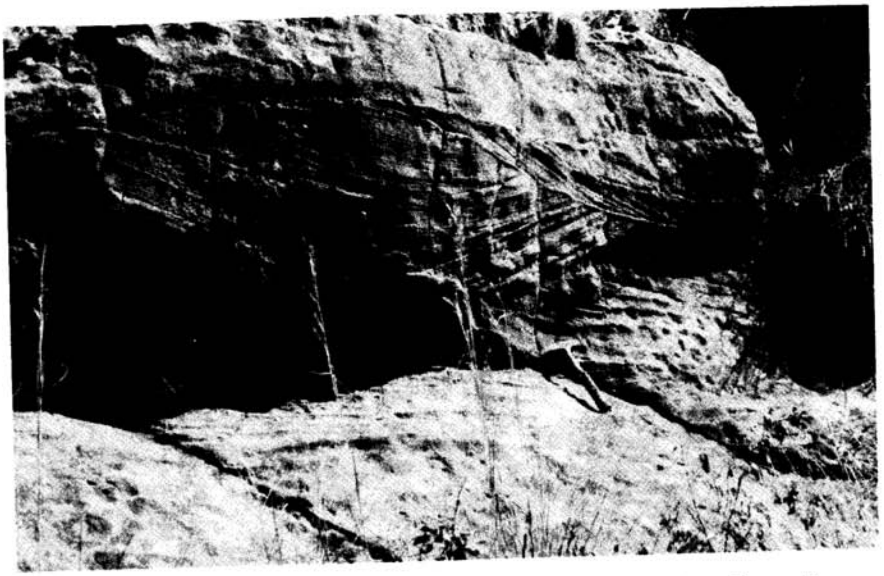

Fig. 5. Coarse-grained trough cross-bedded sandstone of the Molteno Formation.

Vertebrate fossils are normally absent from the Molteno Formation, and have not been found in the park. Although the formation is rich in plant remains in certain areas, none were found during this investigation. The formation was deposited during the Late Triassic Epoch.

4. Elliot Formation

The areal extent of the Elliot Formation is much greater than indicated by Spies (1969). The formation characteristically consists of red mudstone and siltstone with subordinate red and light yellow medium- to fine-grained sandstone beds (Fig. 4, Klerkspruit, Glen Reenen sections). The mudstones and siltstones are blocky-weathering and break down very rapidly to a poor soil, thus forming the negative-weathering slopes on the mountain sides. The mudstones are usually massive and both isolated and layered occurrences of calcareous concretions are found, leading to marl deposits in places. The concretions are 1 cm - 15 cm long, red-brown in colour and often have calcium-rich kernels. In the park, a sandstone which is up to 30 m thick is locally developed and forms prominent cliffs in the eastern extension of the park on the road to Kestell (Fig. 6).

This sandstone represents a local increase in the sandstone content of the formation as indicated by Robinson *et. al.* (1969) during a regional study of the Stormberg Group and was correlated with the Molteno Formation by Erickson (1983). The sandstone is cross-bedded, fine-grained and feldspathic, consisting mainly of angular to subrounded quartz and feldspar grains with specks of pyrite.

The thickness of the formation depends largely on where the lower and upper contacts are taken and it seems as if there is little agreement on either of these. The lower boundary with the Molteno Formation has for the purpose of this study been taken at the point where red mudstone and siltstone overlie the uppermost prominent sandstone of the Molteno Formation. This contact is rarely exposed. The upper contact is normally not sharp (Van Eeden 1937) and was generally taken as the transition zone from red mudstone to fine-grained sandstone (Spies 1969; Beukes 1969; Erickson 1983). For the purpose of this study the boundary was taken at the point where red mudstones of the Elliot Formation, which disintegrate into small blocky fragments on weathering, are overlain by relatively resistant massive fine-grained sandstone of the Clarens Formation, irrespective of colour (Fig. 7).

Fig. 6. Prominent sandstone unit in the Elliot Formation in the eastern extension of the Golden Gate Highlands National Park.

A total thickness of 146 m was measured for the formation and differs from the thickness of approximately 60 m determined by Erickson (1983) due to a difference of opinion concerning the position of the lower contact.

