GEOLOGICAL AND GEOHYDROLOGICAL INVESTIGATIONS

ALONG THE CANGO AND BAVIAANSKLOOF FAULT ZONES

CAPE PROVINCE

by

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SIEN OOK KOEVERT 480

Contents

	Page
A. General	1
B. Geology	2
1. Notes on the Geological Formations	2
(a) Cango Formation	3
(b) 'Q' and 'S' Formations	3
(c) Cape System	4
(i) Table Mountain Quartzite Formation (T.M.S.)	4
(ii) Bokkeveld Formation	6
(iii) Witteberg Formation	7
(d) Cretaceous System	7
(e) Tertiary Conglomerates	9
2. Geological Structure	10
C. Geohydrological conditions in the Cango Fault Zone and adjacent areas	17
1. Springs	18
(i) Mountain Springs	18
(ii) Fissure zone springs in T.M.S. quartzite	18
(iii) Springs in T.M.S. boundary zone	19
(iv) Fault line springs	22
(v) Other springs	23
2. Bore-holes	24
(a) Drilling on the Cango Fault and Baviaanskloof Fault	24
(b) Drilling adjacent to the Cango Fault and Baviaanskloof Fault zones	29
(c) Drilling in T.M.S. boundary and fault zones south of the Cango Fault and Baviaanskloof Fault	35
(d) Bore-holes in Cretaceous Deposits	37

Page

D. Conclusions and Recommendations 38

E. References 41

Appendix - Formation of Enon conglomerate by rock-break process as a result of compression along the Cango Fault zone. 44

List of Illustrations and Tables

Main Map. Cango Fault Zone.

Sheet 1 - West of Calitzdorp (Ladismith District).
Sheet 2 - Calitzdorp to Vlakteplaas (Oudtshoorn Cretaceous Basin).
Sheet 3 - East of Vlakteplaas (Uniondale District).
Sheet 4 - Extension in upper Baviaanskloof (Willowmore District).

Scale 1:50 000. Legend on Sheet 2.
Key Map. Scale 1:250 000 (on sheet 3).

Folder 1 - Diagrammatic sections illustrating movement along Cango Fault and related phenomena in the vicinity of Oudtshoorn.

Folder 2 - Bore-holes at Van Zylsdamme, Ladismith District, Scale 1:5 000.

Folder 3 - Wanhoop. Uniondale District, C.P. Scale 1:15 000.

Figure 1 - Block diagram showing deposition of Wood Beds after movement during Enon Stage. Page 9

Figure 2 - Bore-holes 419 and 420 Georgida, Uniondale District.

Figure 3 - Bore-hole 432, Rooiklip, Uniondale District.

Figure 4 - Bore-holes 531, 532 and 533 at Rietrivier, Baviaanskloof

Figure 5 - Bore-holes near Homestead (Houtkloof) Rietrivier, Baviaanskloof. by S. Meyer

Table 1 - Surface water sources crossing Cango Fault Zone.
Table 2 - Surface water sources south of Cango Fault Zone.
Table 3 - Bore-hole data. Ladismith District.
Table 4 - Bore-hole data. Calitzdorp District.
Table 5 - Bore-hole data. Oudtshoorn District.
Table 6 - Bore-hole data. Uniondale and Willowmore District
Table 6a - Bore-hole data. Wanhoop (Uniondale District).

A. General

The present survey of the geology and geohydrological conditions along the Cango Fault zone was carried out by the writer during July and August, 1970 (west of Ladismith), October and November 1970 (Oudtshoorn area) and between February and September 1971. Detailed geological mapping was carried out during 1971 by Toerien in Baviaanskloof (east of Long. 23°30') and some geohidrological information compiled by Meyer.

Defining a fault as a fracture along which noticeable displacement has taken place between crustal blocks on either side, the Cango Fault may be said to extend continuously in an E-W zone from the western end of the Klein Swartberg Mountains (Biljetsfontein) (Long. 20°50'E), following the southern foot of Klein Swartberg, Groot Swartberg, Slypsteenberg, and Antoniesberg Mountains as far as Wanhoop (Long. 23°40'E). At Biljetsfontein and Wanhoop the apparent displacement along the fault is hardly perceptible. East of Wanhoop, however, Toerien has shown that the displacement increases again and that the Cango Fault is connected to the Baviaanskloof Fault which is said to run more or less continuously in a direction S of E to the coast at Swartkops north of Port Elizabeth. (Ref. Key Map on Sheet 3). It is possible that with further detailed mapping, the Cango Fault may be found, at its western end, to be directly linked to faults which run much further west e.g. that which follows the southern foot of Anysberg.

Along its lenth, the Cango Fault may be divided into three sections.

1. Biljetsfontein to Seven Weeks Poort. (Long. 21°25E). A normal fault. Dip of fault plane about 70°S.

2. Seven Weeks Poort to the vicinity of Barardas (Long. 23°00'E). Along this section, the fault, where observed, is usually near vertical. For reasons given below (pp.) the writer considers this section of the fault to be a high angle thrust along which conpression movement took place at the beginning of Cretaceous times and along which there has been no perceptable movement since.

3. Vicinity of Barandas to Wanhoop, and Baviaanskloof Fault. There may also have been compression movement along this section of the fault at the beginning of the Cretaceous, but the last movement on the fault (probably late Cretaceous or early Tertiary) was normal.

This report is intended as an explanation to the sheets 1 to 4 on which an outline of the geology is depicted, together with positions of bore-holes and main springs. The reader is constantly referred to these maps and to the tables giving data on bore-holes and spring sources. Details which are shown on the maps or given in the tables are not described in detail except where it is necessary to draw attention to some special point concerning the geological structure or hydrogeological conditions.

