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DUNDEE

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THE GEOLOGY OF THE DUNDEE AREA

by/deur

W. LINSTRÖM, D.Sc.

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THE GEOLOGY OF THE DUNDEE AREA

Abstract

The 1:250 000-scale geological map area 2830 (Dundee) is underlain by rocks that range in age from Swazian to Quaternary. The oldest rocks belong to the Nondweni Group and Empangeni Metamorphic Suite, which have a minimum age of 2 940 Ma. They were intruded by the pre-Pongola granite that forms the bulk of the Kaapvaal Craton in this area and are unconformably overlain by the Pongola Sequence which contains lava that has yielded an age of 3 090 Ma. During the early geological history, the area was structurally dominated by the overthrusting of younger rocks onto the rocks of the Kaapvaal Craton. The northern frontal zone of the Natal Structural and Metamorphic Province comprises the Natal Thrust Belt, which contains the Ntingwe and Mfongosi Groups, the latter being overthrust onto the former, and a nappe complex of four flat-lying thrust sheets which passes southwards into a near-vertical belt of deformation. The rocks found in the nappe complex constitute the Tugela Group. The steep belt may represent the downwarped root zone of the nappe complex and defines the southern limit of the frontal zone. South of the steep zone, rocks of the Mapumulo Metamorphic Suite crop out.

Three generations of Precambrian intrusive rocks occur in the area. The age of the oldest is that of the post-Nondweni Group and pre-Pongola Sequence, that of the second corresponds with that of the post-Pongola Sequence and pre-Tugela Group and the youngest with that of the post-Tugela and pre-Natal Groups.

The Natal Group sediments form a clastic wedge that thins rapidly from west to east and from south to north through the area. This group unconformably overlies the basement rocks.

The Karoo Sequence is well represented by rocks which range in age from Carboniferous (Dwyka Formation) to the Jurassic (Letaba Formation). No rocks of Cretaceous age are found in the map area, but a number of Quaternary formations do occur.

A great variety of economically potential minerals occur in the area, but only coal is presently being mined.

Opsomming

Die oudste gesteentes in gebied 2830 (Dundee) behoort tot die Groep Nondweni en Metamorfe Suite Empangeni. Eersgenoemde dagsoom in vier gebiede en bestaan uit basiese lawa, gestreepte chert, kalksilikaatgesteentes, kwartsiet en glimmerskiste. Die lawa is meestal in groenskis verander, en amandel- en kussingstrukture word soms nog herken.

Die Metamorfe Suite Empangeni was aan 'n aansienlik hoër graad van metamorfose as die Groep Nondweni onderwerp en bestaan uit ortopirokseen-granaat-magnetiet-kwartsgranuliete, magnetiet-ortopirokseen-kwartsgneis en amfiboliet wat hipersteen plaaslik bevat. Die gesteentes van die Metamorfe Suite Empangeni kan moontlik met die Groep Nondweni gekorreleer word aangesien albei deur Argeïese graniet met 'n ouderdom van 3 177 ± 60 Ma ingedring is.

Die Pongolavloer bestaan uit grofporfiritiese graniet, sowel as granitiese gneis en gesteentes van die Groep Nondweni. Weens die feit dat die graniet op plekke ook 'n swak foliasie het, is die kontak tussen die twee tipes gesteentes nie skerp nie, maar oorganklik. Beide die gesteentetipes bestaan uit plagioklaas, mikroklien, kwarts en biotiet, terwyl horingblende en chloriet soms voorkom.

Gesteentes van die Opeenvolging Pongola dagsoom in die omgewing van Nkandla, asook langs die Wit-Mfolozirivier. By eersgenoemde lokaliteit is slegs die Groep Nsuze ontwikkel en dit kom voor in die vorm van twee oop sinkliene wat deur 'n oorskuiwing van mekaar geskei word. Die Groep Nsuze bereik hier 'n dikte van ongeveer 8 700 m en bestaan hoofsaaklik uit kwartsiet met 'n bietjie tussengelaagde filliet, gestreepte ystersteen asook konglomeraat en groen andesitiese tot basaltiese lawa. Tuf kom slegs in die onderste gedeelte van die suksessie voor. Ten minste twee plooiperiodes kan in die gesteentes herken word.

In die Wit-Mfolozigebied kom beide die Groepe Nsuze en Mozaan voor en laasgenoemde lê met 'n effense, maar duidelik waarneembare, klinodiskordansie op eersgenoemde. Die Groep Nsuze lê diskordant op die Argeïese graniet en bereik 'n totale dikte van 3 500 m. Dit bestaan uit kwartsiet, moddersteen, sliksteen, dolomiet, ysterryke skalie en lawa. Kleinskaalse stromatoliete, wat 'n besondere verskynsel in gesteentes van hierdie ouderdom is, kom in die dolomiet voor. Die lawa is groen en amandelhoudend en kussingstrukture kan nog daarin herken word. Die Groep Mozaan bereik 'n dikte van 1 200 m en die onderste gedeelte daarvan bestaan uit konglomeraat en kwartsiet met relatief min skalie tussenin, terwyl die boonste gedeelte weer uit hoofsaaklik skalie en ysterryke skalie bestaan.

Die gedeelte van die Strukturele en Metamorfe Provinsie Natal wat in gebied 2830 voorkom, staan as die noordelike frontale sone bekend en kan in verskeie eenhede onderverdeel word. Die mees noordelike deel word die Natalse Oorskuiwingsgordel genoem en dit vorm 'n oos–wesstrekkende sone van 2–5 km breed wat uit die Groepe Ntingwe en Mfongosi bestaan. Die Groep Ntingwe lê diskordant op die Groep Nsuze en met 'n sedimentêre kontak op die ou graniet. Dit bestaan uit konglomeraat, grintsteen, moddersteen en dolomitiese kalksteen. Die Groep Mfongosi oorlê die Groep Ntingwe, met 'n oorskuiwingskontak; eersgenoemde is oor laasgenoemde geskuif. In die westelike sektor bestaan die Groep Mfongozi uit pirokseen- en biotietdraende horingblendegneis, ortoamfiboliet, chloriet- en talkskis en gestreepte ystersteen. In die oostelike sektor bestaan die groep hoofsaaklik uit kwarts-glimmerskis (sporadies met granaat en stouroliet), chlorietskis, filliet en ondergeskikte kwartsiet, terwyl lokaal ystersteen na aan die bokant van die groep voorkom.

Aan die suidelike grens van die oorskuiwingsgordel word 'n dekbladkompleks, waarin vier groot dekblaaie herken kan word, aangetref. Omdat die hele suksessie na die weste hel, dagsoom die dekblaaie in stygende strukturele volgorde van oos na wes. Aan die basis van die groot dekblaaie kom daar dikwels lae en lense van talkskis en serpentiniet voor. Elk van hierdie vier dekblaaie kan in verskeie formasies onderverdeel word, terwyl van hulle ook deur granitiese materiaal ingedring is. Die formasies bestaan hoofsaaklik uit amfibolitiese gesteentes, glimmerskis en kwarts-veldspaat-biotietgneis. Van die amfiboliete in die boonste dekblad het 'n duidelike vulkaniese oorsprong en strukture soos kussinglawa kan nog herken word. Elkeen van die dekblaaie is ook deur basiese en ultra-basiese komplekse binnegedring.

Die dekbladkompleks gaan suidwaarts oor in 'n sone met steilhellende gesteente wat waarskynlik die afgebuigde wortelsone van die kompleks verteenwoordig. Vier formasies, wat uit amfiboliet en kwarts-veldspaat-biotietgneis bestaan, kan herken word. 'n Granitiese gneis is die enigste intrusiewe gesteente wat in die steil sone voorkom.

Die gesteentes in die Noordelike Frontale Sone was aan ten minste drie periodes van vervorming onderworpe. Die eerste periode was vir plooiing verantwoordelik, die tweede vir skuifskeuring en die derde vir die totstandkoming van die dekbladkompleks. Die oorskuiwings wat vir laasgenoemde verantwoordelik was, het van die gesteentes tot 100 km noordwaarts verplaas.

Die Metamorfe Suite Mapumulo onderlê slegs 'n klein gedeelte van die kaartgebied en dit bestaan uit ongedifferensieerde amfiboliet en gestreepte kwarts-veldspaat-biotietgneis.

Sedimentêre gesteentes van die Groep Natal vorm 'n klastiese wig wat die vloergesteentes diskordant oorlê. Die groep word dunner van wes na oos, sowel as van suid na noord deur die kaartgebied. Die opeenvolging begin met 'n konglomeraat aan die basis wat 10 m dik is, gevolg deur 'n opwaarts fynerwordende suksessie van grintsteen, kwartsiet en arkosiese sandsteen, sliksteen en skalie. Die kleur van die sedimente wissel van ligpers tot rooibruin.

Die Opeenvolging Karoo beslaan die grootste gedeelte van die gebied en die volle opeenvolging vanaf die basale Formasie Dwyka tot die Formasie Letaba is verteenwoordig. Die verhouding tussen opeenvolgende litostratigrafiese eenhede is konkordant. Die Formasie Dwyka bestaan uit tilliet met dun lagies sandsteen wat wydverspreid na aan die bokant voorkom. Dit word gevolg deur die Groep Ecca wat bestaan uit goedgelaagde donkergrys skalie en sliksteen van die Formasie Pietermaritzburg aan die basis. Hierop volg middelkorrelrige sandsteen met ondergeskikte donkergrys skalie en enkele dun steenkoollae van die Formasie Vryheid en skalie van die Formasie Volksrust. Dit toon ooreenkoms met dié van die Formasie Pietermaritzburg behalwe dat dit soms ryk aan fosfaatknolle is. Die Groep Ecca word oorlê deur die Formasie Estcourt wat uit fyn- tot middelkorrelrige, soms kruisgelaagde sandsteen en blougrys tot swart, soms koolstofryke, skalie bestaan. Die Formasie Emakwezini, die oostelike laterale ekwivalent van die Formasie Estcourt, is deur groengrys, goedgelaagde, veldspatiese sandsteen en blougrys en swart koolstofryke skalie verteenwoordig. Dun lagies steenkool is dwarsdeur die formasie ontwikkel.

Die Formasie Emakwezini en die opeenvolging wat daarop volg, is tot die oostelike gedeelte van die gebied beperk.

Die Formasie Ntabene volg op die Formasie Emakwezini en bestaan hoofsaaklik uit middel- tot grofkorrelrige kwartsitiese sandsteen en ondergeskikte grys en groen skalie. Hierop volg rooibruin en pers moddersteen met dun tussengelaagde sandsteen van die Formasie Clarens. Die Formasie Letaba oorlê die Formasie Clarens met 'n effense diskordansie en dit bestaan uit 'n dik opeenvolging van basaltiese lawa. Amandeldraende sowel as nie-amandeldraende tipes kom voor.

Karoodoleriet kom wydverspreid voor. Dit is 'n middelkorrelrige donkergrys gesteente wat af en toe klein eerstelinge van veldspaat bevat.

'n Aantal Kwaternêre formasies kom binne die kaartgebied voor. Die Formasie Berea bestaan uit fyn- tot baie fynkorrelrige, bruin tot rooi, kleiige sand en dit lê met 'n diskordante kontak op ouer gesteentes. Die Formasie Port Durnford bestaan uit 'n onderste kleiige sone wat mariene fossiele bevat en 'n boonste sandige sone wat uit beide water- en windafsettings bestaan. Die twee sones word deur 'n laag ligniet, met 'n gemiddelde dikte van 1,3 m, van mekaar geskei. Die Formasie Masotcheni is 'n gelaagde opeenvolging wat hoofsaaklik uit halfgekonsolideerde, kleiige sedimente bestaan en kol-kol voorkom. Ander Kwaternêre afsettings sluit oppervlaksand, duin- en strandsand, asook alluvium in.

Meer as dertig verskillende minerale met 'n moontlike ekonomiese potensiaal kom in die gebied voor, maar slegs steenkool word tans aktief gemyn.

1. INTRODUCTION

The area covered by the Dundee 1:250 000 map is underlain by rocks which range in age from Swazian to Recent. It includes portions of two major Precambrian tectonic provinces, *viz.* the Archaean Kaapvaal Province and the Late Proterozoic Natal Structural and Metamorphic Province.

The former consists of granitoids and gneisses with deformed greenstone relicts. A supracrustal succession, the Pongola Sequence, accumulated during cratonisation in the Late Archaean. This cratonic cover was only gently deformed and metamorphosed to a low or very low grade (Tankard et al. 1982).

The Natal Province comprises metamorphosed allochtonous oceanic crust which has been transported northward onto the Kaapvaal foreland as a series of nappe sheets. Cratonisation during the Late Proterozoic fused these two provinces together (Tankard et al. 1982). They are now partly covered by undisturbed Palaeozoic and Mesozoic platform deposits and Quaternary sediments.

There is a great variation in the physiography of the area. The northern and western parts are characterised by relatively accessible, open grassland with rolling hills and flat-topped mountains. Parts of this area are intensively cultivated. The area to the south and east, underlain by rocks of the Natal Structural and Metamorphic Province, on the other hand, is very inaccessible. It is highly broken, densely bushed country where the local black inhabitants can only practise pastoral farming. The coastal areas in the south-east are less rugged and though intensively cultivated, very densely vegetated.

The north-eastern part of the area is drained by the Black and White Mfolozi Rivers and their tributaries, the western and southern parts by the Tugela–Buffalo River system, while the central part is drained by the Mhlatuze River system.

2. NONDWENI GROUP*

Rocks of this group crop out in four main areas, *viz.* west of Melmoth; south and south-east of Nkandla; around Nondweni; and in the valley of the Buffalo River. The rocks in the first two areas have not been differentiated, but two formations were recognised in each of the other areas. The age of the Nondweni rocks has not been established, but a minimum age can be inferred from the date of 3 199 ± 30 Ma obtained from the pre-Pongola granitic gneiss (T. Elworthy, pers. commun to Charlesworth 1981, p. 389) intrusive into them (Du Toit 1931, p. 52–57; Matthews 1959, p. 280; Watson and McGeorge 1977, p. 8).

* Not yet approved by South African Committee for Stratigraphy (SACS).

