ON THE NATURE OF THE CAPE FOLDING,

BY ANALYSIS OF A STRUCTURAL SECTION
BETWEEN TOWERWATERPOORT AND STRYDOMSVLEI
- DISTRICT WILLOWMORE, C.F.

by J.M. THERON, B.Sc.

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(Thesis submitted in partial fulfilment of
the requirements for the degree of M.Sc. in
Geology at the University of Stellenbosch,
South Africa.)
A structural section of the northern range of the Cape Fold Belt true to the scale mapped, is constructed; as far as possible according to a definite geometrical method.

A stratigraphical column with accompanying type fossils and the different marker horizons used in mapping, is given and described in detail. The structural pattern of the area is analysed and the evolution thereof discussed.

From the section the total depth of folding and crustal shortening that accompanied the structural deformation of the "Fold Belt" are computed.

An attempt is also made to determine to what degree did isostatic balance exist between the Fold Belt and the geosynclinal depression in Post-Molteno Time.
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ACKNOWLEDGEMENTS.

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CHAPTER 1.

(a) INTRODUCTION.

"If the path of a sand grain in a sandstone of the Alps or Appalachians could be traced back to the point of deposition it would be a highly complicated curve, and not a simple horizontal line from one point to the other within one plane."

Nowhere in South Africa is the truth of the above statement more clearly illustrated than in the great fold range of the Swartberg. As a result of this, the research which culminated in the following paper, was undertaken by the writer after a tour of geology students under Professor Dr. M.S. Taljaard in the Eastern Cape Province during July 1957. Actually the idea did not originate on the three-day visit to Vondeling, but had been considered by Dr. Taljaard ever since he had first seen Towerwaterpoort.

The area where the research was done, (see locality map Fig.1.) is particularly suited to the study of a structural section. Not only is the entire Towerwater-poort and Soetendalspoort practically on a level plane but both gorges are passable, within easy reach and more or less aligned on a north-south line. A further factor which facilitated mapping is the surface accessibility of the main structural features due to the differential weathering of the sandstone and shale horizons.

As shown on the locality map the area surveyed stretches over two mountain ranges - Swartberg and Witberg Range respectively - of the Cape Fold Belt and covers approximately 32 square miles. Mapping was done by open-sight and telescopic alidade on a scale of 5 28" = 1 mile (1/12000).
FIG. 1. Distribution of the Cape System in the south and western Cape: Inset: locality map of area surveyed.
Since topographic maps of such a large scale were not available, no base map could be found from which to procure a profile section, thus instituting the necessity of a traverse along the section line by means of an aneroid barometer. The fluctuations due to temperature and pressure variations were corrected for and checked by means of a Paulin-precision barograph kept at base-camp.

A structural section true to scale, could then be drawn across the whole of the Cape System and from it various data bearing on the structural deformation be obtained. Fieldwork was commenced in January and was concluded in March, 1959, except for a very brief re-visit in July of the same year.

(b) HISTORICAL REVIEW.

Since the Table Mountain sandstone forms the most conspicuous features in the Cape Colony, it is only fitting that one of the first named geological units should have been called the Table Mountain sandstone in tribute to the Gateway of Africa.

The first acceptable outline of the geological succession and structure of the Cape Colony was introduced by A.C. Bain (1945, 56). His sequence of formations was:

- Carboniferous (Zuurberg Quartzites).
- Upper Silurian (Fossiliferous Bokkeveld Beds).
- Lower Silurian (Unfossiliferous Sandstone and Conglomerate).

Clay-slate and gneiss with intrusive granite.

Bain, due to never having had the opportunity of correlating the western and eastern rock formations, limited the occurrence of his "Carboniferous" group (Witteberg Series) to the Eastern
Province. A. Wylie (1859) as geological surveyor to the Colony and later E.J. Dunn (1869, '74, '87) by means of his geological maps, not only confirmed the work done by Bain, but improved on it by linking the eastern and western regions.

Dr. R.N. Rubidge (1859, '65) took a different view and considered the present-day Malmesbury slates and the Bokkeveld shales as a unit, with the Witteberg quartzites on the same horizon as the Table Mountain Series.

F. von Hochstetter (1866) supported this view in designating the Bokkeveld as older than the Table Mountain sandstone.

E.J. Dunn (1875) confirming Bain's original succession in a second edition of his map, abandoned the supposed equivalent European names hitherto used and named the formations according to the localities where they occur.

W. Moleneux (1881) preferred not to be drawn into any controversy and simply used the name "Karroo Beds" for the whole present day succession of Cape and Lower Karroo Systems north of the Swartberg. He just mentions the fact of paying a visit to Soutendalsvlei and drew a section, but did not give any specific description of the area.

The two trends, i.e. that of Rubidge and that of Bain, were alternately upheld by Prof. R. James (1884), Prof. E. Cohen (1887) who agreed with Rubidge, and A. Moulle (1884) and A.H. Green (1888) who agreed with Bain's view.

Prof. A.H. Green (1888) published the first detailed stratigraphic column in which he combined the work of Bain, Dunn and Wyley as follows:
Great Unconformity.

6. Ecca Beds.
5. Dwyka Conglomerate.

Unconformity.

4. Quartzites of the Zuurbergen, Zwarteborgen and Wittebergen.
3. Bokkeveldt Beds.
2. Table Mountain Sandstone.

Great Unconformity.

1. Slates and intrusive granite of the neighbourhood of Cape Town. (Malmesbury Beds)

Dr. A. Schenck's (1888) major contribution was by introducing the term "Cape Formation" to include the three present members of the Cape System, but he erroneously propounded a totally new theory according to which the Zuurberg and Witteberg quartzites, and the Table Mountain sandstone were supposed to be contemporaneous with the Bokkeveld beds, the former being the shore equivalent of the latter.

Dr. G. Gurich (1889) did not agree with this and sided with Bain, Dunn and Green.

A.R. Sawyer (1893) included in his report on the "Geological and Mineral Resources of Prince Albert" an "Ideal Geological Section" from the Indian Ocean to Fraserburg, where the following succession was used:

Mesozoic.  

\{ Ecca Conglomerate. \}  \{ Upper (Nieuwveld Beds) \}  \{ Lower (Ecca Beds) \}  \{ Carbonaceous Shales. \} 

\{ Enon Conglomerate. \}  \{ Karroo. \}
Palaeozoic:

- Dwyka Conglomerate
- Silurian, Devonian and Carboniferous.
- Granite (with patches of Gneiss).

In 1935 the Geological Survey of the Cape Colony was formed and only now the correctness of Bain’s original succession was proved by the mapping of G.S. Cortorphone, A.W. Rogers and E.H.L. Schwarz.

G.S. Cortorphone in the 2nd Annual Report of the Survey finally summarized the Cape rocks stratigraphically as follows:

7. Superficial Deposits - Gravels, sands, conglomerates, sandstones and limestones.
6. Ecca Beds - Shales and sandstone (with occasional plant remains).
5. Dwyka Series - Conglomerates and interbedded shales.
4. Witteberg Beds - Mainly quartzites (often with algaline markings).
2. Table Mountain Sandstone - Sandstones and quartzites with occasional shales.

(Marked Unconformity)

1. Malmesbury Beds - Non-fossiliferous slates, phyllites, mica schists and quartzites with intrusive granite, quartz-porphyry and diabase.

Detailed investigation of thickness (Schwarz 1899 on the Bokkeveld), lithology, stratigraphical relationship and hypothesis concerning geological history, now resulted.

E.H.L. Schwarz (1903) thus first mapped and described...
the area on which the writer did his research. A detailed geological map was prepared which accompanied his report, in which the country was sub-divided into seven areas and each described separately as regards geological and geographical features. A lithologic section of the "shales below the Dwyka Conglomerate" was given and the fact that the regular succession of sandstones and shales of the Bokkeveld, common in the west, is different here, and, that it is highly contorted, thus causing trouble in determining their stratigraphic relationship, was remarked upon.

The year 1905 saw the appearance of two volumes which did much in giving a correct and clear picture of the whole, i.e. A.W. Rogers - Introduction to the Geology of Cape Colony and F.H. Hatch and G.S. Corstorphine - Geology of South Africa.

Now for the first time a definite systematic correlation of all the facts were given, together with geological maps of the Colony and South Africa. The latter work gives a very comprehensive stratigraphical table in which correlation is made between South African and European equivalents. Thus the "Cape System" in pursuance of Schenck was accepted and correlated with the Devonian of Europe. The former work again is unique in that it contained the first geological history published until then. As such it was a major contribution to South African stratigraphy. The following years up to 1926 saw the publication of a whole succession of more comprehensive works, i.e. A.W. Rogers and A.L. du Toit (1909), F.H. Hatch and G.S. Corstorphine (1909), E.H.L. Schermar (1912) and A.L. du Toit (1926).

In the latter work there is a detailed account of the South African geology and a comprehensive chapter on South African geological history, which has remained the standard
work even up to to-day. From the pen of du Toit appeared a major contribution to structural geology, in the form of a comprehensive comparison of South African geological features with that of South America (1927) and later (1937) his world-renowned work in support of Wegener’s controversial theory on Continental Drift.

R.H. Rastall (1911) however paved the way as regards the structural aspect of the Cape orogeny in his determination of the amount, cause and result of the Worcester Fault.

E.H.L. Schwarz (1912) erroneously considered the Cape orogeny as being due to the extensive dolerite intrusions of post-Jurassic time.

P.G. Söhne (1934) in his research on the Worcester Fault was able to give a short, but very comprehensive account on the history of the Cape orogeny.

J. de Villiers (1944) after detailed field work on the Cape System, delivered in his review of the Cape orogeny a major contribution on the structural history of that System.

B. Swart (1950) in his research on the Morphology of the Bokkeveld beds in the Western Province, submitted a very clear exposition. His research on primary features and the provenance is most illuminating and instructive. At the same time, his contention that the Witteberg sandstone is only another phase of the Bokkeveld, and, that actually the Cape System should consist of only two member Series, is well worth noting.

During 1925 an investigation was instituted by the Geological Survey on the possibility of finding oil in the Karroo, by A.W. Rogers, but only in 1953, on the work of S.H. Haughton, J.J. Blignaut, P.J. Rossouw, J.J. Spies and
S. Zagt, did a publication of a detailed investigation appear, after boring operations had been completed. In this work the geological sections of 11 boreholes are given. Most of these penetrated up to the white quartzite of the Witteberg, thus giving a true stratigraphical thickness to certain horizons.

D.J.L. Visser (1957) summarized all the known results and combined it in an extensive address as president of the Geological Society of South Africa.
CHAPTER II.

(a) PRESENT DAY TOPOGRAPHIC FEATURES AND DRAINAGE:

(i) Description.

A most impressive aspect of scenery is displayed in the stupendous ravines, cut through the Swartberg Range, in the Gamka-, Seven Week's-, Meiring's- and Towerwaterpoorts. Standing at 5000' on the Swartberg with the railway-line from Oudtshoorn to Willowmore, 2300' below, twisting its way through Towerwaterpoort (Plate 1, ph.A.) there is an unparalleled view over the area surveyed by the writer. (see Fig.1.)

To the south are the red rugged hills around Towerwater Station, built of red Enon Conglomerate, down-faulted against the Table Mountain sandstone by the great Swartberg fault, and weathered into grotesque shapes. (Plate 1, ph.B.)

In the broad intermontane valley between the Swartberg in the north and the Kammanassie - and Kouga Mountains in the south, the Olifants River, meeting the Traka River just south of the poort, winds its way towards Oudtshoorn almost 50 miles away.

Around Rooikop (south-east of Towerwater Station) table-topped hills with steep flanks, appear to constitute a 900' surface, linking up with terraces flanking the Kammanassie Mountains.

Westwards, the great Swartberg Range stretches for almost 130 miles, attaining a maximum height (7632') near Seven Week's-poort.

Eastwards the range, locally known as Slypsteenberg, terminates at Zuurbergpoort near Willowmore. A feature clearly noticeable, Towerwaterpoort being no exception, is
the southward dip of the massively bedded Table Mountain sandstone, due to northward overfolding.

The bare white krantzes soon give way northwards to a succession of foothills covered by dense shrub. Very conspicuous, due to its unbedded character, rough uneven weathering and straw-yellow colour, is an outcrop in a bare ridge. (Plate IV, ph.A.) This rock is considered to represent a tillite phase of the Table Mountain Series outcropping due west of the poort. Also conspicuous, is the first sandstone of the Bokkeveld Series, a quartzitic horizon "showing" as a continuous white ridge striking parallel to the mountain side. (Plate I, ph.C.) The deep valley flanking it on the north side, cut in the softer Bokkeveld shales, is soon replaced by a succession of gently undulating hills. These hills continue on both sides of the Traka River right up to the sandstone horizon forming the cliff-like ridge — so called "Spekboomrant" — south of Vondeling Station. This ridge forms a major topographical feature adjacent to the broad, flat, alluvial plain, which continues right up to the road from Willowmore to Klaarstroom 35 miles to the west, at the northern extremity of Meiringspoort.

At the side of the road, standing vertically and remarkably similar to a thick man-made wall, runs the first sandstone horizon of the Lower Witteberg Series. The succeeding sandstone beds, intricately folded and due to the surrounding shale horizons weathering more easily, form ridge-on-ridge of almost vertical "walls" trending east-west, building successively, synclinal and anticlinal structures for about 2½ miles, throughout the breadth of the area examined. (Plate I, ph.F.) Except for the flood plains of the Vandereys River and Traka River, these ridges continue up to the prominent Witberg Range. (Plate I, ph.E.)
A feature clearly visible, is the evenness in height of the whole range from Tierberg (4239') just east of Prince Albert up to Aasvogelberg (4639') north of Willowmore.

Looking back from the 3403' Trigonometrical beacon on the Witberg west of Soetendalspoort towards the Swartberg, a feature, probably linked with the above is clearly visible, i.e., the plateau just east of Meiringspoort, on which the farms Haggas and Uitnoord are situated, is cut at the same level.

At Soetendalspoort (Plate I, ph.G.) the alternating sandstone and shale horizons so typical of the Witteberg Series are folded into a huge S-loop. Weathering of this latter feature resulted in four parallel trending ranges.

The homestead of Soetendalspoort is situated in a synclinal valley terminating 1 mile east of the farm buildings and widening westwards.

On the northern flank, the conspicuous white marker horizon of the Witteberg Series trends westwards into the distance and flanks Aasvogelberg in the east. The Treka swings westward at its confluence with the Loeriesfontein River, just south of the homestead on Soetendalsvlei and joins the Haarmonspruit River, in aligned strike subsequence, just to the north of the poort. The fairly flat, featureless Great Karroo stretches out up to the Roggeveld-Nieuwveldt escarpment about 70 miles to the north.

Striking from west to east is an unbroken line of hills strewn with angular white blocks. South of Strydomsvlei is a similar line parallel with the first.
These ridges continue eastwards up to Aasvoogelberg. Westwards, the nearest one terminates just west of the road from Sostendalsvlei to Strydomsvlei, 1½ mile from the former homestead, while the northern one continues till just north of the confluence of the Traka and Kouka Rivers.

The climate of the whole area is one of semi-aridity, situated between summer rain from the north to north-west and winter rain from the south (5 to 15 inches per annum). The rainfall is classed as "periodic" - "a regular occurrence of rainy seasons between which long intervals of dryness hold sway." (L.C. King, 1951, p.53)

The courses of the Traka, Kouka, Kommandokraal, Loeriesfontein, Maermanskraal and Vandereya Rivers, are clearly definable from any high vantage point. This, as a result of the mimosas, which, in accordance with the nature of the Karroo, cling doggedly to them in otherwise sparsely covered plains. Their dry courses belie the volume of water which rushes through the poorts after every thunderstorm.

(ii) Evolution of the topography:

The first orogenic deformational phase of the southern portion of the Karroo geosyncline was initiated during Lower Beaufort Time, developing into the "Zwartberg Foldings" with a regional east-west axis. This deformation reached its peak at the begining of Molteno time. Although of great intensity, this orogenic pulse initiated a great northern plainland, eventually covered by Stormberg basalts, and the main east-west divide most probably existed as a topographical feature up to the formation of the great End-Jurassic peneplain.
The dessication of the latter, in the Late-Jurassic, as a result of almost 2000' of renewed regional uplift, left only remnants of the former plain surface at about 6000' in the form of the Great Escarpment and highest summits of the Swartberg Range.

A new erosion surface now resulted, the so called "Gondwana" surface (L.C. King, 1951, p.311), and the waste produced during the dessication, started accumulating in valley-lowlands, the Cretaceous-Jurassic topography being one of high relief (J.W. du Preez, 1944, p.225) - and eventually, to such an extent, that they became totally filled in. This surface is evidenced to-day by remnants at 4000' - 4500', e.g. the Witberg Range and probably also the plateau east of Meiringspoort. The 'fill-in', forms part of our present day Cretaceous System (Lower Enon). It was most probably only on the dessication of this early Cretaceous surface that the present-day topography was initiated.

During a brief cessation of deposition, a differential "sagging" (C.J. Lenz, 1957, p.200) or "submergence" (F. Dixey, 1938, p.151) was initiated and being accompanied by cross-folding, resulted in local "basining". This later caused a complete isolation of the "Enon" basins during the succeeding erosion, e.g. the Outshoorn, Vlakteplaas and Georgida basins. Deepening of these basins followed, due to a "progressive marginal fracturing from north-east to south-west" (A.L. du Toit, 1954, p.571).

This faulting, accompanied by slow uplift, caused a renewal of erosion and the Upper Enon was deposited.

The present South African seaboard had now been
born and intense headward erosion from the coastline inland resulted.

The fault scarps became deeply dissected, resulting in fault-line erosion-scarps, (e.g. Swartberg Range), extensive planation caused the early Tertiary surface and the main southern river-systems evolved. At the same time, most of the narrow gorges striking across the Swartberg were cut.

The remains of the vast Tertiary erosion surface—so called "African" surface (L.C. King, 1951, p.311) - can locally, clearly be seen in the "Tertiary (Eocene-Oligocene) gravel terraces" at 2000' - 2500' elevation. The table-topped hills found in the intermontane valley of the Olifants River and the high-level terraces flanking the Kammanassie and Swartberg Ranges are the remains of this surface, resulting from renewed erosion caused by warping and differential uplift.

After two successive phases of planation and uplift in the Mio-Pliocene and fluctuations of sea-level in the Quaternary, the final stage in the evolution of the present-day landscape was reached, causing the remnants of the last Tertiary surface to lie to-day at about 700' above sea-level.

Clearly, in the area under discussion, the evolution of the present day land-forms are due solely to orogenesis and differential uplift, followed by erosion.

(iii) Evolution of the drainage:

During the E.M-Cretaceous, the well-known "basining" - due to sagging and cross-folding - of the Oxitlahoen basin, et alia, resulted in an inward drainage.
After normal faulting, there must have been extensive erosion of the Swartberg fault-scarp and although most of the fault-scarp streams initially debouched only into the basins (J.W. du Preez, 1944, p.209) it is quite possible that at that time, some, starting as consequent streams, may have begun incising their courses along major joints in the Cape System rocks.

After the deposition of the Upper Eocene beds the incipient "Olifants" river rapidly began undercutting the inward drainage of the different basins as it progressed by headward erosion eastwards.

In the early Tertiary, after warping and slow uplift the "Olifants", as a subsequent river, drained the whole lowland just south of the Swartberg. The former fault-scarp streams, as short subsequent tributaries, now rapidly incised their former channels northwards along major joint directions.

The result is the present-day series of narrow gorges: Seven Week'spoort, Naaringspoort, Torswaterspoort, etc., all youthful subsequent valleys. (C.J. Lenz, 1957, p.324).

By Miocene Time, the subsequent tributaries - the Trala River being one - had succeeded in cutting their way through the divide and had undercut all rivers flowing east or west to the north of it.