B. Geology

1. Notes on the Geological Formations

The established rock formations represented in the Cango Fault Zone and its immediate environs are as under (superficial deposits excluded):-

TOP	
Plateau Terrace Conglomerate (prob. Tertiary age)	
UNCONFORMITY	
Variegated Marls & Wood Beds Formation	Cretaceous
Enon Conglomerate Formation	
UNCONFORMITY	
Witteberg Quartzite and Shale Formation	
Bokkeveld Shale and Sandstone Formation	Cape
Table Mountain Quartzite Formation (T.M.S.)	
UNCONFORMITY	
? Klipheuwel Formation (Arkosic Grits and conglomerate)	
UNCONFORMITY	Pre-Cape
Upper Cango Formation (Grits, slates, phyllites, greywackes, conglomerates)	
Limestone of Cango Formation	
BOTTOM	

Subdivisions of the above formations are denoted in the Legend on Sheet 2 of the main map and their extent is shown on Sheets 1 to 4. The broader setting of the various formations is shown on the Key Map. It is not proposed to describe the rocks in detail here. This has already been done by:- Rogers (1925), Du Toit (1954), Haughton (1928), Du Preez (1944), Du Plessis (1959), Engelbrecht et. al. (1962), Rossouw et. al. (1964), De Villiers et. al. (1964), Haughton (1969), and the writer (1970).

The following points may be stressed or added to the descriptions given already:-

(a) Cango Formation

The extensive occurrence of limestone and calcareous shale between Kruis River and Nels River in Calitzdorp District (Sheet 2) was shown to the writer by Mr. J.G. Nel, Manager of farm Van Zylsdamme, Ladismith District, who owns the farm on which much of it occurs. The rocks are not unlike the limestones of the lower Cango Formation, though none of the characteristic arkosic grits seem to be present. Provisionally these rocks must be regarded as upper Cango but the solution could only be found further detailed mapping.

(b) 'Q' and 'S' Formations

The rocks denoted 'Q' and 'S' at Ou Muragie (Sheet 2) and at Rooiloop (Sheet 3) are classified by Du Plessis (1959) and by Rossouw et al (1964) as upper Cango Formation. The status of these is doubtful. Du Plessis' placing of the slaty rocks of the latter occurrence is presumably due to the fact that they are superposed by T.M.S. quartzite but for reasons given below (pp. 20-21) this does not necessarily mean that they are pre-Cape.

The 'Q' and 'S' rocks at Ou Muragie are chiefly slates and grits (probably arkosic) and are cut by a diabase intrusive. They are not, however, typical of the Cango Formation and although they have a strong near-vertical clearage, the dip of the sandstone bands appears remarkably consistent at 20-30°SSW. Theron tends to agree that the 'Q' and 'S' rocks at Ou Muragie are probably post-Cango.

The writer (1970b) provisionally placed certain rocks, denoted 'Q', immediately south of the Cango Fault at Schoemanshoek (Sheet 2) as Cango Formation and during the course of the present survey, at first referred similar rocks at Opsoek (Sheet 1) and Buffelsbosrivier (Sheet 2) to the Cango Formation on the grounds that they are locally superposed by T.M.S. Quartzite. Again, for reasons given below (pp. 20-21) this superposition of T.M.S. Quartzite does not mean that the 'Q' and 'S' rocks are of pre-Cape age. The writer now considers, as Rossouw et al (1964) suggested, that the 'Q' rocks at Schoemanshoek, Buffelsbosrivier and Opsoek belong to the Bokkeveld formation. In these three latter cases, Theron tends to be in agreement.

It must be pointed out, however, that distinction in the field between rocks of the Bokkeveld and upper Cango Formations with any degree of certainty is very difficult, especially when the rocks of the former are abnormally indurated (as they are along almost the whole length of the Cango Fault east of Seven Weeks Poort) and are usually very poorly exposed if exposed at all; often, their presence can only be inferred from their exclusive occurrence as fragments in the basal Enon formation of the Cretaceous cover. In all cases, the true stratigraphical position of the 'Q' and 'S' rocks could only be determined with certainty by detailed geological mapping, thorough search for fossils, and possibly some drilling.

In the geological profiles given on Sheets 1 to 3, the writer has, except at Ou Muragie, interpreted the 'Q' and 'S' formations as Bokkeveld Formation, but for the time being, they must all be classified as "age uncertain".

(c) Cape System

i. Table Mountain Quartzite Formation (T.M.S.)

It is generally established that this formation may be divided as follows:-

TOP

Uppermost sandstones and shales	C_1SQ
Upper quartzites	C_1Q_2
Upper "shale"	
Lower quartzites	C_1Q_1
Lower "shale"	

BOTTOM

On the maps (Sheets 1 to 3 and Key Map) an attempt has been made to illustrate the geological structure of the area by subdividing the upper and lower quartzites, and by differentiating the uppermost sandstones and shales where they have been observed on the ground. Sheet 4 has been mapped in detail by Toerien (1971).

The boundary between upper and lower quartzites between Long. 21°30E and 22°30'E, where the upper shale horizon has been mapped has been taken from the geological map (Rossouw et al 1964). Elsewhere, the boundary has been inferred from air photographs or first appraisel on the ground.

Criteria used in the latter case are as follows:-

1. The lower quartzites tend to be more massive then the upper quartzites and give rise to a rugged skyline topography characteristic of the higher parts of the Swartberg Mountains between Buffels River Poort (Sheet 1) and Toorwaterpoort (Sheet 3), and of the Kammanassieberg Mountains.