2.1 MHLATUZE FORMATION*

These rocks crop out along the Mhlatuze River south-east of Nkandla, as well as further north, just west of Melmoth. Along the Mhlatuze River the rocks crop out in a large, easterly closing, asymetrical synform. They are intruded by granitic gneiss (Du Toit 1931, p. 29). The succession constitutes an interbedded sequence of schistose basic lava and sediments, which have undergone extensive shearing and recrystallisation in places, due to the intrusion of the granitic gneiss. The basaltic lava has to a large extent been altered to greenschist, which includes chlorite schist, hornblende schist, actinolite schist and even talc schist. Some bands in the volcanic rocks, however, still show well-preserved amygdales, which are usually filled with secondary chlorite and quartz.

The sedimentary rocks include quartzite, cherty quartzite, white micaceous schist, iron formation and subordinate garnet-bearing grunerite schist. Thin jasper bands are present at a few localities. These rocks are usually intensely folded and contorted.

2.2 NKANDLA FORMATION*

This formation crops out in the Nkandla area where it overlies the Mhlatuze Formation, and is unconformably overlain by the Nsuze Group (Du Toit 1931, p. 32). In the main outcrop area it forms part of a huge easterly closing synformal structure. The succession consists mainly of metasedimentary rocks which have suffered low-grade regional metamorphism in addition to dynamic metamorphism. Soft, white or greenish sericitic schist and phyllite, with intercalated thin bands of white quartzite, banded chert and conglomerate, predominate. Schistose bands, rich in kyanite, occur at some localities. Near the top of the formation there is a thick quartzite. The quartzite is usually fine to medium grained and, due to recrystallisation, seldom shows any traces of bedding. Some of the quartzite has such a schistose appearance that it can almost be described as quartz schist. Thin bands of quartz-sericite schist are often intercalated in them. The quartzite is locally somewhat gritty, but does not contain pebbles.

Although the formation consists mainly of altered sedimentary rocks, some dark, basic schist, which may represent metalava, also occurs. A bed of highly sheared amygdaloidal lava crops out at one locality.

2.3 UNDIFFERENTIATED NONDWENI GROUP AND ASSOCIATED ULTRAMAFIC INTRUSIONS

2.3.1 Nondweni Group in the Nondweni area

Around Nondweni the group comprises interstratified basic lava, banded chert, calc-silicate rock and mica schist. These rocks have been described in some detail by Hatley (1975), upon whose work the following description is largely based.

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* Not yet approved by South African Committee for Stratigraphy (SACS).

The basaltic lava is a blue to green fine-grained, dense, usually amygdaloidal rock. Pillow structures are common. It consists of actinolite–tremolite amphibole, clinozoisite, epidote and rare phenocrysts of zoisite, set in a microcrystalline groundmass of feldspar, quartz, opaque minerals, epidote and chlorite. Remnants of pyroxene crystals occur in places. The thickness of the lava is estimated to be in excess of 4 000 m.

Beds of recrystallised chert, varying in thickness from one to several metres, occur conformably interlayered with the lava. The less-recrystallised chert is banded but, as recrystallisation increases, it becomes more vitreous, eventually losing the banding becoming massive and homogeneous. Although the chert varies in colour between white, brown, green, grey and black, it has a simple mineralogy, consisting of quartz with only minor quantities of epidote, chlorite, opaque minerals, amphibole and zeolites.

Beds of calc-silicate rocks, up to 20 m in thickness, are associated with the chert. They are pale green to white in colour with an irregularly banded appearance. They consist of alternating bands of quartz, tremolite, diopside and epidote. Accessory minerals include calcite, plagioclase and sphene.

The rocks of the Nondweni Group in this area have suffered low-grade regional metamorphism (epidote–amphibolite facies). They were also subjected to at least two phases of deformation. The first phase gave rise to isoclinal folds while the second phase was of an open concentric style.

2.3.2 Nondweni Group in the Buffalo River Valley area

These outcrops were first described by Du Toit (1931) and again by Smith (1977a). A body of serpentinite is intrusive into the Nondweni Group in this area. All the rocks are unconformably overlain by the Nsuze Group.

The Nondweni rocks consist mainly of hard, jointed, fine-grained, dark, basaltic lava which is best described as greenstone. The lava is usually vesicular and amygdaloidal. The amygdales are slightly stretched in one direction. The constituents of the lava are green hornblende, epidote, zoisite and rarely quartz.

Thin beds of variably coloured fine-grained chert and quartzite are interbedded with the lava flows. These always display peculiarly streaked and rodded surfaces along the bedding planes due to shearing. Subordinate iron formation, and coarse-grained actinolitic and talcose rocks, are also developed in this sequence.

2.3.3 Ultramafic intrusions (Zse on map)

Small bodies of serpentinite occur east of Nondweni. Although contacts with the adjacent rocks are obscured, the serpentinites appear to be intrusive into the Nondweni Group but are themselves intruded by pre-Pongola granite.

The weathered serpentinite has a very rugged surface which displays nodules, concretions and ridges. When fresh it is uniformly dark green or black, hard and compact. It consists of a groundmass of serpentine with segregations of magnetite. Minute veins of chrysotile are developed in places, while soapstone is found near the eastern contact with the granite.

3. EMPANGENI METAMORPHIC SUITE*

These rocks occur in the Empangeni area, where two formations have been recognised. The Nondweni Group and Empangeni Metamorphic Suite appear to be of a similar age as both have been intruded by pre-Pongola granitic gneiss (Charlesworth 1981, p. 22–27; Matthews 1959, p. 280). They are, however, not grouped together here, due to differences in lithology and degree of metamorphism, as well as the fact that nowhere do they occur in juxtaposition.

Rocks of the Empangeni Metamorphic Suite were described in detail by Charlesworth (1981) from whose work the following description is abstracted.

3.1 LUBANA FORMATION*

Melanocratic pyroxene-garnet-magnetite-quartz granoblastite forms the most prominent rock type of this formation. Interbanded with these granoblastites are magnetite-orthopyroxene-quartz gneiss, garnet orthopyroxenite, clinopyroxene-garnet-plagioclase gneiss and garnet-biotite enderbitic granolite. The rocks are fine to medium grained and vary in texture from granoblastic to distinctly gneissic. A crude banding is locally displayed in the granoblastite. Evidence of folding within the Lubana Formation is sparse, but it appears that at least two phases of deformation can be recognised. Occasional tight intrafolial folds were observed but no reliable orientation data could be obtained. A second phase was responsible for tight westward-plunging folds.

The mineral assemblages show that the rocks have suffered high-grade (granulite facies) regional metamorphism. Charlesworth (1981, p. 234) puts the temperature at which this took place at a minimum of 860 °C at an estimated pressure of 8 to 10 kb.

3.2 NGWENI FORMATION*

This formation is entirely composed of amphibolitic rocks. They are generally foliated, although granoblastic textures do occur. Some of the amphibolite bands are relatively thin and boudinaged.

The amphibolitic rocks consist of hornblende, hypersthene and diopside, with very little plagioclase and opaque minerals. On the basis of their mineral assemblages, Charlesworth (1981, p. 239) concludes that a certain amount of retrograde metamorphism, from very high-grade (granulite facies) down to high-grade (upper-amphibolite facies), took

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place and that, although the relationship between the Lubana and Ngweni Formations is not clear, the latter may represent the retrograde equivalent of the granoblastic rocks of the Lubana Formation (Charlesworth 1981, p.19).

4. PRE-PONGOLA GRANITIC BASEMENT

This granitic basement complex consists of two major units, namely granitic gneiss and homogeneous granite. These rocks are intrusive into the Nondweni Group and Empangeni Metamorphic Suite while they are in turn overlain, with an unconformable sedimentary contact, by rocks of the Nsuze Group.

4.1 GRANITIC GNEISS (Zgn on map)

The granitic gneiss is a well-foliated or banded, fine- to medium-grained leucocratic rock with a granodioritic to tonalitic composition. It often contains conformable darker layers and lenses of hornblende and garnet-biotite gneiss and amphibolite. The foliation has an east–west trend and has been deformed by complex small-scale polyphase folding. The gneiss is porphyroblastic in places while augen and flaser textures are locally developed.

The main constituents of this gneiss are quartz, plagioclase, microcline and biotite. Muscovite and hornblende may be present in small quantities. Biotite often shows alteration to chlorite. An Rb/Sr age of 3 199 ± 30 Ma has been obtained on these rocks (T. Elworthy, pers. commun to Charlesworth 1981, p. 389).

A similar rock type, occurring in the Empangeni area, has been described by Charlesworth (1981) under the name "Nseleni Granitoid Gneiss"*. This has been dated at 3 177 ± 60 Ma (E. Barton, pers. commun to Charlesworth 1981, p. 389). Because of the similarity in age, field relationships and other characteristics, the pre-Pongola granitic gneiss described above and "Nseleni Gneiss" are correlated.

4.2 GRANITE (Zg on map)

The second component of the granitic basement is a grey, coarse-grained and often coarse porphyritic, massive to slightly foliated adamellitic granite. It consists of megacrysts of microcline and plagioclase, small quartz grains and flakes of biotite. The biotite is often altered to chlorite and is locally even replaced by hornblende. The granite has ill-defined gradational contacts with the granitic gneiss but in the vicinity of the contact both rock types are cut by a network of granitic dykes and sheets. Although no dating has been done on the granite within this area a similar rock from an area south-east of Piet Retief has yielded an age of 3 230 ± 80 Ma (H. L. Allsopp *in* Burger and Coertze 1973, p. 18).

* Not yet approved by South African Committee for Stratigraphy (SACS).

5. PONGOLA SEQUENCE

The rocks of the Pongola Sequence in this area crop out mainly along and north-east of the White Mfolozi River, in the vicinity of Nkandla, and along and north-east of the Buffalo River. Although the rocks in the first two areas mentioned were subdivided into formations, no correlation at formation level was possible between them, while the rocks in the Buffalo River area, and a few other isolated outcrops, were not given formation names as they could not be correlated with similar Nsuze rocks elsewhere. The geology of the different areas will thus be described separately.

The "Lochiel Granite"* which the Pongola Sequence overlies unconformably north of the Dundee sheet area (Visser 1949) has been dated at 3 028 ± 14 Ma (Barton et al. 1983) which gives a maximum age for the Pongola Sequence.

A minimum age limit is set by dates of 2 874 ± 30 Ma and 2 931 ± 38 Ma on the Usushwana Complex (Davies et al. 1970) intrusive into the Pongola Sequence, also to the north of Sheet 2830. A date of 3 090 ± 90 Ma (Burger and Coertze 1973, p. 17), on lava of the Bivane Formation, is regarded as unreliable. A more reliable age for the Nsuze Group is given by the U–Pb determination done by Hegner et al. (1984) on felsic volcanic rocks of this group in Swaziland that yielded an age of 2 940 ± 22 Ma. The Bivane Formation which has been selected as the marker unit between the Swazian and Randian erathems by SACS (1980), is therefore somewhat younger than indicated on the 1984 edition of the 1:1 000 000-scale Geological Map of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland.

In the Nkandla area, several lavas occur in the Nsuze Group, none of which can be correlated with certainty with the Bivane Formation.

5.1 WHITE MFOLOZI AREA

The Pongola Sequence in this area is represented by rocks of both the Nsuze and Mozaan Groups. The latter lies with a slight angular unconformity on the Nsuze Group (Pl. 1). This succession was described in some detail and subdivided by Matthews (1967, 1977) and SACS (1980).

5.1.1 Nsuze Group

Resting with an unconformable contact on the granitic pre-Pongola basement, the Nsuze Group is made up of six formations (SACS 1980). They consist of an alternating sequence of sedimentary and volcanic rocks with the total thickness of the group probably exceeding 3 500 m.

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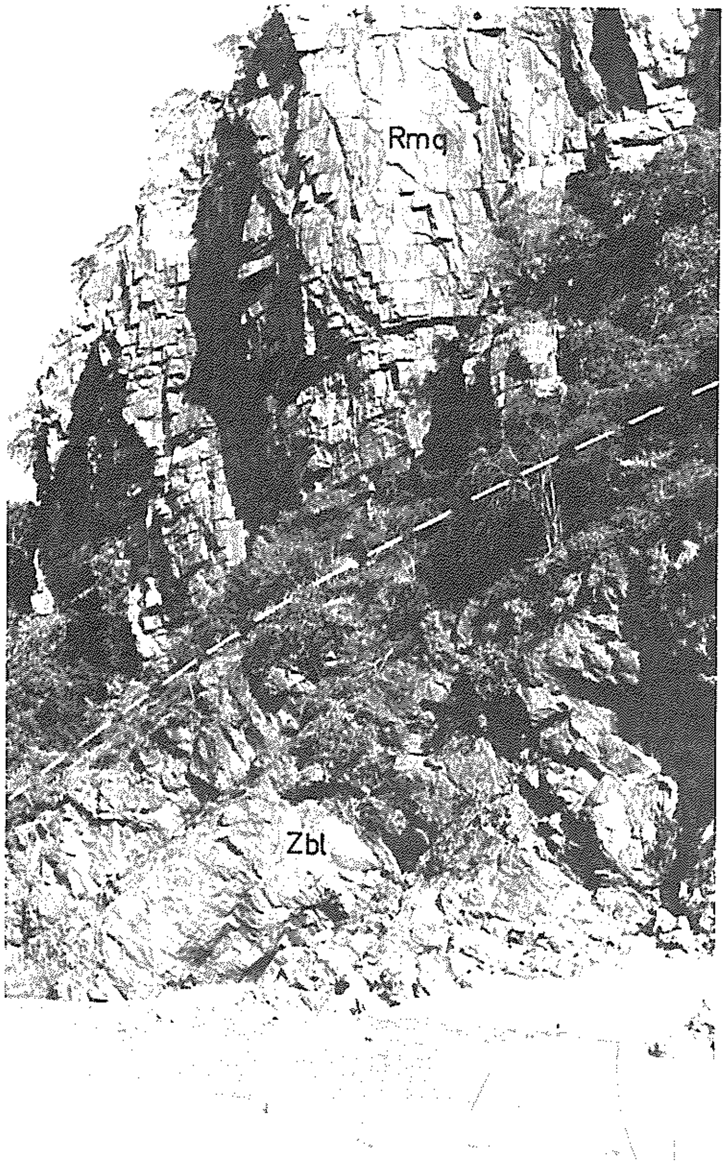

Plate 1 — Angular unconformity between lava of the Nsuze Group (Zbl) and orthoquartzite of the Mozaan Group (Rmq) in the bed of the White Mfolozi River. Photograph by courtesy of V. von Brunn.

