EXPLANATION: SHEET 3126 (1: 250 000)
TOELIGTING: BLAD 3126 (1: 250 000)

QUEENSTOWN

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

REPUBLIC OF SOUTH AFRICA

REPUBLIEK VAN SUID-AFRIKA

Republic of South Africa
Republiek van Suid-Afrika

Department of Mineral and Energy Affairs
Departement van Mineraal- en Energiesake

GEOLOGICAL SURVEY
GEOLOGIESE OPNAME

THE GEOLOGY OF THE QUEENSTOWN AREA

by

M.R. Johnson, Ph.D.

Explanation of Sheet 3126
Toeligting van Blad 3126
Scale/Skaal 1:250 000

Printed by and obtainable from the Government Printer,
Bosman Street, Private Bag X85, Pretoria, 0001
Gedruk deur en verkrygbaar by die Staatsdrukker,
Bosmanstraat, Privaatsak X85, Pretoria, 0001

ISBN 0 621 09001 8

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THE GEOLOGY OF THE QUEENSTOWN AREA

Abstract

Sheet area 3126 is largely underlain by sedimentary rocks of the Beaufort Group (the Katberg and Burgersdorp Formations) and the Molteno, Elliot and Clarens Formations, together with lavas of the Drakensberg Formation. All these units form part of the Karoo Sequence.

The Katberg Sandstone Formation, the oldest sedimentary rock unit in the area, consists of fine-grained lithic sandstones and subordinate mudstones. It was probably deposited by braided streams flowing north-north-west. The overlying Burgersdorp Formation comprises 600 to 900 m of greyish-red mudstones and subordinate fine-grained lithic sandstones forming fining-upward cycles and deposited by meandering streams flowing down a palaeoslope inclined to the north-north-west.

The Molteno Formation, which is up to 450 m thick, consists of alternating olive-grey mudstones and subordinate medium-grained quartzose sandstones constituting fining-upward cycles. Dark-grey shale and minor conglomerate and coal beds are also present. Deposition took place under wet, reducing conditions in a fluviatile regime on a palaeoslope inclined to the north-north-west. Fluviatile fining-upward cycles, comprising fine-grained sublithic to lithic/lithofeldspathic sandstones grading upward into thicker generally greyish-red mudstones, characterize the succeeding 300 to 500 m thick Elliot Formation. Depositional and palaeoslope conditions were similar to those in existence during the deposition of the Burgersdorp Formation.

The Clarens Sandstone Formation consists of a distinctive massive, very fine-grained feldspathic sandstone or coarse siltstone attaining a maximum thickness of 300 m. It represents an aeolian deposit of which the material was transported by winds blowing from the west.

The Karoo Sequence is capped by the basaltic Drakensberg Formation which is about 750 m thick along the eastern edge of the area. Scattered pyroclastic-filled volcanic pipes associated with the Drakensberg volcanicity are present in the outcrop area of the Elliot and Clarens Formations; the largest being 13,5 km across. Subsequent to the extrusion of the lavas the sedimentary strata were intruded by numerous dolerite sills and dykes. A distinctive intrusion having the form of a cauldron subsidence occurs north of the Birds River siding.

Alluvium represents the only Quaternary material and includes both alluvial slope (sheet-wash) and alluvial valley (channel-transported) deposits.

The strata are sub-horizontal and faulting is uncommon. Vertebrate fossils are present in the Katberg, Burgersdorp and Elliot Formations, while plant fossils are fairly common in the Molteno Formation.

Coal (in the Molteno Formation), bentonite (in the Elliot Formation) and illite–montmorillonite (adjacent to dolerite sheets in the Burgersdorp and Molteno Formations) represent the only potentially economic mineral deposits in the area. None are being commercially exploited at present.

Uittreksel

Bladgebied 3126 word grootliks onderlê deur sedimentêre gesteentes van die Groep Beaufort (die Formasie Katberg en Burgersdorp) en die Formasie Molteno, Elliot en Clarens, tesame met lawas van die Formasie Drakensberg. Al hierdie eenhede vorm deel van die Opeenvolging Karoo.

Die Formasie Katbergsandsteen, die oudste sedimentêre gesteente-eenheid in die gebied, bestaan uit fynkorrelrige litiese sandsteen en ondergeskikte moddersteen. Dit is waarskynlik deur gevlegte strome, wat noordnoordwes vloei, afgeset. Die oorliggende Formasie Burgersdorp bestaan uit 600 tot 900 m gryserige rooi modderstene en ondergeskikte fynkorrelrige litiese sandstene, wat opwaarts-fynerwordende siklusse vorm en deur kronkelende strome wat teen 'n noordnoordwes-hellende paleohelling afgevloei het, afgeset is.

