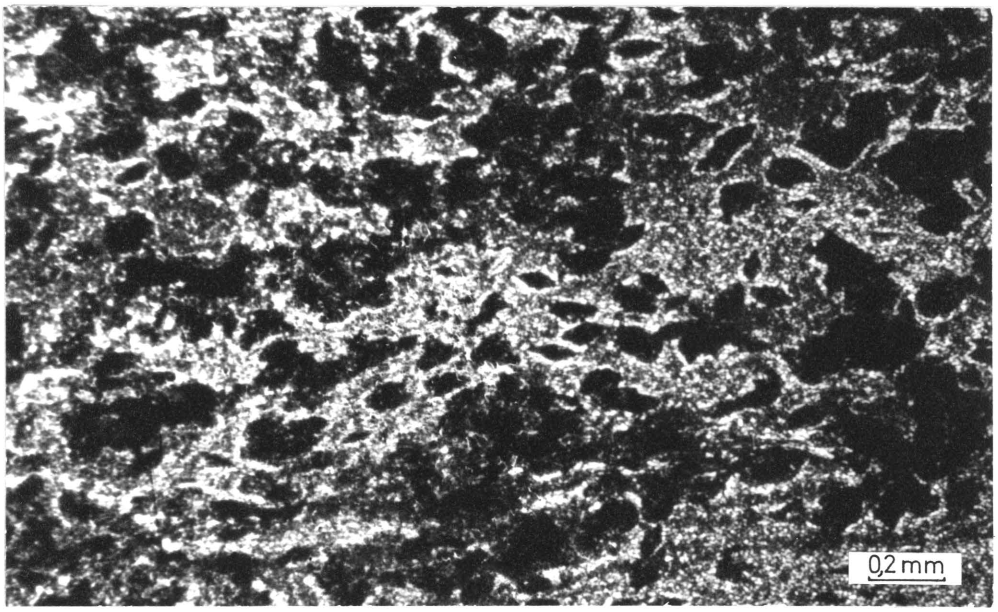


Figure 5: Elliptical grains of magnetite (shards?) in a chert layer (AK501, TS, Timeball Hill Formation, borehole core from Gopane mine, polarized light).

removal of areas of interstitial chlorite by the incipient recrystallization of the quartz grains. As the quartzite is not very homogeneous along or across strike, it can vary in composition from a pure quartzite (AK37) to a chloritoid-muscovite hornfels (AK248), though both these extremes are rare.

Tabular cross-bedding and symmetrical ripple marks are common in the quartzite, whereas interference ripples and sole marks were found only on Buffelfontein 94JP. A ripple marked, ferruginous quartzite with ripple troughs infilled with ferruginous slate (AK260) occurs locally at lat. 25°22'S. Elongated, rounded pebbles and cobbles of chert (AK410, Fig. 6) and a dark green, fine-grained chloritic rock, are randomly dispersed in the quartzite in the east of the area. The chert cobbles resemble chert of the Malmani Subgroup, whereas the chloritic rock appears to be an amygdaloidal lava, perhaps derived from the Ventersdorp Supergroup.

Black, extremely fine-grained laminae rich in detrital heavy minerals as well as laminae rich in metamorphic, idioblastic garnet are intercalated in the quartzite on Buffelfontein 94JP.

The basal 10 m of the quartzite (TF) weathers to a partly ferruginized rock that forms a small but persistent scarp face near the top of the range of hills to the north of the Zeerust-Lobatsi road. A bed of ripple marked andalusite slate, about 5 m thick, overlies the scarp face from the east to long. 25°49'E. Further west the basal quartzite and slate beds make way for a dark green, ferruginous quartzite (AK271) intercalated with slate laminae. A conglomerate (AK285) consisting of subangular, ferruginized quartzite pebbles in a matrix of rounded quartz grains, is sporadically developed near the base west of long. 25°49'E.

A hornfels bed (TL, AK29), about 5 m thick, is interlayered with the quartzite on Buffelfontein 94JP. The hornfels, sometimes carbonaceous, has rhythmic, graded bedding and contains laminae and lenses of quartzite. On Welbedacht 39JO a carbonaceous, andalusite slate bed is exposed on approximately the same horizon, whereas further west along strike the bed outcrops sporadically as a carbonaceous, chlorite slate, which can be intercalated with quartzite laminae.

3. Boshoek Formation

A thin but persistent bed of conglomerate and quartzite is developed between the Timeball Hill and Hekpoort Andesite Formations in the Marico District as well as in southeastern Botswana (Crockett, 1969, p.73). The provisional subdivision of the Transvaal Supergroup (SACS, 1977) in the western Transvaal makes no mention of the bed, and consequently it was named the Boshoek Formation after its stratigraphic equivalent in the eastern Transvaal (Button, 1973, pp.201-207).

On Palmietfontein 92JP, the quartzite (OQ) exhibits trough cross-bedding, flute casts and ripple marks and has undergone intensive soft sediment deformation (Fig. 7). Although medium-grained quartz is the chief constituent of the rock,

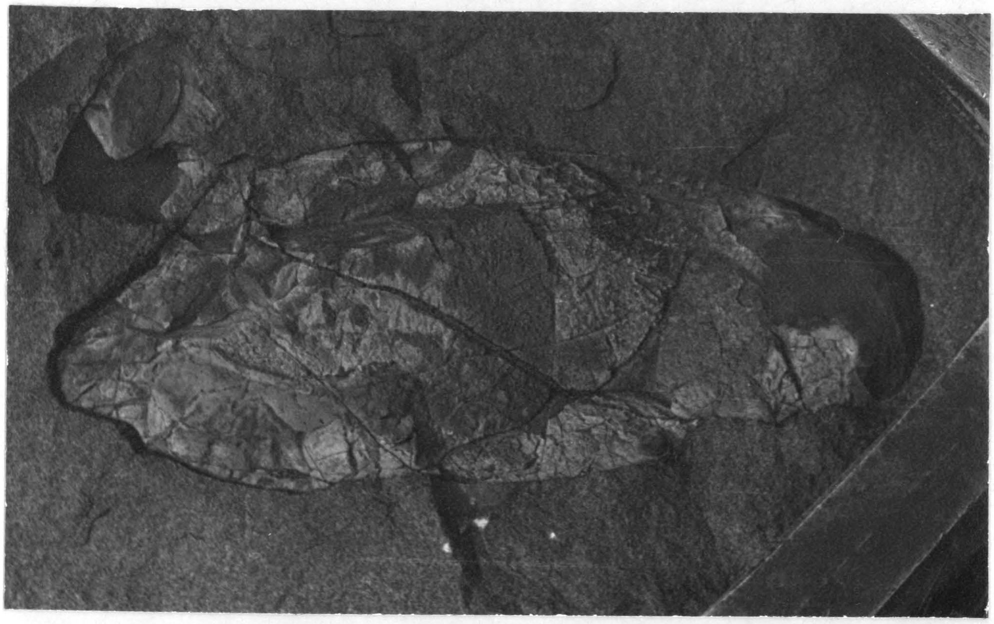


Figure 6: Chert cobble (length 15 cm) in quartzite (AK410, TQ, Timeball Hill Formation, Buffelfontein 94JP).

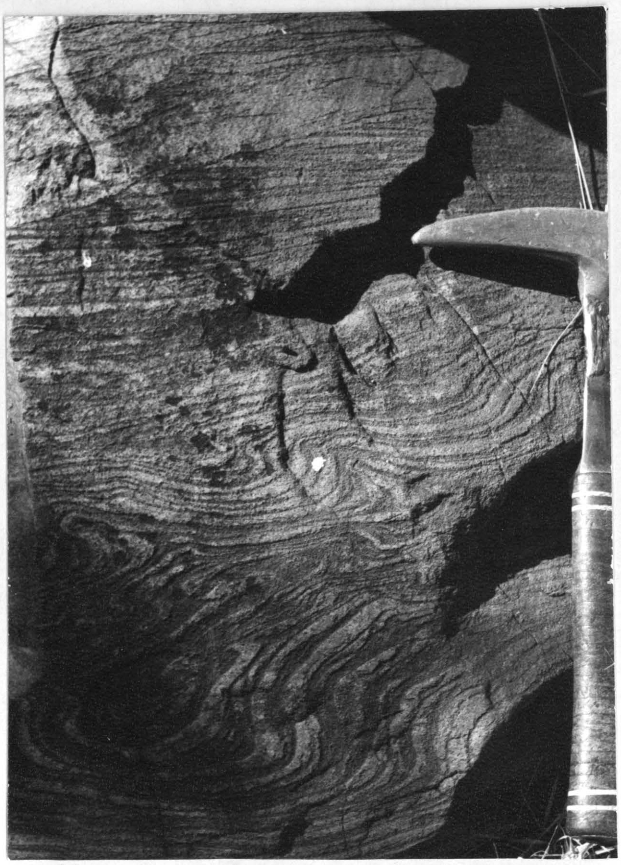


Figure 7: Soft sediment deformation in quartzite (OQ, Boshoek Formation, Palmietfontein 92JP).

varying amounts of metamorphic minerals such as garnet, hornblende, chlorite and plagioclase, indicate that the composition can vary between a quartzite and a hornfels (AK75). Thin beds of andalusite-chloritoid slate (AK50), garnet-anthophyllite hornfels (AK72) and plagioclase-hornblende hornfels (AK77) outcrop near the top of the Formation.

West of long. 25°59'E, the quartzite grades laterally into a chert-pebble conglomerate (OC), which is lithologically very similar to the conglomerate of the Bevet's Conglomerate Member at the base of the Pretoria Group. Unweathered chert pebbles are white, grey or black in colour and set in a ferruginous matrix. Most of the clasts are prolate, rounded to well rounded, and range in size from a few millimetres to 50 mm. The elongated pebbles are somewhat aligned and form an indistinct bedding.

Near Botswana, at long. 25°45'E, a paleoerosion channel cuts through the Boshoek Formation into the slate (TA) underneath. Successive beds of chert-pebble conglomerate, chert-pebble and slate-fragment conglomerate, grit and slate fill the channel (Fig. 8). The thin chert-pebble and slate-fragment conglomerate bed contains somewhat rounded and randomly orientated slate discs, up to 30 cm in diameter, together with rounded chert pebbles, set in a ferruginous, argillaceous matrix (Fig. 9). The bulk of the channel is filled by a grit which contains subrounded grains of chert and quartz, as well as tabular slate fragments, somewhat rounded and aligned with the bedding, in an argillaceous matrix (AK376). It seems evident that the upward-fining cycle of sediments

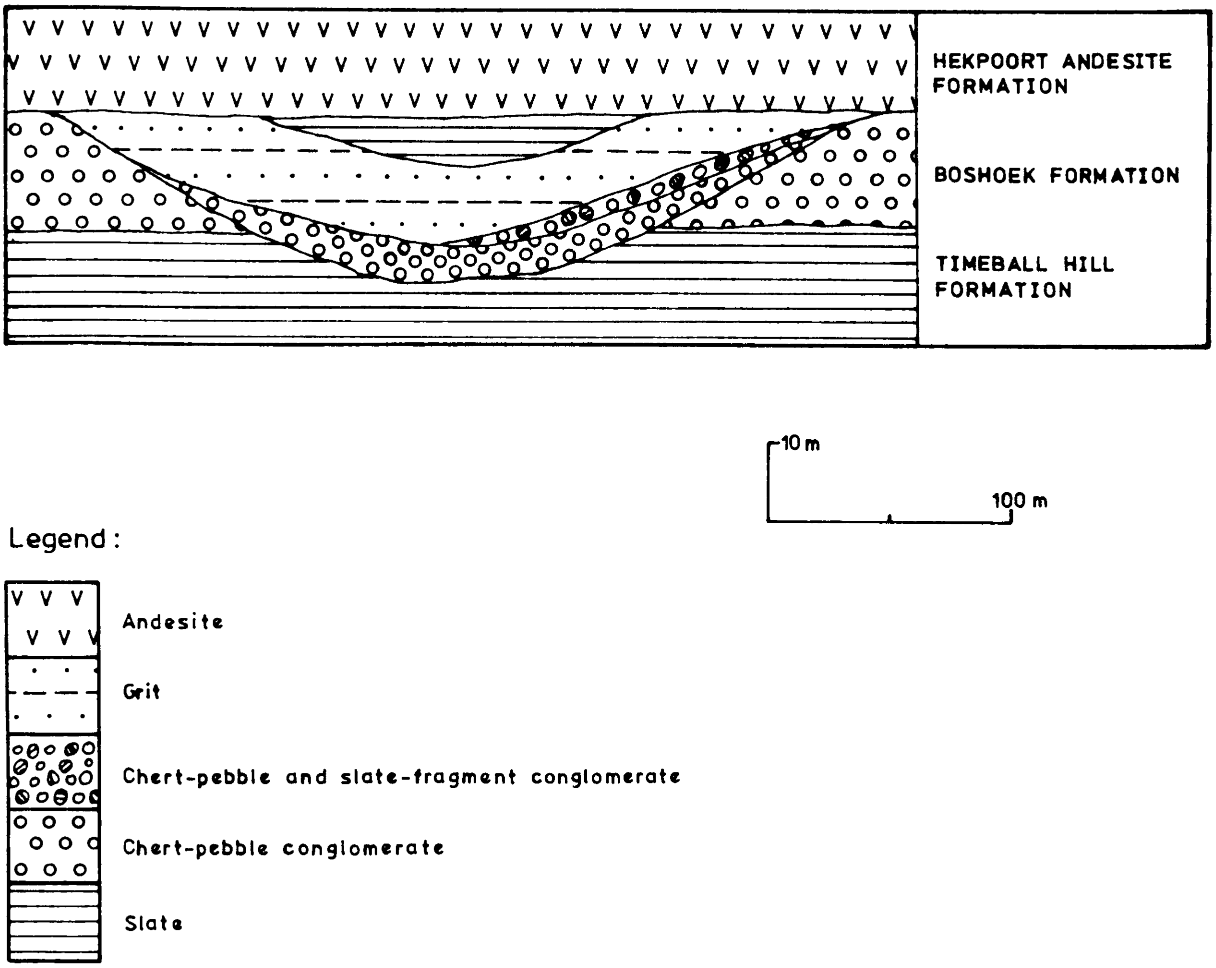


FIGURE 8 : Schematic cross section of the erosion channel in the Boshoek Formation , Moilwaslokasie.

in the channel was caused by a decrease in the energy of the river.