Plaat 1 — Klinodiskordansie tussen lawa van die Groep Nsuze (Zbl) en ortokwartsiet van die Groep Mozaan (Rmq) in die loop van die Wit-Mfolozirivier. Foto goedgunstig deur V. von Brunn voorsien.

The *Bomvu Formation* is a clean, well-bedded orthoquartzitic sandstone with a large lateral extent, resting with a gradational unconformity on the granitic basement. This transition zone, 1 to 10 m thick, consists of a buff-coloured, structureless rock composed of quartz, sericite and vermiculite which was derived from the *in situ* weathering of the granite (Matthews 1967). The contact was put above the zone. A very thin, impersistent conglomerate, with pebbles of up to 5 cm in diameter, usually occurs on the contact between the *in situ*-weathered granite and the quartzitic sandstone.

Overlying the basal quartzite is the first volcanic unit, the *Nhlebela Formation*. It is composed of a relatively thin sequence of dark-green amygdaloidal lava which locally has pillow structures near its base. The *Thembeni Formation* consists predominantly of an interlaminated sequence of mudstone, shale and siltstone. These rocks show flaser bedding, lenticular and graded lamination, small-scale ripple-drift lamination, shrinkage cracks and contain occasional channel-fill grit and sandstone. The shale is finely laminated and green or grey in colour with enclosed laminae of cream-coloured to light-grey siltstone.

The afore-mentioned argillaceous rocks pass upwards into a quartzite–dolomite sequence, the *Chobeni Formation*. The bulk of the formation comprises a monotonous succession of medium- to thick-bedded quartzite with partings of silty shale near the top. However, where this formation crosses the White Mfolozi Gorge it grades laterally into dolomite and carbonate-cemented sandstone which occur as four vertically stacked lenticular bodies. The dolomite is of special significance, as it contains excellent small-scale stromatolites (Pls 2 and 3) which, according to Von Brunn and Mason (1977, p. 254), are very rare in rocks of this age.

The *Bivane Formation* comprises a thick sequence of dark-green amygdaloidal lava. Some small-scale pillow structures occur at different levels. The different flows can be recognised by the presence of well-developed amygdaloidal zones near their bases and tops.

Inliers of ferruginous shale with thin intercalated quartzite, the *Taka Formation*, are found in the valley of the Taka and Buffalo Rivers. They constitute the uppermost formation of the Nsuze Group.

5.1.2 Mozaan Group

The Mozaan Group, which unconformably overlies the Nsuze Group in this area, consists essentially of a lower arenaceous and an upper argillaceous sequence. It has a maximum exposed thickness of approximately 1 200 m (Matthews 1977). When traced south-eastwards the basal beds of the Mozaan Group overstep some 1 200 m of Nsuze strata. The characteristics of the Mozaan succession in the area indicate that it was deposited during an overall transgression with intermittent changes of sea-level.

Three formations could be distinguished in the Mozaan Group in this area (SACS 1980).

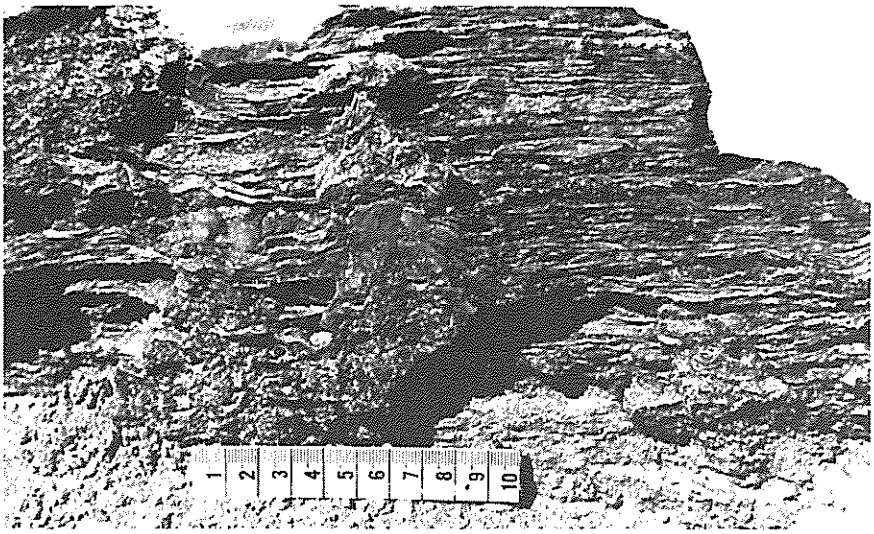

Plate 2 — Stromatolite in dolomite of the Nsuze Group in the bed of the White Mfolozi River. Photograph by courtesy of V. von Brunn.

Plaat 2 — Stromatoliet in dolomiet van die Groep Nsuze in die loop van die Wit-Mfolozirivier. Foto goedgunstig deur V. von Brunn voorsien.

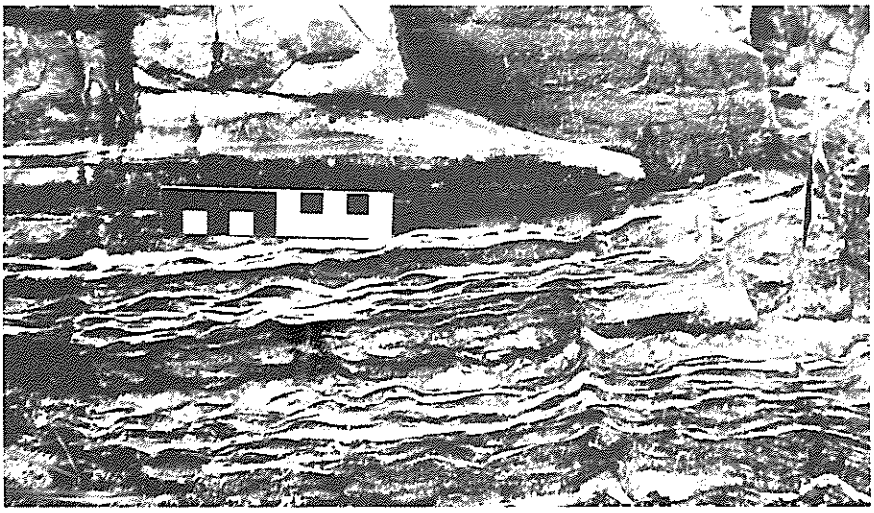

Plate 3 — Silicified undulatory carbonate-rich laminae (possibly an ancient algal mat) in the Nsuze Group in the bed of the White Mfolozi River. Photograph by courtesy of V. von Brunn.

Plaat 3 — Gesilisifiseerde, gekartelde, karbonaatryke laminas (moontlik 'n ou algemat) in die Groep Nsuze in die loop van die Wit-Mfolozirivier. Foto goedgunstig deur V. von Brunn voorsien.

The *Mandeva Formation* is composed of a basal conglomerate and a quartzitic iron formation unit. The conglomerate contains pebbles of vein quartz and quartzite with diameters of up to 200 mm, set in a fine-grained quartzitic matrix. It is of importance because of its locally auriferous nature, for example at the old Denny Dalton Mine. The quartzitic iron formation unit consists of a lower sequence of orthoquartzitic sandstone, followed upwards by green shale and beds of black and red iron formation and finally by an upper sequence of orthoquartzitic to argillaceous sandstone.

The *Mpunga Formation* consists predominantly of dark-grey shale with two or three thin, wedge-shaped intercalations of quartzite. Beds of dark shale with light-coloured siltstone laminae also occur.

The *Qwasha Formation* consists predominantly of ferruginous shale with many thin intercalated quartzitic sandstone beds varying from 0,5 m to 3 m in thickness.

5.1.3 Structural and metamorphic geology

The angular unconformity between the Nsuze and Mozaan Groups is indicative of a period of tilting and erosion prior to the deposition of the Mozaan Group. According to Matthews (1967, p. 58) the dip of the Mozaan strata is the result of slight east-north-easterly tilting that was probably accompanied by minor folding. He also describes faults that only displaced rocks of the Nsuze Group and therefore must be pre-Mozaan in age.

Although the rocks appear to be largely unmetamorphosed, contact-metamorphic effects were detected adjacent to diabase. This is best observed in the dolomitic rocks of the Nsuze Group where it resulted in the formation of a massive talc rock and tremolite schist. The mineral assemblages in these rocks are indicative of the hornblende-hornfels facies of contact metamorphism (Matthews 1967, p. 57).

5.2 NKANDLA AREA

This area constitutes the type area of the Nsuze Group while rocks of the Mozaan Group do not occur here (Du Toit 1931). The Nsuze rocks crop out in two large, west-ward-plunging, synformal structures which are separated by a thrust fault. A total of nine formations can be recognised (SACS 1980, p. 76) which are Hlathini, Mabaleni, Mome, Dlabe, Msukane, Mdlelanga, Qudeni, Vutshini and Mankane. The lowermost five formations occur to the south of the thrust fault and attain a thickness of more than 5 500 m. In the area north-west of Nkandla the lower three of these five formations cannot be mapped separately (Groenewald 1984) and are shown as a single unit on the map. The four formations north of the thrust are estimated to be more than 3 200 m thick.

The succession comprises mainly sedimentary rocks, but a number of substantial units of volcanic rocks are interlayered in the sediments. The sedimentary rocks are mainly quartzite with minor phyllite, conglomerate and iron formation. The quartzite is a white, fine- to medium-grained rock with intercalated gritty layers and conglomerate beds. The conglomerate contains rounded to angular pebbles which vary in diameter from

10 mm to more than 300 mm. Thin cherty beds, as well as thin, contorted bands of iron formation occur at several levels within the succession (Du Toit 1931). Rare occurrences of slate are found as thin conformable beds within the quartzite.

Tuff is only found in the lower part of the group where it occurs as fine-grained, greenish or reddish, rough-weathering, schistose beds containing lithic fragments up to 150 mm in length (Du Toit 1931). The matrix consists of muscovite or chlorite. Lava, which ranges from andesitic to basaltic, is found throughout the succession, usually at or near the top of formations. It is highly sheared in places and altered to chloritic schist (Du Toit 1931), predominantly greenish in colour and contains quartz-, chlorite- and calcite-filled amygdales.

The rocks of the Nsuze Group, especially the sediments, are well bedded, while a strong foliation, parallel to the bedding planes, is also developed. The dips are fairly steep, varying between 50 and 80 degrees. At least two phases of folding can be recognised in this area. The first was responsible for the development of the main foliation, while the second deformed this foliation and resulted in westward-plunging open synforms.

The rocks were also subjected to normal and thrust faulting. This may account for the extensive signs of shearing seen in them. The contact between the lower five and upper four formations of the Nsuze Group is characterised by a substantial tectonic melange zone.

5.3 UNDIFFERENTIATED NSUZE GROUP

The Nsuze Group shown as undifferentiated consists of a repetitive sequence of quartzite, tuff and basaltic lava. A conglomerate bed, up to 15 m thick, is locally developed in the vicinity of the Buffalo River (Du Toit 1931, p. 42–43). The quartzite, in which cross-bedding can be recognised in places, is a fine- to medium-grained rock with intercalated gritty horizons. The lava is usually greenish and amygdaloidal. All the rocks show signs of intense shearing.

6. POST-PONGOLA INTRUSIVE ROCKS

Several episodes of intrusion post-date the deposition of the Nsuze Group. These intrusives include ultramafic dykes, the layered sheet of the Hlagothi Suite, diabase sills and dykes, porphyritic dykes and syenite. All pre-date the main tectonic and metamorphic events which have affected the Nsuze Group (Groenewald 1984, p. 221).

6.1 HLAGOTHI SUITE*

Du Toit (1931) first noticed the layered mafic to ultramafic sills that intruded the Nsuze Group. He termed them the Hlagothi Igneous Complex and described them as a

* Not yet approved by South African Committee for Stratigraphy (SACS).

series of highly altered peridotite, gabbro and diorite. According to Groenewald (1984, p. 164) at least five layered sills can be recognised. Their combined thickness exceeds 500 m, the thickest single unit being about 200 m thick. The rocks, although generally conformable with those of the Nsuze Group, locally transgress and disrupt the sequence. Field relationships indicate intrusion prior to the main deformational events in the area (Groenewald 1984, p. 221).

The Hlagothi Suite consists of differentiated sheet-like bodies in which altered harzburgite, olivine websterite and wehrlite are overlain by olivine gabbronorite and pyroxenite. The upper part of each sheet consists of gabbro and leucogabbro (Groenewald 1984, p. 221). Fine-grained marginal rocks present in some of the sills contain skeletal pyroxene crystals analogous to the spinifex texture of extrusive komatiite (Groenewald 1984).

Gabbro constitutes a major part of the complex, occurring as sheets up to 70 m thick. The gabbro is a greenish grey, medium-grained, unfoliated rock, composed almost entirely of secondary replacement minerals. The mafic and ultramafic rocks of the complex are highly altered but, according to Groenewald (1984, p. 185), they consist predominantly of olivine, two types of pyroxene and plagioclase prior to alteration. Pigeonite, ilmeno-magnetite, biotite and chromite are the most common minor minerals.

Other pre-tectonic intrusions, too small to be shown on the map, occur as cross-cutting, irregular bodies and dykes. These have a gabbroic or pyroxenitic composition.

6.2 SYENITE (Rsy on map)

These coarse-grained syenite bodies are all intrusive into the Nsuze Group (Du Toit 1931, p. 75). The rocks are dark green and consist of hornblende, orthoclase and biotite, with minor amounts of magnetite, sphene, apatite and sulphide.

6.3 DIABASE (Rdi on map)

Diabase sills and dykes have extensively intruded the Pongola Sequence. Although Matthews (1977) regarded them as being pre-Mozaan in age, they were found to be clearly intrusive into the Mozaan Group. These diabases have undergone low-grade metamorphism which altered the original pyroxene to actinolite and chlorite. The rocks have a distinctive greenish colour as opposed to the dark-grey colour of the much younger Karoo dolerite.

7. NATAL STRUCTURAL AND METAMORPHIC PROVINCE

The rocks of this province, which is also generally known as the Natal Mobile Belt, were first investigated by Du Toit (1931), later by Matthews (1959) and more recently by students of the University of Natal as part of the National Geodynamics Project. Their mapping was compiled and published by Matthews and Charlesworth (1981).