Die Formasie Molteno, wat tot 450 m dik is, bestaan uit afwisselende olyfgrys modderstene en ondergeskikte middelkorrelrige kwartssandstene, wat opwaarts-fynerwordende siklusse vorm. Donkergrys skalie en geringe konglomeraat- en steenkoollae is ook teenwoordig. Afsetting het onder nat, reduserende toestande in 'n fluviale omgewing op 'n paleohelling, wat noordnoordwes hel, plaasgevind. Fluviale, opwaarts-fynerwordende siklusse bestaande uit fynkorrelrige sublitiese tot litiese/litoveldspatiese sandstene wat opwaarts in dikker, algemeen gryserig-rooi modderstene gradeer, kenmerk die daaropvolgende 300- tot 500-m-dik Formasie Elliot. Afsettings- en paleohellingtoestande was soortgelyk aan dié wat gedurende die afsetting van die Formasie Burgersdorp bestaan het.

Die Formasie Clarenssandsteen bestaan uit 'n kenmerkende massiewe, baie fynkorrelrige veldspatiese sandsteen of growwe sliksteen met 'n maksimum dikte van 300 m. Dit verteenwoordig 'n eoliese afsetting waarvan die materiaal deur winde vervoer is wat vanaf die weste gewaai het.

Die Opeenvolging Karoo word oordek deur die basaltiese Formasie Drakensberg wat ongeveer 750 m dik is langs die oostelike rand van die gebied. Verspreide vulkaniese pype, gevul met piroklastiese materiaal, wat met die Drakensbergvulkanisme geassosieer word, is in die dagsoomgebied van die Formasie Elliot en Clarens teenwoordig; die grootste liggaam met 'n deursnee van 13,5 km. Na die ekstrusie van die lawas is die sedimentêre lae deur 'n menigte dolerietplate en -gange binnegedring. 'n Kenmerkende intrusie met die vorm van 'n kuilvormige insakking kom noord van die Birds River-sylyn voor.

Alluvium verteenwoordig die enigste Kwaternêre materiaal en sluit beide alluviale glooiingsafsettings (oppervlakgespoel) en alluviale valleiafsettings (kanaalvervoer) in.

Die lae is subhorisontaal en verskuiwings is ongewoon. Vertebraatfossiele is in die Formasie Burgersdorp, Katberg en Elliot teenwoordig, terwyl plantfossiele redelik volop in die Formasie Molteno is.

Steenkool (in die Formasie Molteno), bentoniet (in die Formasie Elliot) en illiet–montmorilloniet (langs dolerietplate in die Formasie Burgersdorp en Molteno) verteenwoordig die enigste potensiële ekonomiese mineraalafsettings in die gebied. Geeneen word tans kommersieel ontgin nie.

1. INTRODUCTION

The sedimentary rocks in the area are all of Triassic age and belong to the Beaufort Group, the Molteno Formation, the Elliot Formation, and the Clarens Sandstone Formation. The sedimentary succession is capped by the volcanic Drakensberg Formation of Jurassic age. All these units form part of the Karoo Sequence. Dolerite intrusions of Jurassic age are common throughout the area, while thin alluvial slope and valley deposits of Quaternary age blanket the older rocks in places.

2. BEAUFORT GROUP

Two formations belonging to the Beaufort Group are present in the area, the Katberg and Burgersdorp Formations, which constitute the Tarkastad Subgroup.

2.1 KATBERG FORMATION

Only the uppermost part of this formation is present and the outcrops are confined to the southern edge of the map area. The Katberg is defined as a relatively sandstone-rich unit forming the lower part of the Tarkastad Subgroup. In this particular area the upper contact has been arbitrarily taken as a horizon below which sandstone is more abundant than mudstone. The contact is, however, completely gradational with the actual transition zone extending over 100 m.

Lithologically the Katberg Formation in this area consists of thick zones of sandstone (up to 20 m or more), with thin irregular mudstone layers and lenses. Alternating with the sandstone zones are thinner zones of mudstone, containing minor interbedded sandstone and siltstone beds and lenses.

The colours of the sandstone range from light brownish grey (5 YR 6/1)* through greenish grey (5 GY 6/1) to very light grey (N7/N8). Primary structures (in order of abundance) are flat bedding, trough cross bedding and planar cross bedding. Micro cross lamination is rare. The sandstone is fine grained and well sorted. Studies undertaken in the area to the south (Johnson 1976, p. 266) indicate that mineralogically the sandstones occurring in the upper part of the Katberg Formation fall into the lithic sandstone field.

The mudstones are greyish red (5 R 4/2) or medium greenish grey (5 GY 5/1) and are structurally massive. Vertebrate remains are present, and several skulls of *Procolophon* and *Lystrosaurus* (belonging to the *Lystrosaurus–Thrinaxodon* Assemblage zone) were discovered.

Palaeocurrent data obtained in the main outcrop area to the south (Johnson 1976, Stavrakis 1979) indicate that the palaeoslope was inclined towards the north-north-west. Deposition probably took place in a braided-stream environment.

2.2 BURGERSDORP FORMATION

The Burgersdorp Formation consists of alternating fine-grained litho-feldspathic sandstone and greyish-red mudstone lithosomes, which constitute the relatively mudstone-rich upper part of the Tarkastad Subgroup. Sandstone on average forms 20 to 30 per cent of this formation; 26 per cent sandstone being measured in a 100 m thick section at Nonesi's Nek north-east of Queenstown. It becomes more abundant, however, towards both the base and the top of the formation.