The formation is interpreted as a fluvial deposit because of the presence of fining-upward cycles and trough cross-bedded sandstone as well as the red colouration of the mudstones (Tucker 1984). Shallow high-sinuosity rivers appear to have dominated the scene, with larger channels developed locally, while shallow lakes existed on the flood-plains. The red colouration of the mudstones and siltstones is due to oxidation of the iron during or shortly after deposition. Palaeocurrent measurements indicate a direction from the east and south-east which agrees with the values found by Erickson (1983).

The Elliot Formation is known for its vertebrate fossil content (mainly dinosaur remains) and a detailed study was undertaken by Kitching (1979) and Kitching & Raath (1984). Fossils of *Massospondylus* sp. (sauropod dinosaur), *Pachygenelus monus* (advanced cynodont), *Clarencea gracilis* (small thecodont), *Lanasaurus scalpridens* (bird-like dinosaur), *Notochampsa* sp. (crocodilian), and unidentified dinosaur eggs, two of which contain embryos, have been described, from the formation in the Golden

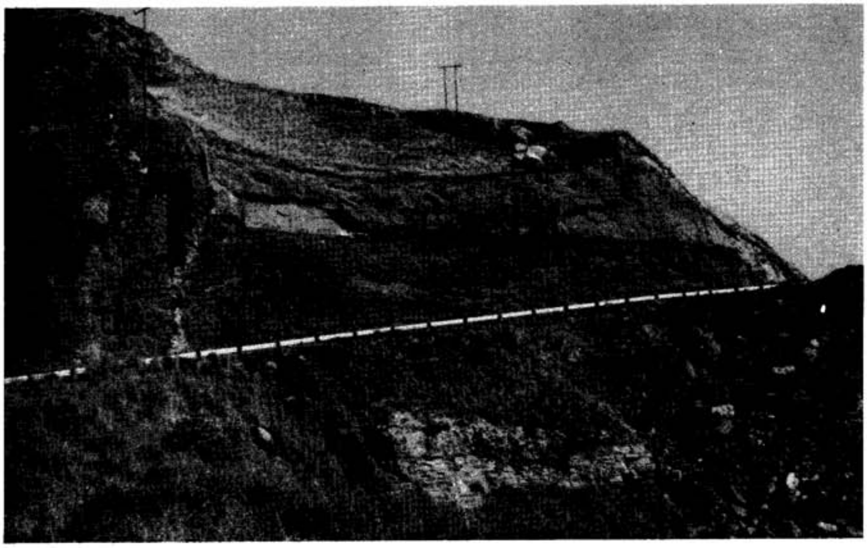

Fig. 7. Red siltstone of the Elliot Formation (E) overlain by massive sandstone of the Clarens Formation (C). A dolerite dyke (do) cuts through the sediments.

Gate Highlands National Park, by these authors. The richest horizons in the park are found in the upper part of the formation and the best outcrops are next to the road to Kestell, immediately south of the Glen Reenen Rest Camp and at Rooidraai. During the present investigation another occurrence of unidentified dinosaur eggs and a few unidentified fossil bones were discovered (Fig. 8).

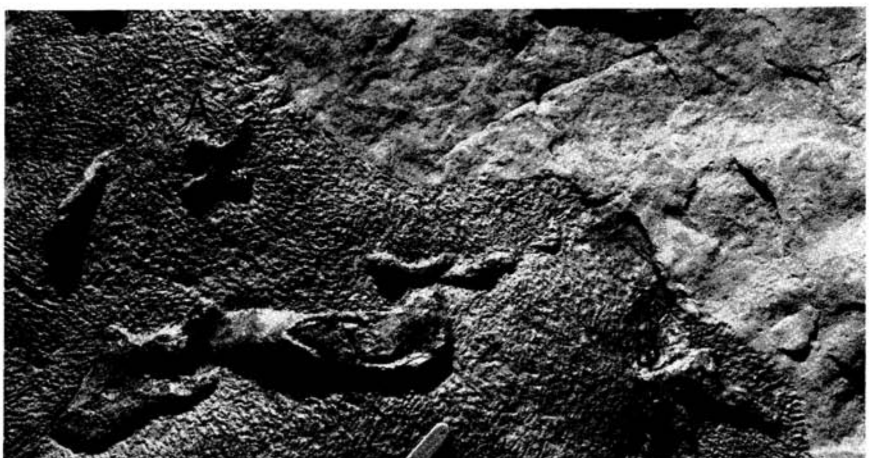

Fig. 8. A fossilised vertebra (A), claw (B) and unidentified bones in the Elliot Formation.