Rapid incision in the softer rocks of the Karroo System after renewed uplift and eustatic movements of sea-level from the late Tertiary to Quaternary, resulted in the birth of numerous streams of varied types and the development of quite a number of different drainage patterns.
(b) RELATIONSHIP OF TOPOGRAPHICAL FEATURES AND STRUCTURAL ELEMENTS:

Differential resistance to weathering and erosion as caused by varying lithologic character, coupled with structural deformation, gave rise to all the prominent topographical features at present displayed in the area.

The Swartberg Range owes its existence as topographical highland to:

(a) its anticlinal fold structure,
(b) resistance of the Table Mountain sandstone to weathering,
(c) the Mid-Cretaceous strike-faulting.

The last feature gave rise to the lowland in the south, and, on erosion, to the fault-line erosion - scarp of to-day.

(Plate I, ph. B.)

The Witberg owes its existence to:

(a) the resistance of the Witteberg sandstone to weathering,
(b) the less resistant Bokkeveld and Karroo System rocks

stratigraphically above and below it.

Although F. Dixey, A.,L. du Toit, et alia, considered the "poorts", through the Swartberg, the result of superimposition, S. Maske and C. Lenz proved them to be characteristically emplaced along well-developed, accessible, joint systems of the Table Mountain sandstone. Major jointing thus causing a structural weakness, along which the subsequent tributaries of the Olifants could, by headward erosion, rapidly cut deep valleys. The Post-Cretaceous diastrophism in the southern and eastern Cape, resulted in: the frequent occurrence of table-topped hills, 'high-level' terraces flanking the mountain sides, incised meanders of the main rivers, a complete dessication of previous river-planed surfaces and consequently, a
rejuvenation of the drainage and topography. Accompanying axial warping, caused many instances of river-capture and was the directive force in the present location and flow direction of many streams, e.g. the southward migration of the Olifants in the Oudtshoorn basin on the post Eocene surface (C.J. Lens, 1957, p.251). A further result of the alternation of the resistant Table Mountain and Witteberg Series and softer Enon, Boldekerveld and Karroo rocks, is reflected in the rapid change of the valley types of the Traka. To the north and south of the two ranges are wide open valleys in flat alluvial country, whereas Towerwaterpoort and Sestendalspoort are both narrow, ungraded valley-floors fenced by precipitous cliffs.

Since the mountain ranges acted as barriers, at the northern extremities of both these poorts, the rivers are locally actively aggrading, whereas erosion is prominent to the south.

Just north of the Swartberg the effect of more resistant strata is repeated in the parallelism of the foothills. The latter are built of Upper Sandstone and Boldekerveld Sandstone while the valley streams all flow subsequently on shale horizons. The small consequent tributaries of these streams flowing into the Traka, are all busy incising their courses along joint planes in the Table Mountain sandstone.

The flat alluvial plain in the vicinity of Vondeling Station, cut in the main shales of the Boldekerveld, forms a sharp contrast to the hilly country just north of the Willowmore - Klaarstroom road. Here is a whole succession of strike ridges (the "hogbacks" of Lobeck), hills due to the quartzitic sandstone horizons of the Lower Witteberg being more resistant to erosion than the surrounding shales.
These hogbacks are arranged in perfect harmony with the strike of the successive horizons (P.C.S., G.S., O.R.S., and W.S.- horizons on legend).

Here too, as is peculiar of intensely folded regions, is an example of the remarkable way in which the surface features can conform to the geological structure, e.g. ridges with anticlinal structure or valleys with synclinal structure, which decrease in height and fade away according to the pitch of the aforementioned structures, or cause two ridges to meet and continue as one. 'Inversion' of the topography however, also occurs. Actually, synclinal ridges and anticlinal valleys are the more common features. The synclinal ridges are very characteristically developed in the area west of Traka and north of the Vandereys River. Due to debris covering the slopes of the hills and the overfolded nature of the rocks, mapping of the structures becomes a tedious and intricate process.

Variations of the above also occur, e.g. a synclinal-anticlinal-ridge, where the major structure is an anticline with a small syncline developed on the crest.

In the main Witberg Range these features are repeated, the first valley in which the homestead of Soetendalspoort is situated, being a valley with synclinal structure. (Plate I, ph. e.)

Some intermediate ridges with anticlinal structure represent the competent cores of former larger structures since removed by selective erosion. (Plate III, ph. D.)

On the north flank of the Witberg Range a succession of flatirons is developed, due to small, northflowing, resequent streams, cutting valleys into the dip-slope of the conspicuous white sandstone horizon of the Witteberg Series. (Plate I, ph. H.)
Stratigraphic column and lithologic criteria of various horizons, inclusive of fossil content:

The stratigraphic sequence, locally present, includes the entire Cape System and some of the lower members of the Karroo System viz. Table Mountain Series, Bokkeveld Series, Witsberg Series (Cape System), Dwyka Series, Ecca Series (Karoo System). The Enon gravels (Uitenhage Series) flanks the Swartberg on the south.

The stratigraphical thickness of the separate units was procured by direct measurement with a tape and using a nomogram, relating degrees of dip to width of outcrop and thickness of units, based on the formula:

\[ \text{Thickness} = \text{Width of outcrop} \times \sin \text{angle of dip} \] (C.M. Nevin, 1949, p.350).

The name "siliceous sandstone" is used throughout, because, in the author's opinion, a quartzose sediment is only termed a quartzite when it becomes impossible to determine the boundaries of original primary quartz-grains. Thus a quartzose sediment, cemented diagenetically by silica to such an extent that fracturing will take place through and not around individual grains, is termed a siliceous sandstone and not a quartzite.
<table>
<thead>
<tr>
<th>Time Scale</th>
<th>South African Nomenclature</th>
<th>Approx. Stratigraphical Thickness in the W.P.</th>
<th>Stratigraphical Thickness as present at Vondeling</th>
<th>Lithological characteristics of the beds as present at Vondeling</th>
</tr>
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<tbody>
<tr>
<td>CRETACEOUS</td>
<td>Uitenhage Series. Eon Beds</td>
<td>1000*+ partial</td>
<td>Red conglomerate full of white sandstone boulders and pebbles.</td>
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</tr>
<tr>
<td>PERMIAN</td>
<td>EDCA SERIES. Upper Shales</td>
<td>10,000* partial</td>
<td>Thin yellowish-brown sandstone horizons alternating or grading into sandy laminated shales, usually grey or yellowish-green in colour.</td>
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<tr>
<td></td>
<td>Dwyka Series. Tilitie</td>
<td>650* 450* partial</td>
<td>Olive-green to black carbonaceous shales, very thinly laminated.</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>2500* 2460* partial</td>
<td>Blue or greenish-grey and very compact, with a fine-grained matrix in which are set pebbles and boulders of an immense variety of rocks, usually angular and of a very wide size range.</td>
<td></td>
</tr>
<tr>
<td>CARBONIFEROUS</td>
<td>Witteberg Series.</td>
<td>242 Phyllite, or Galamite. (or Oalami)</td>
<td>Yellowish-grey cross-bedded sandstone, intensely ripple-marked, containing calcareous, carbonaceous, fossiliferous lenses.</td>
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<tr>
<td></td>
<td></td>
<td>125 Sandy black shales alternating with greenish-grey cross-bedded sandstones and carbonaceous lenses containing fossil stems.</td>
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<td></td>
<td></td>
<td>375 Black shales with interbedded, highly fossiliferous nodules of carbonaceous mudstone.</td>
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<td></td>
<td></td>
<td>250 Thin horizons of yellow-brown siliceous sandstone alternating with grey shales. Lenses of carbonaceous, fossiliferous mudstone are also found.</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>102 Thin horizons (less than 2&quot; wide) and lenses of sandstone in reddish, highly micaceous shales.</td>
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<tr>
<td></td>
<td></td>
<td>1 Brown, siliceous, micaceous sandstone, ripple marked, frequently fossiliferous.</td>
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<tr>
<td></td>
<td></td>
<td>170 Reddish micaceous shales.</td>
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<tr>
<td></td>
<td></td>
<td>17 Brown to yellow-brown sandstone.</td>
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<tr>
<td>Age</td>
<td>Description</td>
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<tr>
<td>750°</td>
<td>Coarse grained (saccharoid), brownish, limonite rich, siliceous sandstone, containing blue and white quartz pebbles.</td>
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<tr>
<td>15°</td>
<td>Grey-brown sandy shales.</td>
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<td></td>
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<tr>
<td>17°</td>
<td>White, fine-grained, siliceous sandstone horizon.</td>
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<tr>
<td>45°</td>
<td>Reddish, micaceous, alternating shales and sandstone horizons.</td>
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<tr>
<td>280°</td>
<td>Black, glossy, phyllitic carbonaceous shales.</td>
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<tr>
<td>1640°</td>
<td>Brownish-pink siliceous sandstone.</td>
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<tr>
<td>40°</td>
<td>White siliceous sandstone horizon (marker), very fine grained.</td>
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<tr>
<td>20°</td>
<td>Massive siliceous sandstone horizons alternating with thin shales.</td>
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<tr>
<td>400°</td>
<td>Thin siliceous sandstone horizons in black sandy shales.</td>
<td></td>
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<tr>
<td>1860°</td>
<td>W.E. White, fine grained, fossiliferous, siliceous sandstone horizon frequently containing fossil blow holes, (marker horizon).</td>
<td></td>
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<tr>
<td>3°</td>
<td>Purple-black siliceous sandstone, highly fossiliferous and eminently wave-ripple marked.</td>
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<tr>
<td>15°</td>
<td>Purplish-pink highly fossiliferous shales.</td>
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<tr>
<td>10°</td>
<td>O.R.S. Orange-red, iron stained, siliceous sandstone, fossiliferous. (marker horizon).</td>
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<tr>
<td>175°</td>
<td>Red and grey micaceous shales.</td>
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<tr>
<td>185°</td>
<td>Grey, red and black micaceous shales and thin siliceous sandstone horizons and lenses.</td>
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<tr>
<td>3°</td>
<td>P.C.S₂. Pinkish-cream siliceous sandstone.</td>
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<tr>
<td>52°</td>
<td>Dark-red, iron rich, argillaceous sandstone.</td>
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<tr>
<td>3°</td>
<td>Thin yellowish-white siliceous sandstone.</td>
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<tr>
<td>20°</td>
<td>Thinly laminated, grey sandy shales.</td>
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<tr>
<td>7°</td>
<td>P.C.S₁. Pinkish-cream siliceous sandstone, (marker horizon).</td>
<td></td>
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<tr>
<td>Depth</td>
<td>Description</td>
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<tr>
<td>350'</td>
<td>Grey, friable micaceous shales.</td>
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<tr>
<td>2'</td>
<td>Blackish-brown siliceous sandstone horizon, highly fossiliferous and eminently ripple marked (B.Q. horizon (marker)).</td>
<td></td>
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<tr>
<td>450'</td>
<td>Sandy grey-red micaceous shales.</td>
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<tr>
<td>30'</td>
<td>Brown saccharoid siliceous sandstone horizon (fossiliferous).</td>
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<tr>
<td>+ 1500'</td>
<td>Black to grey-black, micaceous shales. (The upper 210' here has thin s.s. lenses).</td>
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<tr>
<td>20'</td>
<td>Purplish-brown, coarse, argillaceous sandstone.</td>
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<tr>
<td>200'</td>
<td>Black, carbonaceous shales alternating with sandy shales.</td>
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<tr>
<td>130'</td>
<td>Yellow-brown, micaceous, sandstone (laminated) the upper 15' being a white siliceous s.s.</td>
<td></td>
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<tr>
<td>135'</td>
<td>Black to greenish-grey, finely laminated, slightly micaceous, intensely sheared shale.</td>
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<td>2500'</td>
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<tr>
<td>+ 200</td>
<td>Brown and grey siliceous sandstone horizons alternating with fine grained, very hard, blackish-blue sandstone (a thin highly fossiliferous horizon being present).</td>
<td></td>
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<tr>
<td>90'</td>
<td>Black, green and red shales alternating with similar coloured micaceous mudstones.</td>
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<tr>
<td>195'</td>
<td>Greenish-blue-weathering a dirty yellow-sandy mudstone without lamination, containing angular quartz, jasper and black shale pebbles scattered at random.</td>
<td></td>
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<tr>
<td>+ 125'</td>
<td>Blue-green shales or mudstones, alternating with similar coloured flagstones, (fossiliferous in places).</td>
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<tr>
<td>- 125'</td>
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<tr>
<td>150' - 300'?</td>
<td>Brown and grey siliceous sandstone horizons alternating with fine grained, very hard, blackish-blue sandstone (a thin highly fossiliferous horizon being present).</td>
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</tr>
<tr>
<td>4000'</td>
<td>White, medium grained, siliceous sandstone containing scattered quartz pebbles. (The upper 20' being a very fine grained bluish-brown horizon).</td>
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</tr>
</tbody>
</table>
(a) TABLE MOUNTAIN SERIES (CAPE SYSTEM).

(i) Main Sandstone:

The siliceous sandstone horizons of the Table Mountain Series are in some places interbedded with very thin shale lenses. These shales are usually very finely laminated, highly micaeous and red or grey-black in colour. They, as well as the sandstone units, are conspicuously cross-bedded; the only criterion by which it was possible to establish the overfolded attitude of these horizons. Microscopically the rock consists of subangular to well-rounded quartz-grains, with an average diameter of .5 m.m., accompanied by subordinate mica-flakes cemented tightly, diagenetically, to a mosaic pattern, by amorphous silica. The most common heavy minerals present, are zircon, rutile and tourmaline. The size grade of the zircons and the specific suite of heavy minerals present in these beds in contrast to higher horizons, constitute an important criterion for correlation purposes – because a comprehensive column on heavy minerals is given later, no reference will be made to their presence or absence in the succeeding horizons.

The upper beds tend to change colour and become dark blue. Grain-sizes are much smaller, vary between .3 m.m. – .15 m.m. in diameter, are orientated at random and also diagenetically cemented by amorphous silica with interstitial, finely chloritic-material.

Consisting mainly of quartz grains, these higher beds also contain up to 6.25% of remarkably fresh feldspar grains – types being perthite, microcline and acid plagioclase-feldspar and can actually be classed as sub-arkosic. Another mineral present, although only subordinately, is sericite.
Shearing, as a result of intense structural deformation, although most probably present in the thicker horizons to the same amount, is more conspicuous here. A finer bedding, coupled with stratigraphic position at the top of a massive sandstone unit followed by shales, most probably account for this feature.

The unit, on weathering, gives rise to the same grotesque shapes and magnificent scenery as in the Western Province. (Plate I, ph. A.)

(ii) First Upper Shale:

The Main Sandstone gradually grades into the Upper Shales through colour-change, diminishing of grain-sizes and increase of clay-material, in contrast to the beds at Gemkapoort where "the end of the white sandstones and the beginning of the blue-black beds of the Bokkeveld is so sudden and exact that one can place a knife between them". (E.H.L. Schwartz, 1899, p. 36)

The shale constituents are quartz and micaceous material, with a small amount of acid plagioclase-feldspar and submicroscopic clay-minerals, among which, chlorite is clearly distinguishable. Grains vary in size and degree of angularity, only the smaller showing rounding. The quartz grains set in a clay matrix, have an average diameter of .08 mm. and the entire assemblage shows the normal parallel orientation characteristic of a shale in a section transverse to the bedding. (F.J. Pettijohn, 1949, p.261).

The Table Mountain Series, usually considered unfossiliferous, has however, in the Clanwilliam area, very clearly displayed fossil-tracks attributed to trilobites, and according to B. Swart, a brachiopod occurs in the Upper Sandstone. The Vondeling area also presents undoubted
remains of crinoid-arms (Ophiocrinus). (Plate II, ph. A.)
The latter occur in the aforementioned First Upper Shale
and obviously the upper beds do not conform to the hitherto
accepted conditions, obtained during deposition of the
Table Mountain Series. A feature quite possible when one
considers the extent of the depositional area of this
Series.

(iii) Tillite:

In the accompanying table a case is presented
for naming the following horizon to be described, a
tillite.

See next page - Field diagnostic characteristics of;
### Field diagnostic characteristics of:

**A compacted intra-formational tillite.**

<table>
<thead>
<tr>
<th>Macro diagnostic</th>
<th>The Towerwater Table Mountain Series tillite.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A rough cleavage is developed in a tillite parallel to its strike, but at varying angles to its dip. This causes the tillite to weather into lenticular slabs or into sharp spikes. (II, p. 106)</td>
<td>1. The Towerwater tillite weathers into typical lenticular slabs,</td>
</tr>
<tr>
<td>2. The colour of a tillite usually corresponds to the predominant rock of the provenance and as such the T.M.S. tillite in the Western Province consists of a greenish-blue or reddish mudstone without laminations or bedding. (I, p. 241), (III, p. 319).</td>
<td>2. The rock as such, when fresh is dark blue and without any sign of bedding.</td>
</tr>
<tr>
<td>3. Tillite is characterised by an extraordinary range of size grades and constituents, such as quartz, quartzites, sandstones, red jaspers, enygydialdial diabase, granite, etc, and these are distributed at random, irrespective of size, through a fine grained matrix. (I, p. 241), (VII, p. 213).</td>
<td>3. The size grades found, vary from microscopic to pebbles up to 3&quot; long. As far as constituents are concerned, fragments and pebbles of quartz, shale and jasper are found. (Plate II, ph. B).</td>
</tr>
<tr>
<td>4. Tillite bluish-green when fresh, differs from the weathered material, due to penetration of the ground-water accompanied by oxidation of the ferruginous constituents and thus change to white, ochery or brown colours. (I, p. 242), (IV, p. 532), (III, p. 394).</td>
<td>4. The tillite is characterised in the field by the straw yellow colour to which it weathers.</td>
</tr>
<tr>
<td>5. Tillite is characterised by its toughness, enhanced by the presence of clay which acts as a binder between the fragments of larger size and also by the recrystallization that had taken place - shown by the presence of chert. (V, p. 92.), (II, p. 106).</td>
<td>5. The toughness is clearly shown by its conspicuous weathering and relative topographic prominence to the west of Towerwaterpoort.</td>
</tr>
<tr>
<td>6. Almost a universal associate is varved argillite or slate, showing exceptionally even laminations. (VII, p. 225).</td>
<td>6. The tillite is as such bedded amongst two shale horizons but varves are absent.</td>
</tr>
<tr>
<td>7. The larger pebbles or fragments tend to have snubbed edges, coiled facets and sometimes striations (well elongated blade or rod-shaped shale- and slate-erratics usually have striations parallel or transverse to their longest axis). (VII, p. 221), (II, p. 109), (IV, p. 554), (I, p. 241).</td>
<td>7. A feature clearly visible is the fact that although the smaller grains are mostly broken fragments, the bigger shale pebbles have snubbed edges.</td>
</tr>
<tr>
<td>8. Above and beyond local fragments, a tillite is unique in the characteristic that it contains stones foreign to local bedrock, so called &quot;erratics&quot;. (II, p. 116), (VII, p. 222), (I, p. 272), (V, p. 92).</td>
<td>8. The presence of the jasper as an erratic tend to indicate a linkage with the provenance of the Western Province tillite-some source nearer to the Willowmore area too. (Plate II, ph. B).</td>
</tr>
</tbody>
</table>

### Micro diagnostic.

| 1. Tillite is characterised by a matrix of angular grains and sharp rock particles set in a paste of fine grain. (IV, p. 532) | 1. Examining the tillite by means of a microscope, grains with an average diameter up to 2 - 4 m.m. are set in a matrix with average grain size less than .2 m.m. |
| 2. The bigger angular pieces are found to be grains of quartz and feldspar in a fine matrix richly chloritic and micaeous - the product of low-grade metamorphism of the original clay-component of the tillite. (V, p. 92), (VII, p. 222-223), (IV, p.532). | 2. The bigger grains are quartz, feldspar, shale and jasper, fragments set in a richly chloritic and micaeous, all submicroscopic-groundmass. |
| 3. | Minerals like hornblende, micas and plagioclase-feldspars, notably susceptible to chemical decay, are conspicuous in tillites and are as such usually mechanically broken or abraded. (II, p. 104), (VI, p. 128). |
| 4. | It is commonly found that the smaller rock fragments generally are somewhat more angular and rough than the larger pebbles. (VII, p. 222). |
| 5. | The varved slates associated with a tillite usually tend to show in thin section coarse angular grains of quartz between the laminated layers (indicative of rafting on a microscopic scale). (VII, p. 222). |
| 6. | A tillite is, as such, a definite reflection of the character and composition of the bedrock from which it was derived. (II, p. 114), (VII, p. 221). |
| 7. | A well-known characteristic of a tillite is its organised fabric which is an indication of the direction of movement of the ice at the time of tillite deposition. (II, p. 106), (VII, p. 218), (V, p. 30 – 92). |

| 3. | The feldspars, remarkably fresh, are of three types e.g. microcline, perthite and andesine (Ab₆₀,An₄₀) plagioclase. The mica is muscovite and sericite. The whole as such roughly angular splinters and fragments. |
| 4. | This characteristic is most evident microscopically. |
| 5. | No correspondence possible. |
| 6. | The tillite is actually a glacial sand and agrees as to constitution to such an extent with the Western Province T.M.S. tillite that it must have had a similar provenance. |
| 7. | Near larger pebbles or fragments, there is a marked orientation of the smaller fragments surrounding such a fragment and furthermore some of the larger quartz grains show cracks. |

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III. Gehlke, J., 1930. Structural and Field Geology.
VI. Marr, J.E., 1922. Agricultural Geology.
This horizon is to a great extent covered by scree on the boundaries of the area mapped, and thus — whether continuous to the east and west, the author was unable to determine — is in actual fact much more similar to a glacial sand in accordance with "the gritty sandstone, white in out-crop, but bluish-green when fresh and quite unbedded (Plate IV, ph.A) though crossed by a strong cleavage", found in Mitchells' Pass near Ceres. (A.L. du Toit, 1954, p.242.)