The contact with the overlying Molteno Formation is best defined as the base of a marked upward increase in the sandstone–shale ratio associated with the disappearance of red mudstone. Additional boundary criteria are the practical restriction of carbonaceous shale and coal to the Molteno Formation, the relative coarseness of the Molteno Formation sandstones, and the occurrence of scattered quartzite pebbles and boulders and ferruginous concretions together with a greater relative frequency of scour-and-fill structures and trough cross bedding within these sandstones.

The Burgersdorp Formation in the Queenstown area is probably in the region of 900 m thick (Johnson 1976, p. 253). A minimum of 600 m of

* Numerical designations are of the Rock-color Chart published by the Geological Society of America.

Burgersdorp strata is present in the Bamboesberg range along the western edge of the map on Spitskop 31.

The sandstone and mudstone lithosomes of the Burgersdorp Formation generally form fining-upward cycles ranging from a few metres to a few tens of metres in thickness, the average being in the order of 10 to 20 m. These cycles commence with sandstone which rests with a sharp contact on a scoured surface and grades upwards into the overlying mudstone lithosome. An intraformational mud-pebble conglomerate is often present at the base of the sandstone units.

Individual sandstone lithosomes range up to about 10 m in thickness, the average being about 2 to 3 m. Lithosomes are generally subtabular to moderately lenticular in shape (occasionally highly lenticular). Most sandstones extend laterally over a distance of a few hundred metres to a few kilometres before pinching out. The sandstones possess sharp lower boundaries and generally rest on scoured surfaces displaying variable degrees of relief. Upper boundaries are invariably gradational.

The sandstones vary from light brownish grey (5 YR 6/1) through light olive grey (5 Y 6/1) and greenish grey (5 GY 6/1) to light grey (N7) in colour. Flat bedding (accompanied by parting lineation), trough cross bedding and micro cross lamination (towards the top of the units) are the most abundant primary structures within the sandstones. Although many sandstones, or part of the sandstones, appear to be massive, it is probable that under favourable conditions of weathering most such apparently structureless beds would display internal structures. Cross-bedding dip directions gave vector means of 335° (43 readings, vector strength 0,86) and 325° (16 readings, vector strength 0,97) north-west of Tarkastad and north-east of Queenstown respectively.

The measurement of the long axes of quartz and feldspar grains in thin sections of five samples gave a mean size of 2,56 ϕ and a standard deviation of 0,61 ϕ (n = 5). Modal analyses of the same five samples were carried out and the following average percentages were obtained:

	%
Quartz	42,5
Feldspar	9
Rock fragments	32
Accessories	0,5
Secondary cement	2
Matrix	14

Quartz:feldspar:rock fragments = 51:11:38

On the basis of the above data the average Burgersdorp Formation sandstone is moderately sorted, fine grained and lithic.

The Burgersdorp Formation mudstone lithosomes range from a few metres to a few tens of metres in thickness. The mudstone is generally greyish red (5 R 4/2) to dusky red (5 R 3/4), less commonly medium greenish grey (5 G 5/1) or medium bluish grey (5 B 5/1). Apart from the occasional presence of sand-filled mudcracks and clastic dykes, the mudstones are essentially massive.

Reptile fossils are fairly common in the mudstones of the Burgersdorp Formation. With the exception of its lower beds (which belong to the *Lystrosaurus–Thrinaxodon* Assemblage zone) the fauna of this formation belongs to the *Kannemeyeria–Diademodon* Assemblage zone. Both these genera were herbivorous mammal-like reptiles. Specimens of the above genera as well as specimens of the carnivorous *Cynognathus* and the small herbivorous *Bauria cynops* were recovered from these beds. Fragmentary remains of the large crocodile-like *Erythrosuchus* were also found.

Directional data obtained from cross bedding in the sandstones indicate palaeocurrents flowing north-north-west. The combination of features described above – in particular the association of lenticular, cross-bedded and flat-bedded sandstone and massive red mudstone in fining-upward cycles – are typical of the fluviatile "red bed" facies. The sandstones are clearly channel deposits and the mudstones overbank flood-plain deposits. The high mudstone–sandstone ratio suggests meandering rather than braided streams. The source area, which must have been situated off the present south-eastern Cape coast, probably consisted of a mixed sedimentary–igneous–metamorphic terrain.

3. MOLTENO FORMATION

The Molteno Formation consists of alternating pale, "glittering" fine- to coarse-grained sandstone and pale olive mudstone lithosomes generally forming fining-upward cycles. The mudstone often grades into dark shale (which locally contains abundant plant remains), while occasional conglomerate and coal layers are also present.

Although not mapped, a number of recognizable subdivisions are present within the Molteno Formation. Du Toit (1904) referred to the Indwe and Gubenxa Sandstones, while Robinson et al. (1969) and Turner (1975) respectively introduced the names Boesmanshoek Pass Member and Bamboesberg Member for the strata below the Indwe Sandstone of Du Toit.

Du Toit (1954) assigned a Late Triassic age to the Molteno. However, both Plumstead (1969) and Keyser (1973) considered a Middle Triassic age to be more acceptable. Anderson (1974) stated that the Molteno is of approximately lowermost Upper Triassic (Carnian ?) age.