5. Clarens Formation

The Clarens Formation consists of fine- to very fine-grained light yellow-brown sandstone which forms the conspicuous cliffs in the Golden Gate Highlands National Park (Fig. 9).

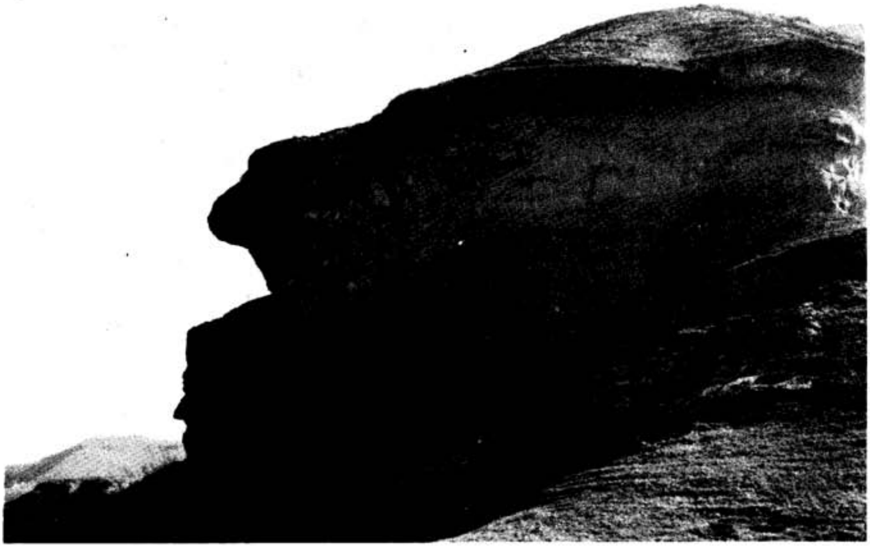

Fig. 9. Sandstone of the Clarens Formation forming conspicuous cliffs, flanking the Little Caledon River.

The formation crops out along the southern and northern sides of the Little Caledon River and adjacent to the major kloofs in the park while the eastern part of the park is largely underlain by it. In the greater part of the park the lower section of the sandstone is red, probably as a result of the leaching of iron from higher up in the succession (Spies 1969) or the effect of oxidizing conditions that prevailed during or shortly after deposition of the lower part of the formation.

The sandstone is in general very uniform (Fig. 4: Eastern Park Boundary Section) and consists mainly of angular to subrounded quartz and a few feldspar grains. Large planar cross-beds are sometimes present in the otherwise massive, thickly bedded sandstone (*e.g.* along the road in the game area). On the northern side of the Ribbok Spruit near the Ribbok Waterfall an isolated thin layer, 2 cm – 5 cm thick, of coarse-grained sandstone occurs at the base of one sandstone bed, but it is not possible to determine its lateral extent due to poor outcrop. Layers of mudstone and shale are developed locally in the sandstone.

The lower boundary with the underlying siltstone of the Elliot Formation is not well defined while the upper boundary with the basalts of the Drakensberg Formation is very sharp. The lower boundary was taken at the point where the red siltstone of the Elliot Formation is overlain by massive sandstone and siltstone of the Clarens Formation, irrespective of colour (Fig.

7) (see earlier discussion). The upper boundary is taken at the contact between the sandstone and the first lava of the Drakensberg Formation. The formation varies in thickness from 130 m to 160 m.