The horizon furthermore agrees with the above characteristics of the "glacial sand" in Mitchells' Pass, in possessing a strong cleavage and being criss-crossed by numerous quartz veins.

In accordance with the "horizon in the midst of shales carrying occasional small facetted pebbles" (A.L. du Toit, 1954, p.242.) discovered by Haughton on Swartberg Pass, this horizon is also situated between two shale horizons, although here about 300' from the top of the Series in contrast to the 600' at Swartberg Pass.

(iv) **Second Upper Shale**:

The overlying shale beds are therefore the Second Upper Shale horizon of the Table Mountain Series, in accordance with the classification in the Western Province.

Examining the red, green and bluish-black shales, one cannot but compare it with the Upper Shales as found in the afore-mentioned region. Thus the succeeding sandstone horizon should stratigraphically become the Upper Sandstone of the Table Mountain Series — here only 90' thick and fossiliferous at the same time, in contrast to ~ 200', and its poorly fossiliferous state in the Western Province.
Rejecting this stratigraphic allocation of the horizons, the Second Shale must become the First Shale of the Bokkeveld and the upper boundary of the Table Mountain Series then becomes the tillite horizon. In considering this opinion the author agrees with R. Swart (1960, p. 476) where he quotes Henson as saying that it is a serious error to "fix stage - boundaries at convenient lithological contacts thus assuming that the same facies changes were everywhere neatly synchronised with those which define the same stages in their type sections."

R.H. Rastall again, emphasised that "it follows that the only real geological date-lines are physical and that stratigraphical subdivisions should be based on tectonics" (1911, p. 165).

Therefore the author fully supports Swart in his contention that the upper boundary of the Table Mountain Series should be drawn at the Glacial Band of the T.M.S. in the west and north-west of the Cape Province and although conforming to the old nomenclature in the stratigraphical column accompanying this paper, advocates that this criterion should also be applied to the Eastern Province where possible.

The shales constituting this horizon are actually fine-grained mudstones and similar to those of the First Upper Shale which lie stratigraphically lower. The only real difference being, that on weathering, certain beds in the shale become friable and of a light, greenish-white colour. Furthermore a certain concentration of iron-rich nodules becomes apparent. These, on weathering, colour the surrounding shale to yellow-brown or deep-red stains.

The Second Upper Shale is about 200' thick and being
less resistant to weathering than the sandstone horizons,
is encountered in topographic lowlands.

(v) Upper Sandstone:

Consisting of about 90% of alternating friable sandstones and siliceous sandstones, the Upper Sandstone gives rise to a long line of hills striking parallel to the mountainside. (Plate I, pi.C.)

The fine-grained (average grain diameter = 2 m.m.) blue-black, siliceous sandstone, on breaking, shows an almost flinty character.

The chief mineral constituents of this rock are quartz, acid-plagioclase and perthite ($\sim 8\%$), cemented to a tight mosaic pattern by diageneric silica, accompanied by mica and a small amount of chert. The grains are orientated at random and show a certain amount of sub-angularity.

The siliceous sandstones alternating with the blue-black sandstones, tend to have a grey colour when fresh, becoming yellow-brown on weathering. Inherently they also differ in having an average grain-diameter varying from 0.2 m.m. to 0.4 m.m. Consisting of quartz, perthite and acid-plagioclase ($\sim 6\%$), mica, chlorite and chert, these grains are cemented by a varying amount of diageneric silica and chloritic material. The grains tend to be rather pitted and chink-marked, mostly subangular in shape and scattered at random.

In places, ripple-marks occur and this diagnostic feature was the most important criterion used in determining the overfolded nature of both these and the surrounding horizons.

Near the base of this horizon there occurs a highly
fossiliferous zone. The small brachiopod Derbyina
whitiorum (Clarke), is present, literally in thousands,
stacked one on the other, singly, or in pairs, in a zone
less than 1" thick. (Plate II, ph. C.) Although a search
was made in this unit for other fossils, none were found, nor
did any of the other underlying or immediately overlying beds
contain Derbyina.

The same highly fossiliferous horizon containing
Derbyina, is found on the farms Dassiefontein and
Schilpadbeen (Fig. 1.) and could be used as a marker horizon
in future mapping of adjacent areas.
(b) **BOKKEVELD SERIES (CAPE SYSTEM)**

(1) **First Shale:**

The First Shale Horizon of the Bokkeveld is a black (when unweathered), otherwise a green to grey finely laminated, slightly micaceous shale. As such, it is a normal shale with average grain-size less than 0.007 mm, and composed mostly of clay-minerals.

Due to the intense structural deformation, resulting in the beds being overfolded, the shale is intensely sheared and has developed a strong cleavage.

Topographically it also gives rise to deeply cut valleys.

(ii) **First Sandstone:**

This unit gives rise to a conspicuous range of hills capped by white krantzes, striking parallel to the Upper Sandstone of the T.M.S. for miles to the east and west of Towerwaterpoort and is a useful horizon for mapping. (Plate I, ph. C.)

The marker horizon - a 15' thick, white, even-grained sandstone horizon, overlying the other beds, - when unweathered, is bluish-white to grey in colour, micaceous and finely bedded.

The less conspicuous underlying horizons appear lithologically similar to those of the Upper Sandstone of the T.M.S.

An interesting feature is the occurrence of stylolites up to 7 mm in length in the upper portion of the white sandstone, probably indicative of intense differential pressure accompanied by solution (W.H. Twenhofel, 1932, p.236). This horizon must be correlated either with the First
or Second Bokkeveld Sandstone of E.H.L. Schwarz (1899, pp. 38 - 40) and the author tentatively suggests the latter horizon.

(iii) **Second Shale:**

Consisting mainly of shales, lithologically these beds vary from thin sandstone horizons through sandy shales to fine-grained fatty shales.

This group also includes a thin, friable, purplish-brown, argillaceous sandstone horizon, (20' thick) which possesses a strong cleavage and is situated stratigraphically about 200' above the top of the Second Sandstone horizon.

In the greenish-grey, fatty shales, succeeding the latter horizon iron-rich nodules occur, staining the surrounding rock yellowish-brown; a feature noticed by Schwarz at Gamkapoort in "the lowermost shales of the Bokkeveld Beds". (1899, p.36).

These shales in turn become more argillaceous and acquire a bluish-black colour. A feature, already visible in the lower fatty shales - causing them to weather in rough splintery masses on exposure - is a very well-developed cleavage, reaching a peak in the blue-black shales.

When the rock is weathered it is extremely difficult to distinguish between the bedding and cleavage planes of these shales.

About 210' from the top of this group the shales become intercalated with sandstone lenses, some up to 4' thick and of similar composition as the Second Sandstone horizon. Simultaneously fossiliferous remains, in the form of worm casts and tracks accompanied by a few small and imperfect impressions of Spirophyton (described later) are found.
Just below the Second Sandstone these lenses become coarser in texture and in some instances can be classified as gritty and arkosic.

(iv) Second Sandstone:

Building a conspicuous ridge, locally known as the Spekboomrant, the Second Sandstone is a grey-brown, coarse-grained, micaceous sandstone. As such it varies in thickness and is throughout thickly bedded.

This horizon is continuous 10 miles eastwards and westwards of the area mapped.

It is fossiliferous and contains plant remains, mostly perfect interior casts and external molds of Bothrodendron-stems.

Considering its stratigraphic position and the fact that it contains plant fossils, its obvious linkage with either the Fourth or Fifth Bokkeveld Sandstone is indicated, although according to Swart in the Third Sandstone "recognisable plant stem impressions resembling that of Bothrodendron" are present in the Wuppertal area (B. Swart, 1950, p. 431).

(v) Third Shale:

The beds of the Third Shale horizon differ from the blue-black shales that preceded the Second Sandstone. They are not only reddish in colour and very finely bedded, but also friable and eminently micaceous. This characteristic, changes upwards and the beds become more sandy, passing into a succession of thin, grey to blue, micaceous flagstone horizons in friable, sandy, red to grey shales. Simultaneously sandy yellow-brown limestone horizons, usually not exceeding 2" in thickness, and wedging out along the strike, make their appearance.
The beds directly below the Second Sandstone contain remains of Spirifer and Orthoceras. There is a sudden increase of perfect Spirophyton impressions in the arenaceous beds.

The flagstones build the flat alluvial plain at Vondeling Station and are cross-jointed and flanked by friable shales. At about 450' above the Second Sandstone, one of these flagstone horizons becomes so arenaceous that it would be considered as a passage-bed to the Lower Witteberg. This horizon weathering to a conspicuous blackish-brown colour was used as a field-marker and named Black Sandstone (B.S.-horizon). It is approximately 2' thick and incompetently folded. Certain thin ferruginous layers cause the rock to show banding.

The sandstone horizons of the Lower Witteberg also show ripple-marks, but this horizon is characterised by a great variety, varying from normal wave ripple-marks to oscillation ripple-marks. (Plate II, ph.II.) It contains fossil worm tracks and casts, large numbers of Spirophyton impressions and layers of little "seeds" or "shells" (described later) similar to those found by Swart at Wuppertal (1960, p.431).

All these features, especially the ripple-marks, are outstanding criteria to determine over-folding or vice-versa when doing a structural investigation.

The B.S.-horizon is succeeded by about 350' of very highly micaceous, soft, friable, fissile shales, containing stacked layers of Spirophyton impressions near the base.
(c) **WITTEBERG SERIES (CAPE SYSTEM).**

This unit of the Cape System, occupies in outcrop, more than half the area surveyed and was definitely the most illuminating, both as regards its fossil content and its structural deformation.

The author, in mapping, found it convenient to make use of local marker horizons and they were given definite names according to their characteristic colour on weathering, as was done in the case of the previously described B.S.-horizon of the Bokkeveld Series.

The accompanying diagram (Fig. 3) will clarify their stratigraphic position, relation to each other and different, visual lithologic characteristics.

![Diagrammatic section (I-J) illustrating the stratigraphic succession of the "Lower Witteberg".](image-url)

**FIG. 3.** Diagrammatic section (I-J) illustrating the stratigraphic succession of the "Lower Witteberg".

- **W.S.** - White Sandstone.
- **O.R.S.** - Orange-Red Sandstone.
- **G.S.** - Grey Sandstone.
- **P.C.S.** - Pinkish-cream Sandstone.
- **B.S.** - Black Sandstone (Bokkeveld).

The Series consisting of such a large variety of
different rock units was sub-divided into three separate portions, e.g.

"Upper Witteberg" shales and sandstones.
Main Witteberg Sandstone and shales.
Lower Witteberg shales and sandstones.

Acting on the suggestion of A.L. du Toit, et alia, as later exemplified, the author mapped the Lower Dryka Shales as "Upper Witteberg shales and sandstones".

The W.B. Series was therefore represented in this area as three separate units and the following conspicuous marker horizons were designated as boundaries:

(iii) "Upper Witteberg" (Reaches from the top of the "massive unit" to the base of the tillite.

(ii) Main Witteberg (Reaches from the top of the W.S.-horizon to the top of the "massive" sandstone composing the bulk of the Witteberg.

(i) Lower Witteberg (Reaches from the first P.C.S.-horizon to the top of the W.S.-horizon.

The boundaries were designated for the following reasons, some of which appear purely arbitrary, others due to definite lithological characteristics.

In sequence from below upwards, the first boundary imposed, is that separating the Witteberg Series, from the Bokkeveld Series i.e. the P.C.S.-horizon.

In the Western Province the base of the Witteberg was taken as the base of the massive sandstone unit (B. Swart, 1950, p.412) but even so "its delimitation from the Bokkeveld Series below is not always easy". (A.L. du Toit, 1954, p.261.)

In the Vondeling area where a succession of sandstone horizons intercalated with shales occurs before the Main Sandstone is reached, the first siliceous sandstone horizon succeeding the B.S.-horizon was considered the boundary.
between the Witsberg Series and the Bokveld Series for the following reasons:

(1) it is clearly distinguishable in the field due to its stratigraphical position as the first thick sandstone horizon succeeding the Third Shale horizon.

(2) it gives rise to massive wall-like outcrops on weathering.

(3) its suite of heavy minerals and their characteristics show a marked difference from those of the preceding horizons.

Pinkish-cream Sandstone (P.C.S._horizon).

This unit consists of two pinkish-cream siliceous sandstone horizons. The lower P.C.S_1—horizon is separated from the stratigraphically higher P.C.S_2—horizon by 75' of alternating shale and sandstone units.

The P.C.S_1—horizon being about 7'' thick, is clearly recognizable in the field. (Plate III, ph. A.) The main constituents are quartz and mica accompanied by a small amount of chert. The grains are closely packed and diagenetically cemented to a mosaic pattern by amorphous silica accompanied by a very small amount of chloritic material. The grains are subangular, orientated at random and have an average diameter of .22 m.m.

Although without any fossil imprints itself, the structural deformation of the P.C.S._horizon is easily determinable. A thin sandstone horizon, not more than a few inches thick, covered by wave ripple-marks and Spirophyton impressions, is situated stratigraphically, just above it and can be used as a marker.

There now follow about 20' of thinly-laminated, grey sandy shales, a 3' thick horizon of yellow-white siliceous sandstone, 52' of dark-red, argillaceous sandstone which weathers easily, thus causing the P.C.S_2—horizon, although
only 3' thick, to stand out. This horizon is the exact replica of the P.C.S₁ - horizon and, trending parallel to each other, these two siliceous sandstone horizons, are very conspicuous, especially when they dip almost vertically.

Arbitrarily chosen in the field as a natural boundary, the author found that he was justified in making this choice, when an investigation of heavy minerals was done in the laboratory and the results obtained, systematically tabulated.

Samples of the upper beds of the T.N.S. and all the sandstone horizons of the Boldeaveld and the "Lower Witteberg" were taken for this analysis. In the Main Sandstone of the W.B₁, chips were successively taken in a line, perpendicular to the strike of the beds, every 20' of the upper 700' of the unit. The "Upper Witteberg" was sampled in the same way, but at intervals of 75'.

The samples taken, were then crushed separately in a steel mortar, care being taken not to crush the grains but only to loosen them. The crushed material was passed through a .25 m.m. sieve, the dust removed by stirring it vigorously with water in a large beaker, and then leaving it for about 3 minutes, after which the water was decanted. The process was repeated until the liquid decanted became almost clear and the material dried. The loss in weight varied according to the "impurity" - a lesser or greater amount of interstitial shaly material - of the sandstone.

The Upper W.B₁ beds had a loss in weight of 25% whereas the loss of the sandstone horizons was in the vicinity of 15%.

At first it was considered to limit the size-grade of the heavy minerals investigated to .25 - .074 m.m., in pursuance of "the practice of comparing the heavy minerals
separated from only one particular size-grade of each sample is a widely used technique designed to compensate for natural fluctuations" (G.M. Koen, 1957, p. 286). However, on weighing the amount of heavy minerals procured from 20 grams of material of different sieve sizes, the following result was obtained:

<table>
<thead>
<tr>
<th>Sieve size in m.m.</th>
<th>Weight of heavy minerals obtained from 20 gms. of material</th>
<th>Weight</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>.25 - .125</td>
<td>.1856 gm.</td>
<td>.93</td>
<td>.93</td>
</tr>
<tr>
<td>.125 - .074</td>
<td>.3953 &quot;</td>
<td>1.98</td>
<td>1.5%</td>
</tr>
<tr>
<td>&lt;.074</td>
<td>.3256 &quot;</td>
<td>1.63</td>
<td></td>
</tr>
</tbody>
</table>

The amount (about 35%) of heavy minerals not examined when working with a size grade from .25 m.m. to .074 m.m. made it imperative that all grains less than .25 m.m. should be considered.

The sand procured after washing and sieving with a .25 m.m. sieve, was reduced to 10 gms by coning and quartering, and each sample then treated with bromoform to separate the heavy minerals mechanically. It was found necessary to clean the concentrates with hot, dilute hydrochloric acid - a preliminary investigation had shown that none of the heavy minerals in the samples were affected by such treatment.

A representative fraction, obtained by another process of coning and quartering, was then mounted in arochlor resin of refractive index 1.6. All the necessary precautionary measures in the mounting and recognition of the suites of heavy minerals were taken.
The mineral suite, as can be seen from the following table, was very simple and consisted of five major constituents excluding the ore fraction. The mineral frequencies in each of the mounts were determined by grain counting and the table prepared by comparing the amount of grains present in every instance as compared with 100 zircons.

See Table on next page.
<table>
<thead>
<tr>
<th>NAME</th>
<th>ZIRCON (100)</th>
<th>RUTILE</th>
<th>TOURMALINE</th>
<th>GARNET</th>
<th>BROOKITE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White</td>
<td>Pink</td>
<td>Zoned</td>
<td>Red</td>
<td>Yellow</td>
</tr>
<tr>
<td>Upper Witteberg</td>
<td>68</td>
<td>-</td>
<td>32</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>Main Witteberg</td>
<td>72</td>
<td>-</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Lower Witteberg W.S. - horizon</td>
<td>64</td>
<td>-</td>
<td>16</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Lower Witteberg O.R.S. - horizon</td>
<td>76</td>
<td>-</td>
<td>24</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>Lower Witteberg G.S. - horizon</td>
<td>68</td>
<td>2</td>
<td>30</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>Lower Witteberg P.O.S. - horizon</td>
<td>64</td>
<td>2</td>
<td>34</td>
<td>10</td>
<td>73</td>
</tr>
<tr>
<td>Second Sandstone of Bokkeveld</td>
<td>66</td>
<td>5</td>
<td>29</td>
<td>44</td>
<td>58</td>
</tr>
<tr>
<td>First Sandstone of Bokkeveld</td>
<td>49</td>
<td>3</td>
<td>43</td>
<td>40</td>
<td>21</td>
</tr>
<tr>
<td>Upper Sandstone of T.M.S.</td>
<td>67</td>
<td>1</td>
<td>32</td>
<td>43</td>
<td>9</td>
</tr>
<tr>
<td>T.M.S. Tillite</td>
<td>77</td>
<td>2</td>
<td>21</td>
<td>29</td>
<td>6</td>
</tr>
</tbody>
</table>

**TABLE 4.**

Quantitative heavy mineral data values presented on the basis zircon = 100.
Except for the absence of monazite and the presence of garnet, the mineral suites characteristic of the Cape System at Vondeling and at Wuppertal, are found to be similar. (B. Swart, 1950, p. 436 - 456). As far as their petrography is concerned:

(1) Zircon:

Zircon is by far the most common mineral present and three similar varieties occur at both localities. 
(a) The colourless variety is either perfectly euhedral or fairly well-rounded in shape, contain both irregular and rodlike inclusions, which are either scattered at random or orientated along definite distinct zones.
(b) Only a few pink grains could be found and they were mostly equant and euhedral.
(c) The zoned and semi-transparent dusty varieties are common in the concentrates. The zonal characteristics are perfectly developed and the crystals are as such regularly and markedly zoned.