The sandstone–shale map of Robinson et al. (1969, Map 5.3) pertaining to their Boesmanshoek Pass Member, indicates that in those areas where its thickness exceeds 100 m (i.e. from the eastern edge of Sheet 3126 to a point west of Molteno) the sandstone content ranges from 30 to 50 per cent, with anomalously high values being obtained at Cala (93 per cent) and west of Molteno (up to 75 per cent). For the strata overlying the Boesmanshoek Pass Member, Robinson et al. (1969) obtained an average of about 30 per cent sandstone (combining the data on their Maps 6.3 and 7.3). Shale forms about 4 to 10 per cent, while conglomerate possibly constitutes about one per cent and coal less than one per cent. Mudstone makes up the rest of the Molteno Formation.

The upper boundary of the Molteno Formation can be fixed using much the same criteria as those applied in fixing its lower boundary (described in the section on the Burgersdorp Formation) since the overlying Elliot Formation represents a "red-bed" facies closely resembling the underlying Burgersdorp Formation. In this case, however, there does not appear to be a very significant change in the sandstone percentage, and the mudstone colour change constitutes the most significant difference between the two formations.

Thickness estimates obtained for the Molteno Formation in the area range from 450 m south-east of Elliot through 400 m in the Cala–Indwe area and 335 m and 290 m west and north-west of Sterkstroom respectively to approximately 250 m south-east of Burgersdorp. In the Cala–Indwe area the Boesmanshoek Pass Member of Robinson et al. (1969) averages about 130 m, but appears to be somewhat thicker (± 170 m) in the southernmost Molteno outcrops. These thicknesses for the Molteno Formation are generally considerably smaller than those given by most previous authors (Johnson 1976, p. 274–275) but somewhat larger than those given by Turner (1975) for comparable areas. To a great extent these differences are due to divergent opinions regarding the placement of the Molteno–Elliot contact.

According to Robinson et al. (1969, p. 14) fifteen to twenty typical fining-upward cycles can usually be distinguished in the area extending from Molteno to the eastern edge of the map. The average cycle thickness is about 20 to 30 m, with a maximum of about 60 m. The base of each cycle represents a scoured surface. The cycle itself usually commences with a thin, relatively coarse-grained layer containing numerous mudstone clasts eroded from underlying material as well as scattered quartzite pebbles and in places boulders. This coarse basal layer is overlain by fine- to coarse-grained sandstone which becomes progressively finer upwards and is in turn overlain by mudstone; the contact between the two being a gradational one. Finally, shale occurs in the upper part of some cycles and coal is occasionally developed near the top (Robinson et al. 1969, p. 15).

Sandstone lithosomes generally range from a few metres to 20 m in thickness; according to Du Toit (1954, p. 297) the maximum thickness is about 60 m. Most sandstones are fairly persistent laterally, tending to form distinct ledges that can in many cases be followed for a few tens of kilometres. The Indwe Sandstone can apparently be followed throughout the map area and extends well beyond it (Robinson et al. 1969, Map 6.2). Lithosomes vary from subtabular to moderately tabular, with width–thickness ratios ranging from about 500 to about 5 000.

The lower boundaries of the sandstones are sharp, channelled and uneven, with erosion depths ranging from a few centimetres for minor irregularities to a few metres in some channels. Upper boundaries with the overlying mudstone are normally gradational.

The colour of the sandstones is mostly light grey (N7) to yellowish grey (5 Y 8/1).

The basal part of each sandstone is usually massive to poorly cross bedded. The bulk of the sandstone displays cross bedding (both trough and planar varieties) and flat bedding, with the former normally predominating except in the finer-grained sandstones. Towards the top of the sandstones flat bedding (with its associated parting lineation) often becomes more common as the sandstone becomes finer grained, while micro cross lamination is typically developed just below the contact with the overlying mudstone unit. Cross-bed sets range up to 1,5 m in thickness. Overturned and deformed cross bedding is present in places. Ferruginous (limonitic) concretions 5 to 7,5 cm in diameter are common in the sandstones.

A number of previous workers have obtained orientation data from cross bedding in the Molteno Formation in this and adjacent areas, and the results have been summarized by Johnson (1976, p. 278–280). Averaging all the available data, a grand mean of 344° and an average vector strength of 0,60 were arrived at. Some of the measurements on which these figures are based were in fact made north of the map area, but it is unlikely that these directions would be significantly different from those obtained from within the actual map area. The cross bedding aximuths give rise to unimodal rose diagrams and indicate that palaeocurrents flowed north-north-west.

Ten samples collected from various localities throughout the map area gave an average mean grain size of 1,30 Ø (thin-section measurement of long axes of quartz grains) and an average standard deviation of 0,57 Ø. Modal analyses were carried out on eight samples and the following average percentages were obtained:

	%
Quartz	72
Feldspar	2,5
Rock fragments	12,5
Matrix	13

Quartz:feldspar:rock fragments = 83:3:14

Other authors have obtained feldspar percentages ranging from 2 to 5. The average sandstone of the Molteno Formation is thus fine to coarse grained, moderately to well sorted and quartzose.