2. The upper quartzites are less thickly bedded and give rise to a smooth skyline topography characteristic of Touwsberg, Sandberg, Gamkaberg, Slypsteenberg, and Antoniesberg.

In general, these broad criteria are found to be in agreement with such features observed in the areas between 21°30'E and 22°30'E, 23°30'E and 24°15'E which have been systematically mapped.

Except in the section of the Cango Fault between Opsoek and Calitzdorp and along the Baviaanskloof Fault and the small outcrops of T.M.S. quartzite immediately south and within 1 km of the Cango Fault can be observed, proved by drilling, or otherwise reasonably inferred, to overly sandstones and slates of the 'Q' and 'S' formation. The rock is usually highly brecciated and it cannot be determined to which part of the T.M.S. sequence they belong.

In the vertical bore-hole G. 23512 (No. 201) drilled at Schoemanshoek east of Grobbelaars River, T.M.S. quartzite was struck at 165 m (541 feet) depth, underlying basal Enon conglomerate.

This could mean either:-

1. At this locality, upper T.M.S. quartzites are adjacent to the south of the Cango Fault as between Opsoek and Calitzdorp.

2. The fault dips at about 45^{o}S here. This is the simplest explanation but not considered likely by the writer since:-

   (a) The two 45^{o} angle holes drilled earlier indicated a steep junction between lower T.M.S. and basal Enon conglomerates. (Whittingham 1970b).

   (b) The line of the fault here runs far too straight across quite steep terrain to be consistent with a 45^{o}S dip.

or 3. This occurence is yet another in which the T.M.S. quartzite is superposed on rocks of the 'Q' formation. It must be noted, however, that the bore-hole continued to 360 m (1180 feet) depth in T.M.S. quartzite without encountering sandstone or shale characteristic of the 'Q' formation.

The writer tends to favour the first of these explanations for this occurrence, which is illustrated on profile D-D' (Sheet 2). For reasons which may become clearer below (pp. 57-58), the occurrence of basal Enon conglomerate above the quartzite tends to support this view.

The uppermost sandstones and shales of the T.M.S. (C_1SQ) have been differentiated on the map wherever they occur along the Cango Fault line, and in certain places elsewhere to the south.

(ii) Bokkeveld Formation

The rocks of the Bokkeveld have, as far as possible been subdivided since the three sandstones of the lower Bokkeveld are important marker horizons from which to obtain an idea of the downthrow of the Cango Fault and to clarify the structure of the area to the south.

These horizons have been observed at Die Poort, Van Zylsdamme and Zoar (Sheet 1), at Volmoed, in the vicinity of Stompdrif Dam (Sheet 2), and at Barandas and Ghwarriepoort (Sheet 3). Elsewhere, they have been interpolated from air photographs and topographical maps.

(iii) Witteberg Formation

The boundary between Witteberg and upper Bokkeveld Formations has been drawn at the beginning of the lowermost quartzites, interbedded with shales, in the lower Witteberg. The boundary has been observed south of Van Zylsdamme and in the vicinity of Hoeks (Sheet 1). Elsewhere it has been inferred from air photographs and topographical maps.

(d) Cretaceous System

There are a few notes to add to the data given by Du Preez (1944), Du Plessis (1959) and by the writer (1970c).

Occurrences of basal Enon (semi-indigenous) conglomerates overlying their respective source rocks at Amaliënstein (Sheet 1) and Buffelbosrivier (Sheet 2) illustrate the principle that the basal Enon conglomerates exclusively contain fragments of the source rock underneath and that the occurrence of such a conglomerate is a reliable indication of the underlying pre-Cretaceous formation.

This principle is demonstrated in the following places:-

	Locality	Source Rock
Sheet 1	W of Amaliënstein	Witteberg quartzite
	Amaliënstein	'Q' Formation
	W of Calitzdorp	T.M.S. Quartzite (upper)
Sheet 2	Buffelbosrivier	'Q' Formation
	Warmwater	Bokkeveld shale & sandstone
	Schoemanshoek (Bh G23512)	T.M.S. Quartzite (upper)
	S of Oudtshoorn	Bokkeveld shale & sandstone
Sheet 3	Rooiloop	'Q' Formation.
Sheet 4	Baviaanskloof	T.M.S. Quartzite, massive

It may further be noted that the hard, massive rocks such as T.M.S. Quartzite and certain sandstones of the 'Q' Formation tend to form large argular fragments which, although vast in number, are few in comparison to the far vaster number of small, platy fragments which overly the softer rocks, such as Bokkeveld shale.

These semi-indigenous conglomerates are observed only to the south of the Cango Fault and completely cover, or may reasonably be inferred to have once completely covered the whole surface of the underlying formation. Where these deposits occur in valleys, e.g. in the Grobbelaars River cliffs at Schoemanshoek, there is some indication of transport whereas on hillside exposures, e.g. at Buffelsbosrivier, the orientation of fragments is haphazard.

The Enon deposits appear to have completely blanketed the old dissected land surface formed by pre-Cretaceous rocks and the present Enon topography reflects the structure of the underlying Cape System rocks.

A suggestion as to the possible origin of these semi-indigenous conglomerates is given in Appendix.

There is still no conclusive proof as to whether the transported Enon-type conglomerates north of the Olifants Valley are true Enon as suggested by the writer (1970c) or whether they succeed the "Variegated Marls and Wood Beds" (W.B.S.) as stated by Du Preez (1945). Nowhere have Enon type conglomerates been observed to overly the mudstones and sandstones of the W.B.S. and nowhere has there been found any conclusive evidence of faults which must otherwise be inferred.