The average grain sizes stay fairly constant throughout.

(2) Rutile:

Except for the four sandstone horizons of the Lower Witteberg, rutile is throughout, second in abundance to the zircon. The varieties present, are in close analogy to those found at Wuppertal.
(a) The yellow variety reaches a maximum in the Second Bokkeveld Sandstone horizon and attains a minimum grain size (.05 x .03 m.m.). It is slightly pleochroic:

X - light yellowish and brown.
Z - Yellow.
(b) The deep red ('foxy-red') variety is almost opaque, has an adamantine lustre, characteristic polysynthetic twinning and distinct pleochroism:

\[ X - \text{reddish brown.} \]
\[ Z - \text{dark red.} \]

(c) Brown rutile is not as commonly found, but the grains are more perfectly euhedral. The pleochroism varies:

\[ X - \text{yellowish-brown.} \]
\[ Z - \text{brown.} \]

(3) Tourmaline:

Three distinct varieties of tourmaline occur and it exceeds the rutile in abundance only in the W.S.- and O.R.S.- horizons of the Lower Witteberg.

(a) Brown tourmaline is the most common type throughout and it frequently has opaque and rod-like inclusions. The degree of roundness of the grains varies immensely but is mostly poor. A marked pleochroism exists:

\[ X - \text{light brown.} \]
\[ Z - \text{dark-brown to black.} \]

A variety of the above is also present with a diagnostic pleochroism:

\[ X - \text{pink.} \]
\[ Z - \text{brown.} \]

(b) The green variety is second in abundance in the tourmaline suite and also frequently contains rod-like and opaque inclusions. Pleochroism varies in intensity but the most common is:

\[ X - \text{light green to colourless.} \]
\[ Z - \text{dark green.} \]

(c) An uncommon blue variety, present throughout, displayed pleochroism:

\[ X - \text{light blue to almost colourless} \]
\[ Z - \text{blue.} \]
(4) Garnet: (Spessartite, N. = 1.800):

The garnet reaches a maximum development in the Upper Witteberg.

(a) The colourless variety is the most common and the grains are usually very angular. Although some grains are perfectly clear, most are slightly opaque as a result of their characteristic shagreen surfaces.

(b) The pink variety, although rather uncommon, usually has a salmon-pink colour and slightly exceeds the colourless garnet in grain size.

(5) Brookite:

Brookite attains a noteworthy abundance in the P.C.S.- and G.S.-horizons, where it exceeds the rutile frequency (TABLE 4). Three varieties are noted: yellow, blue and green. The grains are usually badly rounded and are characteristically striated parallel to the C-axis.

(a) The yellow and blue varieties should actually be considered as one, because frequently both colours are observed in a single crystal. This relationship is definitely not due to twinning, because both halves extinguish approximately simultaneously. Pleochroism varies from blue or bright yellow, to light blue or light yellow.

(b) The green variety is rather uncommon and was only noted in the P.C.S.- and G.S.-horizons. Grain size, shape and outward appearance are exactly similar to the other species. Pleochroism is well developed and varies from greenish-yellow or greenish-blue to light yellowish-green.

Length and breadth measurements of the unbroken zircon grains were also conducted on the same slides as used for the counting and the results used to prepare a diagram.
FIG. 4. Comparative elongation index diagrams.
(Fig. 4.) where the elongation index of 240 zircon grains is compared with the frequency of the ratio.

These two values were obtained in the following way: the ratio, length: breadth, (elongation index) for each grain was determined to the nearest first decimal place and the frequency of the ratios counted as present in each separate sample. The best result was obtained when three consecutive values of frequency, say those for 1.0, 1.1 and 1.2 were added and plotted on the 1:1 ordinate with the elongation index represented on the abscissa.

The following features can be seen when comparing the graphs:

1. there is a marked maximum in the T.M.S. in the frequency of grains with an elongation index of about 1.4,

2. there is a steady migration of this maximum to a larger elongation index, reaching a maximum of approximately 1.7 on nearing the P.C.S.-horizon, accompanied by a successive return to lower values in stratigraphically higher horizons,

3. pronounced subordinate peaks occur in the P.C.S.-horizon and the Main W. B. - although also present, but to a lesser extent, in the Second Bokkeveld Sandstone horizon and the O.R.S.-horizon - in the first instance at about 2.2 and the last instance at 2.3,

4. there is a more even distribution of elongation index ranges in the Second Bokkeveld Sandstone, giving rise to a less pronounced and broader peak.

The similarity of these results when compared with those obtained by means of the same methods by B. Swart in the Western Province, appears very remarkable.

1. Considering the brookite increase, "this mineral becomes
so abundant in the W.B. as to exceed in abundance the rutile". (1950, p.436)

(ii) Considering the measurements conducted on the zircons, "the maxima shift steadily from 1.4 for the T.M.S. to 1.75 for the Witteberg Sandstone". (1950, p.457)

(iii) Furthermore, compare the graph obtained for the Wuppertal area for the W.B. with the one of the area surveyed, and indication of a subordinate peak in the former at 2.5 becomes evident, in agreement with the subordinate peaks in the latter as mentioned in remark 3).

(iv) Glance at the two graphs of the Bokkeveld and the similarity becomes at once apparent.

In contrast to B. Swart, who sampled "one hundred feet of the Witteberg sandstone immediately adjacent to the Bokkeveld Series", (1950, p.435), the author sampled the upper 700' of the same unit. Swart therefore could not find that the elongation index tends to return to lower values when one nears the top of the W.B., and it would be highly interesting to see whether the same feature occurs in the Western Province.

It seems probable that the base of the W.B. is easily determinable wherever present, if, while doing an analysis of the specific suite of characteristic heavy minerals, an abundance of brookite over the amount of other heavy minerals, excepting the zircon is found, a further indication will be an elongation index figure of #1.7.

The P.C.S₁ - horizon thus undoubtedly represents the upper boundary of the Bokkeveld Series.

The upper stratigraphic limit of the Lower Witteberg unit, the W.S.-horizon was instituted as a result of:
(1) the white colour of this horizon in the field. (Plate III, ph. B.)

(2) the stratigraphical position of the horizon just below a 400' succession of thin siliceous sandstone lenses and black sandy shales below the Main W.B. sandstone.

(3) the W.S.-horizon is very closely grouped in the field with the O.R.S.-, G.S.- and P.C.S.-horizons.

White Sandstone (W.S.-horizon).

This horizon is a white, even-grained, (average grain diameter = .25 m.m.) siliceous sandstone horizon, which microscopically was found to consist almost 100% of quartz grains; evidently it was a well-sorted sand. It contains fossil imprints of Spirophyton (although in smaller numbers than in stratigraphically lower horizons) and numerous worm blow-holes and tracks. Actually, Spirophyton remains tend to disappear higher in the stratigraphical column.

Impressions resembling modern sea-mats (bryozoae) were also found in a few places.

Referring to the stratigraphic column, it can be seen that the Main W.B. unit (Plate II, ph. D.) totals 1860' and that its upper stratigraphic limit consists of 20' of a white, topographically very prominent, fairly fine-grained, siliceous sandstone, succeeded finally, by 40' of a coarse-grained, pink to brown, siliceous sandstone. The 20' horizon (white) was used as a marker for field-mapping purposes and a diagnostic feature of the upper 60', worth mentioning, is their massive bedding, which on weathering gives rise to conspicuous krantzes or massive blocks littering the slopes.

The succession grouped as the "Upper W.B." unit consists mostly of shales with a few horizons of siliceous
sandstone near the base and it is a moot point whether they belong to the "W.B." or are part of the Dwyka Series. The Geological Survey mapped the Lower Dwyka Shales as being part of the Witteberg. A. L. du Toit considered: "it is only proper to point out that lithologically they are more akin to the softer beds of the Witteberg Series and that it would be more appropriate to include them in the W.B., thereby making the tillite the real base of the Harroo System." (A. L. du Toit, Geol. of S. Afr., pp. 259, footnote.)

Obviously they represent transitional deposits, but the time value of the stratigraphical hiatus is a problem still to be solved and to draw a definite morphologic boundary may prove to be extremely difficult.

Mapped on the basis suggested by du Toit, the so-called "Upper W.B. unit", includes horizons which contain plant as well as fish remains.

This unit does not appear in the north-western outcrops of the W.B. in the Cape Province. Where present, it varies in thickness, reaching a maximum approximately in the area surveyed.

These beds were found to be about 1650′ thick and comparing this result with those of the Geological Survey we find: (S. H. Haughton et alia, 1953, p.16)

Dwyka River to Droëkloof = 1050′
Droëkloof to Soetendalsvlei = 1210′
Soetendalsvlei to Iseukloof = 2220′
Iseukloof to Miller Station = 1050′

Having presented the characteristics of the "marker" horizons of the Witteberg Series, it now remains to amplify briefly, the lithological character and fossil content of the intermediate horizons of this Series.
(i) Lower Witteberg.

The shales succeeding the P.C.S. 2 are similar in appearance to those that preceded the P.C.S. 1 – horizon. Due to the fine grained shaly matrix being red, and thin interstitial lenses of more sandy material being grey, banding is produced.

Grey Sandstone (G.S.-horizon).

The second marker horizon in this unit is a greyish-white, siliceous sandstone, medium-grained, (average grain diameter = .35 m.m.) closely bedded and stratigraphically by far the thickest sandstone horizon present. In itself unfossiliferous, overfolding or vice-versa, is easily determinable by two diagnostic features:

(a) a thin sandstone horizon (6" thick), highly fossiliferous, with its surface weathered to a purplish-black, manganese colour, occurs about 80° above the upper limit of the G.S.-horizon.

(b) in the 80° separating the above-mentioned fossiliferous horizon from the G.S., there occur yellow-brown sandy lenses of limestone which is absent below the G.S.

The G.S. is succeeded by red, grey and black micaceous shales with thin sandstone lenses and the aforementioned yellow-brown limestone lenses, below the diagnostic fossiliferous horizon.

Orange-Red Sandstone (O.R.S.-horizon).

This siliceous sandstone horizon is surrounded by soft, pink, highly micaceous, fissile shales. It is a white even-grained sandstone, stained orange-red along joints and cracks by Mn-compounds. This feature, accompanied by its highly fossiliferous nature (Plate II, ph. E.) and,
being interbedded with highly fossiliferous shales, makes it an excellent marker horizon. Aided by this horizon, the intense folding of the Lower W.B. was mapped.

During the deposition of these sands, a flourishing plant life existed as witnessed by the numerous remains of plants, worm tracks, etc. Spirophyton too had a maximum development at this time, and all sizes from those with a diameter of 2" to over 1' occur. A few interesting features of these "problematical" impressions, were noted. Differences in imprint are found, in the form of thin "hair-like" striations, lying crosswise to the radial ridges of the structure, in the shale, which is not noticeable in the sandstone. Two possibilities arise: either the impressions are produced by two different agencies; or, and this, in the author's opinion, is the more logical, due to the finer grain-size of the shales, a more delicate impression of the original fossil is reproduced. Distinct individual impressions characterise the arenaceous horizons, while those in the shale are more numerous and less distinctly defined due to overlap or over-imprint.

A further interesting feature encountered was, that impressions exceeding 9" in diameter, tend to consist of separate "leaves" (Fig. 5. and Plate II, ph. F.) whereas a single, radial, vortex-like figure, is usually displayed by those of smaller size (Plate II, ph. G.). A.C. Seward considered these impressions as due to "swirling water" (1903, p.105), whereas T. Fuchs considers their origin due to a worm which produced a spiral cavity in the sand. (1903, p.104) In the author's opinion these impressions are due to a sea-plant which "opened-out" its leaves on reaching a mature stage of growth. (Plate II, ph.F.)
FIG. 5. Spirophyton (half natural-size).

The absence of any carbonised vegetal-matter adhering to the impressions, does not necessarily signify anything, since the same is true of most of the other undoubted plant impressions from the Cape System.

These fossil imprints, accompanied by wave ripple-marks and worm blow-holes, were invaluable criteria in determining the top or bottom of a horizon.

Similar impressions as those noted by B. Swart at Wuppertal (1950, p.431) and by E.H.L. Schwartz at Ceres, "consisting of a number of stout rods projecting from an axis" (Plate II, ph. E.) (1906, p.282), were found by the author and seems to be related in some way to the Spirophytons.

Similar "black inclusions", weathering to a brown limonitic mass and giving rise to problematical "seed" and "leaf" impressions, as described by B. Swart at Wuppertal.
(1950, p.431), were also found.

The type locality of the former impressions is a thin layer, a few inches below the base of the O.R.S. horizon — (Spirophyton seeds?). These imprints appear in some instances similar to small bi-valves or seed-lobes. (Plate IV, ph. H. & I.)

Other common fossil remains are worm blow-holes, worm tracks and casts and large numbers of perfect moulds of Orthoceras.

The pink micaceous shales overlying this horizon, stacked with Spirophyton remains, tend to become slightly more sandy and blackish-brown about 15' above the O.R.S. and grade into a 2' thick purplish-black, (colour probably due to leached manganese) sandstone horizon, richly fossiliferous, intensely ripple-marked and possessing small contemporaneous erosion channels. (evidently similar to the B.S. = horizon).

The Spirophyton impressions, being less numerous on ripple-marked bedding planes, suggest that their preservation was enhanced by "quiet-water" conditions. (Plate II, ph. E.)

This ripple-marked horizon, in conjunction with the O.R.S. was used as a major "marker" horizon.

This horizon is stratigraphically succeeded (up to the W.S.-horizon), by 75' of red, grey and black, sandy, micaceous shales, with thin interstitial siliceous sandstone horizons and lenses, in which Spirophyton still remains the type fossil.

(ii) Main Witsberg:

This unit consists of close on 400' of alternating
shales and sandstone lenses, succeeded by about 1460° of more massively bedded, siliceous sandstone horizons.

The lower 400° - unit consists of essentially the same black, grey and red, sandy shales that preceded the W.S. - horizon, the only difference being that Spirophyton impressions, ripple-marks and all other primary fossiliferous features tend to become less. Simultaneously, frequent sandstone horizons appear, becoming more massive on nearing the base of the Main Sandstone.

The sandstone unit of the W.B. is normally bedded, siliceous sandstone, usually brown to grey-brown in colour and fairly even-grained, except for certain conglomeratic horizons near the top of the succession. It is thinner bedded than the T.M.S. and more frequently intercalated with black and grey, micaceous shale horizons. (Plate I, ph. G.) Cross-bedding occurs throughout the succession and slicken-siding is quite common.

Due to the shale being more susceptible to weathering, the successive series of sandstone beds stand out almost like "ribs". This feature facilitated the structural mapping immensely, and the clarity of all structural features became greatly enhanced. (Plate IV, ph. E.)

Certain horizons near the top are sometimes coarse grits or calcareous sandstones. Frequently, perfect interior casts of Lycopod stems are found, as such, not limited only to certain beds, but scattered at random, although remains appear to be more confined to the upper horizons. (Plate IV, phs. E, F & G.)

(iii) Upper Witsberg:

The horizon succeeding the brown sandstone, is a black, highly cleaved, carbonaceous, fissile shale of soapy
feel. On weathering, where uncovered by debris it gives rise to black smudges against the mountain flank. Due to its bedding and cleavage, it weathers into small, glossy, phyllitic, splinters.

These beds become more sandy and about 200' above the top of the Main Sandstone the beds are reddish micaceous shales.

Thin grey to yellow sandstone lenses make their appearance in the midst of the shale horizons approximately 80' above the reddish shales. Worm-casts and tracks are quite common in these beds.

These beds and the succeeding sandstone horizons are similar to the horizons building the Lower W.B. and evidently represent a return to the conditions of deposition during Lower W.B. time.

The succeeding sandstone horizon varies from top to bottom in colour and grain-size. It is very highly crossbedded and from the Survey's bore-hole results (S.H. Haughton, 1953, p.16) it becomes clear that this specific horizon is continuous, striking from just east of Prince Albert to just west of Klipplaat, and also that it can be a very useful marker in mapping these beds.

It varies "in thickness from 10" to a maximum of 75" (S.H. Haughton, 1953, p.16) and was found to be approximately 18" thick in the area surveyed.

This horizon frequently contains small white and blue vein-quartz, shale and limestone pebbles, and sometimes becomes conglomeratic. It frequently displays broad ripple-marks and due to the pebbles weathering-out, has a "pock-marked" appearance.

This horizon actually consists of two sandstone horizons, separated by 15' of brown, micaceous,
argillaceous sandstones. The lower horizon is cross-bedded to such an extent that it varies in thickness over a distance of a few feet from less than 6" to over 18". This rock is actually a yellowish-brown, siliceous, saccharoid sandstone, containing a fair amount of perthite feldspar. A freshly broken sample shows quite a number of cellular cavities filled by soft, brownish-yellow, powdery limonite, causing the rock to have a spotted appearance.

Compare the results obtained with a section north of Kando's Poort: (E.H.L. Schwarz, 1903, p.88)

"Hard, green, non micaceous shales - 75 yards.
Medium bedded, dense, white quartzite - 11 yards.
The same, more thin bedded - 10 yards.
Papery, sandy, black shales - 15 yards.
Saccarine quartzite with cellular cavities filled with limonite - 1/3 yards.
Papery, black shales - 87 yards.
Top Witteberg Quartzite - 14 yards."

In some places however the upper horizon carries similar saccharoid sandstone lenses and simultaneously the lower horizon also contains pebbles.

This horizon crops out again to the north, but now becomes almost unrecognizable due to the intense deformation it had suffered when folded into two parallel trending anticlines. The normal symmetrical succession of beds expected on both sides of an anticline is totally absent here, and to such an extent, that "it is characteristic of them that even on two sides of the anticline the nature of the rock is often widely different."

(E.H.L. Schwarz, 1903, p. 94)

The beds succeeding the saccharoid quartzite are similar to those that preceded it, viz. reddish, fine
grained, micaceous, fossiliferous shales. This continues for about 150', and then, becoming progressively more sandy, grades into a finely cross-bedded, brown micaceous sandstone, about 170' above the saccharoidal sandstone.

In the sandy shales immediately preceding it, worm-casts and tracks and an incomplete Pelecypod imprint were found. The sandstone and surrounding beds are intensely ripple-marked and cross-bedded and must have been deposited in reasonably shallow water, since primary features such as mud-cracks and oscillation ripple-marks occur. This is in sharp contrast to: "the Lower Dwyka Shales which were deposited in fairly deep and cold water" (I. W. Halbich, 1960), and seems to show that the water depth in which the beds of the unit were deposited, varied, and at Vondeling at the stratigraphical height of the brown micaceous sandstone, attained extreme shallowness. The succeeding 100' consist of thin (less than 2" wide) horizons and lenses of similar sandstone interspersed between the same sandy, micaceous shales that preceded the ripple-marked sandstone horizon. Only those horizons immediately overlying the sandstone horizon show ripple-marks. The beds now slowly change, the shales becoming grey in colour and less micaceous, whereas the sandstone horizons, becoming yellow-brown and slightly thicker, acquire a more friable nature and become calcareous.