Matthews (1981a) states that these rocks form part of the northern frontal zone. The northernmost part of this zone, named the Natal Thrust Belt, is a narrow, 2–5-km-wide, east–west-trending belt in which two lithostratigraphic units, namely the Ntingwe and Mfongosi Groups, have been mapped. In the southern part of the northern frontal zone four large, flat-lying thrust sheets were recognised, each comprising a number of formations and collectively named the Tugela Group. The thrust sheets pass southwards into a steeply dipping to vertical belt of highly deformed rocks, called the *Matigulu Group**, which may represent the downwarped root zone of Matthews's "Nappe Complex". This belt defines the southern limit of the frontal zone (Matthews 1981a).

7.1 NTINGWE GROUP

Rocks of this group rest either with a marked unconformity on those of the Nsuze Group, or with a sedimentary contact on the Archaean granite (Matthews 1959, p. 285). The Ntingwe Group is overlain by the Mfongosi Group. The contact between the two is structural, with the Mfongosi Group overthrust onto the Ntingwe Group (Pl. 4). Although not reflected on the map, three formations are recognised on a larger scale within the Ntingwe Group (SACS 1980).

The basal part of the Ntingwe Group comprises a succession of coarse clastics ranging in lithology from arkosic grit to coarse conglomerate (Pl. 5) and breccia containing rock fragments up to 30 cm in diameter. The succession attains a thickness of 100 m (Matthews 1959, p. 284). These basal beds are succeeded by a sequence consisting of alternating beds of blue mudstone and grit in which rare ripple marks occur. On top of these lie massive to coarsely bedded mudstone and shale, up to 150 m thick, in which impressions of carbonaceous material are found. Occasional conglomerate and thin beds of red and white limestone are intercalated in the shale. Above this argillaceous zones 30-m-thick red, arenaceous, ferruginous, dolomitic limestone occurs. The latter contains numerous interbedded mudstone beds which decrease in thickness upwards. The top part of the Ntingwe Group is represented by a 60-m-thick unit of white limestone. According to Matthews (1959, p. 284) this is a lithographic dolomitic limestone that contains a few thin, intercalated argillaceous beds.

7.2 MFONGOSI GROUP

The Mfongosi Group crops out in a fairly continuous belt along the frontal Natal Thrust Belt and consists of eight formations (Matthews and Charlesworth 1981). Four of these occur west of the Mfongosi Valley and the rest to the east of it.

Matthews (1959, p. 265–266) described the rocks in the western sector and established an apparent stratigraphic sequence. At the base of the succession is an undifferentiated, banded pyroxene-bearing or biotite-bearing hornblende gneiss, on top of which lies

* Not yet approved by South African Committee for Stratigraphy (SACS).

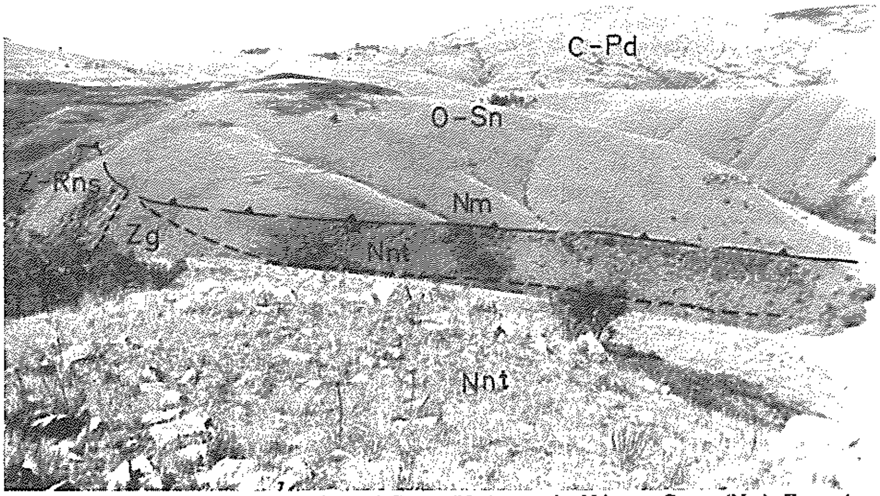

Plate 4 — Overthrusting of the Mfongosi Group (Nm) onto the Ntingwe Group (Nnt). Zg = Archaean basement granite, Z-Rns = Nsuze Group, O-Sn = Natal Group, C-Pd = Dwyka Formation. Photograph by courtesy of P. E. Matthews.

Plaat 4 — Oorskuiwing van die Groep Mfongosi (Nm) oor die Groep Ntingwe (Nnt). Zg = Argeïese vloergraniet, Z-Rns = Groep Nsuze, O-Sn = Groep Natal, C-Pd = Formasie Dwyka. Foto goedgunstig deur P. E. Matthews voorsien.

Plate 5 — Basal conglomerate in the Ntingwe Group. Photograph by courtesy of P. E. Matthews.

Plaat 5 — Basale konglomeraat in die Groep Ntingwe. Foto goedgunstig deur P. E. Matthews voorsien.

coarse, foliated or massive amphibolite. The latter locally contains metamorphosed amygdales and volcanic structures. It is succeeded by laminated quartz-chlorite-sericite schist with intercalated bands of quartz-carbonate-chlorite schist. The latter is sometimes altered to a calc-silicate rock. A pale, fine-grained quartzite, in places pebbly, occurs locally within this unit. These rocks are followed by chlorite-epidote schist in which small amounts of talc, carbonate and albite occur, as well as chlorite-epidote amphibolite. Metamorphosed amygdales and deformed pillow lava indicate a volcanic origin. A band of siliceous iron formation, approximately 6 m thick, is interbedded with the schist and amphibolite. The top part of the succession comprises phyllitic quartz-muscovite (chlorite) schist which contains abundant quartz-secretion veins.

The Mfongosi Group in the eastern sector was described by Smalley (1980) and Charlesworth (1981). In this area the basal part of the Mfongosi Group consists of a succession of fine-grained biotite-muscovite-quartz schist in which porphyroblasts of red garnet and brown staurolite can be locally observed. Associated with these rocks are discontinuous lenses and veins of granular quartz which are concordant with the southerly dipping schistosity. The second unit consists of well-foliated medium- to fine-grained, metabasic, phyllitic schist which contains chlorite and quartz with minor biotite and sericite. The third unit comprises fine- to medium-grained, crenulated, silvery, quartz-sericite schist which weathers to a brownish clay. Small amounts of chlorite often give a pale-green colour to these rocks. The stratigraphically highest unit of the Mfongosi Group in the eastern sector consists essentially of quartz-chlorite-sericite schist with subordinate sandy phyllite, quartzite and banded ironstone. Chlorite-amphibole schist, siliceous chlorite mylonite and garnet-chlorite-quartz schist also occur.

7.3 TUGELA GROUP AND ASSOCIATED INTRUSIVES

The outcrop area of the Tugela Group can be divided into an eastern and a western sector, separated by an area covered by rocks of the Natal Group in the vicinity of Eshowe.

The Tugela Group is present in four sub-horizontal thrust sheets. Due to a regional, but variable, westerly structural plunge, the thrust sheets crop out in an ascending structural sequence from east to west (Matthews 1981a) and comprise the Nkomo, Madidima, Mandleni and Tugela Nappes. Of special interest is the occurrence of extensive, but discontinuous, sheets of talc schist. A number of formations have been recognised in each thrust sheet or nappe and are briefly described.

7.3.1 Nkomo Nappe

The lowermost thrust sheet was mapped in detail by Charlesworth (1981). It is made up of a syenitic gneiss and three amphibolitic formations which were intruded by granite gneiss and a metabasic complex. This nappe crops out in both the eastern and western sectors.

The *Bulls Run Syenite-Gneiss Formation* occurs only in the western sector. It is composed of a medium-grained, mesocratic, syenitic gneiss with potash feldspar, plagioclase and biotite.

The three amphibolite formations have been named the *Khomo, Woshane* and *Mtengu Amphibolite Formations* (SACS 1980; Charlesworth 1981). The first two are in the western sector, whilst the last mentioned is in the eastern sector. They are very similar in appearance, consisting of foliated, fine- to medium-grained, melanocratic amphibolite in which hornblende and plagioclase are the dominant minerals. Biotite and chlorite may be present in subordinate quantities.

The *Halambu Granitoid-Gneiss Formation* occurs in both the eastern and western sectors. It is clearly intrusive, fine to medium grained, and varies in composition from granodiorite to granite. It displays a strongly developed foliation. Biotite is the main mafic mineral, while hornblende may be present in minor quantities. The Halambu Granitoid Gneiss also contains numerous xenoliths of mafic material that are now drawn out to form thin lenticular bands parallel to the foliation (Pl. 6).

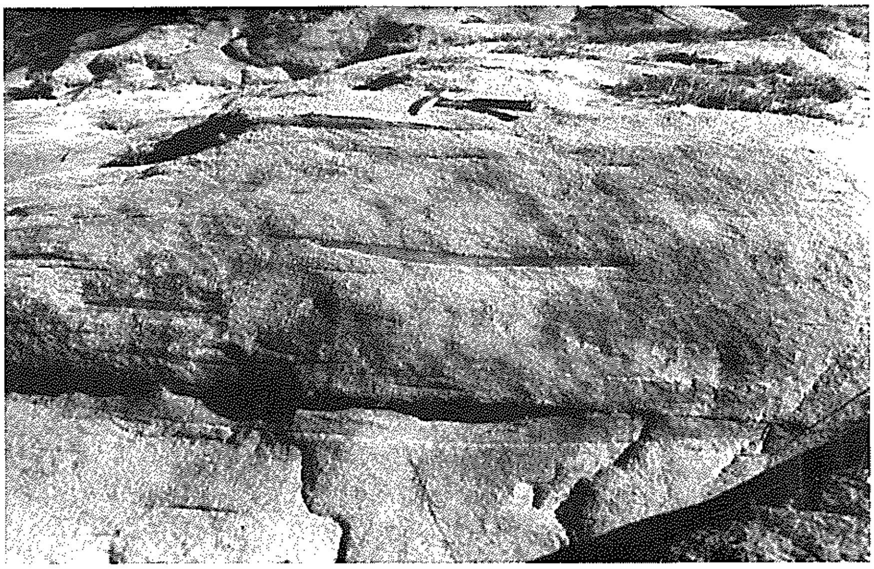

Plate 6 — Stretched-out mafic xenoliths in the Halambu Gneiss. Photograph by courtesy of P. E. Matthews.

Plaat 6 — Uitgerekte mafiese xenoliete in die Halambugneis. Foto goedgunstig deur P. E. Matthews voorsien.

The *Hlobane Complex* occurs in the eastern sector where it is in contact with the rocks of the Mtengu Formation. The Hlobane Complex consists of weakly foliated to massive medium- to coarse-grained meta-igneous rocks. They range in composition from olivine norite through troctolitic gabbro to normal gabbro. The contacts are gradational. Thin anorthosite and serpentinite bands also occur. According to Charlesworth (1981, p. 57) the relationship between the complex and the Mtengu Formation is problematical. He argued that possibly the gabbroic rocks of the Hlobane Complex had intruded the Mtengu Formation, both having subsequently undergone a period of alteration and deformation.

The *Ngoye Granite-Gneiss Formation* was first described by McCarthy (1961) and again by Charlesworth (1981). Both authors described it as a fairly homogeneous intrusive unit. More recent work by Scogings (1985, in prep.), however, revealed the presence of at least eight different types of gneiss and granite in what is generally known as the "Ngoye Massif". For practical reasons these are grouped into four units which are shown on the map. Very coarse-grained biotite granite gneiss, which was regarded by both McCarthy (1961) and Charlesworth (1981) as being the typical lithology of the Ngoye Massif, was found to actually comprise only twenty per cent of the outcrop area (Scogings 1985, in prep.). It is grey to pinkish in colour with pink microcline phenocrysts set in a groundmass of plagioclase, quartz and biotite. Pink to white muscovite-biotite granite gneiss underlies the northern portion of the massif. Biotite is the main mafic mineral, but finer-grained varieties of this granite also contain muscovite and even reddish garnet. The medium-grained biotite-hornblende granite gneiss contains far more microcline than plagioclase with biotite and hornblende as the mafic minerals. Magnetite microgranite gneiss (peralkaline type), is found along the southern boundary of the massif and has magnetite as the predominant mafic mineral. It is a light-pink, fine-grained granite in which microcline perthite greatly exceeds plagioclase. Streaks and pods of coarser quartz and magnetite-rich material, which are usually radioactive, are found in places. Other granitic rocks that occur in minor quantities in the massif include riebeckite-bearing granite gneiss, and a quartz-monzonite gneiss.

Although the Ngoye Granite Gneiss has been placed in the Nkomo Nappe by Charlesworth (1981) and Matthews and Charlesworth (1981), Cain (1973) was of the opinion that it formed a displaced extension of the porphyroblastic gneiss (now called the megacrystic granite gneiss) intrusive into the Mapumulo Metamorphic Suite to the south of this area.

The only ultramafic intrusives in the western sector occur as small bodies of *hornblendite* (Nh on map) and *serpentinite* (Ns on map) which intruded the Khomo Amphibolite Formation.

7.3.2 Madidima Nappe

This tectonic unit was mapped in some detail by Rigotti (1977), Schulze-Hulbe (1977) and Charlesworth (1981). It occurs in both the eastern and western sectors. The above authors recognised six formations in this unit. The only intrusive rocks are a metabasic complex and some small serpentinite bodies. The first is found in the eastern sector and the latter in the western.

The *Silambo, Zwaneni* and *Endlovini* Formations* all consist of essentially amphibolite of similar appearance. The first two occur in the western and the Endlovini in the eastern sector. The amphibolite formations comprise a variety of mineral assemblages in which hornblende and plagioclase are dominant. The amphibolite locally contains garnet or epidote. Both banded and homogeneous amphibolite occurs. Dolomite, quartzite and magnetite quartzite are associated with the homogeneous amphibolite in places.

Both the Zwaneni and Silambo Formations are intruded by small bodies of *serpentinite* (Nu on map).

The *Zidoni Amphibolite Formation* is found in the western sector. It comprises streaky and banded amphibolitic gneiss containing plagioclase, hornblende and biotite. The formation appears to be intermediate in composition between the amphibolite formations and the mica schist and biotite-gneiss formations which will be discussed below. The contacts between the different formations are transitional.

The *Gazeni Mica-Gneiss Formation* consists of micaceous schist and gneiss containing biotite, muscovite, quartz, plagioclase, garnet and staurolite. The rocks are well foliated and fine or medium grained.