Mudrock lithosomes vary from a few metres to a few tens of metres in thickness. The mudstone is normally pale olive (10 Y 6/2), with rare reddish or medium dark-grey (N4) varieties present locally. The shale is medium dark grey (N4) to dark grey (N3). The mudstone is invariably massive, while the shale is laminated or very thinly bedded. Pteridosperm and cycad remains (including well-preserved leaf imprints) are fairly common in the shales. The most abundant forms are *Dicroidium* and *Baiera*.

As in the case of the Burgersdorp Formation the ubiquitous presence of fining-upward cycles coupled with characteristic primary structures in the sandstones and plant remains in the shales point to deposition in a fluviatile environment. In this case, however, the absence of red colouration in the mudrocks as well as the presence of plant remains rather than reptile remains indicates that wetter, reducing conditions characterized the flood plains. The high quartz content suggests that the Cape Supergroup quartzites were a prominent constituent of the source area, while the more humid conditions may also have aided the weathering and elimination of feldspar.

4. ELLIOT FORMATION

No distinct subdivisions have been recognized within the Elliot Formation. Both Du Toit (1954, p. 356) and Romer (1970, p. 117) assign a Late Triassic age to this formation.

The Elliot Formation consists of alternating fine-grained sandstone and predominantly greyish-red mudstone lithosomes, generally occurring as fining-upward cycles. Sandstones constitute about 30 per cent of the total succession.

The boundary between the Elliot Formation and the overlying Clarens Sandstone Formation may be sharp, gradational or intertongued. The precise definition of this boundary has occasioned considerable difficulty in the past (Johnson 1976, p. 293), but in practice most definitions attempt to locate the boundary at the base of a formation which is largely or almost entirely composed of aeolian sandstone or coarse siltstone. The thickness of the formation ranges from approximately 500 m in the Indwe–Elliot area to an average of 380 m in the Sterkstroom–Molteno–Jamestown–Rossouw area, decreasing further to about 300 m in the Burgersdorp–Jamestown area. Local variations of up to 100 m were encountered in the Sterkstroom–Molteno area.

The fining-upward cycles in the Elliot Formation are similar to those in the Burgersdorp Formation. Most cycles are between 10 and 30 m thick, with a maximum thickness of about 50 m.

Sandstone lithosomes are generally between 3 and 15 m thick (averaging about 5 to 8 m), with a maximum thickness of 30 m. Individual lithosomes have a limited lateral extent and can seldom be traced for more than a few kilometres. Most sandstones are sublenticular to moderately lenticular.

The lower boundaries of the sandstones are sharp and uneven, with scours ranging from a few centimetres to one metre or more in depth. Upper boundaries are normally gradational, with the transition zone varying from a few centimetres to a few metres in thickness.

Typical fine- and very fine-grained sandstones are yellowish grey (5 Y 7/2) to dusky yellow (5 Y 6/4), with dirty very fine-grained sandstones commonly being pale red (5 R 6/2 to 10 R 6/2).

The sandstone units are usually massive at their base, while the bulk of the sandstone is characterized by flat bedding (with parting lineation) and trough cross bedding. Sedimentation units are lenticular and usually 30 to 100 cm thick. Micro cross lamination is common towards the top of most sandstones. Calcareous concretions are common, particularly towards the top of the formation. Orientation data based largely on trough cross bedding axes presented by various workers (summarized by Johnson 1976, p. 288–289) give an average direction of 340° for the western part of the area and 40° for the Barkly Pass area north of Elliot.

Three typical sandstone samples collected at Barkly Pass gave an average mean size of 2,50 Ø and an average standard deviation of 0,57 Ø. Modal analyses carried out on the same three samples gave the following average percentages:

	%
Quartz	60
Feldspar	9
Rock fragments	17
Accessories	1
Secondary cement	3
Matrix	10

Quartz:feldspar:rock fragments = 70:10:20

The above figures indicate that the average sandstone of the Elliot Formation is moderately sorted, fine grained, sublithic to lithic/lithofeldspathic.

About two thirds of the total mudstone in the Elliot Formation is greyish red (10 R 4/2) or pale red (10 R 6/2 or 5 R 6/2), the rest being yellowish grey to light olive grey (5 Y 7/2 to 5 Y 5/2) or pale olive (10 Y 6/2). As in the case of the Burgersdorp Formation, the mudstones are invariably massive. Calcareous concretions are present in the mudstones. Reptilian remains occur sporadically, both primitive dinosaurs and advanced therapsid (mammal-like reptiles) being present. The most common form is the herbivorous *Massospondylus*.

In view of their overall lithological similarity it is assumed that the Elliot Formation was formed in a similar depositional environment to that postulated for the Burgersdorp Formation, i.e. a meandering-river regime. The red colour suggests oxidizing associated with subaerial exposure and hence a return to drier conditions than those prevailing during the deposition of the Molteno Formation. The general northerly palaeoslope again indicates a source area situated to the south or south-east, although the anomalous north-north-eastern to north-eastern transport directions measured in Barkly Pass are difficult to account for. The higher quartz and lower rock-fragment percentages indicate that the Cape Supergroup probably featured more prominently in the source area than it did during deposition of the Burgersdorp Formation.