A diagnostic feature of the lower 200' is the occurrence of lenses of black calcareous mudstone. As such, these beds are very fine-grained, sandy and micaceous, and weather to a conspicuous yellow-brown colour. The lenses previously mentioned, do not individually exceed 1' in thickness.
The succeeding 50° of sandy shales acquire a dark grey colour and similar lenses of black, calcareous, carbonaceous material appear. These lenses are in some places almost totally comprised of fossilised plants and vary in size, though seldom less than a few feet in length. The fossils closely resemble "stems of plants, like sedges" (E.H.L. Schwarz, 1903, p.94) and are evidently similar to the so called "Phylloteca" (or Calamites), (Plate IV, ph.K,) discovered by Rogers and Schwarz in the same "hard, black, argillaceous rock" on the Witteberg River south of Laingsburg, (1902, p. 107). In the succeeding 375° a few coarse sandstone horizons appear, which soon give way to black, finely bedded, micaceous shales with only very thin (less than 1" thick) sandstone lenses. These shales are slightly sandy and calcareous and occasionally display cross-bedding, as exemplified by an alternation of lighter coloured sandy and black shaly units.

Black, fine-grained, carbonaceous, mudstone nodules, containing fossils of Ganoid fish and frequent Lycopod stems, are a highly diagnostic feature of these beds. (Plate IV, ph.J.)

There exists quite a difference in the degree of sphericity between these *nodules* and the plant-bearing *lenses*, the former approaching a speroidal form, whereas the latter have a clear flattened lens-like shape. (Fig.6.) The two types are therefore easy to distinguish in the field. A further characteristic of the fish-bearing *nodules* is their conspicuous mode of weathering. They, like the well-known and conspicuous "White Band" also weather white on exposure.
FIG. 6. (a) Diagrammatic cross-section of fossiliferous black shale zone, showing transverse and longitudinal sections of "single fish" nodules with convex upper surfaces, attaining a maximum length of three feet.

(b) Cross-section of carbonaceous, calcareous lenses in black shale.

Covered by scree and alluvium to a great extent along the flank of the mountain just north of Soetendals-poort, a better place for studying these so-called "Upper Witteberg" beds, is the northern-most area, where they are anticlinally and nearly vertically upfolded and flanked by outcrops of true Dwyka tillite.

The fossiliferous nodules tend to be bigger and better preserved too in the latter area (south of Strydomsvlei). These 'nodules' can be used as highly diagnostic criteria in determining the attitude of the beds. They all tend to be flat on one side in contrast to being convex on the other (Fig. 6.). By noting how the convexity is directed it could easily be determined whether the beds were vertical, or overfolded, or not. This determining feature becomes less obvious in beds.
dipping at an angle of 45°, in contrast to those with a
dip higher than 70° and lower than 35°.

This convexity of the 'nodules' is taken to
represent a primary structure, the origin of which can be
explained in the following manner.

Evidently dead fish and bushy plants or driftwood
formed centres for the initial accumulation of fine black
mud, even as it is found to-day, in water carrying fine mud
in suspension. The primary concentration of mud after
totally covering the fish and plants, would acquire a
shape and form determined by the size and thickness of the
bodies covered, hence the very obvious and persistant
 correspondence between the size of a fish-bearing 'nodule'
and the size and the shape of the included 'fish'.

With pressure applied to the enclosing shaly layers,
the sphericity of the nodules was seemingly not lessened
but rather enhanced.

The fish remains, sometimes very complete, usually
occupy the lower \( \frac{3}{2} \) of a 'nodule' on the flattened
side, a feature which strengthens the surmise that it is a
true primary feature of deposition. A very marked
characteristic is, that a 'nodule' occupied by the skeletal
remains of one fish only, has its long axis in correspondence
with that of the enclosed fish. The fossil fish occur
either singly, or up to 10 or more in a single nodule.
Death of large numbers of fish at a particular time and
place stratigraphically, should be considered as being due
to the following possible causes or combination of factors:

(a) sudden changes in temperature,

(b) marked and sudden changes in salinity,

(c) the effects of toxic conditions contributed
    by, or originating in the anaerobic sub-
aqueous breakdown of plant material.
All three factors however, could have obtained simultaneously, and the afore-mentioned causes of death, at present, frequently result in the death of large numbers of fish in the shallow waters of estuaries, marginal littoral lagoons and in the littoral and neritic zones of the continental shelf. It must be noted however, that the place of burial need not be indicative of the place of death, and that these remains could have been transported for varying distances, prior to enclosure by the mud. It is suggested however, that the distance of transportation could not have been great, and that burial occurred, relatively soon after death. The fish impressions, in the case of complete specimens, display a remarkable degree of preservation of their outer body covering. It must also be noted that the fossil remains are not restricted to a single horizon or to one bedding-plane, but are found scattered in a 30° zone near the middle of the black micaceous shales; and furthermore, that their skeletal remains are orientated in all possible directions in the nodule parallel to the bedding of the surrounding shales.

These shales become lighter in colour and the sandstone units once again become thicker and more common in the following 125° of the stratigraphic succession.

Both the grey and black shales and yellow-grey sandstones, contain calcareous material and the sandstones could actually be labelled very sandy limestones. A characteristic of these beds is the clarity with which the fine cross-bedding is displayed.

The plant-rich "lenses", present below the black shales, once again occur, although not as richly fossiliferous as before.
In the succeeding 242' up to the boundary of the tillite, the shales diminish in thickness and more arenaceous beds tend to become dominant. They now also have distinct oscillation ripple-marks and are very finely laminated and cross-bedded. The fossiliferous plant-bearing lenses occur once again and are highly calcareous.

A closer examination will clarify their composition and suffice to stress the points of dissimilarity between them and nodules.

The main features are firstly, the already mentioned difference in their shapes, - i.e. lenses in contrast to spheroidal nodules; - secondly, the nodules weather white whereas the lenses acquire a rough brown surface. When looking along the bedding plane a markedly ribbed effect, caused by bedded and tightly packed plant-stems, can be seen.

The matrix of these lenses consist of a rough fragmentary mixture of fossil material and the rock as such, is a black, fossiliferous, carbonaceous limestone. Evidently it was originally a black, "organic", sulphuretted, limy mud.

In the last 100' before reaching the "stratigraphic" boundary, various siliceous limestone lenses, totally differing from the fossiliferous lenses, appear. These lenses are grey-black, sandy, calcareous mudstone, which on weathering show a surface covered by little "pimples". This is due to certain portions of the rock being cemented by silica, whereas the rest is loosely bound by calcite. Other lenses attain on weathering, the typical feature of a fine grained limestone, characterised by "a maze of sharp pinnacles and points and fluted ridges or lapies".

(A.K. Lobeck, 1939, p.133).
The greenish-yellow, calcareous, sandstone horizons, become thinner on nearing the contact and acquire a slightly coarser grain size.

These sandstone beds, in the upper 300 feet of the unit, contain a reasonable number of fresh grains of acid plagioclase-feldspar, in contrast to the Lower and Main W. L. sandstones, in which feldspar was very scarce. The oscillation ripple-marks found, point to a reasonably shallow-water environment of deposition.

A further notable feature, is the confined occurrence of the heavy minerals, in the more coarse-textured layers of the sandstone. The change to the tillite in this area, is more or less in agreement with the state of affairs most common south of latitude 33°S, according to which "the shales lose their bedded character and apparently become the matrix of coarser constituents within a matter of an inch, without any change in matrix lithology". (I. W. Hällich, 1960). Mention must also be made of certain coarse grits in the form of narrow bands (3 feet wide) outcropping across the strike of the succession.

(d) DWYKA SERIES (KARROO SYSTEM).

(1) Tillite:

The beds represented are the typical green and blue mudstones of this series, containing erratics, varying from microscopic to huge boulders. On weathering, the tillite gives rise to a wasteland covered by loose rubble and uneven lenticular slabs. "Clay balls" (I. W. Hällich, 1960) are of common occurrence. About 2460 feet thick in the area surveyed, the tillite does not vary much and the only diagnostic criterion used in the mapping of the structural section was a thin (1 foot thick) very fine grained mudstone horizon, containing only very small fragments. This horizon
due to its bedded nature, fine-grain and almost flinty character is prominent in outcrop in the midst of the tillite as a sharply demarcated ridge or "wall".

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(ii) Upper Shales:

Of these beds only 450' are represented and they too are the normal olive-green to black shales found elsewhere. Weathering into small lenticular spikes, they cause the more flinty and compact White Band to be set off sharply; and as already described the latter, clearly demarcates the synclinal structure north of Stotendaalsvlei.

Certain of the more massively bedded horizons give rise to the common "box-work" structures usually found in these beds. (I. W. Hälßich, 1960) p.126)

Lenses of grey-brown, crystalline limestone, evidently due to secondary deposition in fissures, are also found.

Occurrences of gypsum, ochre, and in some places carbonaceous bands, almost anthracitic, are common features.

No fossiliferous matter was found, although intensive search for it was not carried out by the author.

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(e) ECCA SERIES (KARROO SYSTEM)

Called the "Greaff-Reinet Beds" by E.H.L. Schwarz (1903, p.95), these beds are the normal intercalated greenish-grey to yellowish-brown shales and sandstones of the Lower Ecca. Limestone nodules and fossiliferous remains in the form of Dadoxylon stems and imprints of Glossopteris, are common features.
The structural attitude of these beds was determined by their lower boundary, the White Band.

(f) Uitenhage Series (Cretaceous System)

(i) Enon Beds: These beds, occurring only to the south of the Swartberg Range, constitute the normal, lower, continental phase of the Cretaceous System, the Enon conglomerate. The occurrence consists essentially of a conglomerate, composed of a red clay-matrix in which well-rounded pebbles and boulders of sandstone and shale are scattered at random. It weathers into rough grotesque shapes as is commonly displayed all along the outcrop area between Towerwaterpoort and De Rust.

A slight indication of bedding is displayed by less pebbly beds of a more sandy and shaly nature. Since the outcrop wedges out in normal unfaulted fashion, about 3 miles to the west of Towerwaterpoort, the unit cannot be very thick locally.
CHAPTER IV.

(a) STRUCTURAL PATTERN AND EVOLUTION OF THE AREA:

Any mapped area, including the Cape Fold ranges and Great Escarpment region in the Cape Province, emphasizes the marked difference between the structural front of the Cape Fold Belt and the erosional front of the Roggeveld-Nieuwveldt Escarpment.

In conformance with the great fold ranges of the world, e.g. The Appalachians, Alps, etc., an intensely folded and relatively elevated region, immediately adjacent to an anomalous horizontally bedded region, is typified in the Cape Fold Belt and the adjacent Bokkeveld Geosynclinal region. The Cape System was deformed as a unit, but due to the marked dissimilarity in the deformation of the competent and incompetent beds, it was found necessary, to divide the area into four different zones and to discuss them separately. These zones from south to north are:

(i) The Swartberg mountain range (reaching from the southern entrance of Towerwaterpoort northwards to the railway-bridge across the Traka).

(ii) The intermontane valley between the Swartberg and the Witberg (reaching from the Railway-bridge to the southern entrance to Soetendalspoort). (Plate I, ph.B.)

(iii) The Witberg mountain range (reaching from the southern entrance to Soetendalspoort to the confluence of the Traka and Loeriesfontein Rivers).

(iv) The area north of the Witberg (reaching from the confluence of the Traka and Loeriesfontein, northwards up to Strydomsvlei).

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(i) The Swartberg range:

This major topographical feature, composed mainly
of about 3000 feet of the lower member of the Cape System, owes its topographical prominence to two structural factors i.e. (a) its anticlinal structure and (b) the fact that it occupies the upthrow side of a normal fault.

The competent, massively bedded sandstone unit shows throughout, a markedly southerly dip, thereby bringing stratigraphically higher horizons into seemingly lower positions as a result of overfolding to the north.

The structural section indicates that the beds are folded into a double anticline of which the northern one is the more prominent. A certain amount of minor folding also occurs.

Because of the close isoclinal folding, even cross-bedding could not satisfactorily be used here in the structural mapping.

Slickeriding is quite common and the beds also display well-developed joint systems. (Fig. 12).

The overfolding is best displayed in outcrop at the northern entrance to Towerwaterpoort where the southerly dip varies between 45° and 60°. (Plate I, ph.C.)

FIG. 7. Section (A.-B.) of step-faulting, (Main T.M.S.) southern entrance to Towerwaterpoort.
The overfolding is abruptly terminated southwards by the Swartberg fault-line scarp, along which fault lines can be traced in outcrop, by intensely brecciated zones, indicating the presence of at least five planes of movement, dipping southward at angles of 70° and 85°, in a zone 500 yards in breadth. This step-faulting is clearly displayed at the southern extremity of Towerwaterpoort. (Fig. 7). The poorly bedded Enon, displays, en masse, a slight northerly tilt towards the subjacent fault plane.

(ii) The intermontane valley:

The area south of the Willowmore-Klaarstroom road, displays, relatively, more competent deformational features, than the area north of the road, and this necessitates that they should be discussed separately.

The structural section indicates that the overfolding is persistent northwards, approximately up to the Second Bokkeveld horizon.

The black shales, succeeding the main T.M.S. sandstone, are intensely sheared and cleaved.

**FIG. 8. Diagrammatic representation (C-D) of structure at northern entrance to Towerwaterpoort.**

- **B.S. 2** - Second Bokkeveld Shale.
- **B.S.S. 1** - First Bokkeveld Sandstone.
- **B.S. 1** - First Bokkeveld Shale.
- **U.S. 3** - Upper T.M.S. Sandstone.
- **U.S. 2** - Second Upper T.M.S. Shale.
- **T.H.** - Tillite horizon of T.M.S.
- **U.S. 1** - First Upper Shale of T.M.S.
- **T.M.S.** - Main Table Mountain Sandstone.
At the northern entrance to Towerwaterpoort, west of the railway-bridge, a clear-cut section of the stratigraphical sequence and structural deformation of the Upper T.M.S. is obtained. (Fig. 8). A minor anticline of T.M.S. sandstone, unfolded through the Upper T.M.S. shales (notated US₁) is present; a feature, often repeated farther west and east, along the mountain side.

The T.M.S. tillite horizon (notated T.H.), displays two marked cleavage directions, (Plate I, ph.D.) dipping northwards at approximately 40° and southwards ± 50°, and striking parallel to the normal strike of the encompassing shales (US₁ and US₂). The northward dipping cleavage is closely spaced, causing the rock to break into small discoidal slabs. The cleavage planes are curved in some places and this cleavage is therefore designated as flow-cleavage. The southward dipping, fracture-cleavage planes, are appreciably wider spaced than those of the flow-cleavage and not as extensively developed. It is more open and clear-cut and since it cuts across the flow-cleavage planes, has clearly developed later. (Plate I, ph.D.) With the change in dip of the encompassing beds US₁ and US₂, interesting cleavage and bedding relationships result, by means of which minor folding could be deduced, from the position of the acute angle in the cleavage rhombohedron, since the angle is controlled by the interrelation of the bedding and the cleavage. The true cause (or causes) of the widening and narrowing of the tillite outcrop, could not be deduced from local field evidence.

Figure 8 and the structural section (Plate V) show that the sandstone horizons (US and BSS₁) are overfolded towards the north at angles varying between 30° and 70°, and prominent dip slopes are frequently displayed.
The structure present between T.K. and the Second Bokkeveld Sandstone horizon, is dominantly synclinal, and was deduced mainly by means of cleavage measurements. Small-scale strike-slip faulting is also present.

![Diagram of structural diagrams illustrating deformation of the Second Bokkeveld Sandstone horizon.](image)

**FIG. 9 (a, b.)** Structural diagrams (E - F), (G - H) illustrating deformation of the Second Bokkeveld Sandstone horizon.

The Second Bokkeveld Sandstone building, the Spekboomrant, just south of Vondeling station, is structurally a perfect example of isoclinal folding. The fossil remains, were useless for the determination of overfolding or vice-versa, and to increase the difficulty, the hill-sides are covered by scree and dense shrub. Two "similar" brown sandstone horizons, both with equal southerly dip, build the two parallel trending hill-ranges, and could either be, two separate horizons, or a single isoclinal folded horizon. Careful examination of the precipitous western cliff, where the Traka cuts across this horizon (Fig. 9 (a)), and consideration of the western cross-cut (Fig. 9(b)) as well as the outlier in the northern hill-range, indicated a single sandstone horizon, almost isoclinal overfolded towards the north. The relatively intense folding of this sandstone horizon is evidenced by small hills with closed anticlinal structure, north of the main outcrop and towards the west.
The B.S.-horizon is the major 'marker' horizon in the adjacent lowland and shows high incompetency although only very shallowly folded.

North of the Klaarstroom-Willowmore road the relatively thin sandstone horizons, P.C.S., O.S., O.R.S., and W.S., are stratigraphically emplaced in thick shale units and display remarkable incompetency. Here, only the major structures were mapped, because on the scale used, three or more successive anticlines over a distance of six feet (Fig. 13 C), could not be represented.

The structural forms present here (Fig. 10), listed (a) to (f) are:

(a) a tightly folded syncline of P.C.S.-horizons;
(b) a more open anticline, displaying a widening outcrop area of P.C.S.2;
(c) a comparatively open syncline, constituting an outlier of O.S.1;
(d) a breached anticline in P.C.S.1;
(e) an asymmetrical, approximately horizontal syncline in O.R.S.2;
(f) a faulted area.
(g) a ridge of asymmetrical synclinal structure in O.R.S.-horizon,

(h) a wide quaquaversal dome-like ridge,

(i) a highly asymmetrical syncline in O.R.S.

Of additional importance, is the contrast between the dip of the northern and southern limbs of the asymmetrical synclines, and the southerly, asymmetrical attitude of h. The former feature is quite normal, where northerly overfolded anticlines have been weathered in such a manner that only the synclinal troughs remain. The anomalous asymmetry of the 'dome' in this region of northward overfolding, is explicable, when the 'dome structure' is seen as part of a southern "anticlinorium", whose development was the controlling factor in the incompetent folding of the dome.

Well-developed isoclinal overfolding is present, north-west of the area included in figure 10 and here an outcropping sandstone horizon could be either a limb of a fold or the slightly breached crest of a closed anticline.

North-east of the area shown in figure 10, zig-zag ridges of similar development as those in figure 10 are encountered. (Plate I, ph. F.)

Just north of the Vandezey River, and west of the road to Soetendalsvlei, an anticlinal structure passes into a parallel syncline, prominently visible, due to the conspicuous weathering of the W.S.-horizon. (Plate III, ph. B.) The succeeding northern anticlinal structure is an example of "box-type" folding. (B. Stoices and C.H. White, 1935, p.157). Towards the mountain flank, 'hogbacks', composed of G.S.-, O.R.S.- and W.S.-horizon occur, and, are stratigraphically overlain by sandstone and shales of the Main Witteberg unit.
(iii) The Witberg range:

In the eastern cliff-face where Soetendalspoort has been cut through the southern range, the overfolding, which occurs sporadically on the southern flanks of this range, is typically developed. (Fig. 11).

![Diagram](image)

**FIG. 11. Overfolded attitude of the Main Witteberg Sandstone (K - L). Southernmost range, Soetendalspoort.**

The synclinal valley in which the homestead of Soetendalspoort is situated, varies in structure along the strike. In cross-section, near the homestead, it is a normal syncline, but generally it appears to be fan-shaped. (Plate V). About 1½ miles east of the homestead, a minor anticline attains a maximum development and due to the termination of the syncline, the two structures coalesce, with accompanied termination of the valley. (Plate III, ph.C.) By contrast, westwards, along the pitch of the syncline, the valley tends to open out.