The *Thawini Gneiss Formation* is composed of light-grey, well-foliated gneiss consisting of plagioclase, quartz and biotite, with or without hornblende. Minor minerals include epidote, garnet, magnetite, sillimanite, staurolite and cordierite.

The *Mlalazi Complex* is found in the eastern sector. It comprises three lithological units, namely a thrust-bound serpentinite body, ultramafic schist and metagabbro. The serpentinite body consists of well-foliated, fine- to medium-grained melanocratic serpentinite, with minor metapyroxenite. Thin layers of talc schist are found along some of the thrust boundaries. A poorly defined layering can be observed locally within the serpentinite body. The ultramafic schist is a dark, fine- to medium-grained rock with varying proportions of talc, amphibole and chlorite. It is locally discordant with respect to the underlying amphibolite formation. The leucocratic to melanocratic gabbro is fine to medium grained, well to poorly foliated and contains numerous inclusions of amphibolite.

7.3.3 Mandleni Nappe

This tectonic unit, mapped by Rigotti (1977), Schulze-Hulbe (1977) and Smalley (1980), is confined to the western sector. It comprises four formations and two intrusive mafic and ultramafic bodies.

* Not yet approved by South African Committee for Stratigraphy (SACS).

The *Dondwana Gneiss Formation* is composed of grey biotite-feldspar gneiss and hornblende-biotite gneiss. The main minerals are quartz, plagioclase and biotite, with subordinate hornblende. Small lenses of garnetiferous gneiss are locally developed. The rocks are highly folded and show prominent migmatitic banding.

The *Dulumbe Gneiss Formation* comprises quartz-biotite gneiss and quartz-sillimanite-garnet-biotite gneiss. It is the only formation in this tectonic unit that is primarily a metapelitic rock. Porphyroblastic garnet is very common, and is concentrated in bands and lenses.

The *Tondweni Gneissic Amphibolite Formation* consists of a dark-coloured hornblende-plagioclase gneiss (with or without diopside and quartz) that is characterised by prominent folded migmatitic banding.

The *Wosi Amphibolite Formation* consists of amphibolite containing more than 50 per cent hornblende and is dark grey to greenish black with white specks of feldspar. It is well foliated with the feldspar occurring in streaked-out lenses parallel to the foliation. Minor quantities of diopside, garnet and epidote are present. Fine- to medium-grained quartzite and magnetite-bearing quartzite occur in this formation as narrow bands or lenses. Their magnetite content varies considerably over short distances. Grunerite is sometimes associated with the magnetite.

The *Sithilo Serpentinite-Talc Complex* is composed of a number of serpentinitic talc schist bodies. Rigotti (1977, p. 29) states that most of the larger serpentinite bodies have transgressive, shallow-dipping contacts. The serpentinite is mainly composed of serpentine and asbestiform amphibole. Chromite and magnetite veins as well as silica ribbing are also present. Interbanded talc schist, talc-chlorite schist, talc-actinolite schist and talc-actinolite-chlorite schist usually form a rim around the larger serpentinite bodies. Rigotti (1977, p. 31) regards the ultrabasic schist as being intrusive into the rocks of the Mandleni Nappe in the form of sills, sheets or dykes, which were subsequently altered to the schistose rocks.

The *Mambulu Complex* is the larger of the two intrusive complexes in the nappe. It is composed mainly of leuco- and melano-gabbronorite, websterite, diallagite and anorthosite (Schulze-Hulbe 1979, p. 44). This complex is intrusive into the Dondwana, Tondweni and Wosi Formations, with the contacts dipping towards the centre of the body. Fine- to medium-grained, alternating lenses of hornblende gabbro, norite and pyroxenite occur near the margin of the complex. They are traversed by coarse-grained pegmatitic dykes of diallagite and anorthosite. The rocks in this marginal zone have locally been amphibolitised to hornblendite. Thin, unconformable lenses of titaniferous magnetite occur throughout the whole body, but are more common in the marginal zone. The central portion of the complex is less basic, but more uniform in composition than the marginal zones. The central part is composed of medium- to fine-grained, greenish grey gabbronorite and is usually unfoliated although the rocks locally have a banded appearance. The whole complex was folded and warped during at least two phases of deformation.

7.3.4 Tugela Nappe

This tectonic unit was investigated by Rigotti (1977), Harmer (1979) and Smalley (1980). It comprises two formations which were intruded by tonalite, sheets of metagabbro, an ultramafic complex, diorite as well as granite.

The *Tuma Formation* consists of an interlayered sequence of metapelitic schist and gneiss, metapsammitic schist and gneiss and metavolcanic schist and gneiss. The metasediments contain abundant muscovite and biotite, in addition to kyanite and garnet. With increasing quartz and feldspar content the metapelite grades into buff- to grey-coloured psammitic gneiss. Rare graphitic schist occurs within this metasedimentary succession. The metavolcanic member includes amphibolite and chlorite-actinolite schist. The amphibolite very often displays grey-green pillow structures composed of a fine-grained aggregate of epidote, hornblende and actinolite with subordinate chlorite. The pillows are separated by a fine-grained matrix of hornblende and chlorite containing globular masses of lava. The pillow structures have been deformed such that their outlines have become locally indistinct. The amphibolite varies from a well-foliated to a massive rock. It is composed mainly of hornblende and plagioclase with minor epidote and or garnet. Where shearing has been intense, the amphibolite has undergone retrograde metamorphism to dark, greenish grey chlorite and chlorite-actinolite schist.

The *Manyane Amphibolite Formation* consists of interfolded medium-grained, streaky, veined, or massive amphibolite (Pl. 7). The rock is composed of hornblende (50 per cent) plagioclase and quartz.

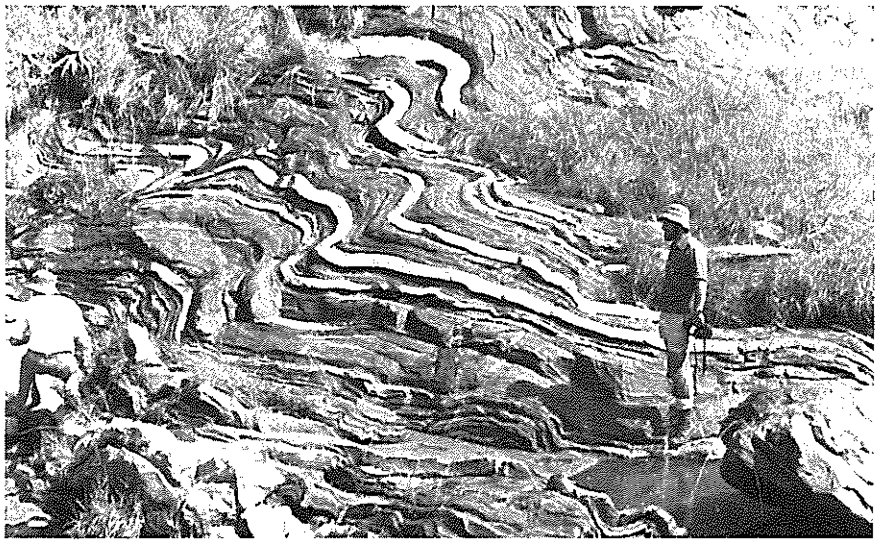

Plate 7 — Typical folded amphibolite of the Manyane Formation.
Plaat 7 — Tipiese geplooide amfiboliet van die Formasie Manyane.

The *Kotongweni Tonalite* contains up to 30 per cent hornblende, with occasional red-brown garnet. It is coarse grained and usually massive, with a foliation only sporadically developed. Coarse-grained pegmatite, some of which is zoned, occurs as narrow sheets and irregular lenses within the tonalite. The tonalite contains rafts of amphibolite, ranging from 10 to 50 cm in length. Harmer (1979, p. 28) regards the tonalite as being intrusive into the Manyane Formation.

The *Tugela Rand Complex* is intrusive into the rocks of the Tugela Nappe. It is composed of a differentiated sequence of ultramafic to mafic igneous rocks. The basal unit is a pale, grey-green serpentinite containing xenoliths of Manyane amphibolite. The serpentinite was subsequently intruded by the other components of the ultramafic suite. These consist of coarse, pale-green serpentinite and black serpentinite, developed by autometamorphism from orthopyroxenite and peridotite dunite (Lambert 1962). A period of intensive folding followed the emplacement of the ultramafic suite. The deformed ultramafic rocks were subsequently intruded by the gabbroic rocks of the mafic suite. The latter is composed of medium-grained websterite, troctolite gabbro and bronzitite norite which grade into each other.

The *Mkondeni Diorite** consists of a variety of medium-grained mesocratic, biotite-bearing dioritic rocks. Harmer (1979, p. 49) noted small quantities of hypersthene in the diorite. The hypersthene-bearing diorite locally grades into mesocratic, medium-grained biotite-hornblende gneiss. Injection migmatite, in which flow folds are a common feature, is usually developed along the contact of the diorite with the amphibolite of the Manyane Formation.

The *Dimane Granite** is intrusive into both the Mkondeni Diorite and the Tugela Rand Complex. It is a medium- to coarse-grained, pink to pinkish orange rock with minor biotite. A westerly dipping foliation becomes apparent with increasing biotite content. Numerous fine-grained, leucocratic, aplitic sheets, possibly associated with the Dimane Granite, cut both the amphibolite of the Manyane Formation and the other intrusive rocks in the Tugela Nappe.

Sheets of metagabbro (Nho on map), consisting of coarse-grained, unfoliated hornblendite grading into plagioclase amphibolite, are found in the Manyane Formation. Relict pyroxene and igneous textures can be seen in thin section and the rocks can be termed metapyroxenite, metagabbro or meta-anorthositic gabbro. These rock types, however, grade into each other. Actual contacts between them and the Manyane Formation were not observed, but Harmer (1979, p. 25) describes some discordant relationships between them and the Manyane Formation, which he regards as proof of an intrusive relationship.

* Not yet approved by South African Committee for Stratigraphy (SACS).

A second meta-igneous complex, the *Macala Complex,* has intruded into the rocks of the Manyane Formation. It consists mainly of gabbroic rocks with minor serpentinite and thin bands of titaniferous magnetite, though no details are known.

7.4 MATIGULU GROUP*

This highly deformed belt of vertical or steeply inclined rocks forms the most southerly thrust unit in the area. It probably represents the down-warped root zone of the Nappe Complex and it defines the southern limit of the northern frontal zone (Charlesworth 1981; Matthews and Charlesworth 1981). However, Cain (1973) stated that these rocks have characteristics more akin to those of the Mapumulo Group than the Tugela Group.

This steep zone was mapped by Schulze-Hulbe (1977) and Charlesworth (1981), who recognised five formations and an intrusive granitic gneiss. Four of the formations occur in the map area.

The *Thondo Amphibolite Formation,* restricted to the south-eastern part of the area, is composed of banded biotite-bearing amphibolitic gneiss displaying small-scale alternations of mafic and felsic material which accentuates the high degree of deformation to which the rocks were subjected. Contacts with the adjacent rocks are largely tectonically modified, though the formation appears to be concordant with, and to grade locally into, the Intuze Gneiss Formation.

The *Intuze Gneiss Formation* occurs in the eastern part of the steep belt. It consists of fine-grained, grey, highly deformed, finely banded and streaky biotite-rich gneiss with numerous infolded, thin, impersistent quartz-feldspar veins and sheets. These differ from the Buhleni Granitoid-Gneiss Formation in their higher biotite content and the occurrence of garnet and sillimanite.

The *Sequembi Amphibolite Formation* also occurs in the western part of the steep zone. It is characterised by a colour index of more than 50 per cent, usually with hornblende dominant. Hornblende amphibolite, locally with diopside and/or epidote are the main rock types. They are well foliated with a dark-green to green-black colour. Agmatite, consisting of breccia blocks and rafts of banded and streaky amphibolite, are common in the amphibolitic rocks of this formation. Thin bands and lenses of magnetite quartzite and dolomitic limestone occur at various levels within the formation.

The *Mpisi Gneiss Formation* is found in the western half of the steep zone. It consists of biotite-feldspar gneiss in which hornblende is present locally. The rocks are strongly foliated and intensely folded and yellow to light grey in colour with a composition that ranges from tonalite to quartz diorite.

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* Not yet approved by South African Committee for Stratigraphy (SACS).

The *Buhleni Granitoid-Gneiss Formation* is intrusive into the Thondo and Intuze Formations and restricted to the eastern and central parts of the steep belt. It consists of a heterogeneous succession comprising banded quartz-feldspar gneiss, biotite granitic gneiss, flaser gneiss and mylonite. The gneisses are fine to medium grained and consist of alternating dark biotite-rich and light-coloured, more quartzo-feldspathic bands. These rocks are furthermore characterised by the presence of bands and lenses of amphibolite and bands of pegmatite.

7.5 MAPUMULO METAMORPHIC SUITE*

Rocks of this suite occupy a very small area in the south-eastern part of sheet 2830. They consist of undifferentiated banded hornblende-bearing gneiss, biotite gneiss, quartzo-feldspathic gneiss and migmatite.

7.6 TECTONICS AND METAMORPHISM

Matthews (1981b) postulates that the evolution of the northern sector of the Natal Mobile Belt commenced with the southward obduction of an ophiolite complex (Tugela and Matigulu Groups) onto an island arc complex (Mapumulo Metamorphic Suite). Subsequent northward movement of this assemblage above a southerly inclined subduction zone brought the ophiolite–island arc complex into a collision situation with the Kaapvaal Craton to the north. During the collision event thrust slices of this complex were driven northward across a volcanic-sedimentary wedge onto the Kaapvaal Craton. Remnants of the wedge, which lay along the southern flank of the craton, are preserved as the Mfongosi and Ntingwe Groups within the Natal Thrust Belt.

Matthews (1981a) states that, although there is an apparent increase in metamorphism southwards from the thrust-front, the original zonation was modified by the northward overthrusting which has brought upper amphibolite facies migmatitic gneisses of the Tugela Group in juxtaposition with greenschists of the Mfongosi Group along the northern boundary of this nappe complex. He came to the conclusion that the rocks of the nappe complex are polymetamorphic and have been affected by at least three major phases of deformation.

The first phase of deformation (D_1) resulted in the development of the large and small-scale, sub-isoclinal folds and a strong, penetrative axial-planar foliation parallel to the lithological layering. This phase of deformation was accompanied by extensive migmatisation, local remobilisation of the granitic rocks and the emplacement of sheets and veins of granitic material. The metamorphic mineral assemblages indicate upper-amphibolite facies of metamorphism.