A distinctive characteristic of the formation is the occurrence of overhangs which form due to weathering of the sandstone (Le Roux 1978) – whence the traditional name Cave Sandstone (Fig. 9). Differential weathering results from various processes. Calcification of the sandstone along certain horizons results in a difference in resistance to weathering. Impermeable mudstone underlying the sandstone causes groundwater to seep out near the base of the sandstone which in turn leads to weakening and faster weathering of the strata. Exudation or salt weathering is the process whereby rock surfaces are scaled off due to growth of salt crystals ($NaCO_3$, $NaSO_4$) by capillary action. According to Le Roux (1978) salt solutions, formed during weathering of the basaltic lava with the aid of CO_2 derived from the atmosphere, move down through the sandstone and crystallise where the solutions seep out near the base. In some instances normal undercutting of the sandstone may also be responsible for the formation of caves. The most impressive example of cave formation is seen in Cathedral Cave where a layer of quartzitic sandstone prevents the fast weathering of the roof of the cave and the sandstone is practically hollowed out from the inside, forming a cathedral-like structure. Behind the Brandwag Rest Camp more examples of overhang formation can be seen.

Calcareous concretions are commonly developed in the sandstone and lead to the formation of interesting weathering features such as honeycomb structures (Fig. 10).

Fig. 10. Honeycomb weathering of the Clarens Sandstone due to different degrees of carbonate enrichment.

Ferruginous concretions are also present and in fresh samples found on Rondawelkop complete cubic crystals of pyrite were found. When exposed the pyrite oxidises to limonite and leaves a red or orange hollow mark in the sandstone.

According to Spies (1969) all the vertebrate fossils in the park were found in the lower part of the Clarens Formation. Kitching & Raath (1984) on the other hand, correlate the main occurrence of fossils with mudstones of the Elliot Formation, thus differing from Spies (1969) regarding the definition of the lower boundary of the Clarens Formation. The fossils of *Pachygenelus* sp. (advanced cynodont) and *Massospondylus* sp. (sauropod dinosaur) have actually been described from the Clarens Formation by Kitching & Raath (1984). According to Beukes (1970) conditions were favourable for animal life throughout the depositional history of the formation.

During the present study the fossil remains of a small Archosaur were found behind the Information Centre of the National Parks Board at Gladstone in the lower part of the Clarens Formation.

The Clarens Formation is interpreted as a typical aeolian (wind-blown) deposit because of the rounding and sorting of the sand grains and the occurrence of large planar cross-beds resembling those in present-day sand dunes. Because of the massive appearance of some sandstone beds, sand was probably redeposited as sand flows in large playa lakes (Beukes 1970; Erickson 1983). The deposition of the formation took place during the late Triassic Epoch.

6. Drakensberg Formation

This formation (also referred to as the Lesotho Formation: see Erlank 1984) is characterised by numerous superimposed outflows of basaltic lava. The formation builds the higher mountains in the GGHNP and individual lava flows can be identified as separate ledges on the mountain sides. A few layers of volcanic ash are interlayered with the basalts and are normally represented by thin layers of very hard, fine-grained, light-red material. The rocks of the Drakensberg Formation are of typical basaltic composition (Visser & Van Riet Lowe 1956) and consist of amygdaloidal and massive flows. The latter are normally compact and exhibit a columnar structure. The rocks are typically very dark in colour, finely to coarsely crystalline and contain mineral-filled amygdales of various sizes and shapes. Amygdales represent cavities formed by the movement of gases through the lava and are filled with quartz, calcite and in some places with the zeolites natrolite and epistilbite (Spies 1969). The filling of small cavities led to the formation of agate while in some places complete crystals of quartz, known as mountain crystal, are found. The best examples of these crystals occur at Kristalpan in the eastern extension of the park.

The lower boundary of the formation is sharp and is taken at the base of the first basalt layer. In many places the contact is very impressive. The first layers of basalt are characterised by numerous amygdales which are preserved as pipe-like structures representing the movement of steam and gas through the lava. The upper boundary of the formation has been weathered away and it reaches its greatest thickness, in the park, at Ribbokkop where a total of approximately 600 m is preserved. The formation was formed during the early part of the Jurassic Period (roughly 190 million years ago).

During the present investigation a possible volcanic pipe was discovered in the kloof running south-west of Cathedral Cave. The pipe is located within the Clarens sandstone and is filled with dolerite, lava and a layer of quartz- and feldspar-rich breccia. Lapilli tuff has been identified in association with the pipe.

Two interesting outcrops of dolerite exhibiting large cavities filled with quartz have been found and may be interpreted as gas-rich intrusions, of doleritic magma into the Clarens Sandstone, that did not reach the surface. One of these intrusions can be seen next to the road in the game area.