Once again, the problem can only be solved by drilling. Between Grobbelaars River and Calitzdorp, there are many places where W.B.S. rocks occur north of the line where a major E-W fault would necessarily have to be inferred (Le Roux - Buffelsdrif - Rietfontein).

It is here suggested that such faulting must have taken place penecontemperareously with the Enon stage and that the W.B.S. rocks encroached over the lower lying parts of the Enon surface.

This is illustrated -

Figure 1

BLOCK DIAGRAM SHOWING DEPOSITION OF
WOODBEDS AFTER MOVEMENT DURING ENON STAGE
NOT TO SCALE

(e) Tertiary Conglomerates

These deposits occur chiefly as hill cappings covering the older formations. They are essentially conglomerates containing fragments of T.M.S. quartzite in various stages of weathering and are bound by a siliceous, sometimes ferruginous or calcareous cement. Their precise age is uncertain. More than one stage may be represented.

Over the low-lying areas, these conglomerates lie horizontally, but on the lower mountain slopes to the north and south, they have a gentle dip (up to about 15^{o}) away from the mountains.

While the rocks of the Cretaceous, Cape, and pre-Cape groups have all been displaced by faulting to some degree, the Tertiary conglomerates do not appear to have been so affected (see profile G-G' Sheet 3).

2. Geological Structure

Along its whole length, the Cango Fault follows the southern flank of the E-W anticlinorial structure which builds up the Swartberg Mountains and Antoniesberg Mountains. The Baviaanskloof fault similarly follows the southern flank of the ESE-WNW trending anticlinorium of Baviaanskloofberg. A similar fault follows the southern foot of Anysberg which may be linked to the Cango Fault at its western end. These anticlinorial structures are situated en échelon.

An E-W trending synclinorial trough is situated to the south of the Cango Fault and, it would appear, generally reaches its greatest depth within a few kilometers of the fault where upper Bokkeveld and Witteberg formations are commonly represented.

It is uncertain as to what extent these features are due to the faulting itself and how far they are due to pre-existing structure. (See Folder 1).

Several subsidiary anticlinal axes occur south of the main synclinorial trough, sometimes within 10 kms of the fault, e.g. Touwsberg, Sandberg (W of Calitzdorf), Dysselberg, Stompdrif, Keurfontein (S of Barandas) and, possibly at Oudtshoorn (tentatively inferred for seismic results). Other anticlinal axes trending E-W are situated within 30 kms of the fault e.g. Rooiberg, Gamkaberg, Kammanassieberg, Ouposberg and Kougaberg (S of Baviaanskloof).

The major E-W Anticlinoria of Outeniquaberg and Langeberg lie to the south of these structures.

The downthrow of the Cango Fault, Baviaanskloof Fault and associated faults is consistently to the south. The throw of the fault cannot be determined on present information since thicknesses of the associated formations are not fully established. A maximum throw of the order 3000 - 4000 m is tentatively suggested.

Some idea of the throw may be obtained along various sections of the fault as given in the following table:-

Section	Formation to N	Formation to S
W of Buffelspoort	Top T.M.S./Lower Bokkeveld	Lower Bokkeveld/ Upper Bokkeveld
Buffelspoort to Hoeks	Lower Bokkeveld	Lower Witteberg
Hoeks to Seven Weeks	Upper T.M.S. Quartzites	Upper Bokkeveld
Amaliënstein	Lower T.M.S.	Lower Witteberg
Amaliënstein to Opsoek	Lower T.M.S.	'Q' Formation (Upper Bokkeveld lower eastward)
Opsoek to Calitzdorp	Upper Cango & basal T.M.S.	Upper T.M.S.

Pre-Cretaceous formations on S side of fault are usually concealed between Calitzdorp and Georgida except at the following places:-

N of Calitzdorp	Upper Cango	'Q' Formation (? lower Bokkeveld)
Buffelsbosrivier	Basal T.M.S.	'Q' Formation (? upper Bokkeveld)
Schoemanshoek	Basal T.M.S.	'Q' Formation (? lower Bokkeveld) and T.M.S. (? upper T.M.S.)
Ou Muragie	Upper Cango	'Q' & 'S' formation (position very doubtful)
Stormpdrif	Upper Cango	Lower Bokkeveld
Rooiloop	Basal T.M.S.	'Q' formation (? upper Bokkeveld)
N of Barandas	Upper T.M.S.	Upper Bokkeveld
Vaalkrans	Top T.M.S.	? upper Bokkeveld
Vaalkrans to Georgida	Lower Bokkeveld	Upper Bokkeveld
Georgida to Rooiklip	Upper T.M.S.	do.
Rooiklip to Wanhoop	do.	Lower Bokkeveld
Wanhoop to Vaalwater	Top T.M.S.	Top T.M.S. or lower Bokkeveld
Vaalwater to Nuwekloof	Lower T.M.S.	Upper and lower T.M.S.
Baviaanskloof	Lower T.M.S.	Upper T.M.S.

This information would indicate that the throw of the rain fault is greatest at the following places:-

1. Along the NW-SE section of the fault between Amaliënstein and Seven Weeks Poort.

2. Between Calitzdorp and Buffelbosrivier (Wynandsrivier).

3. In the vicinity of Rooiloop.

The throw of the main fault would appear to be less then normal in the following sections:-

1. West of Buffelspoort.
2. Between Opsoek en Calitzdorp.
3. Between Schoemanshoek and Ou Muragie.
4. Between Vaalkrans and Georgida (entrance to Ghwarriepoort).
5. Between Wanhoop and Nuwerkloof.