* Not yet approved by South African Committee for Stratigraphy (SACS).

The second phase of deformation was a regional episode of lateral ductile shearing with a component of northward rotation. This resulted in the reorientation of the D_1 fold system to a low, southerly inclination. It also caused the stretching and disruption of the more competent lithological units, especially the granitic rocks. This phase of deformation was accompanied by a slight change of metamorphic conditions to a higher pressure regime, as indicated by the presence of high-pressure minerals in the rocks.

The third phase of deformation resulted in the northward displacement of the nappe complex. It is estimated that the total displacement involved during this period of overthrusting was not less than 100 km. Prior to this thrusting a series of extensive, almost horizontal sheets of ultrabasic material were emplaced more or less parallel to the major fold limbs. These sheets subsequently acted as weak zones along which the rocks moved during thrusting. This nappe-forming episode of deformation was characterised by the formation of wide-spread disharmonic folds indicative of overthrusting to the north. This third phase of deformation took place under amphibolite facies of metamorphism, while there are indications of retrogressive effects along the northern boundary with the thrust belt.

8. NATAL GROUP

Sutherland (1868) first correlated the Natal Group with the rocks of the Ordovician–Silurian Table Mountain succession of the south-western Cape Province. This correlation was accepted by most geologists. Recently, however, Locke (1973), on palaeontological evidence, assigned a substantially younger age to the Natal rocks, correlating them with the Devonian Witteberg Group of the Cape Province.

The Natal Group crops out in the eastern part of the area, where it unconformably overlies the basement rocks. According to Du Toit (1931, p. 80) the floor of the Natal Group was eroded to a fairly even surface south of Mfongosi, while north of Mfongosi, the surface is very uneven. The present outcrop area is characterised by a flat scarp-bounded plateau, as can be seen just north of Kranskop.

The Natal Group sediments comprise a clastic wedge that varies considerably in thickness across the area. This is illustrated by the recorded thickness of a minimum of 15 to 30 m west of Kranskop (Smith 1977, p. 3) to a maximum thickness of about 500 m in the Mhlatuze trough near Eshowe (Du Toit 1931, p. 81). Northwards from here the thickness decreases to only about 150 m near Hlabisa (Watson and McGeorge 1977, p. 8).

The base of the Natal Group is marked by a basal conglomerate (Pl. 8) with an average thickness of about 10 m. This conglomerate consists of well-rounded quartzite boulders with a diameter that ranges from a few centimetres to about 30 cm. It is overlain by a succession of upward-fining sequences of grit, medium- to fine-grained, quartzose sandstone and occasionally arkosic sandstone, siltstone and shale. The sandstone is red to light purple in colour and cross bedded, while the mudrocks are maroon coloured and often very micaceous.

The Natal Group represents a substantial accumulation of fluviatile sediments which were deposited by an extensive braided-river system within a lowland trough, the Natal Embayment (Visser 1974). Hobday and Von Brunn (1979, p. 169) described the trough as an Early Palaeozoic failed rift, a local precursor of Gondwanaland fragmentation. This trough has a regional axial trend directed towards the south or south-west, more or less parallel to the present-day coastline (Matthews 1970). The basal conglomerate was interpreted by Hobday and Von Brunn (1979, p. 174) as having accumulated in an intermontane environment, while the provenance was subjected to rapid physical weathering due to an ineffective vegetation cover. The oxidation of the sediment and arkosic composition of some of the sandstone and consistent south-westerly palaeocurrent direction are indicative of deposition on a sandy alluvial floodplain (Hobday and Von Brunn 1979, p. 178).

9. KAROO SEQUENCE

9.1 DWYKA FORMATION

Rocks of this formation unconformably overlie various older rocks including granitic rocks of the Kaapvaal Craton, the Nsuze Group and the Natal Group. The uneven floor upon which the Dwyka rocks were deposited has resulted in a considerable variation in the thickness of the formation. The thickness ranges from 100 m north of Tugela Ferry to about 180 m near Kranskop (Du Toit 1931, p. 10), 250 m south-west of Babanango (Botha 1938, p. 30) and about 300 m in the Kohlwa Valley (Smith 1977, p. 4).

Plate 8 — Basal conglomerate in the Natal Group.
Plaat 8 — Basale konglomeraat in die Groep Natal.

The main rock type of the Dwyka Formation is a massive tillite. It has a very fine-grained, blue-grey to greenish matrix in which erratics, ranging in diameter from a few centimetres to more than 2 m, occur. The most common erratics are granite, gneiss, schist, diabase, quartzite, andesitic lava and quartz porphyry, which were apparently derived from the underlying basement rocks. Thin sandstone beds, occurring near the top of the formation, are developed over most of the area. This sandstone is usually very fine grained and quartzose, but a few coarser-grained and feldspathic types have been recorded. Other minor rock types include shale with occasional dropstones, and varved shale described by Botha (1938, p. 27).

From glacial striations on the underlying floor rocks (Pl. 9), it appears that the major ice movement was towards the south-west (Smith 1977). In additional Du Toit (1931, p. 81) also records a direction towards the south-east.

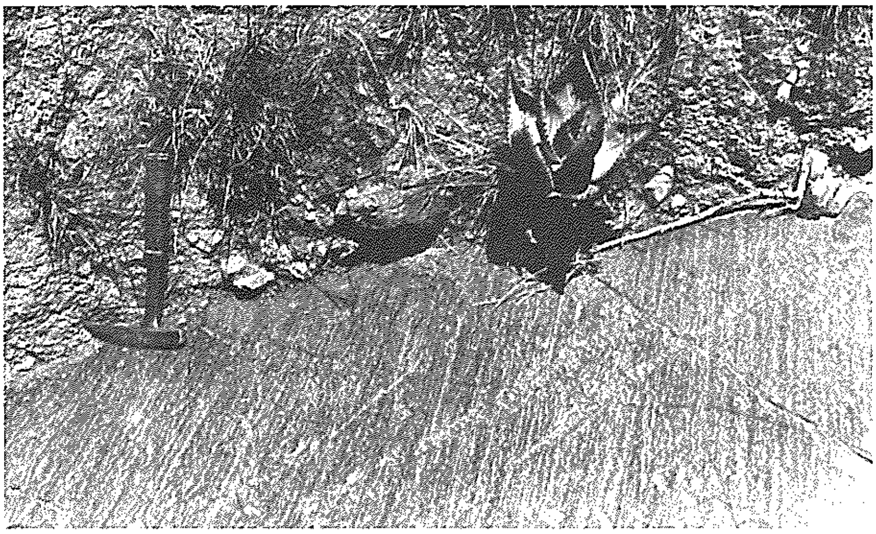

Plate 9 — Glacial striations on orthoquartzite of the Mozaan Group with overlying, weathered diamictite of the Dwyka Formation near Denny Dalton. Photograph by courtesy of V. von Brunn.
Plaat 9 — Gletserskrape op ortokwartsiet van die Groep Mozaan met oorliggende, verweerde diamiktiet van die Formasie Dwyka naby Denny Dalton. Foto goedgunstig deur V. von Brunn voorsien.

9.2 ECCA GROUP

9.2.1 Pietermaritzburg Formation

The Pietermaritzburg Formation overlies the Dwyka Formation with a sharp conformable contact. It consists of a fairly uniform succession of dark-grey, blue or black, usually well-bedded shale showing very little variation throughout the area. It weathers to a yellow, clayey rock that crumbles readily. Silty beds occur near the top of the formation. The thickness of the formation varies considerably over the area. Botha (1938, p. 33) mentions a thickness of about 50 m near Italeni, Watson and McGeorge (1977, p. 12) recorded 150 m near Hlabisa, while Du Toit (1931, p. 88) states that the thickness diminishes steadily in a northerly direction, from about 300 m in the Upper Inadi Valley to 50 m at Isandhlwana. In boreholes drilled in the search for oil a few kilometres south-west at Dannhauser, the thickness of the formation varies from 24 to 80 m.

The Pietermaritzburg Formation is widely believed to have been deposited in an extensive, relatively shallow body of water but the problem of whether it was an open ocean, an epicontinental sea or a large lake has not been settled. A brackish epicontinental sea is apparently favoured by most authors.

9.2.2 Vryheid Formation

The Vryheid Formation lies with a conformable transitional contact on the rocks of the Pietermaritzburg Formation. Interlaminated shale, siltstone and sandstone are developed in the basal part. These beds pass upwards, with increasing grain size, into laminated or cross-laminated, medium- to fine-grained sandstone. This facies is overlain by coarse-grained, cross-bedded sandstone and grits in units of up to 10 m thick (Matthews 1977, p. 11).

The Vryheid Formation can be genetically subdivided into a number of regressive cycles of sedimentation which are mainly of deltaic origin (Van Vuuren and Cole 1979; Hobday 1973). The ideal vertical arrangement of lithofacies from the base upwards are: dark-grey to black prodelta shale and siltstone, grading through a transition zone of interlaminated shale, siltstone and cross-laminated to horizontally laminated fine-grained sandstone, which represents a distal distributary mouth-bar succession. There then follows a thick, fine- to coarse-grained cross-bedded distributary mouth-bar sandstone (Pl. 10) which is sharply overlain by overbank delta-plain siltstone, fine- to coarse-grained sandstone and black shale containing thin coal seams in places, or by thick, medium- to coarse-grained cross-bedded distributary-channel sandstone with scattered thin gritstone and small-pebble conglomerate beds or lenses. Some of these channel sandstones display upward-fining grain-size trends.

In the Dannhauser area, where the Vryheid Formation comprises seven regressive cycles, the third one from the top is terminated by a sequence of upward-fining meander river-valley units and relatively thin upward-coarsening upper delta-plain units containing the two economical coal seams that are mined in the area.

Sandstone of the Vryheid Formation is generally poorly sorted, specifically that deposited in channels, and is slightly to moderately micaceous and feldspathic. Distal distributary mouth-bar successions are extensively load casted and frequently contain slump structures and turbidites with scattered grit grains, and gritty sandstone lenses, indicating very rapid deposition.

The deltas are considered to have been of the fluvially dominated type and progradation was in 'n south-westerly direction (Hobday 1973; Van Vuuren 1983). However, herringbone cross-bedding occurring in the upper parts of regressive units in places (Pl. 11) indicates current reversals either due to tidal currents or storm-generated waves.

Sedimentary structures in distal distributary mouth-bar successions and particularly in thin delta-abandonment units at the top of upward-coarsening cycles are frequently destroyed due to intense bioturbation (Pl. 12). Plant fossils are found associated with the coal. Although they are usually poorly preserved, several species of *Glossopteris* have been identified.

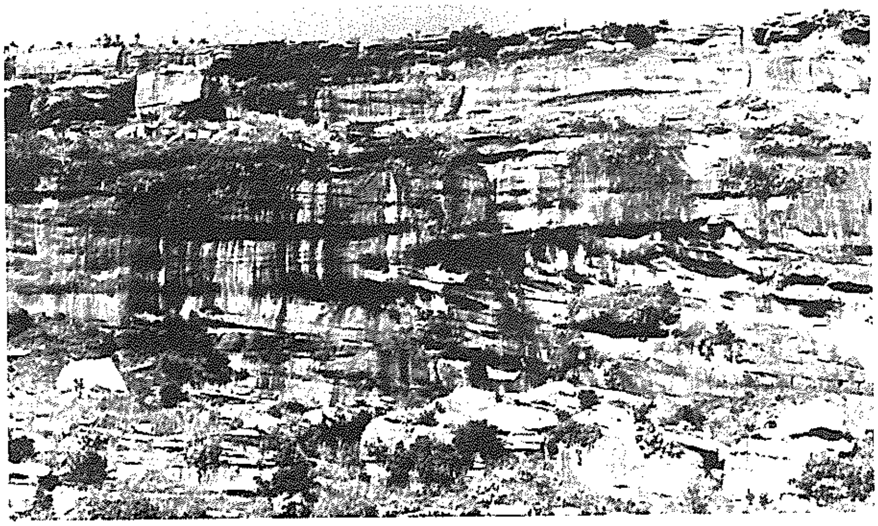

Plate 10 — Large-scale cross-bedding in prograding delta-front deposits in the Vryheid Formation south of Nqutu. Compare boy on top for scale. Photograph by courtesy of V. von Brunn.

Plaat 10 — Grootskaalse kruisgelaagdheid in prograderende deltafrontafsetting in die Formasie Vryheid suid van Nqutu. Vergelyk seun aan bokant vir skaal. Foto goedgunstig deur V. von Brunn voorsien.

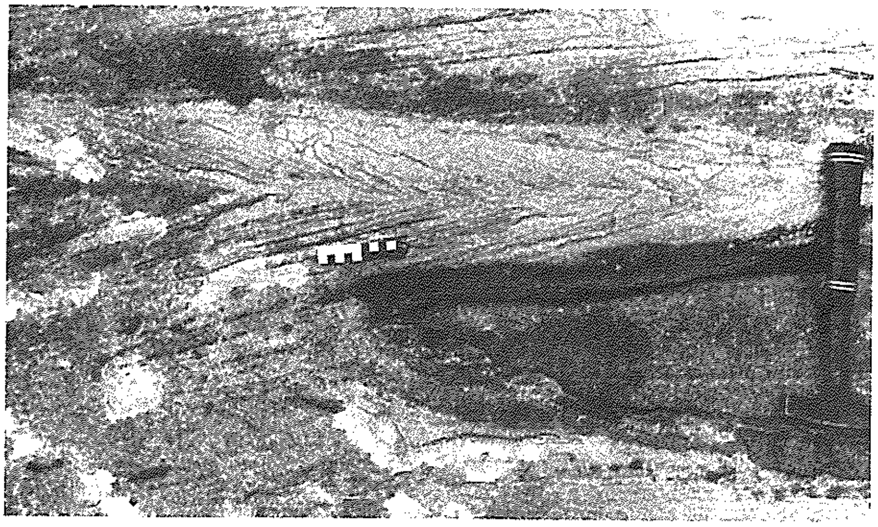

Plate 11 — Herringbone cross-stratification indicating current reversals, either due to tidal- or storm-generated waves in the Vryheid Formation south of Nqutu. Photograph by courtesy of V. von Brunn.

Plaat 11 — Visgraatkruisgelaagdheid wat dui op stroomomkering as gevolg van gety- of stormverwekte golwe in die Formasie Vryheid suid van Nqutu. Foto goedgunstig deur V. von Brunn voorsien.