South-east of the homestead, intense deformation is shown by the conspicuous white 'marker' horizon and the forty foot, massively bedded, brown sandstone horizon, which display columnar jointing and weather into vertical columns and walls up to 100' high. These, as well as the preceding and succeeding beds, have a well-developed joint system (p.76), while shearing along the joint planes is not common. Two major joint directions are displayed, trending N 20°E and
N 75°W. (Fig. 12(a).)

FIG. 12. Histograms of strike directions of:
(a) 234 joints,
(b) 80 slickensides.

C. H. Nevin has stated that: "in folded regions, there may be tension in two directions, making possible the formation of a system of joints. One of the sets that parallel to the strike of the folds, would be strike joints caused by stretching over the crests. The other set, that parallel to the direction of dip, would be the result of stretching brought about by the plunge of the folds." (1949, p. 153).

The N 200°E trending set (usually filled by vein-quartz) is parallel to the dip of the beds and is therefore classed as dip joints, whereas the N 75°W, relatively open set, conforming to the strike, and of frequent occurrence on unbreached anticlinal crests, is classed as strike joints.

These joints obviously originated in an analogous manner as described by Nevin because:
(a) this is a fold region,
(b) the joints are parallel to the strike and dip of the deformed beds,
(c) the forces responsible for the deformation are commonly accepted as compressive, while shearing is uncommon. C. H. Nevin has furthermore stated that: "tension joints associated with compressive stresses are best developed if the confining pressures are not large enough to force the rock to fault along shear planes". (1949, p. 150).

Slickensiding on fold flanks and crests is quite common. A histogram presenting the strike components of
the slickensiding, shows a maximum development parallel to the dip of the beds (Fig. 12 (b)), due to normal slip, occurring on the flanks and crests of syn- and anticlines during folding.

Accelerated weathering along the strike-jointing just north of this area, caused the development of a valley (described in Chapter II (b)) on an anticlinal crest. (Plate III, ph. D.)

FIG. 13 (a), (b). Illustrating structures in north flank of Witberg Range west of Soetendalspoort. (c). Illustrating close folding in Lower Witteberg Sandstone.

The beds composing the northern Witberg Range and constituting the northern limb of the major anticline in this area, dip northwards constantly at about 60°, except for a few minor folds. Towards the east of the 'poort', an interesting relationship obtains between topography and structure. The white 'marker' horizon, displaying a series of minor folds, provides a key to the local deformation. West of the poort, the beds in the range flank are deformed into an overfolded syncline (Fig. 13 (a)). Still further westwards, an anticline and syncline, intermediate and parallel to the first pair, have developed. (Fig. 13 (b)). On the
mountain flank, the erosional outliers of synclinal structure occur as white patches in the surrounding grey and brown sandstones. The main structural section (Plate V), due north of Trigonometrical beacon 3407, displays a small syncline, almost on top of the mountain, succeeded northwards, by an infolded tract of Upper Witteberg shales and a clearly visible anticline in a narrow cross-cut valley, respectively.

(iv) North of the Witberg up to Strydomsvlei.

Northwards of the Witberg, a low range of hogbacks of resistant Upper Witteberg sandstone horizons, parallel the flank of the mountain. Due to the two very well-developed directions of jointing, these sandstones weather into rhomboidal slabs.

FIG. 14. Showing occurrence of the grit bodies in Upper Witteberg horizons.

Approximately one mile south-westwards of the Soetendalsvlei homestead, between the Traka and the mountain
range, a succession of totally unbedded grit-lenses strike at almost right angles to the normal bedding of the encompassing sediments (Fig. 14). The lenses are from 2' - 5' in width and vary in length from 20' to 350'. To explain the present mode of occurrence of these lenses, a detailed investigation of their probable origin was required. (Plate IV, ph. C.) It is visualized that, the following, four 'mechanisms', may be applicable:

1. Normally interbedded grit lenses in shales which had been deformed by later pressures and subsequently exposed by erosion in their present aberrant positions.

2. Filled-in, contemporaneous erosion channels (by gritty sands).

3. Filled-in, geologically recent fissures or open joints (by gritty sands).

4. Filled-in, fossil, post-diagenetic fissures (by gritty sands).

To crop out, as stipulated in origin No. (1), almost perpendicular to its former depositional position, the lenses must have suffered extreme deformation. Although the presence of some movement is evidenced by slickensides and slight drag-folding (measureable in inches) on either side of these grit lenses (Fig. 15 (c)), clearly recognizeable horizons are offset only one foot. Under the microscope, slight granular deformation is displayed by the finely cracked quartz-grains, but recrystallization, gliding or shattering, is absent. Some movement evidently took place along the sides of these "fill-ins", but not of such an intense degree as would have caused the deformation visualized in (1).

2. The erosion channels were cut across and into the bedded shales and were subsequently filled in by coarse sand. Such channel-fills can be termed "wash-outs" or
"shoe-string sands"—of common occurrence in the petroleum fields of America (A.I. Leuorsen, 1943, p.918). Far less pronounced vertical movement is required by this theory to explain the present-day-attitude of these grits.

(3) The strike of these "fill-ins" and that of the major dip joints, in conjunction with the possible 'provenance' of the filled-in material, related to recent, probable directions of transport, have been investigated. The strike of the "fill-ins" (Fig. 14) as compared to the direction of strike of the joint system in this area (Fig. 12 (a)), stresses the parallelism of these structures, to the regional dip joints. B.C. Escher (1949, p.338) has described the formation of similar structures as due to the filling-in of gaping earthquake fissures in unconsolidated sediments by loose debris washed in from above; conceivably the same mechanism may operate in thoroughly consolidated rock. An investigation of the heavy mineral suites of the grits and the encompassing beds revealed the following results:

### TABLE 5.

Quantitative heavy mineral data values presented on the basis zircon = 100

<table>
<thead>
<tr>
<th></th>
<th>Zircon (100)</th>
<th>Rutile</th>
<th>Tourmaline</th>
<th>Garnet</th>
<th>Grains counted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>White</td>
<td>Pink</td>
<td>Zoned</td>
<td>Red</td>
<td>Yellow</td>
</tr>
<tr>
<td>Grit</td>
<td>55</td>
<td>0</td>
<td>45</td>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>
Both rocks contain the following characteristic heavy minerals.

(a) a small number of tourmaline grains uncommonly pleochroic from X = pinkish-brown to Z = dark brown,
(b) tourmaline grains (pleochroic; X = yellowish-brown to Z = brownish-black) with irregular opaque inclusions and transparent bubbles,
(c) frequent brown euhedral tourmaline grains in contrast to the broken fragments of the blue and green varieties,
(d) fairly well-rounded zircons of both varieties, frequently containing rodlike inclusions,
(e) conspicuous, prismatic, foxy-red rutile grains, strongly pleochroic; X = brownish-red to Z = dark blood-red,
(f) garnet grains with marked shagreen surfaces are common, in contrast to the colourless and transparent type,
(g) brookite which is very rarely present.

Approximately the same different mineral quantities obtain excepting the garnet and to a lesser extent the rutile.

The Dwyka tillite is usually characterised by the presence of relatively large amounts of garnet (I. W. Halbich, 1960) and it thus appears as if the tillite could have been the provenance of the grit, the lower members of the Cape System here being devoid of garnet.

The local and fossil direction of drainage has been from the Cape System rocks towards the Dwyka tillite since Late Karroo Time (F. Dixey, 1938, pp. 135-164). The debris that would have filled such an open fissure, thus had as provenance an area devoid of garnet, and it therefore appears as if the grits do not have this mode of formation. The adjacent rocks also carry garnets (Table 5) but of smaller grain size than those in the grits. The latter can therefore not represent local concentrations derived from the former.

It appears thus that the heavy minerals of the gritty stringers were derived from a similar provenance region as
those in the Upper W.B. and Dwyka tillite sediments, but that their transportation was accompanied by high competency currents.

4. "Clastic dikes" (R.R. Shrock, 1948, p.212) or "sand dikes" (R.A. Daly, 1926, p.36) are well-known features and are described as being indicative of fissures caused by ancient earthquakes. Under these circumstances a gritty layer must necessarily have been:

(a) stratigraphically above the present position of the "fill-ins", or
(b) below the present position of the "fill-ins", or
(c) in an overlying bed subsequently removed by local erosion before the succeeding beds were deposited (R.R. Shrock, 1948, pp. 212-220).

The absence of any evidence of normally interbedded grits or local diastems, causes this mode of origin to be disregarded.

From the above considerations it was concluded that origin No. 2 complies best with field evidence and it remains to be explained how the infilled channels became structurally deformed and came to occupy their present positions.

The origin of scour channels in littoral and neritic deposits may however be questioned, but Kuenen's description of the "turbulent motions" present on the sub-aqueous plane surface, and the direct relation of grain size and turbulence to deposition, will dispel any doubts, since "particles heavier than water show a sinking movement superimposed on the turbulence" (Ph. H. Kuenen, 1950, p.253).

It is the author's opinion that the deformation of these high competency stringers was accomplished in the following manner: (Fig. 15, a-c).
FIG. 15 (a, b, c) Representation of mode of emplacement of grit bodies in Upper Witteberg horizons.

In stage (a), three grit stringers are shown in separate elevations, across the strike of the surrounding bedded muds, prior to deformation.

During stage (b), after diagenesis, at the initiation of folding, a joint system begins to develop across the bedding. (only the dip joints shown here).

During stage (c), with more intense deformation, the dip joints, under tension, tend to open and the grit is forced upwards and downwards into its present vertical position.

The local beds just north of Soetendalsvlei are folded into a huge asymmetric synclinal structure, trending parallel to the mountainside between Klaarstroom and Aasvogelberg. Within the major structure minor incompetent structures occur.

Striking parallel to the main anticlinal fold of the Witberg, are two anticlines composed of Upper Witteberg shales and sandstones. Small-scale strike-faulting is evident in the shale beds, becoming more pronounced in the northern area where the beds dip vertically on approaching the northern contact with the Dwyka tillite. Except for this steeply-dipping zone, the shale beds are very shallowly folded. (Plate IV, ph. D.)

In contrast, the sandstone beds are incompetently
deformed into anticlines, cropping out along the contacts of the Upper W.B. unit and the Dwyka tillite. A seeming stratigraphic hiatus tends to appear on the flanks of these anticlines. The anticline nearest to Zoetendalavlei has its northern flank either in direct contact with Dwyka tillite, or separated from the latter by only a few feet of shales. (Plate V). Similar features appear in the anticline near Strydonsvlei. (Plate III, ph.E.)

The anticlines are very conspicuous in the field, due to:
(a) the weathered white sandstone blocks lying scattered on the flanks,
(b) these resistant beds being selectively weathered, give rise to hills.

Due to extensive "flowage-folding" in the incompetent overlying and underlying beds (G.W. Bain, 1931, p.524), the resultant structures of the competent sandstone, vary from normal anticlines to asymmetric, to northward overfolded and recumbent anticlines. Within the main northern anticline, in its south-eastern corner near the road to Strydonsvlei an almost totally unbreached, recumbent anticline crops-out as a hill (Plate III, ph.F.).

These horizons were noted by E.H.L. Schwarz (1903, p. 94): "North of Zoetendal's Vley there is a long outcrop of shales below the Dwyka Conglomerate, in which the quartzites in these beds are largely developed". This sandstone, in the isoclinally folded anticlines, and the sandstone, outcropping in the mountain flank, towards the south, display marked differences as well as significant similarities.

(1) The sandstone at the mountain flank is a normal,
massively bedded, brownish-grey, siliceous, saccharoidal sandstone, with small limonitic cellular pits. In contrast, the anticlinally folded sandstone is strongly banded, consisting of light greyish, quartzose layers, alternating with thin brown laminae.

(2) The banded sandstone displays marked laminar corrugations (R.R. Shrock, 1949, p.263), in vivid contrast to the undisturbed, massive bedding of the saccharoidal sandstone.

(3) Characteristic of the saccharoidal and the laminar corrugated sandstones, is the unusual occurrence of interbedded, thin, sandy, limestone lenses and nodular bodies in both.

(4) An environmental similarity is displayed by the shales, stratigraphically overlying the laminar, corrugated and saccharoidal sandstones, as reflected in similar vertebrate fossil- and plant-bearing lenses, occurring in both outcrop localities.

(5) The conglomeratic, "pock-marked" horizon, present in the mountain flank, is represented in the anticlines by an evengrained, laminar, corrugated sandstone, containing angular fragments of opalescent black and white quartz pebbles.

It was only by consideration of these features and their relation to the origin of the anticlinal structure, that it was possible to link these two sandstone outcrops stratigraphically.

The evidence of the highly contorted structures observed, coupled with the obvious laminar corrugations (Plate III, ph. F), intimated intense deformation of a thin sandstone horizon in the midst of shales. However, in thin sections, the sandstone reveals no signs of intense deformation such as cracking, crushing, optical and mechanical
strain, or extensive recrystallization of the quartz grains. This sandstone therefore, occurs as a normal, unaltered sediment with somewhat sub-angular quartz grains, except for the aforementioned laminar corrugations along bedding-planes which appear as contortions in vertical section. (Plate III, ph. H.)

In the author's opinion, the anticlines acquired their present position and attitude, as a result of the incompetence of the surrounding shales. During the period of compression, the sandstone horizon was deformed into closed isoclinal, anticlinal folds. The shales overlying the sandstone moved away from the anticlinal crest in truly incompetent manner, thus giving the impression in outcrops, that the sandstone horizon moved actively upwards through the shale. This sandstone wedge, ultimately attained the anomalously higher stratigraphic position in places at the shale-tillite contact due to the plastic flow of the encompassing shales.

On closer examination of the "linear corrugation" so clearly displayed in these sandstone anticlines, it is found that:

1. they are not small dragfolds related to the main structures,
2. they do not conform to the normal attitude of a dragfold parallel to the anticlinal axis. In the southern sandstone anticline, the general strike of the fold axis is N60°W and although conforming to it to a certain extent, the linear corrugations tend to acquire a strike of N47°W on nearing the eastern boundary of the area. A more pronounced divergence exists between the strike of the anticlinal axes and that of the corrugations in the northern anticline. The discrepancy varies here from 80° to 20° and thus totally eliminates dragfolding as origin of the corrugations.

The total absence of any sign of intense deformation
in the quartz grains, shows that this linear structure, was produced in the sediment, prior to lithification.

Deformation in unconsolidated sediments has been ascribed to:

1. sliding on a slope;
2. compaction over any rigid body;
3. lateral movement through pressure of the overlying sediments;
4. thrust of surface agencies;
5. recrystallization.


Consider, however, in the case of:

1. a thin sandstone horizon lying on a thick succession of fine mud and overlain by a few feet, if any at all, of similar material
2. this succession being deposited on the slightly sloping, almost featureless continental shelf; according to Shepard: "the average slope is 4° for the first 2000 meters. Off large deltas, the slopes are gentle and smooth, averaging 1° to 2000m, but with numerous irregularities - due to slumping and pressing out of soft strata? - " (F.P. Shepard quoted by Ph. H. Kuenen, 1950, p. 155);
3. the absence of any major orogenic disturbances at this time.

The corrugations characteristic of the anticlines north of Soetendalsvlei, are most easily explained by a certain amount of sliding between the sand and mud horizons prior to lithification, because "a variety of structures due to sliding of soft muds has been recognized" (Ph. H. Kuenen, 1950, p. 241).

This would also explain the "pseudo-flow" structure featured on the bedding planes in outcrop, the prominence of which, is enhanced by weathering. (Plate III, ph. G.)

A marked similarity is displayed by the small "linear folds and tiny 'fault-scarps', of a few centimeters in height
and several meters in length" (R.R. Shrock, 1948, p.265) and the "linear folds" or "corrugations" in the anticlines. The corrugations are disposed "parallel to the strike of thinly laminated . . . . . . layers" and "are believed to have been formed as a result of slight down dip thrusting of a few laminae."

(Shrock, p.266). A photograph (Plate III, ph.H.) of a polished section across the strike of these corrugations in the sandstone is in close agreement with the features figured by Shrock, (1948, Fig. 230, p.266).

This submarine sliding on such a slight slope was probably triggered during the geosynclinal history, by earth-tremors, (Shepard, Kuenen, Emery, Shrock and Cuming) because "if hydroplastic sediments lying on a slope of a few degrees are suddenly jarred, as they would be during an earthquake, the internal cohesion of some parts is reduced and masses of the sediment slide down the slope usually only a short distance." (Shrock, 1948, footnote, p.265).

The banding of the laminar corrugated sandstone which is absent in the saccharoidal sandstone, indicates merely a facies change during the deposition of the sediments, resulting in alternating sandstone and thin silty layers.

(b) THE RELATIONSHIP OF THE LOCAL STRUCTURES AND THOSE IN RELATED REGIONS.

The southern range (Towerwaterpoort) forms part of the northern chain of the Cape Fold Belt and is situated almost at the termination of the complex fold range of the Swartberg, commencing in the Anyasberg and ending south of Willowmore. At its eastern termination (Suurbergpoort, Willowmore) the Swartberg is a simple anticline becoming structurally far more involved towards the west, but ending once again at its eastern extremity (Anyasberg) in another simple anticline.
MAP OF THE VONDELING AREA SHOWING

T. M. S.

BOKKEVELD

De Ploeg

Witloem
The Swartberg is part of the east-west trending flexures of the Fold Belt and the area of its syntaxis with the north-south trending flexures is in the vicinity of Worcester - Ceres. The east-west trending flexures, compose in the south-west, the Langeberg Range, which, broadening towards the east, into a compound anticline and building successively the Outeniqua, Tsitsikama, Langkloof and Kouga Ranges, runs parallel to the northern Great Swartberg fold range. The east-west ranges thus trend in a gently curved belt, at least 100 miles wide, from Worcester to the Fish River in the east. (Fig. 1.)

The overfolding at Towerwaterpoort, is characteristic, from Prince Albert eastwards, while in the south, the Swartberg Fault is the southern boundary of the range. Northward overfolding is of common occurrence in the Langkloof, the Bevisanskloof and other adjacent areas of the Cape Fold Belt.

The main structure of the Swartberg Range is a double anticlinal fold accompanied by minor folds. In Towerwaterpoort, the strike of the subsidiary folds, evidently parallel the axis of the main range and therefore in contrast to Meiringspoort, a section of a mountain side "is repeated in the rest" (E.H.L. Schwarz, 1903, p.74).

Isoclinal structure characterizes the eastern fold-ranges of the east-west trending flexures, and is evidenced at Towerwaterpoort, as throughout the Swartberg, by isoclinal, northward overfolded anticlines. (Plate I, ph.A.)

Indication is given at Towerwaterpoort (Plate V.) of divergence of the planes of crumpling, upwards, or "fanwise", as described by E.H.L. Schwarz at Meiringspoort (1903, p.81).

Neither the lower members of the T.M.S., nor the intensely folded Cango Beds, - (containing evidence of a Pre-Cape orogenic cycle) - are locally present.
DISTRIBUTION OF FOLD AXES AND FAULTS
Striking parallel to the Swartberg, trends the Witberg Range, the anticlinal structure of which, is continuous from Prince Albert to Steytlerville in the east, and is known eastwards, successively, as the Witteberg and Groot River Heights.

The structure of the Witberg and the succeeding eastern ranges, consists of northerly overfolded anticlines, giving rise to steep southerly dips.