4. Hekpoort Andesite Formation

The only major volcanic episode in the study area was the outflow of the Hekpoort lava (HA). Pahoehoe lava (Engelbrecht, 1973, p.43) is predominant and consists of massive lava (AK48),which sometimes contains columnar, hexagonal cooling cracks (Fig. 10) as well as zones rich in spheroidal amygdales that represent the tops of lava flows. Rarer aa lava has irregularly shaped amygdales, which often make up more than half of the volume of the rock.

Thin beds of a very fine-grained, cherty rock (HT, AK58) occur throughout the volcanic sequence and, because of the thinly bedded nature of the rock on Palmietfontein 92JP, probably represent tuff beds laid down among the eruption centres. Laminae and lenses of tuff are often intimately associated with aa lava (AK325). A portion of the tuff appears to be of a non-volcanic origin, for although the tuffs and lavas are mineralogically very similar, zircon grains are common in the pyroclastic rocks but absent in the extrusives.

The end of the Hekpoort lava outflow is marked by a poorly exposed bed of massive, andalusite-muscovite hornfels about 5 m thick (HH, AK95). Near Botswana the rock is rich in chlorite and no andalusite is present (AK378). A similar sericite rock is developed at an equivalent level in the succession in the eastern Transvaal. Button (1973, pp.212-213) is of

Figure 9: Randomly orientated slate discs and chert pebbles in a conglomerate in an erosion channel (OC, Boshoek Formation, long. 25°45'E).

Figure 10: Plan view of columnar, hexagonal cooling cracks in lava (HA, Hekpoort Andesite Formation, Palmietfontein 92JP).

the opinion that the sericite rock represents a metamorphosed, residual paleosoil, formed by the chemical weathering of the lava. A similar origin is plausible for the hornfels in the study area.

5. Strubenkop Shale Formation

a. Magnetite-rich quartzite (SQ)

The quartzite at the base of the Strubenkop Shale Formation can vary in mineralogical composition from a pure quartzite to a hornfels. Generally, however, the rock is a magnetite-rich, fine- to medium-grained quartzite with an andalusite-rich matrix (AK98). Masses of the subidioblastic magnetite crystals partly replace the andalusite and quartz crystals. Monocrystalline quartz grains predominate except near Botswana where chert grains are plentiful.

Hornfels laminae intercalated with the magnetite-rich quartzite consist mainly of interlocking andalusite crystals as well as magnetite, muscovite and quartz (AK226), while chloritoid is an important constituent in the Gopane area (AK359).

The hornfels laminae are sometimes broken into pellets and deformed as a result of the dessication of the original mud layers, pointing to periodic subaerial conditions during deposition (AK227, AK359). Pellets can have deferruginized rims (Fig. 11, AK226).

A zone of garnet-andalusite hornfels is developed between long. 25°56'E and Gopane. It is characterized by rhythmic, graded bedding and the sporadic presence of lazulite, a pleochroic, blue phosphate mineral (AK225).

North of Gopane, a highly weathered diamictite outcrops at the base of the magnetite-rich quartzite. It consists of small, rounded, chert pebbles sparsely distributed in a ferruginous, fine-grained quartzite characterized by large, rounded grains of zoned zircon (AK355).

b. Biotite-andalusite hornfels (SS)

In an andalusite-poor zone of the biotite-andalusite hornfels bed on Rietgat 91JP, the rock contains many nodular structures with a diameter of up to 2 mm. These consist of large biotite crystals and some muscovite crystals surrounded by a rim of inclusion-free quartz. A myriad of tiny, somewhat orientated needles, perhaps sericite, are included in the quartz of the groundmass (Fig. 12, AK92).

c. Sericite slate (SL)

The sericite slate often exhibits rhythmic, graded bedding as well as symmetrical ripple marks and some sole marks (AK337). A thin bed of clay pill conglomerate outcrops north of Gopane (AK331). Small folds of unknown origin are to be seen on Rietgat 91JP.

6. <u>Magaliesberg Quartzite Formation</u>

Cross-bedding and ripple marks, usually asymmetric, are common in the quartzites. Flat-topped ripple marks and superimposed ripple marks in the troughs of ripple marks (Fig. 13), were probably caused by a drop in the water-level and run-off

Figure 11: Plan view of hornfels pellets with clear borders in magnetite-rich quartzite (SQ, Strubenkop Shale Formation, Gopane).

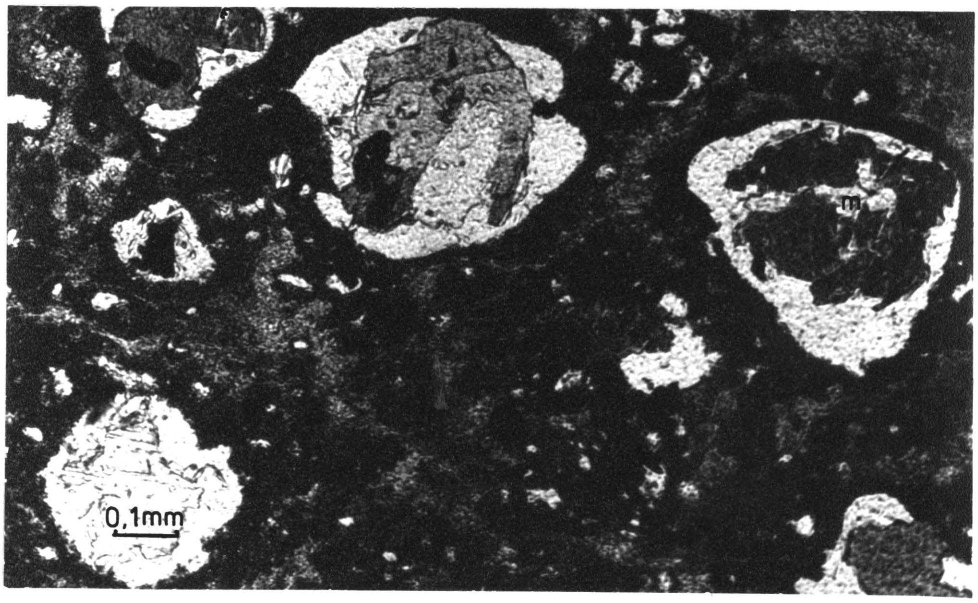


Figure 12: Nodular structures containing biotite, muscovite (m) and a clear rim of quartz in a groundmass of sericite and quartz (AK92, SS, Strubenkop Shale Formation, Rietgat 91JP, polarized light).

effects due to the emergence of the sediment (Button and Vos, 1976, p.6).

The lowest hornfels bed (AS) intercalated with the quartzite on Bergfontein 60JP has unusual cylindrical cavities weathered into the bedding-planes (Fig. 14). Although they could represent zones of faster weathering along joints, their origin is by no means clear. A tremolite hornfels in which the amphibole is sometimes asbestiform (AK116) is associated with the limestone bed (AL) on Bergfontein 60JP.

Thin beds of conglomerate, intercalated near the base and top of the quartzite from long. 25°50'E to the Botswana border, contain poorly sorted, subrounded pebbles of quartzite in a matrix of quartz grains and iron oxides (AK381).

C. INTRUSIVE ROCKS

A number of mafic dykes and sills have intruded the study area. Most conspicuous are the sills of the Marico diabase suite (SACS, 1977), which are generally thicker in the argillaceous beds than in the arenites.

There were at least two periods of sill intrusion, the first of which took place before the emplacement of the Bushveld Complex. These sills were metamorphosed to an amphibole hornfels, with the amphibole either a green hornblende (AK109) or a colourless cummingtonite ($Z\hat{}c = -16^{\circ}$ to -17°, AK166, Bambauer, 1959) which is sometimes asbestiform (AK166). Plagioclase laths, commonly saussuritized, as well as olivine

Figure 13: Casts of superimposed ripple marks in troughs of ripple marks in quartzite (AQ, Magaliesberg Quartzite Formation, Hartbeestlaagte 58JP).

Figure 14: Bedding plane of hornfels with cavities perhaps caused by faster weathering along joints (AS, Magaliesberg Quartzite Formation, Bergfontein 60JP).

(AK1) and zoned clinozoisite (AK119) can be present.

The second set of sills were probably intruded simultaneously with the emplacement of the Bushveld Complex. The sills are unmetamorphosed and consist of norite, in which the orthopyroxene is usually a subhedral to euhedral hypersthene, with crystals up to several millimetres long (AK159). Olivine crystals with resorbed edges can be present (AK159) but, when absent, some anhedral clinopyroxene usually occurs (AK178). Cummingtonite can replace hypersthene (AK218). Lenticular magnetite layers are exposed in a sill on Welverdient 24JO (section VI.B.).

Dykes, probably all of post-Bushveld age, cut across the strike of the formations along certain preferred orientations (section IV.C.). These dykes are not exposed in the mapped area, although Kingsley (1961, p.12) reports weathered diabase outcrops in the Malmani Subgroup to the southwest.

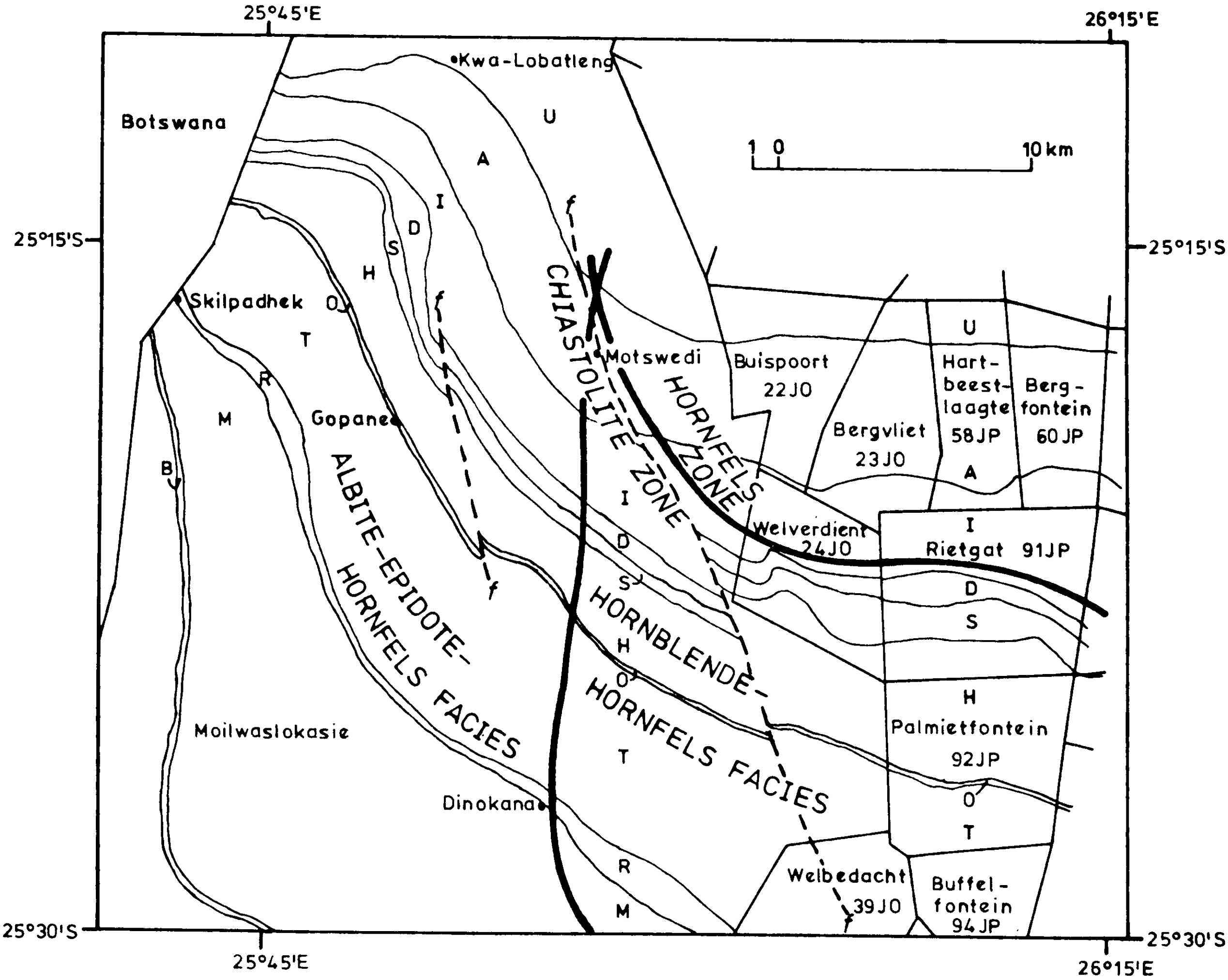
III. METAMORPHISM

A. INTRODUCTION

The mapped area lies within the large contact aureole of the western lobe of the Bushveld Complex, and both zones of progressive metamorphism recognised by Hall (1909, pp.120-123 and 1914, pp.xxx-xxxi) are present. The inner (hornfels) zone or Groothoek type of metamorphism is developed east of the Motswedi fault and north of the Daspoort Quartzite Formation, whereas the rest of the Transvaal Supergroup in the area is part of the outer (chiastolite) zone known as the Longsight type of metamorphism (Fig. 15).