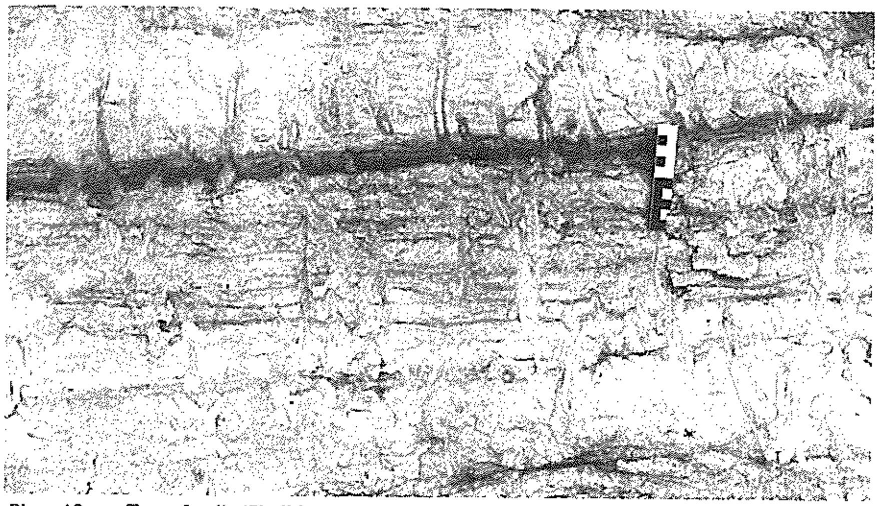

Plate 12 — Trace fossils (Skolithos) and bioturbation of deltaic sandstone in the Vryheid Formation south of Nqutu. Photograph by courtesy of V. von Brunn.

Plaat 12 — Spoorfossiele (Skolithos) en bioturbasie van deltaïese sandsteen in die Formasie Vryheid suid van Nqutu. Foto goedgunstig deur V. von Brunn voorsien.

The Vryheid Formation attains a thickness of 445 m south-west of Dannhauser, 400 m near Tugela Ferry (Hobday 1973) and thins towards the south and south-west due to gradation of sandstone in its upper and lower parts into shale of the Volksrust and Pietermaritzburg Formations respectively. The Vryheid–Volksrust and Vryheid–Pietermaritzburg Formation boundaries are therefore highly diachronous.

Concomitant with the total thinning towards the south, the whole succession becomes also more "marine". The most fluvial part, containing the economic coal seams in the Dannhauser–Dundee area, grades southward into lower delta-plain deposits in which conditions were unfavourable for the development of thick coal seams, and eventually into an offshore succession (Van Vuuren 1983).

9.2.3 Volksrust Formation

This formation conformably overlies the Vryheid Formation and the contact is taken at the top of the topmost sandstone of the Vryheid Formation. The Volksrust Formation is composed mainly of blue-grey and black, well-laminated, fissile shale, while thin lenses of fine-grained siltstone occur in places. Phosphate nodules are characteristic (Du Toit 1918), for example at a locality just outside Weenen. Plant impressions and trace fossils have been documented at various localities (Watson 1976; Visser and Bishop 1976). Visser and Bishop (1976, p. 42) give a thickness of 168 m for this formation in the Dundee area while Watson (1976, p. 12) records 250 m near Jobskop.

The depositional environment is considered to be similar to that of the Pietermaritzburg Formation.

9.3 ESTCOURT FORMATION

The Estcourt Formation crops out only in the south-western corner of map 2830, where it rests conformably on the shale of the Volksrust Formation. According to Watson (1976, p. 13) the boundary is transitional. The transition beds consist of fine- to coarse-grained sandstone, sandy shale and shaly sandstone with interbedded basal black shale. The contact is usually taken at the base of the first sandstone, following on the Volksrust shale.

The Estcourt Formation above the transition zone is composed of massive or cross-bedded, fine- to coarse-grained, feldspathic sandstone and dark blue-grey or black, locally carbonaceous shale. The finer-grained sandstone displays symmetrical ripple marks. Cross-bedding in the coarser sandstone indicates a source area to the north or north-east. No true thickness for the Estcourt Formation could be established as the overlying Tarkastad Formation is absent in this area. A minimum thickness of 300 m has, however, been estimated (Watson 1976, p. 14).

Well-preserved fossil leaves from this formation have been identified as *Glossopteris indica* Schimper and *Glossopteris pseudocommunis* Kovacs by Dr É. Endrődy-Younga (written communication to Watson 1976). Moulds of fresh-water bivalves were also found and identified as *Paleodonta cf. Castor*, *Paleomutela sp.*, *Carbonicpla sp.* and *Kidoda sp.*

The Escourt Formation was deposited in a fluvio-deltaic environment.

9.4 EMAKWEZINI FORMATION

This formation occurs in the south-eastern part of the area, where it overlies the Volksrust Formation with a conformable but gradational contact (Beater et al. 1974). The contact is usually taken at the level where the first sandstone appears. The Emakwezini Formation can be regarded as the lateral equivalent of the Estcourt Formation.

The base of the formation is marked by black, locally carbonaceous shale which grades upwards into a more arenaceous succession in which plant remains are found. The remainder of the formation consists of fine- to medium-grained and, locally, even coarse-grained sandstone alternating with siltstone and grey or grey-green shale and mudstone. The sandstone is greenish grey or buff in colour, well bedded and usually feldspathic. Thin beds of maroon mudstone and black carbonaceous shale are common. The shale is in places very micaceous. Thin coal seams, up to 1,5 m thick, occur throughout the formation. Calcareous nodules, displaying marked cone-in-cone structures, were found at some localities.

The Emakwezini Formation thins from north to south from 550 m east of Hlabisa (Watson and McGeorge 1977, p. 17) to 380 m west of Empangeni (Beater et al. 1974, p. 70). This is in accordance with the recorded palaeocurrent directions that show sediment transport to have been from the north and north-east. Plant remains are often found in the argillaceous sediments. *Phyllotheca ramsa* as well as several species of *Glossopteris* have been identified.

The environment of deposition of this formation is thought to have been similar to that of the Estcourt Formation.

9.5 NTABENE FORMATION

The Ntabene Formation lies with a conformable contact on the Emakwezini Formation. Its base is taken at the top of the uppermost carbonaceous shale unit in the succession (Du Preez 1978). It has proved difficult to establish a thickness for the formation, though Watson and McGeorge (1977) estimated it to be about 200 m thick in the area east of Hlabisa. Although no diagnostic fossils were found in this formation it is thought to be Triassic in age.

The formation consists of sandstone and shale with a clear preponderance of sandstone over shale. The sandstone is usually medium grained and slightly feldspathic, but a coarse-grained, gritty variety, consisting mainly of quartz, is found at a number of places. The sandstone is cross-bedded and shows well-developed liesegang structures. The shale is usally indurated, well bedded and grey to green in colour.

The Ntabene Formation was probably deposited by braided rivers under fairly arid conditions.

9.6 NYOKA FORMATION

The Nyoka Formation follows conformably on the Ntabene Formation and reaches a thickness of some 250 m (Du Preez 1978). The main lithology is a bright-red or purple mudstone in which calcareous concretions occur. Relatively thin beds of fine- to coarse-grained sandstone are interbedded in this mudstone. The sandstone is yellow, grey, white or reddish in colour, and is feldspathic. The Nyoka Formation is tentatively placed with the Ntabene Formation in the Triassic although no diagnostic fossils have been found in either of these two formations (Du Preez 1978).

This formation was probably deposited by slow-flowing meandering rivers under arid conditions.

9.7 CLARENS FORMATION

This formation overlies the Nyoka Formation conformably. It thins from 45 m in the south, just west of Empangeni (Du Preez 1978), to 20 m in the north, just east of Hlabisa (Watson and McGeorge 1977).

The main lithology of the Clarens Formation is a cream, white or slightly pinkish, very fine-grained, poorly bedded, massive sandstone. Small calcareous concretions occur scattered throughout and thin intercalated lenses of reddish and blue-grey mudstone occur locally. The sandstone locally shows minor baking effects near its upper contact with the basalt of the Letaba Formation. Sandstone of the Clarens Formation is generally considered to be aeolian in origin with a transport direction from the west.

9.8 LETABA FORMATION

The Letaba Formation overlies the Clarens Formation with a slight disconformity representing a buried, arid land-surface. The formation dips towards the south-east at an angle of 8 to 45 degrees (Du Preez 1978). Thin interbedded lenses of fine-grained sandstone occur near the base of the formation at a few localities.

The Letaba Formation constitutes a thick succession of amygdaloidal and non-amygdaloidal basaltic lava flows. Bristow (1976) noted that the average thickness of the lava flows is about 5,5 m and that auto-brecciation of flow tops took place in some cases. The flows are usually continuous along strike over long distances. In the amygdaloidal lava, the amygdales are concentrated in the uppermost third of the flow with a thinner amygdaloidal zone at the base. The amygdales have been filled in with zeolites, calcite, chalcedony, quartz, opal, chlorite and, rarely, epidote.

Based on textural and mineralogical differences, Bristow (1976) has identified three basalt types in the Empangeni area. These are non-porphyritic amygdaloidal basalt (the most common type), feldsparphyric basalt and olivine-rich basalt. The former two types constitute by far the major proportion of the basalt pile and may be grouped together as normal, olivine-poor basalt. The olivine-rich basalt consists of forsteritic olivine phenocrysts, set in a coarse-grained groundmass of plagioclase and augite, while the other two types contain augite and plagioclase and only rarely forsteritic olivine.

It has proved difficult to determine the exact thickness of the Letaba Formation and many different figures have been arrived at by various authors, for example 1 600 m (Du Toit 1929), 4 572 m (McCarthy 1961) and 4 100 m (Bristow 1976). Du Preez (1978) concluded that a thickness of about 3 600 m was the most likely.

9.9 KAROO DOLERITE

Numerous intrusions of Karoo dolerite occur in the area, especially in the rocks of the Ecca and younger formations of the Karoo Sequence. They are completely absent in all rocks of post-Jurassic age. Very few dolerites have been intruded into rocks of pre-Permian age, and even feeder dykes ascending through these rocks are scarce. Most intrusions are in the form of sills, assuming all possible attitudes, from concordant to highly transgressive. Small faults are occasionally found along dykes.

Although not shown on the map, a number of different types of dolerite have been described by various authors. McCarthy (1961) used the relative age of intrusion, mineralogical composition, textural and chemical differences to distinguish between three types of dolerite in the area around Empangeni. In the Dundee area Visser and Bishop (1976) used the same criteria to differentiate between nine kinds of dolerite. These dolerites are, however, chemically very similar.

The typical dolerite is a dark blue-grey, fine- to medium-grained, crystalline rock which is usually equigranular. Some rocks, however, may contain small feldspar phenocrysts. The rocks contain augite and labradorite, which are generally ophitically intergrown, pigeonite and fayalitic olivine occurring in minor quantities and accessory opaque minerals and rare quartz.

10. QUATERNARY ROCKS

10.1 BEREA FORMATION

A brownish red, clayey sand forms a distinctive lithostratigraphic unit in the south-eastern part of area 2830, and represents the northward continuation of the well-known Berea Formation of the Durban area. It lies with a disconformity on rocks which range from the Tugela Group in the west to possibly Senonian siltstone in the east outside this area (Du Preez 1978).

According to Du Preez (1978) the lithology of the Berea Formation is a remarkably uniform, fine- to very fine-grained sand. The sand is generally equigranular and non-calcareous, while the individual grains are usually subrounded to well-rounded. The main constituents of the sand are quartz, with variable clay contents and a small proportion of heavy minerals including ilmenite, magnetite, rutile and zircon. In the field the sand usually appears firm to compacted, unbedded, though it may in places contain a basal boulder bed.

McCarthy (1967, p. 154) described this formation as being a residual deposit representing the end product of weathering of the underlying calcarenites of the Bluff Formation (not exposed in area 2830). He (1967, p. 136) assigned a Pliocene age to the formation, while an Acheulian age, based upon human artefacts found along the base of the formation, was suggested by Davies (1976).

10.2 PORT DURNFORD FORMATION

This formation crops out intermittently along the coast in the vicinity of Port Durnford and never attains any great thickness (Du Preeez 1978). It consists of two main members which are locally separated by a thin lignite bed (Hobday and Orme 1974, p. 143; Du Cann 1976). McCarthy (1967, p. 162) suggested that the lower argillaceous member be correlated with the Harbour Beds at Durban. On the map, however, the Port Durnford Formation is shown undifferentiated. The members are:

(i) A lower argillaceous member, consisting mainly of water-deposited mudstone, lignite and clay. It is about 10 m thick and contains small shells near the base, followed upwards by mammalian and fish remains, fossil wood, sandy beds with oyster shells and foraminifera, and rare fish remains in the upper 4 m. Anderson (1907, p. 121) reported mammalian remains also near the base of the formation. McCarthy and Orr (1978) also described the occurrence of a rhinoceros tooth in the basal strata of the formation. Bedding in the sands and clayey sediments is usually poorly preserved as a result of bioturbation.

(ii) A lignite bed averaging about 1,3 m in thickness is found intermittently between 1 and 3 m above sea-level (Hobday and Orme 1974, p. 144). Abundant logs and other wood fragments occur within the lignite.

(iii) An upper arenaceous member, comprising arenaceous deposits of both water-deposited and aeolian sand with thin lignite beds. The sand is characterised by large-scale cross-bedding. Relatively impersistent carbonaceous sand beds and even lignite beds are present at various levels within this member.

Hobday and Orme (1974, p. 145) consider this formation to be the result of sedimentation in a major barrier-lagoon complex, the shoreline configuration and sea-level being approximately the same during deposition as at present. They estimate the age of the formation (1974, p. 148) to be between the late Middle Pleistocene and the Middle Upper Pleistocene, and proposed that it was deposited during a marine transgression of Sangamonian age that began well below present sea-level and culminated about 8 m above present sea-level.

10.3 MASOTCHENI FORMATION

This is a thin sedimentary deposit of variable thickness found in valley bottoms and along hillsides, and on the flood plains of the larger rivers. The sediments are partially consolidated and easily eroded, so that the outcrop area of this formation, although limited, is characterised by deeply incised dongas with numerous small buttress-like features. The average thickness of the formation is 2 to 5 m, but a thickness of up to 15 m occurs locally, as for instance near Pomeroy.