The intermontane valley tends to widen eastwards and westwards of Vondeling, as the two ranges diverge. The Bokkeveld sandstone horizons in the Vondeling area are very poorly developed or totally absent as a result of their tendency to wedge out along the strike. This feature, in conjunction with the intense incompetent folding here, causes the structural attitude of the Bokkeveld to have certain characteristic features. The relatively thin sandstone horizons suffered a high degree of 'incompetent' folding, and as a result of the almost continuous vertical attitude of the beds, dip-slopes and 'hogback-ridges' are typically developed. Comparing the structural attitude of the Bokkeveld Series here with that in other areas, certain features are observed. In the Wuppertal and Ceres areas, the Bokkeveld Series is deformed into low, open folds, which, on weathering, give rise to low ridges and table topped hills (A.L. du Toit, 1954, p.251) (B. Swart, 1950, p.415). This attitude slowly changes in the Worcester, Touws River, Caledon, Bredasdorp and Swellendam areas, where gentle flexures occur, accompanied in certain localities, by steeply dipping beds. The Oudtshoorn, Willowmore, Langkloof and Bavianskloof areas again, are characterized by highly incompetent deformation of the Bokkeveld Series, accompanied by normal faulting with the downthrow side towards the south. The other members of the
Cape System display the same relation of difference in the amount of folding in the three areas. This feature can be due to:

1. more intense deforming compressive forces in the south-eastern fold-areas;
2. a longer application of the deforming forces in the south-east;
3. two totally different periods of orogenesis in the north-west and south-east.

The fact that the intensity of folding changes in the area of syntaxis seems to point to two different ages of orogenesis, or at least, a recurrent orogenic cycle in the south-east, which was absent in the north-west. The structural attitude of the shales is most easily determined through the presence of the resistant sandstone horizons, because of the tendency of the shales to weather into valleys or lowlands.

The shales possess a strong cleavage throughout and joints and quartz-veins are common. Everywhere, some of the joints significantly show the same relation to the folding as described for the Vondeling area and evidently originated during the orogenesis of the Fold Belt.

The Second Bokkeveld Sandstone horizon is characteristically, intensely folded, up to where the Klaarstroom - Willowmore road crosses it, 10 miles to the east and 16 miles to the west of Vondeling. According to the amount of weathering, one or two ranges, composed of sandstone, occur.

The highly incompetently folded succession of Lower Witteberg sandstone horizons (Plate I, ph. F.), north of the Klaarstroom road, is a structural feature common in the inter-montane valley, on either side of the mapped area, for at least 20 miles eastwards and 14 miles westwards of Vondeling.
North of the Witteberg Range, the relation between topography and structural deformation, as evidenced by the white marker horizon at Soetendalspoort, is continued east-, and westwards. "Sandstone dikes" and incompletely filled fissures, seem to be a common feature of the Beaufort-West - Prince Albert areas. Here "sandstone dikes" vary in thickness between 2 to 8 inches and cutting across the bedding of the surrounding sediments from north to south, attain lengths of 4 miles. (P.J. Rossouw and J. de Villiers, 1953, p.20). In outward appearance they closely parallel the occurrences south of Soetendalsvlei. The former have a "green-gray colour", consist of "angular, unsorted grains of quartz, plagioclase and chalcedony in a fine grained ground-mass of micaceous and sandy material", show a "tendency to weather into flat slabs" and "fill tension-fissures which probably resulted from regional deformation of the area". Their origin is ascribed to "shearing caused by earthquakes" and intrusion of the dike material under pressure from the underlying formations.

The two anticlines, composed of the laminar, corrugated sandstone, continue eastwards almost up to Aasvogelberg. Similar, so-called "intrusive sandstone", occurs in the Eastern Province (E.D. Mount, 1945, p.23) but on a much smaller scale.

The "Tygerberg Anticline" near Prince Albert has already been the object of controversy (E.H.L. Schwarz, 1903; C. Sandberg, 1906; A.W. Rogers, 1908). According to Schwarz: "The Witteberg quartzites occur in a narrow anticline, which has, as it were, been forced through the Dwyka conglomerate, the latter rock forming 'jaws' through which the more adaptable quartzite has been squeezed, just as lead may be forced between the jaws of a vice" and instead of the normal succession of shales between the Dwyka tillite and the Witteberg Series "at this place...the conglomerate rests
directly on the main quartzites." (1903, p. 91).

The significant agreement between the "Tygerberg Anticline" and the two anticlines north of Soetendaalsvlei in the form of:

(1) outward appearance,
(2) the apparent stratigraphic hiatus, seems to indicate a similar mode of formation for both. Therefore doubt is expressed as to the "squeezing" of the "Tygerberg Anticline" through the overlying beds. Could it not have acquired its present aberrant position in a similar way as described for the laminar corrugated anticlines?

To the north, structural deformation soon diminishes in the massive horizontally bedded Karroo sediments.

In conformity with the rule, that, on the deformation of a geosynclinal trough, the profile is usually asymmetric, with the deepest part nearest to the upward moving "continental segment" (A.C. Lawson, 1927, p.260); according to A.L. du Toit (1954, p.265), it is only in the southern area of the Karroo Geosyncline, that a maximum thickness of sedimentation had been attained. Apparently, the Cape Fold Range, is the former 'ge-anticlinal highland', with its adjacent basin of depression, the Karroo Geosyncline. (Fig. 16).

The sediments were deformed during the cycle of orogeny, which was initiated in Lower Beaufort Time. This does not necessarily imply a single phase of deformation, since "orogenies are not confined to a single short burst of orogenic activity....but several active phases of mountain building occur during a rather long period of general tectonic unrest." (L.M.R. Rutten, 1949, p.1769). The same condition, in the form of four pulses, is evidenced here, and has been discussed in detail by J. de Villiers (1944, p.202)
and by I.C. Rust (unpublished thesis). Prior to the orogeny of Lower Beaufort Time, there is no evidence, from the initiation of deposition of the T.M.S., of any diastrophic movements, either at Vondeling or elsewhere in the southern Cape. Accepting this aspect of du Toit's research on continental drifting, the "Cape Geosyncline" is considered as a part of the late Palaeozoic "Samfrau Geosyncline", which formed the "southern" margin of Gondwanaland during Silurian Time. (A.L. du Toit, 1937, p.62). It was as such an east-west "trough" or "fossa" which received its sediments from a northern cratonic highland (Fig. 16 (a)), in accordance with the: "high continental margin bordering a shallow sea, the two regions being in isostatic balance, the degradation of the land determines a negative load, which will be compensated by the transfer of mass from beneath the sea to beneath the land. The latter will accordingly rise and the sea-floor will be depressed. The depression will inaugurate a geosyncline which... tends to fill-up". (A.C. Lawson, 1927, p.272). The deposits of the "Cape Geosyncline" (the Cape System) are represented by typical, continental-shelf sediments, which attained a maximum thickness of 10,000 ft in the pre-Dwyka time. A slight orogenic pulse, originating from the north-west at this time, was the first deformational phase, but only in Beaufort-Time, was intense deformation of these sediments initiated, in the southern Cape. The later, Molteno-Time orogeny, was a period of very intense deformation in the south-eastern Cape, which did not notably affect the western-s-western portions of the Fold Belt. (J. de Villiers, 1944; A.L. du Toit, 1954; F.G. Söhnge, 1934). The difference in intensity of folding, as found in the south-east, south-west and north-west with its included area of syntaxis, is explicable on this basis. Thus, in conformity with: "the long established orogenic law, that great ranges are built
A. SILURIAN TO DEVONIAN

SECTION THROUGH "SAMFRAU GEOSYNCLINE"

Initiation of "basining" causing the shallow "Cape Geosyncline" (embayed continental shelf)

B. CARBONIFEROUS TO LOWER BEAUFORT

Mild unilateral orogenic deformation of "Cape Geosyncline" accompanied by northward migration of "basining" effect and initiation of the Karroo Geosyncline

C. BEAUFORT TO EARLY STORMBERG

Epeirogenesis accompanied by orogenesis giving rise to geanticlinal highland in the south which supplied the detritus for the infilling of the Karroo geosynclinal basin

FIG. 16 (a, b, c). Showing the successive stages in the evolution of the "Cape and Karroo Geosynclines" from Silurian to early Stormberg-Time.
out of geosynclines laden with excessive sedimentation at continental borders" (A.C. Lawson, p.257) the initiation of the "Swartberg Range" resulted. It is difficult and quite unsatisfactory, to date these pulses, according to the global, orogenic phases outlined by Joly (1925), Stille (1924, '40), Umbgrove (1942) and (L.M.R. Rutten, 1949, p.1763), because "times of orogeny in the one continent do not correspond to times of orogeny in the other" (R.C. Moore, 1936, p.1305).

This is especially true, when the orogenic phases of the northern and southern hemi-spheres are compared. The successive orogenic pulses that deformed the former Cape Geosyncline, thus belong initially to the Hercynian or Variscan (Carboniferous) movements and terminate in the Neokimmeric during Jurassic Time. (L.M.R. Rutten, 1949, pp. 1757-1766).

The main deforming force, as common in the Fold Range and also locally, seems to have been the result of "pressures that came from the south", (A.L. du Toit quoted by J. de Villiers, 1944, p.196) evidenced by the east-west trend of most of the plications of the Swartberg and the other deformed units. The southward axial concavity in the Cape Fold ranges (the Swartberg included) is described by J. de Villiers as being due to:

"the expression of the folding was influenced... by the granite massifs which formed rigid nuclei... around which the arcs of the folds wrapped themselves." (1944, p.205).

Further evidence of the direction of the deforming agency is the northward overfolding, clearly displayed locally and throughout the area. It was either a force moving northwards that caused the tectonism of the "Swartberg Range", or under-thrusting directed southwards. The latter force is only applicable if the theory of overfolding at geosynclinal margins, as advocated by A.C. Lawson (1927), is accepted.

This theory has been mentioned and considered by J. de Villiers (1944, p.205) but no proof of any thrust-faulting either in
the Vondeling area or elsewhere in the Fold Range has been found as yet, and thus, the latter theory seems locally, to be untenable. In accordance with the case at hand, where the Bokkeveld shales are infolded under the massive 5000' T.M.S. unit, consisting of relatively more immobile sandstone units, is the impossibility in the Appalachians "that the weak Ordovician shales should have forced themselves downward into regions of greater strain and pushed aside the massive Cambrian quartzites". (A. Keith, 1923, p.337).

The extensive normal strike-faulting of Mid-Cretaceous Time resulted locally, in the Swartberg- and the parallel-trending Langeberg-fault. These faults occupy positions parallel to the major assymetric anticlines, due south of their crests. Evidently, the relief of excessive compression took place in these loci. The cause of the tensional stress, is generally ascribed to southward tension, on the fracturing of Gondwanaland, which reached its maximum development, off the southern coast of Africa during Mid-Cretaceous Time.
CHAPTER V.

(a) MEASUREMENTS OF STRUCTURAL DEFORMATION FEATURES.

It will be attempted to determine:

(i) the crustal shortening within the northern-most range of the Cape Fold Belt, i.e. the Swartberg Range,
(ii) the depth of deformation,
(iii) the amount of isostatic balance in existence between the southern highland and the northern basin of depression.

A structural section true to scale was constructed (Plate V.). Due to a high amount of asymmetry and plastic flow, it was found impossible to reconstruct the folding everywhere, according to the procedure outlined by Busk (H. G. Busk, 1929), and recourse was made to free-hand drawing.

Correct determination of the structure, involved a geological survey of that a two-mile wide strip be mapped, across the strike of the entire Cape System outcrop.

(1) Crustal shortening:

Crustal shortening has been widely studied and applied to different fold ranges. (A. Heim in the Alps, Le Conte in the Coast Ranges of California, Claypole in the Appalachians of Pennsylvania, etc.) A remarkable variation in the various values for the transverse shortening during deformation - up to 74 miles in the Alps - was found.

Certain rules have to be applied when computing crustal shortening. The most important are:

(1) "As far as practicable, the same formation should be measured throughout a section.

(2) The strongest formations available, should be selected for measurement.
(3) From the places where the strong formations plunge below the surface, to places where they reappear, only the most gentle curves should be assumed.

(4) From places, where the formation which is being measured is lost, because removed by erosion, only the most gentle practicable curves should be assumed, to the places where the formation reappears. (C. R. van Hise, 1898, pp.22 - 24.)

Adhering to these rules, and with a scaling wheel, the amount of shortening involved, from Strydomsvlei to Towerwaterpoort, was determined. The results were substituted in the formula \(100 - \frac{b}{a} \times 100\) "which indicates the amount of shortening in \(\%\), where "the distance "a", is between two points along the bedding" and "the present horizontal distance between the two end points = "b"" (E. Cloos, 1940, p.849.).

The 'percentage shortening', was firstly determined for six individual distances of a mile, and secondly for the total main cross-section (Plate V) and the measurement for both, was conducted along the following datum - lines:

(1) The Main T.M. Sandstone - Upper Shale contact, from the northernmost fault plane, to a position approximately vertically below the Second Bokkeveld Sandstone horizon. This was chosen because the upper boundary of the competent Main T.M.S. could be fairly accurately reconstructed.

(2) The Second Bokkeveld Sandstone horizon, from the same but stratigraphically higher position on the fold limb, where the previous measurement terminated; because, from here the structural deformation of the Main T.M.S. datum - line could only be approximately reconstructed.

(3) The O.R.S. - horizon from the Klaarstroom-road, up to the Witberg flank, was chosen because this competent sandstone horizon was the most common marker horizon in outcrop up to
(4) The upper boundary of the Main Witteberg Series (the white marker horizon) from the Witberg flank up to Strydomsvlei, because it was the conspicuous upper boundary of a competent sandstone unit, outcropping extensively.

Each of the six, individual mile-long sections, was chosen for specific reasons.

In the Swartberg section, reaching from the northern-most fault-plane, to the northern flank of the range, and the foothill region from the T.M.S. - tillite to the Second Bokkeveld Sandstone outcrop, it was attempted to determine the amount of shortening, as evidenced in the main anticlinal region of the cross-section.

The Lower Witteberg region was investigated only along areas where the bedrock was exposed, or where the marker horizons outcropped.

The Main Witteberg region was investigated from the offset in the northern range southwards, in order to determine the shortening caused by the main anticlinal folding of the Witteberg Series.

The one-mile section, from the road to Traka P.O., to approximately the Traka River, was investigated to determine the shortening involved in the synclinal trough of Ecca.

The other important reason, for the choice of the specific sections, was to see to what extent, the competent and incompetent units were individually shortened, and to compare their individual percentage of shortening.

In the lowland from Spekboomrant to the Klaarstroom
road, the alluvial plain, at the confluence of the Traka and Vandereys Rivers, the main anticlinal arch of the Witberg, the synclinal trough at Soetendarlvlei, and the two highly incompetently folded anticlines north of Soetendarlvlei, where the marker horizons did not outcrop (being either covered in alluvium or totally eroded), only very simple folding was postulated.

Throughout the sections along which the crustal deformation could be measured only the most competent horizons were employed as datum-lines and only regions where the structure was above suspicion, were considered. Whenever an off-set was made to a new datum line, care was taken, to resume as far as possible at the same, but stratigraphically higher position on the fold limb or crest.

The measurements were mostly conducted as near the surface as possible, because, the farther upward, or downward, from the recorded data, the folds were projected, the greater the possible error, for measuring the 'shortening' became.

The effect of the various other factors, which may influence crustal shortening, such as: gliding on the limbs of the folds, the opening of fissures, the amount of mashing etc., was considered irrelevant in the Vondeling area.

Each section, was measured at least three times and the mean value taken. The three measurements did not differ by more than 1%, and the mean representative value is therefore fairly accurate.

Even when measurements were conducted along other horizons in some sections, instead of along datum lines, the values obtained for the shortening, did not differ from the obtained values by more than 5%.

Thus the 'percentage shortening', represents a fairly accurate minimum value.
The shortening will not vary appreciably along the strike of the folds over a distance of two miles and therefore, the accuracy of the values obtained for the separate areas, was compared with the percentage shortening obtained from additional sections parallel to the main cross-section.

The results are presented in Table 6.
TABLE 6.

Percentage shortening over various sections.

<table>
<thead>
<tr>
<th>Section</th>
<th>Distance</th>
<th>% Shortening</th>
<th>Mean</th>
<th>Total Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Swartberg Range</td>
<td>1 Mile</td>
<td>55%</td>
<td>49%</td>
<td></td>
</tr>
<tr>
<td>T.M.S. - tillite horizon to Second Bokkeveld Sandstone</td>
<td>1 Mile</td>
<td>43%</td>
<td>+ 47%</td>
<td></td>
</tr>
<tr>
<td>Swartberg &amp; foothills up to 2nd Bokkeveld Sandstone (parallel to main section and east of it)</td>
<td>2 Miles</td>
<td>43%</td>
<td>44.5%</td>
<td></td>
</tr>
<tr>
<td>The same but west of main section.</td>
<td>2 Miles</td>
<td>46%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower W.B., from Klaarstroom road to approx. confluence of Traka and Vandereyrs Rivers.</td>
<td>1 Mile</td>
<td>22%</td>
<td>22.5%</td>
<td></td>
</tr>
<tr>
<td>Lower W.B., from approx. confluence of Traka and Vandereyrs Rivers to southern flank of Witberg.</td>
<td>1 Mile</td>
<td>23%</td>
<td>+ 21%</td>
<td></td>
</tr>
<tr>
<td>Lower W.B., from Klaarstroom road to southern flank of Witberg. (parallel to main section).</td>
<td>2 Miles</td>
<td>19%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>Witberg Range from approx. middle of synclinal valley to northern offset.</td>
<td>1 Mile</td>
<td>35%</td>
<td>35%</td>
<td>32%</td>
</tr>
<tr>
<td>Witberg from southern to northern flank (parallel to main section).</td>
<td>1 1/2 Miles</td>
<td>29%</td>
<td>29%</td>
<td></td>
</tr>
<tr>
<td>Synclinal trough of infolded Ecca from road to Traka P.O., to approx. bed of Traka River.</td>
<td>1 Mile</td>
<td>19%</td>
<td>19%</td>
<td>+ 20%</td>
</tr>
<tr>
<td>Synclinal trough north of Witberg (parallel section)</td>
<td>2 Miles</td>
<td>20%</td>
<td>20%</td>
<td></td>
</tr>
</tbody>
</table>
A marked difference is displayed in the percentage shortening of the various mile sections.

The relatively high 'percentage shortening', evident in the Swartberg and the Witberg, in contrast to other regions, is caused by the larger amplitude of the folds composed of more competent beds.

The agreement between the values obtained for the two separate miles in the Lower W.B. out-crop area (* - *), displays the similarity of deformation this area had suffered.

The anomalously low value of the synclinal trough in relation to the folds of similar amplitude, can be explained by the even reconstruction of the synclinal shape as required by van Hise’s laws. Characteristically, this structure would be accompanied by subordinate incompetent folds, especially here, where there are alternating shale and sandstone units. A more realistic reconstruction of this synclinorium, with accompanying, incompetent subordinate folds, over a distance of two miles, gave a value of 36% for the shortening involved. In the author's opinion this value is far more realistic than the value given in table 6.

Comparing the 'percentage shortening' of the different one mile sections, in the main section, with the 'percentage shortening' of the parallel trending, two mile sections, the most notable feature that emerges, is the close agreement of the values for the sections where the folds have a relatively small amplitude. In the Swartberg and Witberg, where the amplitude is larger, a correspondingly increased inaccuracy accompanies the reconstruction of the folds. The result is the varied percentage of shortening obtained for the parallel sections.

The average of these determinations, should however, be a fairly accurate value for the 'percentage shortening'
The percentage shortening of the main structural section, from the Swartberg fault to Strydomsvlei is 29.0%. This amounts to a shortening of about 4 miles over a measured distance of 13.5 miles. Before the orogenesis of the Cape Fold Belt therefore, the undeformed sedimentary beds along this section had a length of 17.5 miles.