7. Karoo Intrusive Rocks

Several dykes and a few sills of dark, fine- to coarse-grained dolerite occur in the GGHNP and intrude the sedimentary as well as the volcanic rocks underlying the park. The dolerite dykes are normally long linear structures and can be followed for many kilometres while dolerite sills represent horizontally intruded doleritic magma. Faulting along the dykes is not uncommon and may reflect fault-lines that existed before intrusion of the doleritic magma (Fig. 11).

Fig. 11. Example of faulting along a dolerite dyke (do) on the Rhebuck Trail. Clarens Sandstone (C) is upthrown relative to Drakensberg Basalt (D).

The dolerite cooled faster along the outer margins of the dykes and sills, which led to the formation of finer crystals in these areas as compared to the central part of the intrusions. According to Spies (1969) volcanic glass occurs in association with a dolerite dyke.

Although Visser & Van Riet Lowe (1956) stated that no dolerite sills have been found in the basalts a few do in fact occur. Spies (1969) described a large and extensive dolerite sill that intruded on the contact between the Clarens Sandstone and the Drakensberg Basalt. Although a sill is present at this horizon, for instance above Cathedral Cave, it is not as extensive as indicated by Spies (1969). On the eastern side of the Ribbok Spruit the sill becomes a vertical dyke running along the valley side. A thinner sill is intruded into the Clarens Sandstone and can be seen in the cliffs on the southern side of the road between the Information Centre of the National Parks Board at Gladstone and the Brandwag Rest Camp. The sill is approximately 3 m thick and can be followed for nearly a kilometre before it appears to change to a vertical dyke which cuts the road close to the Brandwag Rest Camp.

The most impressive example of dolerite intrusion in the park is the prominent dyke that runs past Brandwag Buttress, with another associated dyke dipping at 35° to the east (Fig. 12). The two dykes merge to the south and north of this point and to the south this composite dyke is up to 75 m wide.

Fig. 12. Multiple intrusion of dolerite at the Brandwag Buttress. The dyke running next to the buttress is not exposed, while the steeply dipping dyke to the east thereof is clearly visible.

The dyke narrows further to the south where it can be followed along the Rhebuck Trail to Generaalskop where it again becomes a prominent sill up to 20 m thick (Fig. 13). Another sill can be observed in the basalts on the eastern side of Wodehousekop and it is very difficult to determine the exact extent due to its similar appearance to massive basalts.

Where sandstone is intruded by dolerite it is baked to form a hard quartzitic sandstone which is much more resistant to weathering, causing overhanging walls of rock like the one observed south of the road between Brandwag Rest Camp and Gladstone. The same process is responsible for the formation of the columnar-jointed quartzitic sandstone which overlies Cathedral Cave. The faster weathering of the underlying softer sandstone resulted in the formation of the cathedral-shaped structure.

Fig. 13. A prominent dolerite sill (do) cutting through Drakensberg Basalt on the slopes of Generaalskop.

Most dolerites in South Africa were intruded between 150 and 180 million years ago.

8. Recent Deposits

Geologically recent deposits comprise coarse-grained gravel and beds of medium- to fine-grained sand and silt, with interbedded layers of grit. Detailed descriptions are given by Visser & Van Riet Lowe (1956). They described nine terraces of gravel deposits in the region of the park and ascribed periods of incision of the Little Caledon River to wetter periods that prevailed in the area.

The gravel consists of angular to well-rounded boulders and pebbles of basalt, dolerite and sandstone as well as subangular fragments of quartzitic sandstone and occasional stone implements.

Fragments of shale and tuff are water-worn and the stone implements exhibit various degrees of rolling. From the poor sorting and angular nature of the gravel it is clear that the constituent material has not been transported far. The gravel is normally embedded in fine-grained sand which is derived from the Clarens or Drakensberg Formations. The sandstone and basalt boulders are usually well rounded and intensely weathered where exposed, tending to disintegrate. The gravel is overlain by fine-grained, sometimes well-bedded, sand with thin beds of interlayered grit. In some exposures a rude current-bedding is evident. All the recent terraces are covered by a black clay-rich turf soil and where not ploughed are overgrown by grass.