Metamorphic assemblages were arranged into pelitic and psammitic, basic and calcareous associations (Table 2). Pelitic and psammitic assemblages were subdivided according to the principal minerals present, whereas the basic assemblages were subdivided into intrusive and metavolcanic rock groups. The assemblages of each of the two metamorphic facïes present in the area mapped were then plotted onto ACF and A'KF diagrams (Fig. 16, Fig. 17, Winkler, 1976, pp.35-48). Numbers on the diagrams correspond to the numbers of the metamorphic assemblages in Table 2 and Table 3.

Many of the assemblages which contain amphibole also have clinozoisite as a component. Although no clinozoisite pseudomorphs of amphibole could be detected microscopically, the metamorphic grade is too high for epidote-class minerals to be associated with assemblages such as quartz-hornblende-plagioclase. The clinozoisite is therefore regarded as a



Legend

U Bushveld Complex

Formation:		Group:	
A	Magaliesberg Quartzite	Pretoria	Transvaal Supergroup
I	Silverton Shale		
D	Daspoort Quartzite		
S	Strubenkop Shale		
H	Hekpoort Andesite		
O	Boshoek		
T	Timeball Hill		
R	Rooihoogte		
M	Penge Malmani Subgroup	Chuniespoort	
B	Black Reef Quartzite		

FIGURE 15 : Metamorphic zones and facies in the Transvaal Supergroup, Western Transvaal.

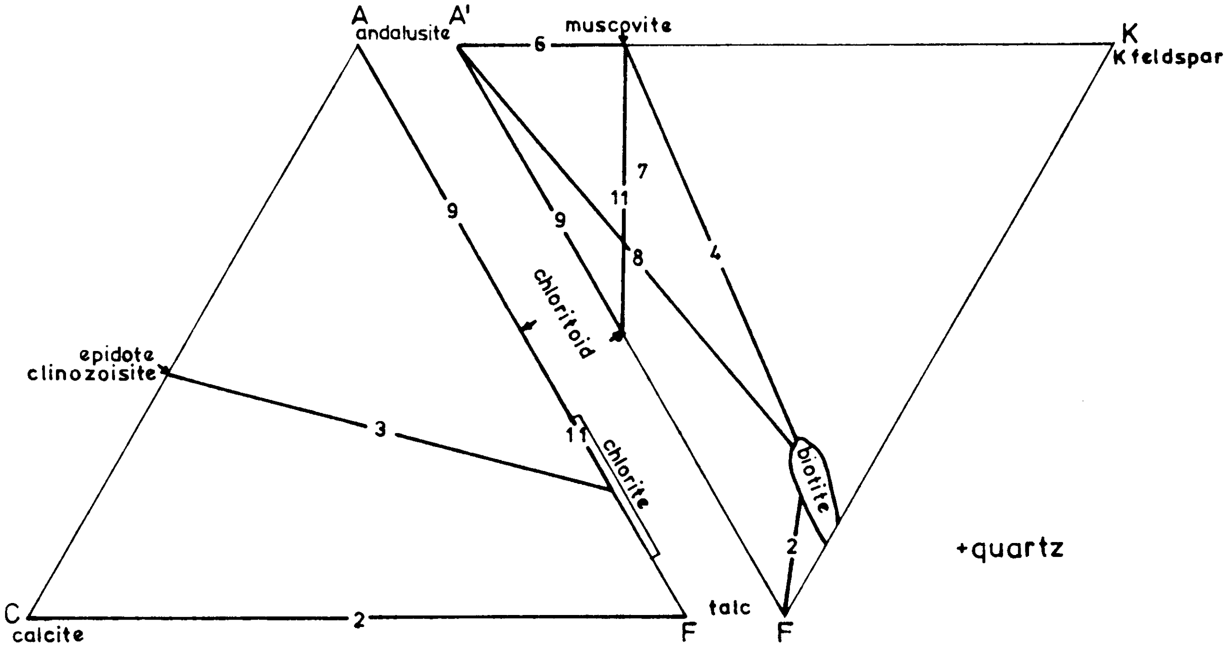
Table 2 : Metamorphic assemblages of the study terrain

assemblage number	quartz Q	anthophyllite A	cummingtonite C	hornblende H	andalusite N	garnet G	cordierite O	muscovite M	biotite B	chlorite L	chloritoid R	K-feldspar K	plagioclase P	clinozoisite Z epidote E	AK sample number	map symbol of beds	albite-epidote-hf (facies)	hornblende-hf (facies)
a. Pelitic and psammitic assemblages:																		
Amphibole hornfels																		
23	Q	A				G			B				P?		72	OQ		x
24	Q	A							B						127	AS		x
25	Q	A		H				M^x							153	AQ		x
26	Q		C				O		B						114	AS		x
27	Q		C										P	Z^x	192	AQ		x
27	Q		C							L^x			P	Z^x	208	YQ		x
28	Q			H						L^x			P	Z^x	147	IS,AS		x
28	Q			H					B^x				P	Z^x	77	OQ,IS		x
Cordierite hornfels																		
18	Q				N		O	M^x	B			K	P		102,169	IS		x
19	Q				N		O	M	B						148	IS		x
20	Q						O	M	B						84,173	SL,IS		x
21	Q						O	M	B			K	P		120	AS,IS		x
22	Q						O		B				P		177	AS		x
Garnet hornfels																		
14	Q					G		M		L^x					75	OQ		x
15	Q					G			B	L^x					242	TS,TL		x
16	Q					G		M	B	L^x				Z^x	243	TS		x
17	Q				N	G		M		L^x					94,225	SH,SQ		x

<u>Andalusite hornfels</u>																		
6	Q				N			M		L^{x}					98,226	SQ,TS		x
6	Q				N			M							95,227,362	HH,SQ	x	x
7	Q				N			M	B						85,92	SS,IS,OQ,TS	x	x
8	Q				N				B	L^{x}					101	SS		x
8	Q				N				B						100	SS	x	x
<u>Chloritoid hornfels</u>																		
9	Q				N			M^{x}		L^{x}	R				359	SQ	x	
10	Q				N			M^{x}	B	L^{x}	R				29,38,45	TL,TS,TA		x
10	Q				N			M^{x}	B		R				50	OQ		x
11	Q							M		L	R				248,369	TQ,SS,SQ	x	
<u>Micaceous hornfels</u>																		
3	Q									L				E	315	RI	x	
3	Q									L				Z	303	RC	x	
4	Q							M	B	L					339	OC,TQ	x	
5	Q							M		L					519,287,376	RS,TQ,TS,OC	x	x
30	Q							M	B						36	TS,SQ		x
b. <u>Basic assemblages:</u>																		
<u>Meta-intrusives</u>																		
28	Q			H									P		109			x
<u>Metavolcanics</u>																		
28	Q			H					B^{x}				P		60	HA		x
28	Q			H				M^{x}	B^{x}				P		48	HA		x
28	Q			H					B^{x}	L^{x}			P		57	HA		x

c. Calcareous assemblages:

assemblage number	quartz Q	calcite I	talc T	tremolite D	phlogopite F	chlorite L	spinel S	AK sample number	map symbol of bed	albite-epidote-hornfels facies	hornblende-hornfels facies
2	Q	I	T		F			402	RS,MD	x	
12		I	T	D	F			524	MD		x
-	Q	I	T			L		512	RQ	x	
-	Q	I					S	133	AL		x



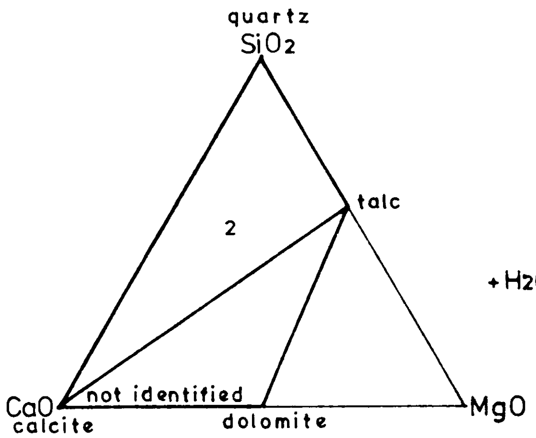


FIGURE 16: Diagrams representing metamorphic assemblages of the albite-epidote-hornfels facies from the study area.

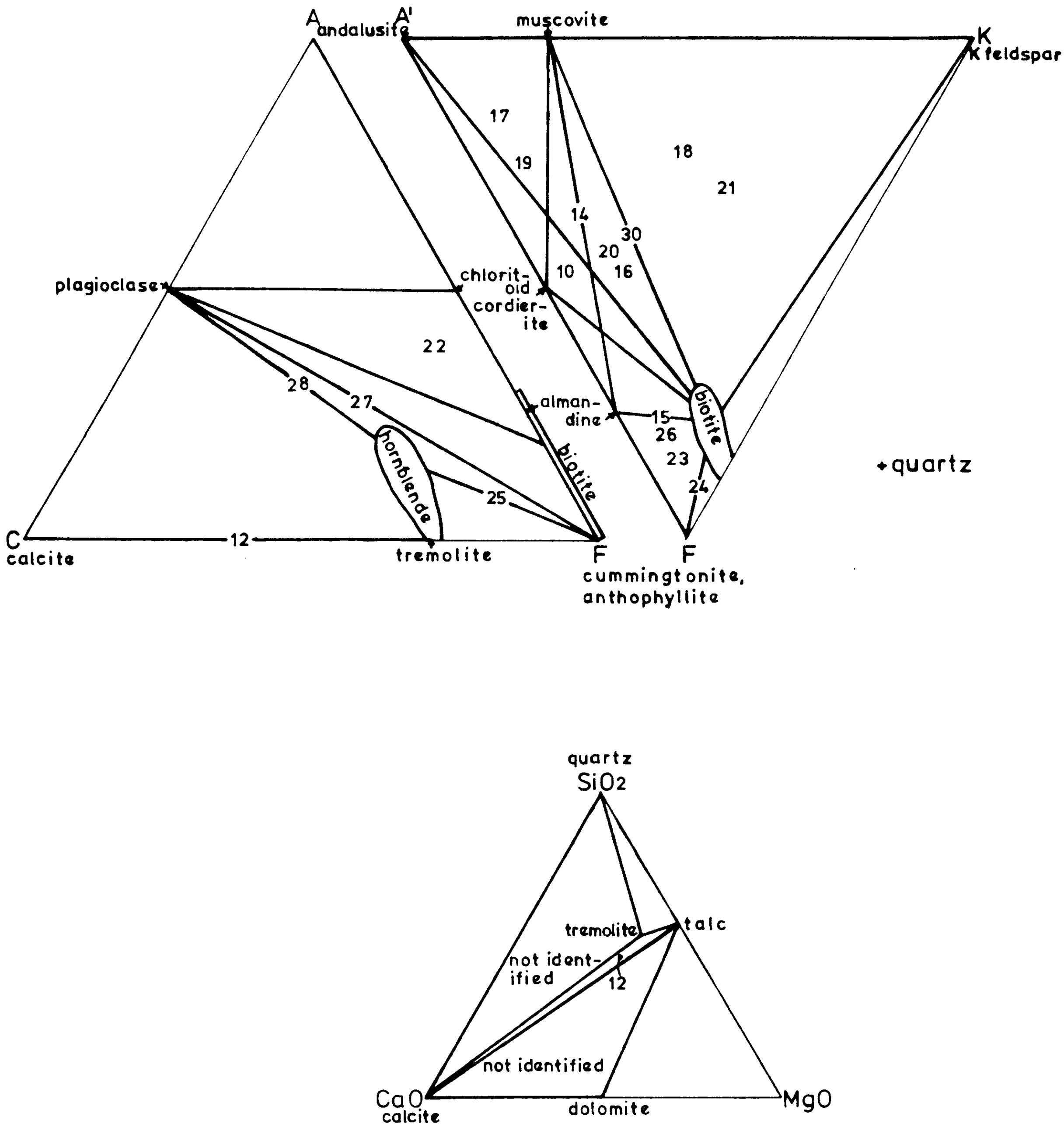


FIGURE 17: Diagrams representing metamorphic assemblages of the hornblende-hornfels facies from the study area.