5. CLARENS SANDSTONE FORMATION

The Clarens Formation consists of very pale orange or cream fine- to very fine-grained sandstone or coarse siltstone plus minor mudstone intercalations in places. Topographically this unit forms the characteristic impressive cliffs which are often undercut at the base and hollowed out to form shallow caves.

Beukes (1969, p. 26 ff) suggests that three distinct subdivisions could generally be identified within this formation: a basal massive silty sandstone member, a middle generally cross-bedded fine- to very fine-grained sandstone member and an upper member composed of massive siltstone and silty sandstone. In the map area the uppermost member is generally substantially thicker than the rest. However, the middle zone is not always present and even where this material does occur there is no proof that definite correlation from one locality to the next is possible – each example may represent an independent local development.

Du Toit (1954, p. 356) and Romer (1970, p. 117) both give a Late Triassic age for the Clarens Sandstone.

The upper boundary with the basalts of the overlying Drakensberg Formation is generally conformable, either sharp or intertongued, the transition zone being up to 30 m or more. In places the contact is unconformable, with an uneven, sometimes deeply eroded surface.

According to Beukes (1969, Pl. XI E and XII) the maximum development of the Clarens is in the area north of Elliot where thicknesses are in the region of 200 to 300 m. The formation attains a maximum thickness of 305 m a short distance beyond the northern edge of the map, due north of Elliot. Elsewhere thicknesses generally vary between 20 m and 80 m, whereas in places the formation is absent altogether. Considerable thickness variations can occur over relatively short distances.

The colour of the sandstone/siltstone ranges from yellowish grey (5 Y 7/2) through very pale orange (10 YR 8/2) to greyish orange pink (5 YR 7/2).

One of the most striking features of the bulk of the Clarens Sandstone is its extraordinarily massive, structureless appearance. Beukes (1969, p. 16), however, expresses doubt as to whether all, or even most of the "massive" beds are really without any original internal structures. Nevertheless, the unusual grain size of the massive zones (coarse silt/very fine sand) and their close similarity to loess, which are generally massive as a result of having formed through the accumulation of material carried in suspension, suggest that most of the Clarens Sandstone is probably genuinely structureless.

Medium- to very large-scale trough (festoon) or tabular cross bedding is locally present in the lower part of the sequence. Micro cross lamination is occasionally present. Symmetrical ripple marks occur near the base of the formation, associated with thin- to medium-bedded sandstone/siltstone.

Desiccation cracks have been observed in the interbedded mudstone (Beukes 1969, p. 16; Robinson et al. 1969, p. 32). Beukes (1969, p. 17–18) also describes three kinds of concretions occurring in the Clarens Formation: oval to spheroidal calcareous concretions which are 2 to 15 cm in diameter, irregular, sometimes coalescent calcareous concretionary bodies up to 30 cm in diameter and oval or spheroidal siliceous concretions formed through silicification around a nucleus after deposition of the sandstone.

Beukes (1969, Fig. 18) gives cross-bedding dip orientations which average at about 80° for the map area. High vector strengths (in the region of 0,85) were obtained.

Measurement of the long axes of quartz/feldspar grains in thin sections of three typical samples from Barkly Pass north of Elliot gave an average mean size of 3,90 Ø and an average standard deviation of 0,63 Ø. Similar mean-size values were obtained by Beukes (1969) and Le Roux (1974) for massive sandstone in the Clarens Formation using samples collected from the entire *circum*-Lesotho outcrop area. The cross-bedded sandstones are somewhat coarser; samples collected by Beukes giving an average sieving mean of 3,2 Ø (Beukes 1969, p. 168).

Modal analyses carried out on the three samples from Barkly Pass gave the following percentages:

	%
Quartz	36
Feldspar	20
Rock fragments	8
Accessory minerals	–
Secondary cement	1,5
Matrix	34,5

Quartz: feldspar: rock fragments = 56:31:13

Silicified wood, vertebrate fossils (including one or more fish genera and eight reptile genera) and crustaceans are known to be present in the Clarens Formation (Du Toit 1954).

According to Du Toit (1918, p. xxxv) the general characteristics of the "Cave Sandstone" and its equivalents force one to regard this formation as being mainly an aeolian deposit comparable in certain respects with the Pleistocene loess of the Northern Hemisphere. It appears to have been formed at the conclusion of a period of semi-aridity evidenced by the Elliot Formation. A certain, though probably limited, amount of water must have been present, as shown by the scanty remains of fishes and crustaceans, whereas terrestrial life was represented by dinosaurs.

Beukes (1969, p. 92) has queried the suggestion that the massive sandstone/siltstone constituting the bulk of the Clarens Formation represents an ancient loess, chiefly on the grounds that it is too coarse grained. However, a review of the literature indicates that this is not a valid objection; a full discussion is contained in Johnson (1976, p. 298–300). In the case of the cross-bedded sandstone, the presence of large-scale tabular cross-bed sets (commonly over 2 m thick), composed of fine- to very fine-grained well-sorted sand and displaying remarkably consistent palaeocurrent directions over a large area, can only be accounted for if these sandstones do indeed represent ancient aeolian dune deposits.