A.L. du Toit (1937, p.86) states: "the Indian Ocean does not mark the southern limit of the Zwartberg foldings, which limit must be situated much further south – beyond the Agulhas Bank maybe." The total width from the northern extremity of the Swartberg range to the edge of the continental shelf is approximately 200 miles. A north-south shortening of 30% over this distance means that originally, the undeformed Cape System had a N-S width of ± 260 miles.

Accepting du Toit's theory of continental drift, the supposed propagation of the Cape Foldings in eastern Argentina, attains a width of 140 miles and in the Falklands of 125 miles. (A.L. du Toit, 1937, p.87). If the crustal shortening in this area also amounted to 30%, the original width of the deposit must have been at least 190 miles.

In conformity with the above the total shortening of the Cape Fold Belt would therefore vary between 40 and 60 miles.

In all the above calculations, only the horizontal component of the folding has been considered.

Table 6. clearly shows a much larger value for the 'percentage shortening' of shorter sections, than the value obtained for the entire main cross-section. Even the total average of the shorter sections (±32%), is in excess of the latter value. This corresponds with what E. Cloos and A. Heim found in the anthracite area of eastern Pennsylvania
and the Jura Mountains, respectively. Their explanation is: "Longer sections show lower value, since local and very intense disturbances are compensated by broad anticlines and synclines." (E. Cloos, 1940, p.849)

(ii) Depth of folding:

The average elevation of the Cape System unit, due to the folding, could naturally not be determined accurately, because erosion of the unit had already been initiated in Lower Molteno Time.

Therefore:

(1) the Swartberg anticline, up to the upper boundary of the Main Witteberg, was reconstructed;

(2) the total thickness of the T.M.S. involved in the folding was taken to be 5000'.

From the completed anticline (Plate V) a fairly accurate estimate of the average thickening of the Cape System, due to the folding, could be determined. As widely accepted and advocated (J. de Villiers and A.L. du Toit), the uplift or 'mountain-building', that caused the present-day mountain chain of the Fold Belt, originated during the orogeny of the Cape System. The average uplift is therefore directly related to the thickening of the crust.

The value obtained for three separate sections, varied between 17,000' and 13,000'. A mean value of 15,000' for the elevation, and the amount of crustal shortening, were used, to determine the "average thickness of the folded shell by means of the equation:

\[ l \cdot u = s \cdot d \]

where \( l \) equals the present length of the section; \( u \) equals
the amount of uplift; s equals the amount of shortening
the section has suffered; d equals the unknown thickness (W. Bucher, 1933, p.153), or depth of folding. Therefore:

\[ d = \frac{1}{s} \times \frac{13.54 \times 2.84}{3.913} = 9.8 \text{ miles}. \]

The local, minimum, depth of folding, according to W. Bucher's method, appears to be approximately 10 miles, which is well within the depth range of 13.2 miles, for the Appalachians (W. Bucher, 1933, p.153).

R.T. Chamberlain (1910, p.244) used the same equation in his computation of the depth of folding attained in the Appalachians, but he determined the depth of folding, for six separate sections, and described the significance and variability of the wrinkled shell of each section separately.

Buchner disagreed with this procedure, and, using results obtained by Bailey Willis in one of his compression box experiments (1891, p.232), he proved that by determining the depth of folding for the whole section a far more accurate value could be obtained (1933, pp. 153 - 154).

It still remains an open question however, as to which of the methods, as outlined by Bucher or Chamberlain, is the better, because M.K. Hubbert (1945, p.1652) cast grave doubts on the acceptability of the results. Bailey Willis attained in his 'compression box' experiments.

The total length of section, over which Chamberlain computed his values, is in the vicinity of 66 miles. The length of the Vondeling section is altogether 13 miles, and because the depth of folding did not vary much over this short distance, the results the author obtained, on applying Chamberlain's method, were irrelevant.
(b) ELEMENTS BEARING ON THE THEORY OF ISOSTATIC ADJUSTMENT.
(Time interval - Lower Beaufort to Post-Molteno).

The theory of isostasy is so well known, that the concept needs no detailed reference, except that it is a process by which: "If over sufficiently large areas there be a superficial shift of load, the disturbance of crustal balance caused thereby will be compensated by transfer of mass in depth from the loaded to the unloaded region."

(A.C. Dawson, 1927, p.257).

This compensation of crustal balance, causes the development of a depression, in the area receiving sediment, and a corresponding rise in the provenance region. Therefore "geanticlinal belts border the outer sides of geosynclines, and, as indicated by the characteristics and thickness of deposits in the geosynclines, are inferred to have been repeatedly and sometimes strongly, elevated so that they supplied most of the sediments of the geosynclines."

(R.C. Moore, 1936, p.1808). The factors controlling the relation between the total thickness of sediments received and the total uplift or depth of folding, at a certain time, are:

(i) the shape and size of the basin receiving the sediments in relation to the upfolded tract,
(ii) the mass (and S.G.) of the 'provenance rock', in contrast to the mass (and S.G.) of the sediments deposited in the geosynclinal basin,
(iii) the degree of isostatic balance obtaining,
(iv) the amount by which the mass of geosynclinal sediments may have been altered by sub-crustal movements or deformation,
(v) to what aerial extent, a downwarping of a uniform nature existed throughout the basin.

As widely accepted and advocated (J. de Villiers
and A.L. du Toit), the uplift or mountain building, that helped to cause the present-day mountain chain of the Fold Belt, originated during the orogeny of the Cape System.

Before the theory of isostasy can be applied to the southern geanticlinal highland in relation to the Karroo geosyncline at Pre-Red Bed Time, the following features have to be considered. The total vertical thickness of material eroded from the Fold Belt, need not be equal to the maximum thickness of sediment deposited in the Karroo geosyncline.

The Karroo sediments for instance, deposited in a relatively shallow basin throughout, were nevertheless, in isostatic balance with, the thick, though linear geanticlinal provenance region, because the basin of deposition, occupied a much larger surface area than the geanticlinal provenance. Only by coincidence will the maximum thickness of the sediment deposited, and that of the rock eroded, be equal.

Furthermore, the total maximum thickness of the Karroo System - 35,000 - (A.L. du Toit, 1954, p.267) was probably never attained in any one particular place, because "the maximum thickness of the Molteno Stage - - - 2200' - - - was attained not far south of the present erosion scarp."

(I.C. Rust, 1960) The Molteno Stage, was moreover, never deposited in the south where the geosyncline attained its maximum depth. At Pre-Red Bed Time thus, a maximum of 26,000' of sediments (Dwyka, Ecca and Beaufort) had accumulated in the southern portion of the geosyncline. It is of no value therefore, in the determination of isostatic relationships, to compare the "maximum" thickness of the Karroo sediments (35,000'), with the amount of uplift in the geanticlinal area. The occurrence of Witteberg sandstone pebbles in the Molteno Stage, seems to indicate that in the
south, during Molteno Time, the erosion of the Fold Belt had progressed to such an extent, that an appreciable amount of the Witteberg Series had been eroded. It is considered, that a reasonable estimate of the 'vertical thickness' of rock eroded from the geanticlinal highland at close of Molteno Time, would be less than the total thickness of the Witteberg Series. This value (1500') is only considered for the Vondeling area (Fig. 17, A - B). Logically, it could never have been similar over the entire Fold Range region. In some places, denudation had most probably not yet reached the Witteberg Series, while in other areas the Bokkeveld or even the T.M.S. may have already been exposed.

![Diagram](https://scholar.sun.ac.za)

FIG. 17. Thickness of provenance region drawn against the basin of sedimentation at end of Molteno Time (vert. scale 4 x hor. scale).

The erosion of the Witteberg was preceded by the removal of all overlying rock, but to what thickness the since eroded Dwyka, Ecca and Beaufort Series, covered the deformed Cape System beds, is an open question. It is considered that the thickness of this 'cover' had a value roughly 1/3 of the total thickness of sediments concerned. It is thought that this value (18700'), would represent a realistic value of the thickness of the Karroo sediments which covered the Witteberg, because the geosynclinal basin is considered to have had its southern boundary, roughly, near
the middle of the present-day Fold Belt, and the different sedimentary units therefore, probably wedged out abruptly, southwards.

From the reconstructed anticline (Plate V), and accepting the postulated erosion of 1500', it can be seen that a 14,000' (2) block of deformed Cape System rock (Bv. and T.M.S.) in the Swartberg area, had yet to be denuded, after deposition of the Molteno.

In the Vondeling area (Fig. 17, A - B), erosion seems therefore, to have removed a total thickness of 10,000' by Pre-Red Bed Time. This value is the sum total of the erosion postulated for the Karroo System \( \frac{1}{3} \) total \( (1500') \) plus the Witteberg (1500') at this time. A similar column of rock may have been eroded in other parts of the Fold Range. This vertical thickness of eroded sediments was determined by:

(i) Intensity of erosion throughout the folded provenance region.
(ii) Variation in the depth of the geosyncline along its southern margin.
(iii) The position of the southern boundary of the geosynclinal basin of deposition.
(iv) Variation in intensity of mountain building throughout the geanticlinal highland.

It would however be wrong to compare the maximum amount (26,000') of Karroo sediments accumulated in the geosyncline with the thickness sediment removed by erosion in the Vondeling area up to the end of Molteno Time. The amount of rock eroded in the 'area of maximum height' plus that derived from other sources is the value to be used, if any comparison at all is to be made with the maximum thickness of sediments deposited in the Karroo Geosyncline.

As a result of the deformation, the Cape System was
thickened by \( \frac{1}{2} \), from a normal stratigraphic thickness of 10,000', to 15,000' in the Vondeling area. (Plate V)

Although no record of any diastrophic movements can be found in the southern Fold Belt, in the form of sedimentary material or unconformable relationships, it does not necessarily exclude the possibility that at the time of the "Cedarberg Foldings" (A.L. du Toit, 1954, p.569) sub-aqueous movements had been initiated in the south. The Orogenesis of Lower Beaufort Time is of course proven by "the pebble-beds of the East London area." (A.L. du Toit quoted by J. de Villiers, 1944, p.195).

The time interval from Post-Witteberg to Pre-Red Beds is approximately 75 million years, whereas that from Early Beaufort to Pre-Red Beds it is \( \frac{1}{2} \)25 million years. (A.L. du Toit, 1954, p.25). The tempo of movement vertically was 10,000' in 25 million years (i.e. \( \frac{400'}{\text{million years}} \)). This also signifies that the tempo of erosion was 400' in a million years, or \( \frac{400'}{1000 \text{ years}} \).

It must however be remembered that the deformation of the Fold Belt resulted from a succession of pulsations and therefore 400' need not necessarily have been the erosion every million years. Sometimes this value was most probably twice the amount, or even more!!

From the end of Molteno Time to the present day \( \frac{9000'}{\text{(i.e. 19,000' - 10,000')}} \) have been stripped. (Plate V). Therefore a mean value for the erosion in the Vondeling area from Early Beaufort Time to the present day, amounts thus to approximately 19,000'.

Investigations on the possibility of isostatic balance being in existence during Post-Molteno Time, can only be carried out, if a clear picture can be presented of
the subcrustal isostatic movements in the sialic and simatic layers during the geosynclinal-geanticlinal phase.

It is rather uncertain whether isostatic balance existed between the basin of deposition and the Fold Belt during Post-Molteno Time, in view of the fact that the enormous outpouring of andesitic lavas ended the geosynclinal phase. It seems more logical to postulate 'isostatic balance' for Post-Stormberg Time.

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(c) CONCLUSIONS:

The fossiliferous nature of both the Upper Shale and Sandstone horizons of the T.M.S. and the absence of any fossil remains in lower Bokkeveld beds, point to a marked difference between conditions present during deposition of these units as compared with those in the Western Province. The fossiliferous remains found, are indicative of the fairly shallow water of a continental shelf.

It seems furthermore, from the results obtained on investigating heavy mineral frequencies, that the lower boundary of the W.B. Series can be clearly delimited by means of a sudden brookite affluence.

In the Vondeling area as common east of Karroo Poort, the normal gradual transition from W.B. Series to Dwyka Series without the least indication of any unconformable relationship, exists. Mapped by the Geological Survey as Upper Witteberg, the presence of fossil fish (e.g. Holuridae, Platysomidae - Prof. J.P. Lehman) is an indication of its relation with the Upper Dwyka Shales. It seems evident therefore that the earlier denomination of "Lower Dwyka Shales" (A.L. du Toit, 1954, p.269) - for at least most of the
unit - is more correct and that this unit should be grouped with the Karroo System.

Two of the fish species (Holuroidae, Platysomidae) have been identified as belonging to the Mississippian epoch of Europe - written communication from Prof. J.P. Lehman of the Mus. Nation. Hist. Natur., Paris - thereby dating these "Upper Witteberg" beds as Lower Carboniferous. This is clear proof that the beds in which these fossils are found, belong to the Permo-Carboniferous succession of the Karroo System.

The presence of pre-consolidation sliding, indicative of earthquake movements is to be expected during the formation of a geosyncline and is as such a clear indication of the adjustment of isostatic balance between the basin, receiving sedimentary material, and the provenance, supplying the sediments.

Although there exists a close similarity between the Cape Fold Belt and most of the great mountain chains of the world, this correspondence is especially true of the folded Appalachians, because the manifestations as to its birth and origin as displayed in its structural deformation and attitude, are in close correspondence with that of the Cape Fold Belt.

For the measured length of 13.5 miles the crustal shortening of the Cape System in the Vondeling area attained 4 miles. An estimate of the shortening of the total width of the folded Cape System sediments before the supposed breakaway of Gondwana, gives a shortening varying from 40 - 60 miles. The total depth of folding of the Cape System attained a value of approximately 10 miles.

These values can be compared with those of most of
the great fold ranges of the world and indicate furthermore a medium intensity in the deformation of the Cape Fold Belt.

The average rate of erosion in the area, where the Cape Fold Range attained a maximum development, was approximately 10,000', from Lower Beaufort to End-Molteno Time, and in the Vondeling area, the erosion approximates 19,000' from Lower Beaufort Time to the present day.

In order to understand the orogeny of the Fold Belt clearly it becomes a necessity to know:

(i) to what maximum depth the crust was deformed,
(ii) where this maximum deformation took place,
(iii) whether some of the folded portions descended in depth into the zone of plastic deformation or quasi-flowage?

All these questions can only be answered, if a section true to scale, is drawn across the entire width of the Fold Belt and Chamberlain's method in the determination of the depth of folding be applied.

Seeing that "the crumpling in the coastal belt reached its maximum development approximately along the 24th meridian" (A.L. du Toit, 1920, p.37), which lies 250 miles east of Vondeling, it will only be possible to present an accurate picture of the deformation after a succession of profiles similar to the one at Vondeling have been drawn. In this manner, the relative increase or decrease of the structural deformation, eastwards or westwards of Vondeling, (in accordance with similar investigations done in the Appalachian fold region (E. Cloos, 1940, pp. 845 - 872), will be clearly envisaged.

These profiles across the Swartberg can also be used to reconstruct the topographic surface of the range and the actual attitude of this surface attained, during the successive
stages in its development.

Only then, by means of this altitude of a pre-
determined block of the geanticlinal highland and with
application of all the other information on rock-density,
sub-crustal layers, thermal gradient, etc., will it be
possible, to determine a worthwhile approximation of the
isostatic balance in existence, between the Fold Belt and
the Geosynclinal Basin, during the successive deformational
stages.
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PLATE I

PHOTO A. Towerwaterpoort; steep, southerly dipping, isoclinally folded Main T.M.S, with almost featureless plain in background, built partly of Enon Conglomerate and contorted Bokkeveld.

PHOTO B. Swartberg fault-line scarp with coarse fault-breccia of Main T.M.S. in foreground. Left, in middle distance, are grotesquely weathered hills of red Enon Conglomerate on the downthrow side of the fault.

PHOTO C. Northward overfolded Main T.M.S, with T.M.S, Tillite horizon in foreground and two parallel trending ridges at left built successively by Upper Sandstone of T.M.S, and First Sandstone horizon of the Bokkeveld.

PHOTO D. Flow cleavage (dipping to the left) and fracture cleavage (dipping to the right) in the T.M.S, Tillite horizon.

PHOTO E. View looking south: in far distance Cuteniqua-Tsitsikamma Range, in the near background the Swartberg Range with Towerwaterpoort, in the foreground the inter-montane valley (Lower W.B. and Bv.), in the near foreground the Witberg Range.

PHOTO F. Close (isoclinally), northward over-folding in O.R.S.-horizon, typical in the Lower W.B. outcrop area south of the Witberg Range.

PHOTO G. Soetendalspoort; vertical dipping Main W.B. Sandstone in southern range of the Witberg. Valley to the left has synclinal structure.

PHOTO H. Tillite plains to the north of Soetendalspoort out through Main W.B. Sandstone (view looking south). Conspicuously developed flatirons appear to the left of the poort.
PLATE II

PHOTO A. First Upper Shale of T.M.S. containing fossil crinoid imprints.

PHOTO B. Sample of T.M.S. Tillite horizon with jasper (arrow) and shale (above 3") erratics.

PHOTO C. Upper Sandstone of T.M.S. containing fossil imprints of Derbyina whitiorum.

PHOTO D. Lycopod imprints in Main W.B. Sandstone (Witberg Range).

PHOTO E. Highly fossiliferous O.R.S.-horizon (marker) covered by imprints of Spirophyton and problematical "wheel-like" impressions (latter indicated).

PHOTO F. Perfect "flower-type" Spirophyton impressions. (See Fig. 5.)

PHOTO G. Spirophyton displaying a single, radial, vortex-like figure (6" diameter).

PHOTO H. Interference ripple-mark on B.S.-horizon in Third Shale of Bokkeveld Series.
PLATE III


PHOTO B.  Ridge with synclinal structure (W.S₁-horizon) in foreground; Lower W.B. outcrop-area in middle distance; Swartberg Range far background.

PHOTO C.  Witberg Range; termination of valley with synclinal structure. Note minor anticline and synclines in the center. In foreground the conspicuous weathering of the White marker horizon of the Main W.B. appears.

PHOTO D.  As result of accelerated weathering along strike joints, a valley has developed on an anticlinal crest. The W.S₁-horizon (Lower W.B.) crops out between two ranges built by Main W.B. (Witberg Range).

PHOTO E.  Ridge-like outcrop of saccharoid sandstone with anticlinal structure and laminar corrugations, in direct contact with Dwyka tillite (right foreground).

PHOTO F.  Northward recumbent anticline in saccharoid sandstone ("Upper W.B." beds). Note laminar corrugations!

PHOTO G.  Laminar corrugated sandstone, containing quartz pebbles and displaying "pseudo-flow" structures on bedding planes.

PHOTO H.  Cross-section of laminar corrugated sandstone.
PHOTO A. Bare ridge-like outcrop of coarse unbedded T.M.S. tillite (west flank of Towerwaterpoort.)

PHOTO B. Highly folded sandstone horizons of Main Witteberg showing rib-like outcrop of these resistant beds. (Witberg Range).

PHOTO C. "Grit-lenses", striking almost perpendicular to the normal bedding which can be seen in the foreground and left background.

PHOTO D. Almost horizontal attitude of black shales of "Upper Witteberg" beds (south of Strydomsvlei.)

PHOTO E. Cast of Lycopod stem in Main W.B. (Witberg Range) exceeding 18" in length.

PHOTOS F & G. Fossil casts of two different Lycopod imprints in Main W.B. beds.

PHOTOS H & I. "Shell" and "seed" imprints characteristic of the Lower W.B. Sandstone horizons.

PHOTOS J & K. Lycopod (?) and "sedge-like" Phyllotecta (Calamites) imprints in black, calcareous, carbonaceous lenses of "Upper W.B.".
GEOLOGICAL SECTION AND MAP
OF THE
NORTHERN PORTION OF THE CAPE FOLD BELT
BETWEEN STRYDOMSVLEI AND TOWERWATERPOORT