These deposits are geologically recent, and contain implements used by ancient man, indicating ages of as far back as the Early Stone Age (up to 0,7 million years ago).

Structure

Slight folding of the Karoo rocks in the vicinity of the park has been described by Van Eeden (1937), but in the park itself the strata are nearly horizontal (Spies 1969) (Fig. 3).

The dolerite dykes and sills are of different ages and dykes, in some instances, cut through dolerite sills. Dykes are in many cases intruded into fault planes, and this explains why displacement occurs along them. The best example can be observed along the Rhebuck Trail about 800 m beyond Brandwag Buttress where a displacement of 60 m occurs (Fig. 11). A second fault, also intruded by dolerite, has less displacement along it and can be seen in the eastern extension of the park, on the road to Kestell, where the best indication of faulting is the displacement of sandstones of the Elliot Formation.

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REFERENCES

BEUKES, N.J. 1969. *Die sedimentologie van die Etage Holkranssandsteen, Sisteem Karoo.* M.Sc. thesis, University of the Orange Free State, Bloemfontein.

BEUKES, N.J. 1970. Stratigraphy and sedimentology of the Cave Sandstone Stage, Karoo System. *Proc. Gondwana Simposium 1970:* 321-341.

ERICKSON, P.G. 1983. *A palaeoenvironmental study of the Molteno, Elliot and Clarens Formations in the Natal Drakensberg and northeastern Orange Free State.* Ph.D. thesis, University of Natal, Pietermaritzburg.

ERICKSON, P.G. 1984. A palaeoenvironmental analysis of the Molteno Formation in the Natal Drakensberg. *Trans. geol. Soc. S.Afr.* 87: 237-244.

ERLANK, A.J. (ed.). 1984. Petrogenesis of the volcanic rocks of the Karoo Province. *Spec. Publ. geol. Soc. S. Afr.* 13: 1-395.

KITCHING, J.W. 1979. Preliminary report on a clutch of six dinosaurian eggs from the Upper Triassic Elliot Formation, Northern Orange Free State. *Palaeont. afr.* 22: 41-45.

KITCHING, J.W. and M.A. RAATH. 1984. Fossils from the Elliot and Clarens Formations (Karoo Sequence) of the northeastern Cape, Orange Free State and Lesotho, and a suggested biozonation based on tetrapods. *Palaeont. afr.* 25: 111-125.

LE ROUX, J.S. 1978. Die ontstaan van grotte en holtes in die kranse van die Clarenssandsteenformasie in die Golden Gate-gebied. *S.A. Geographer* 61: 23-29.

ROBINSON, D.N., H.M. BEER, F.M. NUTSCH and F. TRUMPELMANN. 1969. The geology and oil potential of the Stormberg Group. SOEKOR Rep. No. SV 610f. (Unpubl.).

SOUTH AFRICAN COMMITTEE FOR STRATIGRAPHY (SACS). 1980. *Stratigraphy of South Africa.* Handbook geol. Surv. S. Afr. 8. Pretoria: Government Printer.

SPIES, J.J. 1969. Die geologiese en geomorfologiese geskiedenis van Golden Gate Hoogland Nasionale Park. *Koedoe* 12: 184-198.

TUCKER, M.E. 1982. *The Field Description of Sedimentary Rocks.* Milton Keynes: The Open University Press.

TURNER, B.R. 1975. *The stratigraphy and sedimentary history of the Molteno Formation in the main Karoo Basin of South Africa and Lesotho.* Ph.D. thesis, University of the Witwatersrand, Johannesburg.

TURNER, B.R. 1984. Palaeogeographic implications of Braid Bar Deposition in the Triassic Molteno Formation of the eastern Karoo Basin, South Africa. *Palaeont. afr.* 25: 29-38.

VAN EEDEN, O.R. 1937. The geology of the country around Bethlehem and Kestell with special reference to oil indications. *Mem. geol. Surv. S. Afr.* 33: 1-68.

VAN EYSINGA, F.W.B. 1975. *Geological Time Table.* Amsterdam: Elsevier Scientific Publishing Company.

VISSER, D.J.L. and C. VAN RIET LOWE. 1956. Die geologie en argeologie van die Klein-Caledonriviervallei. *Mem. geol. Surv. S. Afr.* 47: 1-66.