Palaeowind directions as deduced from cross-bedding azimuths indicate that the source area for the Clarens Sandstone must have been situated to the west of the present outcrop area. The very fine grain size indicates a considerable distance of transport, while the high feldspar content suggests that feldspathic sandstone and/or granite-gneiss was common in the source area. The present distribution of wind-blown sandstone correlatable with the Clarens Formation demonstrates that the original loess-dune blanket was extremely extensive and that the source area was probably situated to the west of the Cape–Karoo basin, i.e. in what is now South America.

6. DRAKENSBERG FORMATION

The Drakensberg Formation in this area consists of dark-grey basaltic lavas with subordinate tuff and sandstone intercalations in its lower part. Lock et al. (1974) named three separate formations as well as various members within the Drakensberg succession immediately to the north of the map area, but these units are probably fairly localized and they are at present regarded as informal units.

The Formation reaches a maximum thickness of about 750 m at Ben Dearg peak on the eastern edge of the area.

The following description of the petrology of the lavas is based largely on Du Toit's account (1954, p. 304–305). Both the massive, coarsely crystalline and easier-weathering vesicular varieties are encountered. The alternation of harder and softer layers often produces distinct terracing and gives the basalt a stratified appearance. Individual flows average about 3 to 5 m in thickness. The lavas are augite-plagioclase rocks with or without olivine and whereas most are true basalts, some closely approach the augite andesites; enstatite andesites even having been recorded from Pronksberg south of Jamestown. The texture varies from granulitic to subophitic. The vesicles are normally filled with agate, calcite or zeolites. Pipe amygdules 100 to 250 mm long are commonly present at the base of individual flows.

In the basal part of the Drakensberg Formation layers of tuff, agglomerate and ash as well as sandstone similar to the Clarens Sandstone are frequently present. These layers range up to a few tens of metres in thickness and may be quite extensive laterally.

7. VOLCANIC PIPES

Numerous volcanic pipes associated with the Drakensberg volcanicity are present in the northern half of the area. These pipes are confined almost entirely to the Elliot and Clarens Formations. They vary considerably in size and shape. Most are a few hundred metres in diameter, but the larger volcanic bodies north-west and west-south-west of Jamestown are respectively 9 and 13,5 km long.

While a few pipes are plugged with lava, the majority are filled with pyroclastic material containing fragments of sedimentary rocks and lava. In many cases fine-grained sandy material is so abundant that the material closely resembles the Clarens Sandstone.

The pipes appear to have formed immediately prior to or during the earliest phases of lava extrusion and are apparently of shallow origin. The majority became extinct without ever having poured out lava. During their existence, which was largely characterized by explosive activity, the aeolian Clarens Sandstone was still being deposited, allowing the wind-blown sand and dust to mingle with the products of explosion or even to fill up the open throat of the volcano (Du Toit 1954, p. 307).

8. DOLERITE AND RELATED INTRUSIVE ROCKS

Sedimentary strata throughout the area have been extensively intruded by numerous sills, inclined sheets and dykes of dolerite. Emplacement took place during the Jurassic, largely subsequent to the extrusion of the Drakensberg lavas.

It is noticeable that the dolerite sills and sheets become less abundant on going upwards in the stratigraphic succession, with the intrusions in the Drakensberg Formation consisting almost entirely of narrow vertical dykes.

Virtually all the sheet-like intrusions are inclined at various angles to the bedding, and often form characteristic basin-shaped intrusions which may in fact form part of a single, widespread, undulating sheet (Meyboom and Wallace 1978). Since the sheets are rarely horizontal and normally form the dip slopes of cuestas of which the outcrop in the scarp slopes does not represent the full thickness of the dipping body, it is difficult to determine their true thickness. In general the sheets seem to range from a few metres to over 100 m in thickness, with the thick sheet which forms the Andriesberg north of Queenstown attaining an apparent thickness of over 300 m in places. Most dykes are between one and ten metres wide and range from a few kilometres to a few tens of kilometres in length, the maximum length being about 40 km.

Du Toit (1954, p. 364–365) summarizes the petrological characteristics of the Karoo dolerite. According to him they are composed chiefly of about equal proportions of plagioclase (An_{60-80}) and augite. They are divisible into two principal types: the olivine-poor or olivine-free tholeiites and the olivine dolerites. In the thinner sheets and in the dykes the texture is usually porphyritic, whereas in the thicker bodies it is ophitic, with laths of labradorite partially or completely included in pyroxene crystals.

Eales and Booth (1974) describe what they termed the "Birds River Gabbro Complex", an intrusion of gabbroic rocks with a longer axis of 13,5 km situated north of Birds River siding some 20 km south-west of Dordrecht and having the form of a cauldron subsidence. Du Toit (1906, 1912) also mentions the existence of this feature. According to Eales and Booth, emplacement was accompanied by the uplift of the Molteno, Elliot and Clarens Formation sediments, followed by collapse and fragmentation of the roof. Huge xenoliths now occur as much as 700 m above their normal level in undisturbed areas. The fusion of the Clarens Sandstone produced sanidine-bearing granophyres. Intersertal tholeiites were emplaced in the earliest stages, while fractionation of later, olivine-normative, Kokstad-type magma led to pegmatitic derivatives. The emplacement of the complex appears to have pre-dated the main phase of flood-basalt effusion.