A basal boulder bed is often present. It grades upwards into finer-grained sediments, consisting of poorly stratified, pale yellow-brown, sandy clay. This usually contains abundant silcrete nodules. Fossil plant roots, often preserved by silcrete that formed round the original roots, are seen in places. This succession is normally unconformably overlain by a layer of topsoil up to 1 m thick.

The formation was deposited in Quaternary times during interfluvial periods (Visser and Bishop 1976, p. 56). Many implements from the Middle Stone Age have been found in the finer sediments of the Masotcheni Formation.

10.4 YOUNGER SURFACE SANDS

Most of the flat or slightly undulating, low-lying plain to the west of Port Durnford is covered by this sand. This plain lies between 15 and 70 m above sea-level. The sand generally rests disconformably on sand of the Port Durnford Formation but overlaps onto that of the Berea Formation near Felixton.

The predominant colours of the sand comprising this succession are grey, red-brown, orange-brown, dark-brown and mottled red-brown. The red-brown and orange-brown varieties occur above the mottled sand, with red-brown sand underlying most of the coastal plain. Grey sand predominates in the south. The variation in colour is due to coating of the quartz grains by a film of iron oxide and silica. The sand is mostly fine grained, well sorted, equigranular and unconsolidated or, locally, semi-compacted. Thin beds of clay, claystone, aeolianite, ironstone hardpan nodules and occasional fossil-soil layers occur in this sequence (Du Preez 1978). Macrofossils are rare, but microfossils, usually species of benthonic foraminifera, are common.

The thickness of the sequence is on average from 50 to 80 m, but increases gradually eastwards. Du Preez (1978) estimates the age of the succession at Middle to Late Pleistocene, or Holocene.

10.5 DUNE AND BEACH SAND

Dune and beach sand are shown collectively on the map as they occupy only a limited area. Recent beach sand occurs between the coastline and the foot of the coastal dunes. It is a fine- to coarse-grained quartz sand that contains variable amounts of feldspar, fragmented shelly material and dark grains of heavy minerals, mainly ilmenite. Sand occurring in recent dunes, in a belt adjacent and parallel to the beach zone, has an ill-defined landward contact where it overlaps the Port Durnford Formation. These younger dunes consist of white-weathering or light-brown, fine-grained quartz sand which is slightly calcareous in places. The dunes rarely reach a height of 10 m and, being mobile, they encroach upon the older fixed dunes. Du Preez (1979) states that these deposits range in age from uppermost Pleistocene to Holocene.

10.6 ALLUVIUM

No distinction has been made between lacustrine and fluvial deposits occurring in the area. The former occurs in or around inland depressions near the south-eastern corner of the area and it is predominantly clayey. There are, however, also accumulations of black or dark-grey muddy sand and silt with organic material. The fluvial deposits are usually found along the larger rivers and consist of boulders, gravel, sand, silt and clay. The thickness of these beds ranges from less than one to more than 5 m.

A number of fairly large landslides have been mapped especially in the Babanango area. These generally originate at or near the contact of the Pietermaritzburg and Vryheid Formations. According to King (1948) they are caused by the ideal conditions of a steep hill-side, composed of pervious sandstone, overlying highly plastic clayey shale.

11. ECONOMIC GEOLOGY

A large variety of mineral occurrences are found in the area. The majority are of no economic importance. The only commodity that is being actively mined on a large scale is coal occurring in the Vryheid Formation. Most of the information incorporated in the Appendix was taken from Coetzee (ed.) 1976. All the occurrences as well as a complete list of references, are tabulated in the Geological Survey's Open File Report No. 130, "Mineral deposits and occurrences in South Africa, Sheet 2830, Dundee", released in 1979.

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APPENDIX—LIST OF MOST IMPORTANT MINERAL OCCURRENCES

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Gold	Denny Dalton Mine on Tussenby 411, Babanango District	Basal Mozaan conglomerate	Gold-bearing conglomerate	Previously mined	Von Backström 1965
Gold	Enterprise Mine near Nondweni	Swazian granite	Associated with quartz veins	Very localised; visible gold can be seen in some occurrences	Coetzee (ed.) 1976
Gold	South of Nkandla	Schist of the Mfongosi Group	Occurs along shear zones associated with the nearby Mfongosi Thrust Fault	Previously mined; operations ceased during the nineteen twenties	Schutte 1976 Du Toit 1931 Snyman 1956
Gold	Nsuze Gold Fields near Nkandla	Nsuze Group	Syngenetic gold in conglomerate	Potential poor	
Gold	Phoenix Mine on Tugela River, north-east of Kranskop	Tugela Group	Associated with a quartz shear zone	Prospected without success	
Gold	Tugela Location, immediately south of Phoenix Mine	Tugela Group	Associated with a quartz-impregnated shear zone	Not viable; operations ceased during 1937	
Gold	West of Eshowe near confluence of Matimofa and Amatikulu Rivers	Tugela Group	Associated with quartz veins along a shear zone	Ore body apparently exhausted	

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Gold	North bank of Tugela River, Native Reserve no. 19	Tugela Group	Gold-bearing quartz veins associated with shear zones	Prospected; values poor	
Silver	Mfongosi Mine, 2,5 km north of the confluence of the Mfongosi and Tugela Rivers	Mfongosi Group	Quartz veins in schists	Area prospected over a wide area	Coetzee (ed.) 1976 Hatch 1910 Goldberg 1976
Prehnite	Krantzkop 1376, close to Kranskop village	Natal Group	Not known	Unimportant	Coetzee (ed.) 1976
Chromium	Tugela Rand 1974, north of Kranskop	Tugela Rand Complex	Bands and irregular bodies of chromitite containing up to 25 per cent Cr_2O_3	Previously mined; recently prospected again; results unknown	Coetzee (ed.) 1976 Du Toit 1931 Snyman 1956 Du Preez 1976
Chromium	Sithilo near Eshowe	Sithilo Complex	Irregular bodies of chromitite	Small-scale prospecting done	
Copper	Cooper's Store, north of Nkandla in Umhlatuze valley	Syenite intrusive into Mfongosi rocks	Secondary mineralisation along joint planes and quartz veins	Previously mined	
Copper	Dania Mine, east of Nondweni on Togekry 10986	Contact between Archaean granite and intrusive serpentinite	Disseminated mineralisation along contact; ore body is lenticular	Previously mined	Coetzee (ed.) 1976

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Copper	Subeni Mine on Goudhoek 481, Babanango District	Archaean granite	Associated with shear zone in Archaean granite	Not viable	Schutte 1976
Copper	Magdalena Mine on Schoonuitzicht 385, south of Vryheid	Archaean granite	Associated with a quartz vein	Previously mined on a small scale	
Copper	Goodricks Workings, north-east of the confluence of the Buffels and Umgeni Rivers	Schist bands in Archaean granite	Associated with quartz veins	Not viable	
Copper	Sweet Home 6130, north of Melmoth	Archaean granite gneiss	Associated with a sheared quartz vein	Very little prospecting has been done	Snyman 1956
Copper	Qudeni 25 near Ntingwe	Syenite dyke	Mineralisation occurs in the dyke	Unimportant	Du Toit 1931
Copper	Gem Mine in Nsuze River north-west of Nkandla	Nsuze Group	Associated with a syenite dyke intrusive into the Nsuze rocks	Previously mined	Coetzee (ed.) 1976
Iron	Alleta 4350, Brakfontein 155, Davelsfontein 4348, Morgenstond 3347, Prestwick 2415, Stanmore 2412, Hillside 9953, Cuthbert 12444; all situated north and east of Dundee	Vryheid Formation	Black sideritic bands interbedded in the sediments	Previously mined	Coetzee (ed.) 1976 Geol. map sheets 2829 B (Elandslaagte) and 2830 A (Dundee) Wagner 1928

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Iron	On the Tugela River below Middle Drift	Mambulu Complex	Bands of titaniferous magnetitite	Little prospecting undertaken	Du Toit 1931 Coetzee (ed.) 1976
Iron	Outcrop areas of Tugela Group	Tugela Group	Banded ironstone as thin beds in rocks of the Tugela Group	Unknown	Du Toit 1931
Lead	Mfongosi Lead-Silver Mine, 2,5 km north of confluence between Tugela and Mfongosi Rivers	Mfongosi Group	Associated with quartz veinz in the Mfongosi schist	Locally prospected	Coetzee (ed.) 1976 Snyman 1956 Hatch 1910 Goldberg 1976
Manganese	Kranzkop 1376, east of the village	Dwyka Formation	Bed of bog manganese, 2 m thick	Extent unknown	Du Toit 1931
Molybdenum	South-east of Eshowe	Archaean granite	Scattered flakes in the granite	Unimportant	Coetzee (ed.) 1976
Molybdenum	Near Sibudeni		Associated with pegmatite vein	Unimportant	Coetzee (ed.) 1976
Nickel	Naaukloof 7431, north-east of Nkandla	Serpentinite intrusive into Nondweni Group	Mineralisation is disseminated in serpentinite	Investigated by mining company; not viable	Coetzee (ed.) 1976
Niobium, Tantalum	Ngoye Granite, west of Empangeni	Ngoye Granite Gneiss	Occurs disseminated in granite gneiss	Unknown	Scogings 1985

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Tin	Mtonjaneni near the confluence of the Mtunja and Mfula Rivers east of Melmoth	Archaean Granite Gneiss	In pegmatite that intruded granite gneiss	Uneconomic	Coetzee (ed.) 1976 Schutte 1976
Titanium/ Thorium	Along coast	Quaternary	Coastal dune deposits	Mined north of Richards Bay	
Titanium/ Thorium	Bulls Run Estate, north-north-west of Eshowe	Quaternary	Eluvial and alluvial deposits probably derived from the Bulls Run Formation	Unimportant	Von Backström 1962 Willemse 1940
Thorium	West of Empangeni	Ngoye Granite Gneiss	Crystals in the peralkaline phase of the granite gneiss	Not known	Scogings 1985
Tungsten	Near Melmoth	Amphibolites of the Nondweni Group	Unknown	Unimportant	Coetzee (ed.) 1976
Uranium	Naaukloof 6099 and Nineve 6100, west of Melmoth				Norman 1977
Uranium	Denny Dalton Mine	Basal Mozaan conglomerate	Alluvial deposits	Very low values; prospected 1969; not viable	Schutte 1976 Von Backström 1965
Uranium	West of Empangeni	Peralkaline phase of the Ngoye Granite Gneiss	Unknown	Not known	Scogings 1985

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Vanadium	At the confluence of the Tugela and Mambulu Rivers	Mambulu Complex	Vanadiferous and titaniferous magnetitite bands	Reserves are 22 million tons; average grade: 45,92% Fe, 11,53% TiO_2 and 0,56% V_2O_5	Coetzee (ed.) 1976
Zinc	Dania Mine, north-east of Nondweni	Contact between the Archaean granite and intrusive serpentinite	Associated with copper minerals; ore bodies lenticular	Contains 7% Zn	Snyman 1956
Zirconium	Bulls Run Estate, north-north-west of Eshowe	Bulls Run Formation	Large crystals in the gneiss up to 1 cm in diameter; also alluvial and eluvial deposits derived from the gneiss	Large reserves but proportion of zirconium to waste extremely low	Von Backström 1962 Willemse 1940
Zirconium	West of Empangeni	Peralkaline phase of Ngoye Massif	Crystals in granite	Not known	Scogings 1985
Chrysotile asbestos	Tugela Rand, north of Kranskop and Sithilo, near Eshowe	Ultramafic bodies intrusive into Tugela Group	Very thin veins; fibres very short	Unimportant	Snyman 1956 Du Toit 1931
Tremolite asbestos	Near Nondweni	Serpentinite intrusive into Nondweni Group	Fibres are 5–10 cm long and very brittle	Unimportant	Coetzee (ed.) 1976 Du Toit 1931

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Coal	Newcastle/Dundee Coal Field	Vryheid Formation	Seams interbedded with sediment	Most important commodity in area; eight mines in operation	Coetzee (ed.) 1976 Visser and Bishop 1976
Corundum	Manyalete Hill	Aplite veins intruded into serpentinite of Tugela Group	Crystals in aplite veins	Deposits are thin; corundum altered to marganite	Du Toit 1931
Fluorspar	Hlabisa area	Quartz veins in Dwyka Formation, Natal Group and basement rocks	Associated with quartz veins that vary in width and length and widens with increasing depth	Previously mined but all activities have ceased	Coetzee (ed.) 1976 Snyman 1956
Graphite	Near Nqutu and Nondweni	Nondweni Group	Graphite-bearing schist	Graphite extremely impure	Snyman 1956
Gypsum	At confluence of Nadi and Tugela Rivers	Recent deposit	Lumps and crystals on old terrace of Tugela River	Gypsum is pure and may be of importance in future	Coetzee (ed.) 1976 Du Toit 1931 Snyman 1956
Kaolin	Immediately west of Eshowe	Sandstone of Natal Group	Occurs in fault zone about 1 m wide	Unimportant	Snyman 1956
Kyanite	South of Nkandla	Nkandla Formation	Occurs as crystals in quartzite and quartz-sericite schist	Rocks average 43% kyanite; reserves large	Meinster 1978

Commodity	Locality	Stratigraphic unit	Morphology	Importance	Literature
Limestone	Outcrop area of Ntingwe Group	Ntingwe Group	Limestone	No prospecting undertaken; reserves large	Du Toit 1931 Matthews 1959
Magnesite	North of Kranskop in Tugela Valley	Tugela Rand and Sithilo Complexes	Thin veins, maximum 60 cm wide, in ultramafic rocks	Unimportant	Coetzee (ed.) 1976 Du Toit 1931 Snyman 1956
Mineral pigment	On portion B of Irondale 6012 in the Dundee District	Vryheid Formation	Bed of sideritic iron ore changed into soft mixture of hematite, goethite and limonite	Presently being mined	Coetzee (ed.) 1976
Muscovite	North of Melmoth	Pegmatite veins in amphibolite of the Nondweni Group	Books of muscovite up to 15 cm thick	Unimportant	Coetzee (ed.) 1976
Pseudocoal	Vicinities of Glencoe and Dundee	Vryheid Formation	Thin veins	Unimportant	Coetzee (ed.) 1976
Stone aggregate	Throughout area	Mainly dolerite and granite		Numerous quarries in operation	
Talc	Nondweni area on Mount Vernon 10965	Along contact of granite intrusive into serpentinite	Mixed with tremolite	Previously mined; not viable	Coetzee (ed.) 1976 Snyman 1956