Table 3 : Metamorphic associations

Association	Number
Albite-epidote-hornfels facies	
quartz-calcite-talc-phlogopite	2
quartz-chlorite-epidote/clinozoisite	3
Intermediate associations	
quartz-muscovite-biotite-chlorite	4
quartz-muscovite-chlorite	5
quartz-muscovite-biotite	30
quartz-muscovite-andalusite	6
quartz-muscovite-andalusite-biotite	7
quartz-biotite-andalusite	8
quartz-andalusite-chloritoid	9
quartz-andalusite-chloritoid-biotite	10
quartz-chloritoid-muscovite?-chlorite?	11
Hornblende-hornfels facies	
calcite-tremolite-talc-phlogopite	12
quartz-almandine-muscovite	14
quartz-almandine-biotite	15
quartz-almandine-biotite-muscovite	16
quartz-almandine-andalusite-muscovite	17
quartz-cordierite-andalusite-biotite-K-feldspar-albite	18
quartz-cordierite-andalusite-biotite-muscovite	19
quartz-cordierite-biotite-muscovite	20
quartz-cordierite-biotite-muscovite-K-feldspar-albite	21
quartz-cordierite-biotite-plagioclase	22
quartz-anthophyllite-biotite-almandine	23
quartz-anthophyllite-biotite	24
quartz-anthophyllite-hornblende	25
quartz-cummingtonite-cordierite-biotite	26
quartz-cummingtonite-plagioclase	27
quartz-hornblende-plagioclase	28

retrograde metamorphic alteration of amphibole or perhaps plagioclase and was not plotted on the ACF diagrams of the hornblende-hornfels facies (Fig. 17). For similar reasons, chlorite is also considered to be a secondary mineral. In many instances it was difficult to decide whether muscovite was secondary or primary.

B. METAMORPHIC FACIES

When the crystalline hornfelses of the Silverton Shale Formation on Bergfontein 60JP are compared with the slightly metamorphosed "slate" of the Rooihoogte Formation at Gopane mine, it becomes evident that there is a considerable decrease in the metamorphic grade from the northeast to the west of the study area. Metamorphic assemblages typical of the albite-epidote-hornfels facies are developed in the west, but these make way for assemblages typical of the hornblende-hornfels facies in the east along a line which passes approximately from Dinokana in the south to Motswedi in the north (Fig. 15).

Index minerals used to mark the appearance of the hornblende-hornfels facies are tremolite in the dolomite assemblages and almandine, cordierite or amphibole in the pelitic and psammitic assemblages. Hornblende is found throughout the outcrop of the lava of the Hekpoort Andesite Formation.

C. METAMORPHIC ASSEMBLAGES

1. Albite-epidote-hornfels facies

a. Talc-calcite-phlogopite(-dolomite,-quartz)(2)

Two zones of progressive metamorphism, viz. an inner tremolite zone and an outer talc zone, have been distinguished in the Malmani Subgroup, south of Dinokana, by Martini (1976, p.628). In the talc zone, the dolomite has been metamorphosed to talc and calcite in the presence of quartz and water with the result that remnants of dolomite are only found in quartz-free zones. The calcareous bed (AK402) apparently intercalated with the slate (RS) of the Rooihoogte Formation (Section II.B.1.a.), is also part of the talc zone. Talc occurs as platy aggregates, up to 3 mm long, whereas calcite forms a fine, anhedral groundmass which contains tabular, pale brown to colourless pleochroic phlogopite crystals.

b. Quartz-chlorite(-epidote,-clinozoisite)(3)

Quartz-chlorite-epidote or clinozoisite are parageneses in pelites and psammites of the Rooihoogte Formation in the Skilpadhek-Livingstone's Poort area. Rare, yellowish green epidote forms idioblastic crystals in the chloritic groundmass of slates (RI, AK315), whereas xenoblastic clinozoisite and chlorite occur in the quartzites (RC, AK303).

2. Intermediate assemblages

a. Quartz-muscovite(-biotite,-chlorite)(4,5,30)

Micaceous metamorphic assemblages were distinguished in all the sedimentary formations of the Pretoria Group below the Magaliesberg Quartzite Formation (Table 2). X-ray diffraction runs and staining with sodium cobaltinitrite (Hutchison, 1974, p.23) confirmed that the ubiquitous muscovite is not pyrophyllite or paragonite. Tiny grains of plagioclase (0,05 mm), together with muscovite, quartz and chlorite (AK386), in the slate of the Silverton Shale Formation near Botswana are probably of dètrital origin.

b. Quartz-andalusite(-muscovite,-biotite)(6,7,8)

Micaceous, andalusite hornfelses and slates occur throughout the Pretoria Group below the Magaliesberg Quartzite Formation.

The andalusite-muscovite hornfels (6, HH) in the upper Hekpoort Andesite Formation has coarse columnar aggregates (AK95) or idioblastic crystals (up to 2 cm in length) of andalusite in the east. Andalusite crystals not only decrease in size and amount towards the west, but are also largely replaced by multicrystal-pseudomorphs of sericite (AK362). Retrogressive metamorphism has also resulted in the partial replacement of andalusite idioblasts by muscovite and quartz (Fig. 18) in the lower slate bed (TS) of the Timeball Hill Formation. Laminae of andalusite-muscovite hornfels in the quartzite (SQ) of the Strubenkop Shale Formation are characterized by xenoblastic aggregates of andalusite choked by tiny magnetite and quartz inclusions (AK227).

Quartz-andalusite-biotite-muscovite (7) is a common association in the study area, especially in the biotite-andalusite hornfels (SS) of the Strubenkop Shale Formation. The andalusite is generally poikiloblastic with many quartz inclusions (AK85, SS) but idioblastic crystals, 0,5-3 cm in length, can occur in the east in rocks of the Timeball Hill (TS), the Boshoek (OQ) and the Silverton Shale (IS) Formations.

In the assemblage, biotite is generally strongly pleochroic dark olive green or reddish brown to pale brown as well as poikiloblastic, whereas muscovite is usually the minor phase.

The biotite-andalusite hornfels (SS) of the Strubenkop Shale Formation also displays the assemblage quartz-andalusite-biotite (8). Quartz is present mainly as poikiloblasts in the andalusite and biotite crystals. The biotite is strongly pleochroic in shades of olive green (AK100) and can be replaced by chlorite (AK101).

c. Quartz-andalusite-chloritoid(-biotite)(9,10)

The original mud pellets in the quartzite (SQ) of the Strubenkop Shale Formation have been metamorphosed to the association quartz-andalusite-chloritoid in the Gopane area (AK359). Microlayering, parallel to the bedding plane, is present in the andalusite-rich groundmass of the pellets as a result of alternating magnetite-rich and magnetite-poor zones. Some pellets have clear rims of andalusite, free of magnetite inclusions. Larger, secondary, subidioblastic magnetite crystals are in many places associated with pleochroic blue to colourless, tabular chloritoid in nodular structures, especially in the quartzite that surrounds the pellets. Chlorite largely replaces the chloritoid.

The metamorphic assemblage quartz-andalusite-chloritoid-biotite (10) of the hornblende-hornfels facies is associated with sericite and some chlorite, both probably secondary, in the Timeball Hill Formation and Boshoek Formation (OQ).

The andalusite varies from poikiloblastic crystals (AK29, TL) to idioblastic chiastolite crystals about 1 cm in length (AK45, TA). Subidioblastic, tabular chloritoid crystals can contain quartz inclusions in the shape of an hour-glass. The colour of the chloritoid is pleochroic light blue to colourless in the lower beds (TL, TS) and pleochroic pale green to colourless higher up in the sequence (TA, OQ). Decussate chloritoid crystals, about 0,1 mm in length, form the major part of some laminae in the interbedded hornfelses of the quartzites of the Timeball Hill Formation on Buffelfontein 94JP, although parts of the microlayers can be replaced by aggregate pseudomorphs of andalusite (Fig. 19, AK29, Spry, 1969, Plate XII, p.152). Biotite crystals are generally pleochroic dark olive green to light brown and poikiloblastic.

d. Quartz-chloritoid-muscovite?-chlorite? (11)

The tenuous assemblage quartz-chloritoid-muscovite?-chlorite? (11) occurs in the quartzite (AK248) of the Timeball Hill Formation and in the slate bed (SS, AK369) of the Strubenkop Shale Formation. However, muscovite (usually in the form of sericite) and chlorite appear to be secondary.

3. Hornblende-hornfels facies

a. Calcite(-tremolite,-talc,-dolomite,-quartz,-phlogopite, -scapolite) (12)

Tremolite-bearing assemblages in the calcareous rocks of the Malmani Subgroup, southeast of Dinokana, indicate that the

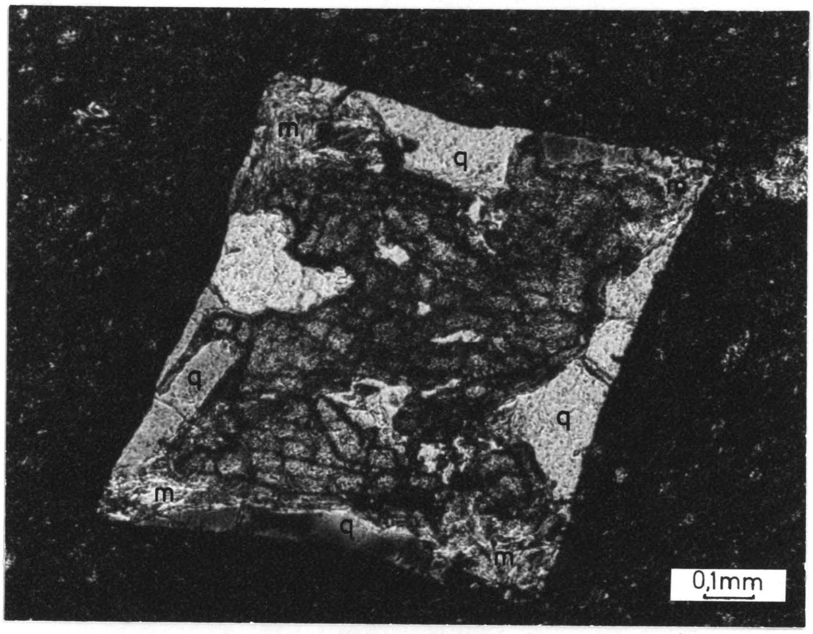


Figure 18 : Muscovite (m) and quartz (q) which partly replace an andalusite idioblast set in a groundmass of sericite. A rim of iron oxides is developed between the andalusite and the secondary minerals (AK20, TS, Timeball Hill Formation, Buffelfontein 94JP, polarized light).

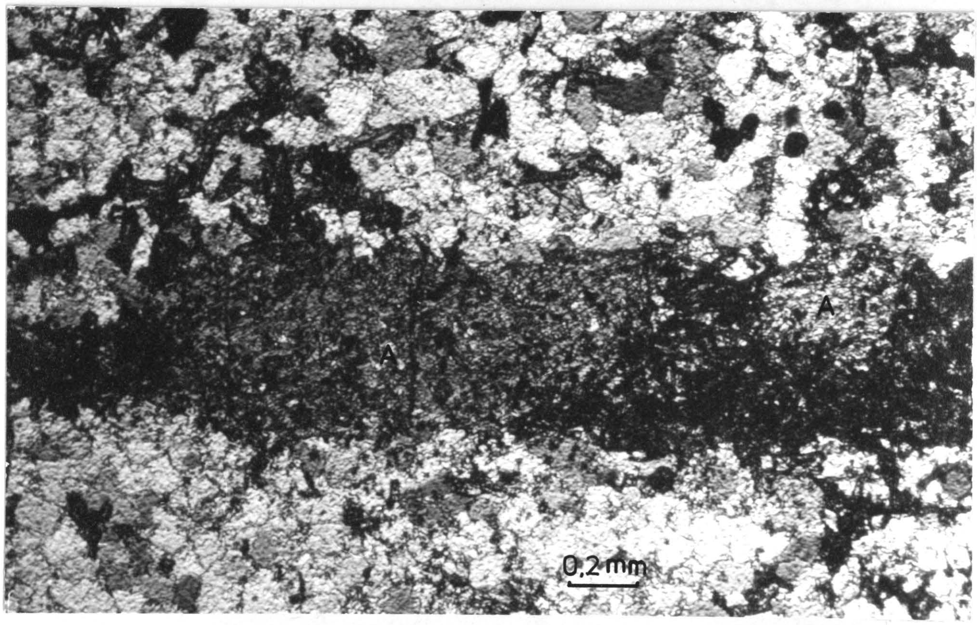


Figure 19 : Aggregate pseudomorphs of andalusite (A) after chloritoid (dark) in a hornfels lamina in quartzite (AK29, TL, Timeball Hill Formation, Buffelfontein 94JP, polarized light).

metamorphic grade was of the hornblende-hornfels facies. In this tremolite zone (Martini, 1976, p.628), the assemblage calcite-talc-tremolite-phlogopite (AK524) was identified, although in areas richer in quartz, the paragenesis calcite-tremolite-quartz, and in areas poorer in quartz, the association calcite-talc-dolomite, are to be expected (Winkler, 1976, p.114).

Columnar, in many places radial, aggregates of tremolite and talc increase in amount towards the contact with the Penge Formation. Here the tremolite can be the major constituent of the rock. Phlogopite and scapolite are relatively rare.

b. Quartz-almandine(-biotite,-muscovite)(14,15,16)

The association quartz-almandine-muscovite (14) occurs in the quartzite of the Boshoek Formation (OQ, AK75), with the garnet commonly replaced by chlorite. The assemblages quartz-almandine-biotite (15, AK242, TS) and quartz-almandine-biotite-muscovite (16, AK243, TS) were distinguished in the hornfelses of the Timeball Hill Formation.

Pink almandine crystals, 1 mm in diameter, are xenoblastic or hypidioblastic and are commonly so inclusion-choked that the garnet crystal forms only a thin matrix around quartz grains. Biotite and muscovite, when present, are small (0,1 mm) flakes and can be replaced by chlorite.