In general, the throw of the Baviaanskloof fault appears to be less than that of the Cango fault but in Baviaanskloof, where pre-Cretaceous rocks are generally much better exposed along the fault than along the Cango fault, Toerien has mapped a number of branch faults running more of less parallel to the line of the main fault. A similar pattern of branch fault may be expected along the section of the Cango Fault between Calitzdorp and Georgida where the rocks immediately south of the fault are largely concealed by Cretaceous deposits. The most important of these is inferred between Ou Muragie, Hazenjacht and Buffelsdrif.

In Ladismith District, there is little evidence of branch faults of any importance except between Hoeks and Seven Weeks Poort, where a series of brecciated zones in upper T.M.S. quartzites appear to branch north-eastwards from the main fault line. Brecciation in quartzites must, however, be regarded as an indication of fracturing and not necessarily of any appreciable fault displacement.

Along the section of the Cango Fault west of Seven Weeks Poort, the fault appears to be normal, the fault plane dipping at 70^{o}S.

East of Seven Weeks Poort, however, the nature of the fault is obscured since between Seven Weeks Poort and Georgida, and in parts of Baviaanskloof, Cretaceous deposits largely conceal the underlying formations south of the fault line. It may reasonably be inferred, however, that the fault is normally dipping (between 70^{o}S and 70^{o}N) for the following reasons:-

1. Along the greater part of its length, the fault line runs straight, irrespective of the topography.

2. The fault is observed to be steep or vertically dipping at the following places:-

	(a)	east of Opsoek.	
Sheet 1	(b)	on the north sides of Kleinberg and Sandberg west of Calitzdorp.	
	(c)	west of Besemkop, north of Calitzdorp	Brecciated T.M.S. Quartzite adjacent to basal Cretaceous deposits observed dipping steeply to N
Sheet 2	(d)	southern entrance to Coetzeespoort	
	(e)	Doringkloof, W of Schoemanshoek	
	(f)	in Grobbelaars River at Schoemanshoek	
Sheet 3	(g)	at Rooiloop	

3. Several bore-holes have been drilled close on the south side of the fault in places where the T.M.S. quartzites on the north side of the fault dip at 40 - 50^{o}S. Such bore-holes, intended to strike the T.M.S. quartzite at depth have frequently penetrated rocks of the Cretaceous or 'Q' formation to far greater depths than expected or have encountered soft muddy rock to full depth, showing that the dip of the fault is considerably greater than that of the quartzite formation to the north.

These include:-

Bh. 56 at Opsoek, Bh. 87 at Kweekrall, Bhs. 90 and 91 at Buffelskloof (entrance to Coetzeespoort), Bh. 273 at Waterkloof (Vlakteplaas), Bh. 421 at Georgida, Bh. 426 at Vaaldraai, Bhs. 438, 442, 446 and 450 at Washoop and Bh. 526 at Rietrivier (Baviaanskloof).

4. 45^{o}-angle bore-hole G. 23511 and 23512 at Schoemanshoek (Ref. Nos. 202 and 201a respectively) indicated a steep junction between Basal Enon conglomerates and T.M.S. quartzites although the latter rocks, north of the fault, are observed to dip at 40-50^{o}S.

5. Toerien (oral communication) has given a provisional estimate of 70^{o}S for the dip of the Baviaanskloof Fault.

In considering further the nature of this fault, attention should be given to the present disposition of the basal Cretaceous deposits immediately south of the Cango Fault. Between Seven Weeks Poort and Toorwater Poort, these rocks are invariably observed to dip northwards at angles from 10° to 30°N. When they were deposited, it is to be expected that they should have lain horizontally or even dipped slightly southwards, as do the Tertiary conglomerates along the southern flanks of the Swartberg Mountains. If profiles are adjusted to bring these deposits to lie horizontally, as may be illustrated by rotating sections B-B' and D-D' anticlockwise through 10-30°, (Ref. Folder 1) then the dip of the Cango Fault would be steep to the north, i.e. it was reversed in attitude at the beginning of Cretaceous times. This assumes that rocks of the 'Q' and 'S' formation are mainly Bokkeveld. It is therefore postulated that the Cango Fault, at least over the distance from Seven Weeks Poort to the vicinity of Barandas, was a high-angle thrust fault formed by compression movement at the beginning of Cretaceous times. This interpretation is further supported by the following considerations:-

1. Rocks of the 'Q' and 'S' formation are often abnormally indurated, thus adding to the difficulty of assigning them to any of the established formations. This induration may be due to compression.

2. "Outliers" of T.M.S. quartzite south of the Cango Fault which appear superposed on rocks of the 'Q' and 'S' formation may be interpreted as remnants of blocks thrust over from the north adjacent to the fault.

Such superposed T.M.S. blocks occur at the following places:-

(a) Opsoek.
(b) Witkop, farm Doornkraal, N of Stompdrif Dam.
(Ref. Data from bore-holes 256 and 257).
(c) Vlakteplaas (Skruwe Kop).
(d) Rooiloop.
(e) Struisvogel (Witkop).
(f) Toorwater.

These blocks of T.M.S. quartzite south of the fault do not occur west of Seven Weeks Poort, neither have they been observed east of Toorwater Poort. As far as can be observed, the T.M.S. quartzite in each case directly overlies rocks of the 'Q' formation and never overlies Cretaceous rocks. Nor are Cretaceous rocks observed to overly these T.M.S. blocks.

3. The prescence of basal Enon conglomerates, composed almost exclusively of angular or sub-angular fragments of the rocks which they directly overlie could be indicative of conpression at the beginning of Cretaceous times. In the writer's view, these deposits have formed by a "rock-break" process such as might be expected to occur at the ground surface to dissipate internal stresses in the underlying rock formation which are set up when extensive horizontal movement is not possible as in the case of a low-angle thrust. This hypothesis is outlined in appendix. (pp. 57-58)(Ref. Figure 1).