The width of the contact metamorphic zone adjacent to intrusions is proportional to the thickness or width of the dolerite body. The mudstones are affected to a much greater extent than the sandstones, being changed into a hard, black, flinty rock known as "lydianite". Syntectic assimilation of the country rock has in places resulted in the formation of granophyric material. Veins of mobilized sediment may also be injected into the dolerite.

9. QUATERNARY DEPOSITS

Alluvium represents the only Quaternary deposit shown on the map. It embraces both alluvial slope (sheet-wash) and alluvial valley (channel-transported) deposits, with the former predominating. The alluvial slope deposits range from a thin veneer to about two metres in thickness, whereas the alluvial valley deposits are usually a few metres thick. Since it is usually difficult to draw a definite line between these two kinds of alluvium, they have been combined for mapping purposes.

Except for the north-eastern quarter of the map most of the mountains in this area are capped by dolerite and the slopes of such mountains are normally partially mantled with dolerite scree. This material often grades into sheet-wash deposits at the foot of the mountains.

10. STRUCTURAL GEOLOGY

The strata are generally horizontal or dip at low angles (less than 5°). Steeper dips may be present locally in close proximity to dolerite intrusions. Faulting is relatively uncommon, and those faults that do occur do not show very large displacements. Gentle basining has resulted in low (1 to 3°) regional northward dips.

11. ECONOMIC GEOLOGY

11.1 AGGREGATE

Dolerite is abundant throughout most of the map area and in a fresh state is eminently suitable as aggregate in concrete and for road construction.

A large quarry is in operation in a thick, steeply dipping dolerite sheet west of Queenstown. Weathered dolerite is frequently used in the construction and surfacing of untarred roads.

11.2 BENTONITE

According to Schmidt (1976, p. 277) bentonitic material is present in the Pronksberg, 17 km south of Jamestown, in the form of a 1 to 2 m thick montmorillonite layer situated about 120 m below the top of the Elliot Formation. Thin lenses of sandstone and cherty material are locally interbedded with the montmorillonite, which in places grades into more shaly material or even wedges out completely. The montmorillonite was probably formed by the alteration of volcanic ash after its deposition in water.

X-ray diffraction analysis of a relatively pure sample showed that it consists mainly of montmorillonite and about 5 per cent quartz. It has been estimated that up to one million tons of bentonitic material may be present at this locality. However, it appears that the variable quality of the material together with the fact that the steep flanks of the mountain will render mining difficult and expensive, may make the deposit as a whole uneconomic.

11.3 COAL

Turner (1971) has reviewed the coal deposits of the north-eastern Cape Province, and the following summary is based on his publication.

The coal in this area occurs in the Molteno Formation in three main seams known as the Indwe, Guba and Molteno seams. The Indwe is the lowest seam in the coal-bearing succession and has been noted at outcrop in most parts of the coal field. It is a composite seam that exhibits considerable variation in seam structure and thickness within comparatively short lateral distances. The seam is well developed at Indwe where it was mined extensively in the past, but away from the old workings it is discontinuous and thin.

The Guba seam lies about 25 to 30 m above the Indwe seam and is a multiple-bedded coal which locally attains a mineable thickness around Indwe and Molteno, where this seam was worked extensively in the past. The most promising development of the Guba seam today is in the Hogg's Kloof and Little Guba valley south of Indwe. From a mining point of view the coal seam here is more suitable than the Indwe seam as it contains fewer shale partings which are generally confined to the upper part of the seam. The Molteno seam is of poor quality and is too thin and impersistent laterally to be of any economic value. At most outcrops the coal is represented by carbonaceous shale with a few bright coal lenses.

In terms of volatile content the coal ranges in rank from a low-volatile bituminous coal to anthracite. The calorific value is rather low, with an average of about 23 MJ/kg and an ash content of 29 per cent. Two comparative thermal-performance tests show that Indwe coal has 11 and 8 per cent volatiles respectively, which makes them greatly inferior to Witbank coal. Because of the numerous shale partings in the seams the cost of working the coal is high. Furthermore, on exposure to weathering the shale partings tend to lose some of their adhesive power and the coal slacks. The widespread intrusion of the coal by dolerite and the consequent metamorphism of the coal has had an adverse effect on its quality and suitability for commercial use.

At a minimum thickness of 1,0 m, the in situ mineable reserves are estimated at 40 million tons (De Jager 1983). However, the physical-chemical properties of the coal and the high cost of mining make it unsuitable for general use.

11.4 ILLITE–MONTMORILLONITE

Deposits of interstratified illite–montmorillonite clay have been discovered on a number of farms situated south-east of Burgersdorp. According to Schmidt (1976, p. 280) the deposits appear to have been produced from Burgersdorp and Molteno Formation shale by hydrothermal alteration caused by the intrusion of dolerite sheets and possibly by the alteration of the chilled border zones of these sheets. The clay invariably occurs along the contacts of the thicker dolerite sheets and shale and is between 0,5 and 1,5 m thick.

The clay is no longer exploited, but was used in the ceramic industry as an ingredient in an insulator body in which it acts as a bond in the green ware and as a flux during firing.

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