An attempt was made to determine the composition of the garnets by measurement of the refractive index, cell constant and density (Winchell, 1958, pp.595-600). However, the density could not be determined with enough accuracy because of numerous tiny inclusions in the garnet. The refractive index was measured with the use of an 8:1:1 mixture of methylene iodide, phosphorus and recrystallized sulphur. Results for three garnets indicate a refractive index of between 1,812 and 1,818 and a cell constant of between 1,156 and 1,159 nm, which, with the use of Winchell's charts, show that the garnets are almandine-rich. The ratio of FeO/MgO is about 9, which is in keeping with Turner's statement (1968, p.223) that almandine can be the aluminous phase in rocks with a high FeO/MgO.

c. Quartz-almandine-andalusite-muscovite (17)

In the garnet-andalusite hornfels beds (SQ and SH) of the Strubenkop Shale Formation, are also rocks that contain the paragenesis quartz-almandine-andalusite-muscovite (17) with secondary chlorite. Xenoblastic garnet crystals are either scattered evenly throughout the rock (AK225, SQ) or form 0,5-1,0 cm thick laminae of nearly pure garnet aggregates (AK94, SH). The pink garnet crystals are about 1 mm in diameter and have quartz, andalusite and opaque minerals as inclusions. The refractive index is 1,818, the cell constant between 1,154 and 1,157 nm and the ratio of FeO/MgO is about 7, which indicate that the main component is almandine.

Associated with the garnet is tabular muscovite and chlorite, the latter replacing the garnet. Poikiloblastic andalusite crystals contain quartz inclusions or occur as idioblastic crystals, 0,2 mm in length, in the garnet-rich laminae.

A pleochroic azure blue to colourless, biaxial negative mineral which is interstitial to quartz grains, is presumed to be lazulite. It has third order blue interference colours under crossed nicols (AK225). The mineral occurs in some of the quartzite and hornfels beds of the Strubenkop Shale Formation and is associated with andalusite, garnet, muscovite and chlorite, the latter mineral replacing the lazulite.

d. Quartz-cordierite-biotite(-andalusite,-muscovite,-K-feldspar,-plagioclase)(18, 19, 20, 21, 22)

Metamorphic assemblages which include cordierite and biotite occur mainly in the hornfelses of the Silverton Shale and Magaliesberg Quartzite Formations. The hornfelses are dark, crystalline rocks, commonly micaceous, which weather differentially to expose andalusite crystals, if present, as well as relict sedimentary structures such as cross-bedding and laminar bedding.

Xenoblastic cordierite crystals vary greatly in amount but have a ubiquitous sieve texture, due mainly to quartz inclusions. Biotite flakes are generally displaced to and concentrated on the rims of cordierite crystals. These biotite crystals are usually small (0,1 mm), somewhat poikiloblastic and idioblastic with strong reddish brown to pale brown pleochroism.

The quartz-cordierite-biotite-andalusite-K-feldspar-albite (18, AK102, IS) and quartz-cordierite-biotite-andalusite-muscovite (19, AK148, IS) assemblages are developed in the bed above the graphitic slate of the Silverton Shale Formation.

Andalusite porphyroblasts vary from poikiloblastic, idioblastic crystals (AK102) to corroded chiastolite crystals about 0,5 cm in length (AK169, AK148). Inclusions in the chiastolite consist of a mass of tiny quartz, biotite and opaque mineral crystals. Potassium feldspar xenoblasts are poikiloblastic and perthitic, with a small amount of intergrown albite (AK102).

Higher up in the hornfels beds of the Silverton Shale Formation and in the intercalated hornfels beds (AS) of the Magaliesberg Quartzite Formation, no andalusite was formed. Parageneses distinguished are quartz-cordierite-biotite together with muscovite (20, AK173, IS), muscovite-K-feldspar-albite (21, AK120, AS) and plagioclase (22, AK177, AS). The rare plagioclase assemblage (22) is characterized by tiny xenoblasts of plagioclase (0,05 mm) that exhibit polysynthetic twinning according to the albite law. Hornfelses of the Silverton Shale Formation often contain idioblastic magnetite crystals (0,5 mm) with a thin rim of muscovite surrounded by a biotite-free corona (AK120).

The assemblage quartz-cordierite-biotite-muscovite (20) is rarely developed in the upper slate bed of the Silverton Shale Formation (SL, AK84). Hornfelses of the Silverton Shale Formation with this paragenesis sometimes contain ovoids, about 1 cm in diameter, which consist of anhedral quartz crystals and long biotite crystals as well as radiating tourmaline prisms (AK173). These structures resemble pebbles but probably represent areas of optimum recrystallization.

Cordierite, plagioclase and K-feldspar were identified in uncovered thin sections by staining with sodium cobaltinitrite and amaranth (Hutchison, 1974, pp.21-22).

e. Quartz-anthophyllite(-biotite,-garnet,-hornblende) (23, 24, 25)

Anthophyllite, a typical phase in magnesian assemblages of the hornblende-hornfels facies (Turner, 1968, p.224), is a relatively scarce amphibole in the study area. The association quartz-anthophyllite-biotite-garnet (23) was identified in a thin hornfels bed above the quartzite bed of the Boshoek Formation (OQ). Anthophyllite is present as long, prismatic crystals or as fibrous aggregates, which can display a bow-tie structure, and has a slight light green to colourless pleochroism. Garnet crystals, generally idioblastic, are smaller (0,3 mm) and not as poikiloblastic as those of other assemblages. Some tiny, polysynthetically twinned xenoblasts of plagioclase were distinguished in the hornfels but appear to be only in contact with quartz (AK72).

Fibrous anthophyllite is in association with quartz and biotite flakes (24, AK127, AS) in the lowest of the intercalated hornfels beds of the Magaliesberg Quartzite Formation. A quartzite underneath this bed contains the paragenesis quartz-anthophyllite-hornblende (25, AK153, AQ). Colourless, columnar hornblende crystals ($Z\hat{}c = 23^{\circ}$, measured on crystals with high interference colours) and anthophyllite can be replaced by muscovite pseudomorphs.

f. Quartz-cummingtonite(-cordierite,-biotite,-plagioclase) (26, 27)

Quartz-cummingtonite-cordierite-biotite (26) is the assemblage developed in the lower hornfels bed (AS) of the Magaliesberg Quartzite Formation. Colourless cummingtonite is present as long, thin, prismatic crystals, characteristically twinned, in a groundmass of small amphibole needles. Cordierite xenoblasts have brown to light brown pleochroic biotite inclusions (AK114).

Quartzites of the Magaliesberg Quartzite Formation (AK192) and xenoliths of the Rayton Formation (AK208) in the marginal norites of the Bushveld Complex, contain the assemblage quartz-cummingtonite-plagioclase (27). Cummingtonite crystals form fibrous or bladed aggregates as well as veins and can be replaced by chlorite. Plagioclase xenoblasts are very small (0,05 mm) and twinned according to the albite law. Secondary clinozoisite is commonly associated with small, subhedral magnetite crystals (0,1 mm).

g. Quartz-hornblende-plagioclase (28)

The typical assemblage of basic hornfelses is quartz-hornblende-plagioclase (28, Turner, 1968, p.193), which was distinguished in hornfelses of the Boshoek (OQ), Hekpoort Andesite (HA), Silverton Shale (IS) and Magaliesberg Quartzite (AS) Formations as well as in some diabase sills (AK109).

Hornblende columnar and fibrous aggregates, which can have a bow-tie structure, exhibit a slight or marked pleochroism in various shades of green. The hornblende is rarely twinned and can be replaced by biotite, chlorite or clinozoisite.

Amphibole porphyroblasts in diabase can exhibit a pleochroic green to colourless hornblende core surrounded by a colourless amphibole rim, because of epitaxial growth-zoning (AK200). This indicates a change in physical or chemical conditions during metamorphism so that equilibrium could not be established (Spry, 1969, p.164).

Plagioclase crystals are very small in the metamorphosed sedimentary and volcanic rocks of the study area. In the metamorphosed sedimentary rocks, the plagioclase crystals appear to be replaced by clinozoisite in places. In the metavolcanics, quartz, biotite and hornblende pseudomorphs after an unknown mineral are occasionally encountered (AK60, HA).

D. METAMORPHIC REACTIONS AND P-T CONDITIONS

In the silicious, dolomitic limestones of the Malmani Subgroup, dolomite, quartz and water have reacted as a result of low-grade metamorphism.

$$3 \text{ dolomite} + 4 \text{ quartz} + 1\ H_2O \rightleftharpoons 1 \text{ talc} + 3 \text{ calcite} + 3\ CO_2 \quad (1)$$

Martini (1976, p.269) estimates the temperature of development of the talc zone, i.e. the albite-epidote-hornfels facies, at between 400 and 450°C and the total fluid pressure in the order of 2 to 4 kb, if the molar percentage of carbon dioxide was not less than 10 per cent.

The tremolite-bearing assemblages of the hornblende-hornfels facies were produced from the talc-bearing associations at a higher temperature and possibly slightly lower pressure.

5 talc + 6 calcite + 4 quartz ⇌ 3 tremolite + 6 CO_2 + 2 H_2O (*2*)

Reaction (*2*) proceeds within a very large range of partial pressure of carbon dioxide at temperatures of between 500 and 590^{o}C and total fluid pressures of 2 to 4 kb (Winkler, 1976, pp.112-121). Equilibrium conditions for reactions (*1*) and (*2*) at variable temperatures and partial pressures of carbon dioxide for certain constant fluid pressures have been established (ibid.). Where the two isobaric univariant curves intersect, an isobaric invariant point is generated. The curve that this invariant point produces in the temperature-pressure plane, is plotted on Figure 20 as curve (*3*) (ibid., p.117), and indicates the first possible appearance of tremolite.

1 tremolite + 3 calcite + 2 quartz ⇌ 5 diopside + 3 CO_2 + 1 H_2O (*4*)

No diopside was formed in the Malmani Subgroup which shows that the temperature needed for reaction (*4*) was not realised, i.e. between 525 and 575^{o}C at a pressure of 2 kb and between 600 and 630^{o}C at a pressure of 4 kb. Equilibrium conditions for the bivariant reaction (*4*) are plotted on Figure 20 (ibid., p.122).

In the pelitic beds with the assemblage quartz-muscovite-

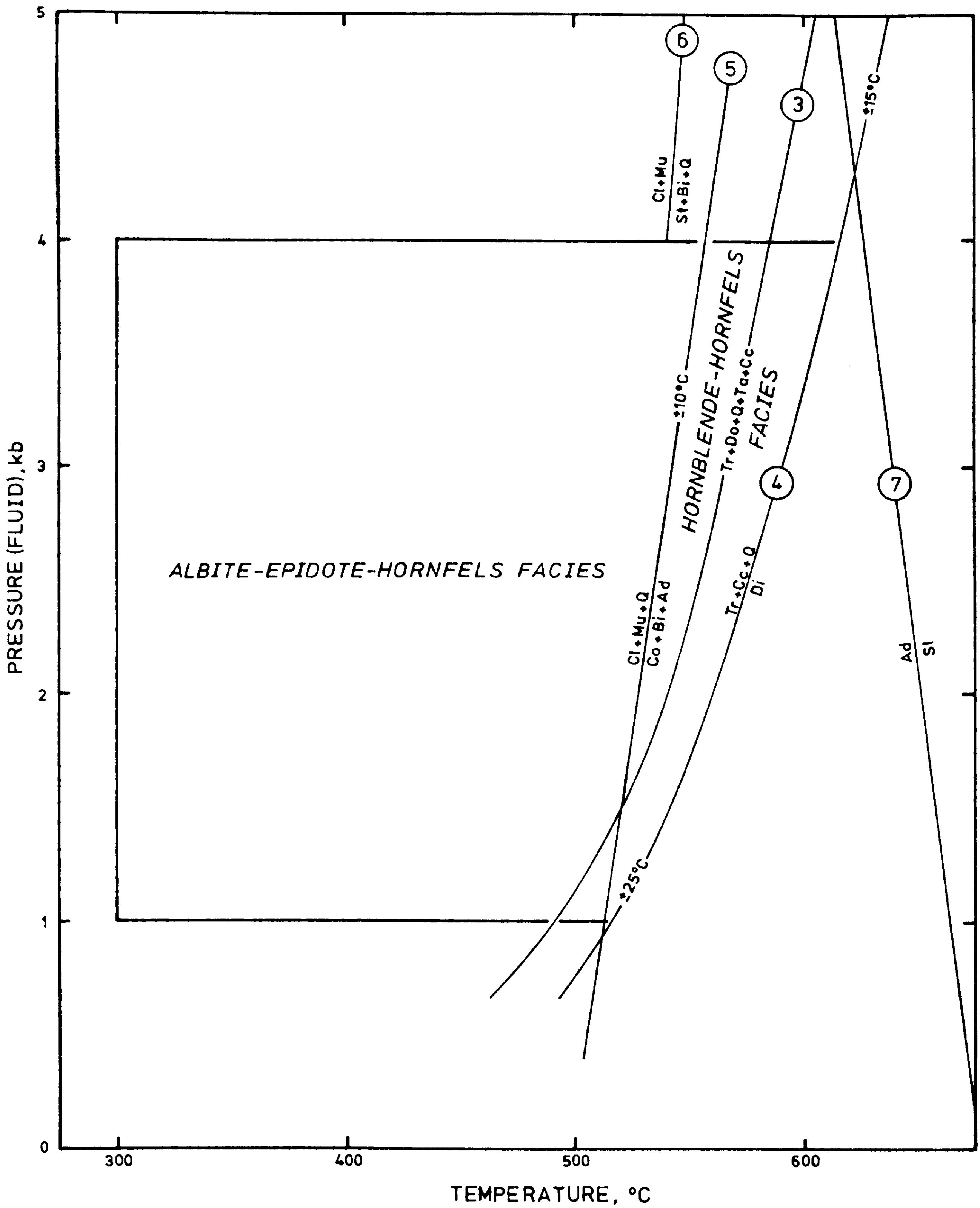


FIGURE 20: Reaction curves relevant to the study area.