The present dip of the Cretaceous rocks to the north and rotation of the fault plane into a vertical or normal position could be attributed to subsequent downwarping to the north. Such downwarping movements were completed prior to deposition of the Tertiary conglomerates.

The chief argument against the theory that the Cango Fault, between Seven Weeks Poort and Barandas, is a high angle thrust, is provided by bore-hole 171a. Drilling of this bore-hole indicates that the fault plane there dips at about 50°S. This does not necessarily rule out the high-angle thrust theory for the following reasons.

(a) The bore-hole is situated at a point where the fault runs ENE for a short distance - this is the sharpest flexure observed along the Cango Fault for the whole of its length. (Baviaanskloof Fault excepted). The abnormal dip of the fault plane here may be due to abnormal downwarping to the north.

(b) Cretaceous deposits are not exposed at this point and the dip of the fault plane in early Cretaceous times cannot be determined. It is possible that, before their removal by erosion, the Cretaceous rocks had a dip of more than 40°N - that may be the very reason why they have here been removed by erosion (an abnormal occurrence in this area) to expose the rocks of the 'Q' formation.

Where T.M.S. quartzites are observed adjacent to the Cango Fault, the rock is usually fractured, with quartz veining, and is locally brecciated. The brecciation appears, however, to be characteristic of certain zones in the quartzite which may run obliquely to the main fault and does not seem to be necessarily related to movement along the fault itself. The quartzite in the T.M.S. overthrust blocks occurring south of the fault line appears to be strongly brecciated in every case, however.

Further, it is observed that brecciation occurs most consistently in T.M.S. quartzite adjacent to the Cango Fault along the section between Seven Weeks Poort and Hoeks, where there is evidence of normal movement only. Possibly the brecciation process is facilitated by conditions of tension or may be hampered under conditions of intense compression.

It is uncertain how far eastwards along the Cango Fault and the Baviaanskloof Fault the conditions of compression at the beginning of Cretaceous times persisted. In the writer's view, referring to consideration (3) above (p. 21) the occurrence of basal Enon conglomerates to the south of the fault zone may be indicative of compression conditions at the time of deposition. In this case, it is inferred that such conditions persisted along the whole length of the Baviaanskloof Fault to the coast at Swartkops. The writer believes, however, that the section along which the most <u>intense</u> compression occurred is defined by the outcrop of the Cango inlier to the north between Seven Weeks Poort and Barandas, that is, the section along which there was the greatest displacement.

Eastwards from Barandas, the <u>last movement</u> on the Cango Fault and the Baviaanskloof Fault was normal.

1. Between Barandas and Slypsteenkop, there is a distinct steep fault scarp which is not observed further west.
2. East of Toorwater, Enon conglomerates are commonly observed to dip southward close to the Cango Fault. This is probably caused by drag during the last movement.
3. From detailed mapping, Toerien has concluded that the Baviaanskloof Fault is normal and has a general dip of about 70°S. He did not comment on the writer's suggestion that thrust movement may have taken place at an earlier stage.

This last normal movement along these faults must have taken place after downwarping movements to the north had ceased and (in the area covered here) before deposition of the Tertiary conglomerates.

C. Geohydrological Condtions in the Cango Fault Zone and adjacent areas

The most important aquifers in the Cango Fault Zone and the surrounding area are:-

1. The quartzites and uppermost sandstones of the T.M.S.
2. Cavernous limestones of the lower Cango Formation - certain springs discharging water into Grobbelaars River and Wynands River are from this source. These are shown on the Key Map and are described in separate reports (Rossouw et al 1964 and Whittingham 1969, 1971a).

With certain exceptions, detailed below, all strong supplies of ground water, from springs or from bore-holes, are derived from these formations or from formations directly overlying them. (The present investigation does not include water from wells or bore-holes of less than 30 m depth sunk into alluvial deposits which may locally yield strong water supplies of variable quality).

Details of the water supplies from surface sources (springs) are given in Tables 1 and 2 and details of bore-holes drilled for water supply are given in tables 3, 4, 5, 6 and 6a.

1. Springs

These may be divided into five categaries:

(i) Mountain springs. These are shown on the tables as having their sources "over 500 m", "over 700 m" or "over 900 m". Of these, the only sources which have been visited are Hoeks River (the main tributary of Grobbelaars River - Ref. Whittingham 1971) and Vermaaks River. The sources appear to be as a rule, in lower quartzites of the T.M.S. (below the upper shale horizon) and, in the case of Hoeks River and probably many others as well, where the quartzite is highly fractured or brecciated. Most of the sources listed may be regarded as permanent and many other kloofs are reported to have premanent mountain springs which do not reach the foot of the mountain. It may be observed from Tables 1 and 2 that the flows from these springs are subject to considerable fluctuation depending on the rainfall. During the exceptional drought of 1969-1970, most of these springs were greatly reduced in strength and a number of them dried up completely.

It may be inferred that these sources are derived from meteoric water stored in fractures in the quartzites of the T.M.S., replenishment of which is directly dependent on the rainfall.

(ii) Fissure zone springs in T.M.S. quartzite.

Of the springs listed in tables 1 and 2, these include Buffelsfontein (near Van Wyksdorp), Waterkloof and Doringkloof (Gamdouwsberg), Badspoort and Uitzigt (Lower Gamka), Aristata (Seven Weeks Poort) and Schilpadbeen (Ghwarriepoort).

These sources are, as a rule, at a comparitively low altitude in mountain areas. Their flow is reported to be constant, independant of rainfall conditions.

The flow (notably at Buffelsfontein) appears to emanate from open fissures in the wuartzite which, in the cases quoted, belong to the upper T.M.S. The water is commonly mineralized and Fe/Mn oxides are deposited close to these springs, indicating that the water is derived from considerable depth. *Water temperatures exceed 20°C (except Schilpadbeen) and one spring (Badspoort) is thermal (temp. 33°C). Minor faulting and brecciation in the quartzite may be observed at these sources, as at Buffelsfontein, but such features are not always evident. It is more inportant to consider that these springs occur in zones of open fissures, formed under conditions of crustal tension.

Several other springs of a similar nature are reported to exist in the area north and east of Van Wyksdorp, in Gamkaberg and Sandberg (S of Oudtshoorn and Calitzdorp) and in Ghwarriepoort. It is likely, too, that similar springs may contribute to the flow of the mountain springs rising in Swartberg and Kammanassie Mountains (notably Waterkloof-Jagersrivier which is reported to maintain a remarkably constant flow). (Water temperatures in Swartberg, Kammanassieberg and Ghwarriepoort are usually 17-19°C).

(iii) Springs in T.M.S. Boundary zones.

The remainder of the springs which have been heighted in Table 1 in Uniondale District (between Rooiloop and Wanhoop). Die Poort (Ladismith District), and the undermentioned springs listed in Table 2 fall into this category - Warmwater (Swellendam), Rietfontein (E & W), Danielskraal, Welgerust, Warmwater (Calitzdorp), and Dysselsdorp (all springs). It may be noted that these include four thermal springs - Warmwater (Swellendam), Warmwater (Calitzdorp - 2), and Toorwater hot spring. Seven of these springs occur close

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*According to information from Toerien obtained from field work in Baviaanskloof area, the most likely primary source of Fe/Mn material is from the upper T.M.S. quartzites immediately overlying the upper shale band. Therefore such deposits are not to be expected from springs emanating from the lower T.M.S. unless there are other sources of Fe/Mn material below the upper shale band.

to the Cango Fault usually on the north side, as do many other seepages between Barandas and Wanhoop, but this is, in the writer's opinion, incidental to the fact that they are in a T.M.S. boundary zone, whether faulted or not.

Whether the flows from these springs are strong or weak, whether the temperature is hot or normal, the flow from them is reliably reported to be constant except in so far as it has (in Ladismith area) been temperarily or permanently affected by earthquakes (such as the Tulbagh earthquake of 26.9.69), and no fluctuation attributable to the long drought of 1969-1970 was noted. These springs, with the exception of that at Rooiloop, are mineralised and the spring outlets are veneered by ferruginous sludge or surrounded by black concretionary deposits or veneers of Fe/Mn oxides*. With the exception of Rooiloop spring, they are in a boundary zone of upper quartzites of the T.M.S. The waters of the warm springs are slightly sulphyretted.

To this list of springs given in Tables 1 and 2 could further be added the springs of Paardepoort, Hoeksrivier, and Groot Groenefontein in the Grobbelaars River catchment area (See Key Map). These springs flow out from the boundary zone (unconformity) between lower T.M.S. quartzite and lower Cango Formation (Ref. Whittingham 1971a); the water is of normal temperature (17 - 19°C) and is not mineralised*.

The occurrence of the weaker springs, and seepages not listed, may be attributed to the forcing out of water under pressure, from such fractures in the T.M.S. quartzite as are available to conduct the water, against the impermeable shales and sandstones which are adjacent to the aquifer, whether by faulting, unconformity, or by normal sedimentary sequence. The altitude of the springs is related to the altitude of the T.M.S. boundary and the strength of flow of the springs apparently bears no relation to the altitude.

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*See footnote on previous page.

It is not clear whether the pressures causing outflow of the water are hydrostatic, or whether tectonic forces operative at depth must be invoked. The fact that certain of the weaker springs in Ladismith District have shown an apparent permanent increase (e.g. those at Rietfontein) and other water supplies an apparent permanent weakening since the Tulbagh earth tremor of 26.9.69, would suggest that the latter may be the case.

The emergence of strong springs is here attributed to fissuring of the underlying rock formations. Open fissures are caused by crustal tension and appear to be localised in occurrence. Strong springs emerge where such fissures reach the ground surface. The thermal springs occur where fissures are adequate to permit rapid rise of water from great depth to the surface before it has cooled. This has been implied by Kent (1949, p. 255). Cool water may emerge where the fissures are more constricted or penetrate only to shallow depth. The frequency of occurrence of strong water supplies along the T.M.S. boundary zones has to be explained since fissuring can affect all rock formations (e.g. Karroo sediments in Aliwal North - Colesburg area and the T.M.S. quartzite itself in Van Wyksdorp area). It is suggested that the boundary zone between the massive, rigid, T.M.S. quartzite and the relatively incompetent formations adjacent to it forms a zone which would be abnormally susceptible to fissuring. That is, if tensional forces are operative in an area, the boundary zone, whether normal, unconformable, or faulted would be a natural zone of weakness along which fissures would most easily develop.

It must be stressed that such fissuring is localised and, as far as is known, except in the vicinity of Toorwater hot spring, is not evident anywhere along the Cango Fault zone east of Seven Weeks Poort.

Toorwater hot spring, Varsfontein (½ km to west) and bore-hole 400 (1 km to east) must, in fact, be regarded as freak occurrences of strong water so close to the Cango Fault. At the present time, the hot spring outlet is enclosed in concrete and the source cannot be examined. An old report (Taylor 1928), however, describes a vertical, circular, smooth-walled pipe, at least

50 feet deep, resembling a bore-hole, from which the spring emerged prior to 1903. In 1903, according to Taylor's report, blasting operations caused the pipe to be blocked so that the spring followed a new outlet from fractures about ½ meter away. If Taylor's report is correct, the existence of a circular pipe is suggestive of an explosion vent which may have provided an outlet for the thermal water. Such an explosion may also have caused the opening up of fractures along the fault zone in the near vicinity.