Curves (3) and (4) after Winkler (1976, p.122), (5) after Hirschberg and Winkler (1968, p.17), (6) after Hoschek (1969, p.227) and (7) after Althaus (1967, p.35).

Q = quartz, Cl = chlorite, Ad = andalusite, Mu = muscovite, Bi = biotite, Co = cordierite, St = staurolite, Tr = tremolite, Do = dolomite, Cc = calcite, Di = diopside, Ta = talc, and Sl = sillimanite.

chlorite (5) of the albite-epidote-hornfels facies, Turner (1968, p.117) estimates a lower limit of stability of $300^{o}C$ and P_{H_2O} = 3 kb (possibly somewhat lower). However, no accurate temperature and pressure measurements exist for the formation of this assemblage from sedimentary clay, quartz and feldspar detritus.

The appearance of biotite in quartz-muscovite-biotite-chlorite (4) may be the result of reaction between muscovite and chlorite to produce biotite as well as muscovite and chlorite, the latter two being richer in aluminium than the reagents (Turner, 1968, p.117).

Pelitic assemblages which contain chloritoid and were subjected to low-grade metamorphism, indicate special chemical compositions such as a high Fe/Mg ratio and a relatively high aluminium content, together with a low potassium, sodium and calcium content (Winkler, 1976, p.210). This should preclude the formation of biotite from chloritoid-bearing assemblages, but biotite pseudomorphs after chloritoid are present in the interbedded slates (TL, AK29) of the Timeball Hill Formation. Winkler (1976, p.212) notes that the assemblage chloritoid-chlorite-muscovite-quartz (11) is typical of low-grade metamorphism but is not diagnostic of a specific zone.

Almandine is commonly associated with biotite in the study area. The possible geneses of some of the almandine-bearing associations are as follows:

chlorite + $biotite_a$ + quartz ⇌ garnet + $biotite_b$ + H_2O
(Chakraborty and Sen, 1967, p.210)

chlorite + epidote + muscovite ⇌ garnet + biotite + H_2O
(Brown, 1969, p.1671)

chlorite + muscovite + quartz ⇌ almandine + biotite + H_2O
(Thompson and Norton, 1968, as referred to by Winkler, 1976, p.215)

Cordierite-bearing assemblages are found only in the relatively high temperature, low pressure region of the area mapped, i.e. in the inner hornfels zone (Hall, 1909, p.121 and 1914, p.xxx). The cordierite is formed in reactions that involve the elimination of chlorites and micas.

chlorite + muscovite + quartz ⇌ cordierite + biotite + H_2O

biotite + muscovite + quartz ⇌ cordierite + K-feldspar + H_2O
(Turner, 1968, p.128)

chlorite + muscovite + quartz ⇌ cordierite + biotite + andalusite + H_2O (5)

Hirschberg and Winkler (1968, p.17) state that reaction (5) "characterizes the facies boundary between the albite-epidote-hornfels facies and the hornblende-hornfels facies" for conditions of low pressure and a starting material of iron-rich and magnesium-rich chlorite. The equilibrium conditions for the bivariant reaction (5) are plotted on Figure 20.

The preceeding data indicate that the pressure-temperature conditions that caused the albite-epidote-hornfels facies to develop ranged from 300 to 500°C and from 1 to 4 kb. Conditions needed for the formation of the hornblende-hornfels facies were 500 to 600°C and 1 to 4 kb (Fig. 20).

IV. STRUCTURE

A. INTRODUCTION

In the study area, the Transvaal Supergroup has an arcuate northwest strike that becomes eastwest near the border with Botswana. The Supergroup is characterized by a decrease in outcrop width from east to west by most of the formations. Despite this, the Pretoria Group actually increases in thickness by about 15 per cent because the dip of the strata doubles from east to west. In the eastern sector, the lower formations dip about 7° towards the centre of the basin, and the dip increases gradually along strike to 15° near the international border. The upper formations generally dip a few degrees more steeply than their lower counterparts, probably because the tempo of subsidence of the basin was greater towards the centre (Crockett, 1972, p.284).

A fault zone is apparently responsible for the decrease in thickness of the Malmani Subgroup from 1 700 m southwest of Dinokana to 120 m at Skilpadhek over a strike length of 18 km (section IV.B.).

A comparison with the stratigraphic thicknesses reported by other workers in adjoining areas as well as in other parts of the Transvaal basin is shown in Table 4, from which thinning of the Transvaal Supergroup towards the east in the southwestern part of the basin is evident (section V.A.).

Table 4 : Thickness of the Transvaal Supergroup in various areas of the Transvaal basin

Group	Formations as in Western Transvaal	Lobatsi[1] (m)	25°45'E[2] (m)	26°00'E[3] (m)	Enzelsberg[4] (m)	Central[5] Transvaal (m)	Eastern[6] Transvaal (m)
PRETORIA	Rayton	915				1050?	3610
	Magaliesberg Quartzite) Silverton Shale)	990	870	790	1550	900	2200
	Daspoort Quartzite) Strubenkop Shale) Hekpoort Andesite) Boshoek) Timeball Hill (TA))	1340	1055	1035	860	900	670
	Timeball Hill (TS,TQ)) Rooihoogte)	1070	900	550	n.d.	310	660
	Total	4315	2825	2375	n.d.	3160?	7140
CHUNIESPOORT		+2000	220?	1750	n.d.	1040[7]	1700
	Black Reef Quartzite	15	25	25	n.d.	20[7]	500
WOLKBERG							2000
TOTAL		+6330	3070?	4150	n.d.	4220?	11340

Notes: n.d. not determined

1. After Crockett (1969, pp.59, 62 and 64(a))
2. This investigation
3. This investigation
4. After Engelbrecht (1973, p.5)
5. After Visser (1969, pp.i-ii)
6. After Button (1973)
7. After Knyaston (1929, p.14)

B. GRAVITY SLIDES AND ASSOCIATED FAULTS

In southeastern Botswana, the Transvaal Supergroup has been greatly deformed by a series of gravity slides and associated faults (Crockett, 1971, pp.215-220). The international boundary virtually forms the border between this region of great structural complexity and the mapped area's simple structural controls.

Fieldwork on the South African side of the border indicated that the traces of some of the faults in Botswana extend into South Africa. The Woodlands reverse fault A (Crockett, 1971, p.219) has an arcuate southern extension that displaces the Timeball Hill Formation by a vertical distance of 70 m at Pytlaganyane (Fig. 21). To the north, the Boshoek Formation is displaced some 900 m along the trace slip of a fault which is the extension of a fault in the Strubenkop Shale Formation in Botswana (Folder).

Humphrey (1911, pp.12-13) considers the disappearance of the banded ironstone of the Penge Formation (PF, section V.A.) and the rapid reduction in thickness of the Malmani Subgroup towards the northwest to be due to a high-angle strike fault that increases its net slip in the direction of the Botswana border. Crockett (1969, pp.159-165) traced the fault, the so-called Schilpadshek slide, into Botswana and described it as a low-angle fault zone along which the first gravity slide in the Lobatsi area took place. Present fieldwork suggests that the fault zone enters South Africa near the contact between the Malmani Subgroup (MD) and the slate of

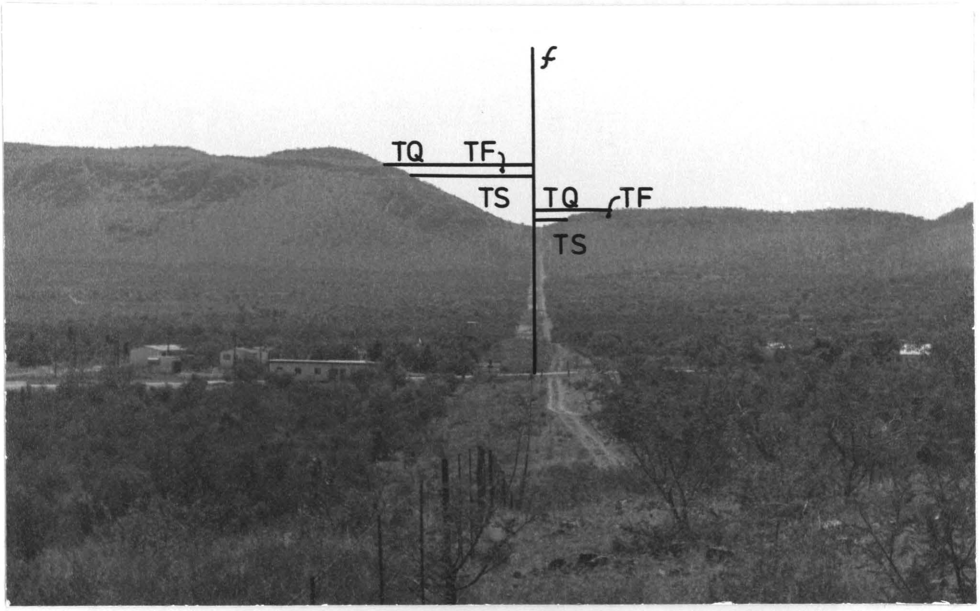


Figure 21: View (looking north) of the Woodlands reverse fault A displacing the TS, TF and TQ beds of the Time-ball Hill Formation by a throw of 70 m at Pytlaganyane. Skilpadhek border posts in the middle distance. Right is South Africa, left is Botswana.

the Penge Formation (PS) and gradually traverses into the lower formations of the Subgroup where it dissipates. Humphrey (1911, p.12) and Kingsley (1961, pp.9-10) report quartz reefs with northnorthwest or northsouth traces which cut across the upper formations of the Malmani Subgroup and represent a zone of faults in the Skilpadhek area.

C. POST-BUSHVELD FAULTS AND LINEAMENTS

Faults and slides discussed in section IV.B. all belong to a structurally unique part of the Transvaal basin, whereas structures described below are more typical of those found in the larger part of the basin. These post-Bushveld structures have developed under tensional conditions as is shown by the presence of horsts, grabens and dykes and have a near vertical dip as the rectilinear strikes indicate.

The trace length and bearing of photo-lineaments and faults, excluding those discussed in section IV.B., were measured and plotted on a rose diagram (Fig. 22). A ten degree interval and radial scale of 1:1 000 000 were used (Hills, 1963, p.149). Fault outcrop length and orientation were plotted on the upper semicircle, whereas the lower semicircle was used for the trace length and orientation of the photo-lineaments. The trace length was plotted in preference to the number of structures because of the small total amount of the latter. The total measured length of trace is 230 km for thirty structures.

A bimodal fault alignment, viz. a dominant northnorthwest direction and a minor eastwest orientation, is evident from

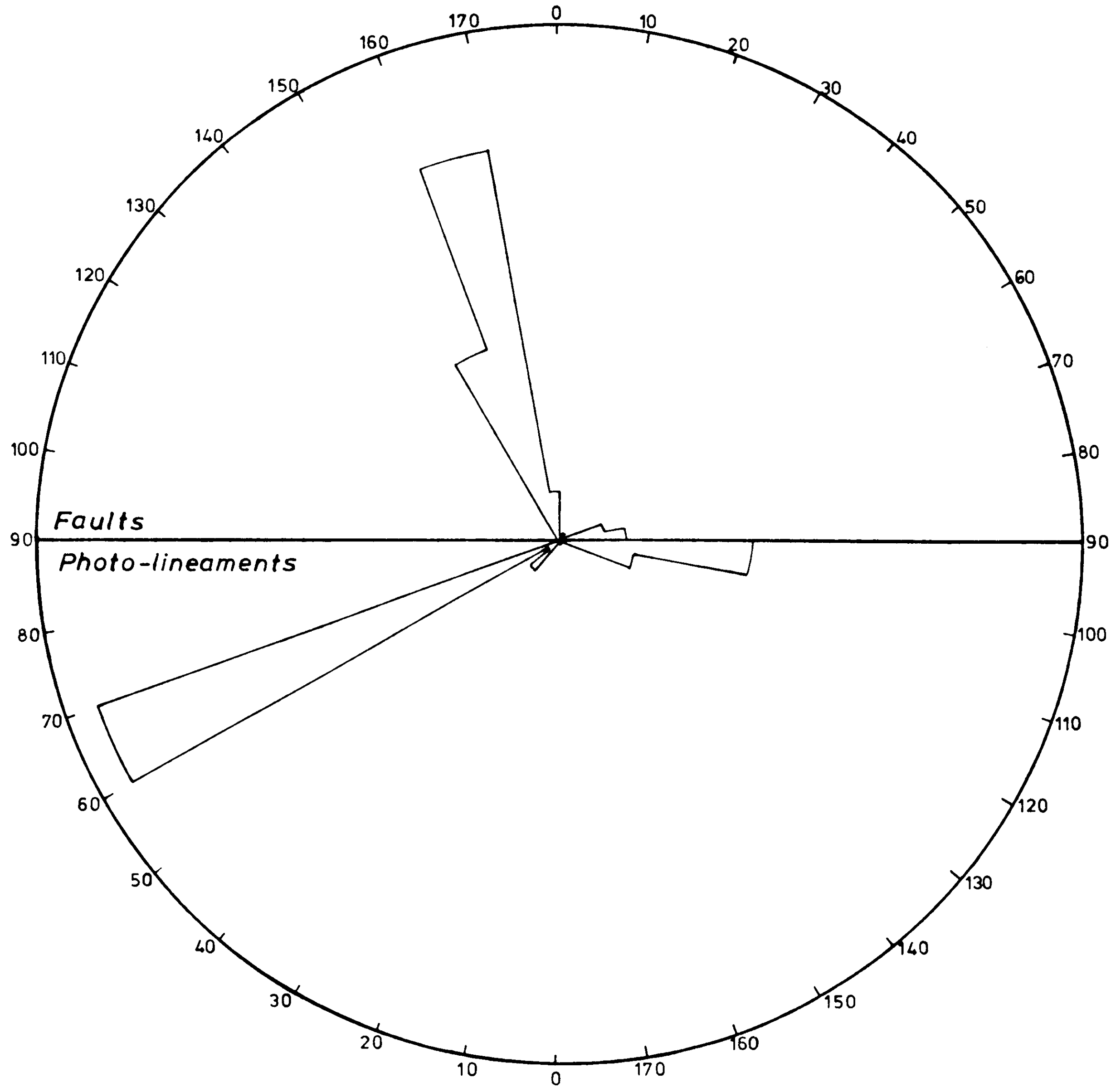


FIGURE 22: Rose diagram of trace length and orientation of faults (upper semicircle) and photo-lineaments (lower semicircle) in the study area.

the rose diagram. The NNW faults are a group of step faults that translate their western blocks horizontally to the south and transverse strata of the Transvaal Supergroup. Largest is the Motswedi fault which can be traced from Motswedi to Welbedacht 39JO and displaces the Strubenkop Shale Formation by 2 km. Two small grabens occur on Palmietfontein 92JP and southeast of Motswedi respectively. A small horst on Rietgat 91JP is due to faults with a similar orientation.

A small eastwest fault, which cuts across the upper formations of the Chuniespoort Group, is of great local economic significance as a strong spring at Dinokana rises from it. Ten kilometers northwest of Dinokana, a set of faults cuts approximately eastwest across the Timeball Hill Formation. The aeromagnetic survey map (Geological Survey of South Africa, 1971) reveals a dyke-type lineament that corresponds with this fault zone.

Photo-lineaments plotted on the lower semicircle of the rose diagram are usually bush traces developed mainly on quartzite dip slopes. These bush traces are small, steep-sided valleys with alluvial floors and are covered by a dense growth of bush and trees. Two photo-lineament orientations exist in the study area, viz. a dominant eastnortheast direction and an eastwest alignment (Fig. 22). An ENE structure, referred to as the Bergvliet lineament (Folder), traverses the study area as a prominent photo-lineament and represents a diabase dyke at least in the Malmani Subgroup (Kingsley, 1961, p.12). From the aeromagnetic contour map, the lineament can be traced for a distance of 115 km from the above-mentioned outcrop to where it is lost in the Pilanesberg dyke-swarm northwest of Pilanesberg.

Richards and Walraven (1975, p.274) interpret the eastwest lineaments detected by the aeromagnetic survey and on ERTS imagery mosaics as a major post-Bushveld dyke system with an en echelon extent of almost 300 km. The aeromagnetic contour map indicates that the EW bush trace west of Motswedi, as well as the set of faults northwest of Dinokana, coincide with the postulated eastwest dyke system lineaments. However, the 10 km long EW bush trace in the quartzite (TQ) of the Timeball Hill Formation on Buffelfontein 94JP, Rykvoorby 96JP and Doornrivier 97JP has no corresponding magnetic anomaly. It must also be noted that the eastwest faults are aligned between N070° and N090° whereas the photo-lineations are orientated between N090° and N110°, which perhaps indicates that only the photo-lineaments are related to the EW dyke system.

The ENE and EW dyke systems are younger than the major NNW faults because these faults have not displaced the dykes to any noticeable degree.

D. STRUCTURAL EVOLUTION

About 3 000 my ago the stable Kaapvaal craton was formed, upon which a succession of depositional basins developed; the Transvaal Supergroup being laid down in the fourth such basin (Hunter, 1975, p.6). The Transvaal basin developed by subsidence along an eastnortheasterly aligned axis and had active northern margins and gradually subsiding southern flanks (Hunter, 1975, p.7).

Structural evolution of the western part of the Transvaal basin has been largely controlled by the Vryburg arch, a prominent rise of granitic domes, which underlies the basin in the area mapped (Hunter, 1975, Fig. 4, p.9).

Some aspects of the depositional history of the Transvaal Supergroup in the study area are presented in section V.B. It appears that the rate of sedimentation about equalled the ever increasing rate of basin subsidence till the end of Pretoria Group time, when accelerated subsidence triggered off gravity slides in the Lobatsi and Segwagwa areas of Botswana and the western strip of the area under investigation (Crockett, 1971, pp.224-226).

Intrusions of diabase sills in the Transvaal Supergroup were the precursors of the emplacement of the layered sequence of the Bushveld Complex. Emplacement probably occurred through a vent, manifested by a pronounced gravity high in the Goudini area. Although the present day cover of mafic rocks of the Bushveld Complex to the north and northeast of the area mapped is extremely thin (Biesheuvel, 1970, p.281), the thickness of mafic rocks in the northeast must have been considerable to produce the extensive metamorphic aureole in the underlying sediments.

Because of the decrease in the metamorphic grade towards Botswana, isograds of the metamorphic aureole cut across the formations of the Pretoria Group in the study area (Fig. 15).

These extend into the Malmani Subgroup to form an inner tremolite zone and an outer talc zone of progressive metamorphism, which extend as a prominent tongue south of Zeerust (Martini, 1976, p.628). A thinner Pretoria Group, laid down on a paleoridge in this area, would have brought the Bushveld Complex closer to the Malmani Subgroup and caused the metamorphic transgression (Martini, 1976, pp.626-629). Although the thickness of the Pretoria Group could have been less vertically above the tongue, the thinning of the Group towards the east, north of Zeerust, is less than the corresponding widening of the aureole. Another possibility should be borne in mind, viz. that of a transgression of Bushveld rocks into the floor above Zeerust, similar to the transgression at Burgersfort or in the Potgietersrus area.

Towards Botswana the thickness of the igneous cover diminished rapidly and it is doubtful if any appreciable amount of mafic rock ever crossed the present day border. As a consequence, the rocks of the Transvaal Supergroup west of the Motswedi fault suffered only a low grade of metamorphism. The Rayton Formation is apparently assimilated to such a degree by the norite of the Bushveld Complex in the area mapped that only small xenoliths (YQ) remain, yet it is in situ and unmetamorphosed in the Lobatsi district.

Three post-Bushveld structural directions, viz. eastnortheast, northnorthwest and eastwest, are dominant in the study area. The structures are surface manifestations of deep-seated crustal trends as is shown by their disregard of the attitudes of the strata of the Transvaal Supergroup. Hunter (1975, p.14) points out that the NNW and ENE structures have been dominant on a large scale in the Kaapvaal craton from the earliest Precambrian to Transvaal times.

The flanks of the Gaberone basement granite dome, part of the Vryburg arch, underly the study area, and the dome's body outcrops to the west in Botswana (Hunter, 1975, p.9). Crustal adjustments to a possible isostatic rise of the Gaberone dome in post-Bushveld times could have caused the NNW faults. A last major structural event in the area was the emplacement of the EW and the ENE dyke systems.

V. PALEOGEOGRAPHY

A. PROXIMITY OF A BASIN FLANK

According to Crockett (1972, p.283), the strata of the Transvaal Supergroup in the Lobatsi-Ramotswa region of Botswana, i.e. the western part of the Transvaal basin, never extended very much further than their present outcrop. Most evidence from the study area supports the proximity of such a basin edge to the north and northwest in Botswana.

Several lateral lithofacies changes in the area mapped indicate a higher energy environment to the west and thus, possibly, a nearby basin flank. The most remarkable lateral lithofacies change occurs in the Penge Formation in the Skilpadhek area, where the nonclastic banded ironstones (PI) grade laterally, over a distance of a few metres from east to west, into a clastic, ferruginous slate (PS). Although the lateral gradation is not exposed, the banded ironstone bed, near its western termination, grades upwards into a coarse-grained slate which is continuous with the top of the ferruginous slate (PS). Banded ironstones of the Penge Formation eventually reappear on the northern side of the basin in the Thabazimbi district, the intervening outcrop being clastic.

In the Pretoria Group, the prime lateral lithofacies change is in the Boshoek Formation, where a chert-pebble conglomerate (OC) grades basinwards into a quartzite (OQ) on Palmietfontein 92JP. Thin conglomerate and grit beds are developed in the quartzites of the Timeball Hill, Daspoort Quartzite and Magaliesberg Quartzite Formations near Botswana but lens out towards the east. On the other hand, thick argillaceous beds (up to 40 m on Bergfontein 60JP) interlayered with the quartzites of the Timeball Hill and Magaliesberg Quartzite Formations, are present in the east of the terrain, but rapidly wedge out towards the west on Moilwaslokasie and none cross into Botswana.

Lateral increase in the amount of detrital chert in the sedimentary rocks of the Pretoria Group from east to west in the area under discussion indicates a nearby chert provenance to the west and, consequently, a shoreline in between the source and the deposit. Chert, similar to that found in the Malmani Subgroup, occurs as clasts in most of the arenaceous and rudaceous beds of the Pretoria Group near Botswana, but in the east only the conglomerate of the Bevet's Conglomerate Member (RC) and the quartzite of the Boshoek Formation (OQ) carry significant, though reduced, amounts of chert pebbles (section II.B.2.a.).

Other possible source rocks for the Pretoria Group include basement granites, felsites from the Kanye Volcanic Group in Botswana and volcanics from the Ventersdorp Supergroup.

A factor militating against a nearby basin flank is that the formations do not appear to thin out as the basin margin is approached (Table 4). Crockett (1972, p.285) does, however, note direct evidence of a reduction in thickness of the formations of the Pretoria Group towards the basin edge in the Ramotswa area.

B. DEPOSITIONAL HISTORY

The sedimentary rocks of the Transvaal Supergroup in the study area record an increase in the energy-levels during deposition with regard to time and proximity to the basin margin. Increase in energy-levels with time was caused by the increase in the rate of subsidence in the Transvaal basin (Crockett, 1972, p.288).

In the Chuniespoort Group, the rocks are mainly chemical precipitates, whereas the sedimentary beds of the Pretoria Group are largely detrital. Very little clastic fill entered the basin during Chuniespoort times because the surrounding country was peneplaned (Crockett, 1972, p.287). The Malmani Subgroup was laid down in a shallow, open, epeiric sea (Truswell, 1977, p.45) in which algae could precipitate carbonate. Banded ironstones of the Penge Formation formed under a cold, oxygen-deficient atmosphere (Beukes, 1973, p.1001) in an arm of the Malmani sea cut off from the ocean by a wave-built bank of carbonate detritus (Button, 1973, p.158). Near the shore there was a limited amount of detrital sedimentation in the arm of the sea, which resulted in the formation of the slates (PS) of the Penge Formation.

After the deposition of the Chuniespoort Group, most of the Transvaal basin underwent a period of uplift and denudation, which resulted in a limited amount of erosion of the Penge Formation in the study area. During the ensueing marine transgression, the chert-pebble conglomerate of the Bevet's Conglomerate Member was deposited. This is a true conglomerate because there is no direct contact with the chert provenance of the Malmani Subgroup in this area, and it is therefore not a residual breccia as is the case in other parts of the basin (Visser, 1969, pp.15-17).

Most of the beds of the Rooihoogte Formation were deposited in a shallow marine environment. In the Skilpadhek area, borehole cores from the Gopane mine (Fig. 3) indicate a sequence that has both linear and lobate (deltaic) clastic shore characteristics (Selley, 1970, p.99). An initial delta might have been partly destroyed by strong currents, which then formed a linear clastic shore above the deltaic remains. An argillite with upward-coarsening, rhythmic, graded bedding (RS, AK519) represents the delta front. Overlying this is a sequence of intercalated quartzites, coarse-grained slates and carbonaceous slates as well as a thin, stromatolitic, dolomitic limestone, all of the Polo Ground Member. The lower zone of the Polo Ground Member may mark the transition from the delta to the linear clastic shore. A basal erosion surface, overlain by a thin chert-pebble conglomerate (AK518), is typical of a distributary channel, whereas above this the stromatolitic limestone bed (AK520) and mud flakes in the quartzites (AK510) suggest a possible tidal flats environment. The carbonaceous slate (AK516), which extends into the Timeball Hill Formation (TS), was formed under low-energy swamp conditions in a reducing environment.

Glaciation, centred over the mountains of the Vryburg arch southwest of Zeerust, led to the deposition of a blanket of glaciomarine sediments in the southwestern and central Transvaal basin in the upper Timeball Hill Formation. Subsequent extensive erosion removed the southwestern deposits (Visser, 1971,pp.197-198). Neither glacial deposits nor signs of extensive erosion could be found in the slate (TS) of the Timeball Hill Formation, probably because neither event reached so far north.

A deepening of the Transvaal basin after the deposition of the Timeball Hill Formation caused an eustatic marine regression which left the basin margin relatively raised. This led to a high-energy environment wherein the conglomerates and quartzites of the Boshoek Formation were deposited. Earthquakes that preceeded the outflow of the lava of the Hekpoort Andesite Formation perhaps caused the soft sediment deformation structures in the above-mentioned quartzites (Fig. 7).

No pillow lava was detected in the Hekpoort Andesite Formation in the mapped outcrop or in the adjacent area to the east (Engelbrecht, personal communication, 1977), and it is assumed that the lava was extruded subaerially. Intercalated tuffs were probably deposited in lacustrine environments. If the hornfels (HH) at the top of the Formation does represent a chemically weathered paleosoil (section II.B.4.), it indicates a humid, probably hot climate at the end of the Hekpoort Andesite Formation.

Deposition of the Strubenkop Shale Formation took place in a shallow water environment that was periodically exposed to the air, as is indicated by the presence of mud flakes, dessication cracks and a clay pill conglomerate (Section II.B.5.). The quartzites of the Daspoort Quartzite Formation are interpreted as beach sands and the quartzites of Magaliesberg Quartzite Formation as a shallow marine deposit (Truswell, 1977, p.54).

VI. OXIDE AND SULPHIDE MINERALIZATION

A. NSUTITE AT SKILPADHEK

Nsutite, the mineral equivalent of synthetic gamma-manganese dioxide, is an essential constituent of battery-grade manganese ore (Ortlepp, 1964, p.149) and is presently being mined at the Gopane Manganese Mine. The manganese ore body is part of the Polo Ground Member of the Rooihoogte Formation and occurs below the top quartzite unit of the Member. The ore body has a variable thickness of up to 7 m, a dip of 15^{o} to the north or northeast and a strike length of 10 km from the Livingstone's Poort area to the border where it carries on into Botswana.

The manganese ore mined is a mixture of earthy yellow goethite and gray manganese oxides (AK411), sometimes botryoidal (AK279), together with quartz and muscovite. Nsutite, pyrolusite and cryptomelane are microscopically intergrown in felted masses or tiny crystals (≃1-50 μm, AK279a). The botryoidal, rhythmic-concentric units, about 5 mm in thickness, consist of nsutite layers of various crystal sizes or fibres, alternating with cryptomelane or pyrolusite layers (AK279).

Evidence points to the ore body having originated by the weathering and replacement of the stromatolitic, dolomitic limestone bed of the Polo Ground Member. Incipient replacement of the limestone can be seen in the borehole core (AK520) at a depth of 58 m, where black patches of manganese oxides have replaced some of the carbonate (Fig. 23). A core sample

(AK522) from an unknown depth, is largely ferruginized and manganized but still contains carbonate and stromatolitic structures. A sample from the mine workings (AK523) has the typical appearance of the ore, but contains relict columnar stromatolite structures and no carbonate (Fig. 24).

Zwicker et al. (1962, pp.246-247) point out that manganoan nsutite (74,64 per cent manganese dioxide; 11,02 per cent manganese oxide) commonly forms from the oxidation of rhodochrosite or manganoan calcite. The manganoan nsutite is, in turn, converted to nsutite (90,57 per cent manganese dioxide; 2,60 per cent manganese oxide) by further oxidation. "Nsutite appears to form at ambient temperatures in a slightly alkaline environment such as that afforded by carbonate minerals in contact with oxygen-rich waters. It has never been found in typical hydrothermal assemblages" (ibid., p.261). It is thus feasible that ore formation is still in progress below the ground water table (25 m) at the Gopane mine. In four boreholes logged in the Skilpadhek area, the stromatolitic limestone at depths of 50-60 m is only slightly replaced by manganese oxides. No ore was intersected. The manganese ore body may, therefore, only extend 30 - 40 m below ground level.

B. MAGNETITE IN A NORITIC SILL ON WELVERDIENT 24JO AND RIETGAT 91JP

In the valley between the Daspoort Quartzite and Silverton Shale Formations east of the Motswedi fault is a diabase sill, poorly exposed and noritic in composition. Prospecting

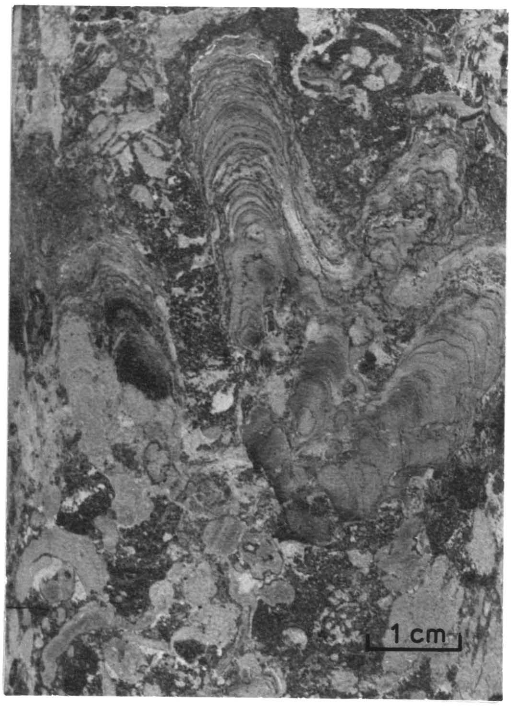


Figure 23: Stromatolitic, dolomitic limestone with black manganiferous areas and clastic infill between the stromatolites (AK520, RQ, Polo Ground Member, bore-hole core from Gopane mine).

Figure 24: Manganese ore with relict stromatolites (AK523, RQ, Polo Ground Member, specimen from waste dump, Gopane mine).

holes dug through alluvium into the sill reveal lenses of magnetite, up to 30 cm thick, in a weathered, magnetite-rich norite.

The magnetite is generally fine-crystalline, although some samples have cubic crystals up to 5 mm in size. Martitization of the magnetite to hematite, along the octahedral (111) planes, starts at the crystal faces and has, in places, altered a great deal of the crystals, although hematite is usually only a minor constituent (AK216). No ilmenite was observed but quartz and muscovite are present as accessory minerals (Groeneveld and De Wet, 1960, p.2). The noritic host rock contains many subhedral magnetite crystals, up to 1 mm in size (AK218).

C. OTHER IRON ORE OCCURRENCES

Iron oxides and hydroxides are abundant in the area mapped and deposits located are listed in Table 5. Magnetite, hematite, goethite and limonite are variously intergrown and rhythmic precipitation textures were observed (AK333). Specular hematite veins are rare and appear to be of limited extent.

D. SULPHIDES

Sulphides, mainly pyrite, are found in the carbonaceous slates, hornfelses and sill rocks of the study area. At Gopane mine, borehole cores show the basal carbonaceous slates (TS) of the Timeball Hill Formation to be rich in pyrite nodules, veins and laminae. The bedding is often compressed around the nodules.

Table 5 : Iron ore deposits in the area mapped

Bed	Sample number	Locality and important minerals
PI	-	Entire outcrop; magnetite and hematite
RC	-	Near Dinokana; hematite
TF	AK245	25°56'E; magnetite, hematite, some specularite
TF	AK253	25°48'-25°50'E; magnetite, hematite
TF	AK285	25°20'S; magnetite, hematite
TQ	AK260	25°22'S; hematite
SQ	AK226	Most of outcrop; mainly magnetite
SS	AK333	25°50'E; hematite
DF	AK361	25°15'S; mainly magnetite
MQ	AK181	Bergvliet 23JO; hematite
MQ	AK141	Bergfontein 60JP; specularite, hematite
MQ	AK383	25°49'E; specularite, hematite
di	AK216	Welverdient 24JO, Rietgat 91JP; magnetite

Hornfels (AS), interbedded with the quartzites of the Magaliesberg Quartzite Formation on Hartbeestlaagte 58JP, can contain euhedral pyrite crystals. Magnetite, with exsolution lamellae of ilmenite, and pyrrhotite that contains blebs of chalcopyrite, surround and appear to replace the pyrite (AK143).

VII. SUMMARY

An 860 km^2 area of the Pretoria Group and the upper formations of the Chuniespoort Group between Zeerust and the border with Botswana was geologically mapped on a scale of 1:50 000. This part of the Transvaal Supergroup was subdivided into formations according to the proposed scheme of the SACS (1977).

In the Chuniespoort Group, the bulk of the rocks are chemical precipitates except for the clastic beds of the Penge Formation near Botswana. A succession of mainly quartzite and slate beds as well as a thick volcanic horizon form the Pretoria Group. Hornfelses are developed in the northeast of the study area. Diabase sills intruded the Pretoria Group before and during the emplacement of the Bushveld Complex. The older sill rocks are metamorphosed to an amphibole hornfels, whereas the younger intrusives have a noritic composition.

The Bushveld Complex metamorphosed the underlying Transvaal Supergroup in such a manner that the metamorphic grade is highest in the northeast and decreases from north to south across the strike as well as from east to west along the strike. Metamorphic assemblages typical of the hornblende-hornfels facies in the east of the study area are separated from those of the albite-epidote-hornfels facies in the west by a line roughly linking Motswedi in the north to Dinokana in the south. The first appearance of tremolite in the talcose, silicious limestones at the top of the Malmani Subgroup is regarded as the boundary between the two facies in

the south. Appearance of cordierite, formed by the elimination of chlorite and muscovite, in the hornfelses of the Silverton Shale Formation near Motswedi, marks the start of the hornblende-hornfels facies. Other metamorphic index minerals of the hornblende-hornfels facies in the area are anthophyllite, cummingtonite and almandine, whereas talc and epidote are typical of the albite-epidote-hornfels facies. Chloritoid and andalusite are widespread throughout the terrain. Andalusite crystals can be several millimetres long in the east but diminish in size and amount towards the west. T-P conditions for the albite-epidote-hornfels facies are estimated at between 300 and 500^{o}C and between 1 and 4 kb. For the hornblende-hornfels facies, the temperature ranged from 500 to 600^{o}C and the total fluid pressure from 1 to 4 kb.

A rapid reduction in thickness of the mafic cover of the Bushveld Complex appears to be the cause of the decrease in the metamorphic grade towards the west. The unassimilated, unmetamorphosed Rayton Formation at the top of the Transvaal Supergroup in adjacent southeastern Botswana is absent across the border in South Africa and this suggests that the mafic rocks of the Bushveld Complex did not transgress very far into Botswana.

The gravity slides and associated faults characteristic of southeastern Botswana end near the South African border, except for the Schilpadshek slide which is responsible for the rapid thinning of the Malmani Subgroup near and in Botswana.

Post-Bushveld fault orientations are EW and NNW with the latter predominant. Largest of the NNW step faults is the Motswedi fault, which displaces the Strubenkop Shale Formation by 2 km (Folder). A minor EW fault gives rise to the strong spring at Dinokana. Predominant ENE together with EW photo-lineations appear to represent dyke systems younger than the NNW faults. The Bergvliet lineament (ENE, Folder) can be traced for 115 km on the aeromagnetic contour map and represents a diabase dyke, which outcrops in the Malmani Subgroup. The three post-Bushveld structural directions, viz. NNW, ENE and EW, are the surface expressions of deep-seated crustal trends and disregard the changes in the strike of the strata of the Transvaal Supergroup. Crustal adjustments to an isostatic rise of the underlying Gaberone basement granite dome, which is part of the Vryburg arch, could have caused the NNW faults.

A suspected nearby original flank of the Transvaal basin in Botswana could be the cause of several lithofacies changes, which reflect a higher energy environment to the west, in the Transvaal Supergroup. Banded ironstone of the Penge Formation grades laterally into a ferruginous slate towards the basin margin, whereas the amount of conglomerate in the Pretoria Group decreases basinwards.

The Chuniespoort Group was deposited in an epeiric sea with the banded ironstones precipitated in an arm of the sea cut off from the main basin by a wave-built bank of carbonate detritus. Near the shore, the chemical precipitates make way for the slate of the Penge Formation. After the uplift and denudation of the Chuniespoort Group, a bed of conglomerate initiated the deposition of the Pretoria Group. The upper Rooihoogte Formation is interpreted as a partly destroyed delta overlain by linear clastic shore deposits. No evidence of glaciation was discovered in the upper Timeball Hill Formation. Lava of the Hekpoort Andesite Formation was extruded terrestially in a number of flows and is capped by a metamorphosed paleosoil. The quartzites of the Daspoort Quartzite Formation are interpreted as beach sands, whereas the quartzites of the Magaliesberg Quartzite Formation were formed in a shallow marine environment (Truswell, 1977, p.54).

Nsutite, a battery-grade gamma-manganese dioxide ore, is mined at Skilpadhek in a body which is a replacement of a bed of dolomitic limestone in the Polo Ground Member. Ore formation could still be in progress in the oxygen-rich zone of the ground water, which would mean that the ore does not extend more than 30 to 40 m below ground level.

Many small iron ore deposits were located in the area, the most remarkable being the magnetite lenses in a noritic sill on Welverdient 24JO and Rietgat 91JP. Much pyrite has formed in the carbonaceous slates of the Timeball Hill Formation.

VIII. ACKNOWLEDGEMENTS

Thanks are due to the author's promoters, professors C P Snyman and G von Gruenewaldt, for their help and patience. The writer is also in debt to Mr Chris Potgieter, who reviewed the sedimentary sections, Mr Johann Engelbrecht and the other staff members of the Department of Geology and the Institute for Geological Research on the Bushveld Complex of the University of Pretoria.

My friends, Imants Kavalieris and John Fabray, helped remap part of the Chuniespoort Group. Mr Van der Westhuizen, manager of the Gopane Manganese Mine, is thanked for his hospitality and the local farmers and tribesmen are remembered for their friendliness. The laborious tasks were carried out by Mrs Louise Botha who typed the manuscript and Erica Mitchell who coloured in the maps.

Financial assistance from the Geological Survey of South Africa, the Council for Scientific and Industrial Research and the General Mining and Finance Corporation is gratefully acknowledged.

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