The springs at Dysseldorp are included in this category since, although the springs emerge from fractures in Enon conglomerate and superficial gravels, their proximity to the T.M.S. boundary is clear (Ref. Sheet 2). These springs are not strong but are permanent. The water is mineralised as is indicated by veneers of Fe/Mn oxide on the surrounding rocks. The nearby bore-hole (No. 540) is not deep and the tested yield (17 000 l/h) does not indicate the full water potential here. The springs were reported to decrease during the 1969/70 drought, but this might well have been apparent due to increased usage of water from the surrounding area where other supplies of water were very scarce.

It is to be noted that certain springs, notably at Brits se Vlakte and Georgida either ceased to flow or were reduced in strength when nearby artesian bore-holes 404 and 419 were drilled.

(iv) Fault line springs

In addition to the springs included in category (iii) above, which occur where the T.M.S. boundary is faulted, there are a few other springs which emerge close to fault lines.

Springs at Hazenjacht and Toorfontein (Sheet 2, Table 2) occur close to the line of an inferred fault branching from the Cango Fault between Ou Muragie and Buffelsdrif. These springs emerge from fractures in Enon conglomerate. Their source is obscure. The flow of the spring at Hazenjacht was reported to have decreased during the 1969-1970 drought though the springs at Toorfontein is said to be constant.

The most important springs in this category are those at Studtis in Baviaanskloof (Ref. Sheet 4, table 1). They occur on the south side of the line of a fault branching S of W from the Baviaanskloof Fault. Immediately north of the fault, lower quartzites of the T.M.S. are exposed and are highly brecciated. The south side of the fault is covered by superficial deposits. From the map, it would appear possible that Bokkeveld shales may occur underneath but the bore-hole records (Nos. 535, 535a, 536, 537) indicate that T.M.S. quartzite (presumably upper quartzite) occurs at relatively shallow depth.

The flow of these springs is said to be constant and the temperatures (24-25°C) suggest that the water has thermal affinities. Although there is little evidence that the water from the springs is mineralised, water from the nearby artesian bore-hole (537) leaves a characteristic ferruginous sludge deposit on the casing. The origin of these springs could be attributed either to emergence along the fault line, where the quartzite is abnormally brecciated on the north side, or alternatively to local fissuring. At one stage, is is reported by the owner, Mr. J.G.F. Nortje, when the artesian bore-hole (537) was deepened from 99 m to 106 m, the normal artesian flow (31 000 l/h) increased and the flow from the westernmost outlets of the west main spring ceased to flow. This fluctuation was said to be temporary only - after 3 months the artesian flow of the bore-hole and the west main spring reverted to normal.

(v) <u>Other springs</u>

The Buffelskloof spring emerges from the northern bank of Vlei River. It's flow is not constant and it may be caused by seepage from river gravel.

The source of the Lopenrivier spring is obscure. It rises out of sandy ground overlying Cretaceous sandstones and mudstones of the Wood Beds Stage. It's marked fluctuation during the 1969-1970 drought indicates that it is directly dependent on rainfall and may de derived from water stored in alluvial or talus material.

2. Bore-holes

This geohydrological investigation was initiated primarily to find out facts about the results of drilling for water supplies along the Cango and Baviaanskloof Fault zones and to assess the possibilities for further drilling therealong.

Data from existing bore-holes along the Cango Fault zone and in the area to the south is given in Tables 3, 4, 5, 6 and 6a for Ladismith, Calitzdorp, Oudtshoorn, Uniondale/Willowmore Districts, and farm Wanhoop (Uniondale District) respectively.

On each table, the data on bore-holes situated along the southern foot of the Swartberg and Antoniesberg mountains, near to the Cango Fault have been tabulated first. Sites of the bore-holes numerated in these tables are shown on Sheets 1 to 4.

Yield symbols are also depicted on the maps alongside the bore-hole where appropriate (see Legend). This is to give some idea at a glance where the successful and unsuccessful bore-holes are located. In this respect, it may be noted that 20 000 l/h is a minimum yield which can suitably be utilised for irrigation purposes. Many farmers, especially those using overhead irrigation equipment, specify that it is uneconomical to pump a bore-hole yielding less than 35 000 l/h since pumping costs, together with other costs, may exceed the returns from the crop under irrigation.

(a) Drilling on the Cango Fault and Baviaanskloof Fault

There has been in the past, much anticipation that high yields of water can be obtained by drilling to intersect the Cango Fault at depth, in places where T.M.S. quartzite occurs on one side of the fault. In some places, such as the section between Hoeks and Seven Weeks Poort and on farm Wanhoop, the T.M.S. quartzite immediately north of the fault is highly brecciated in a similar way to the brecciated zones from which high yields of fresh water are obtained elsewhere in the Cape Province. Similar strong water supplies might for this reason be expected along the Cango Fault zone. This idea has been popularised by Joubert (unpublished reports and 1970 p. 4).

Results of drilling on the Cango Fault to date have generally been disappointing.

The following bore-holes are known to have intersected the Cango Fault:-

Bh. 15 - Van Zylsdamme (Table 3)

The Cango Fault zone, between Witteberg quartzite/shale and lower Bokkeveld shale, was intersected at 44 m depth. Muddy water was struck on the fault.
Drilling was continued to 91 m but no increase in water was noted. Bore-hole caved in partially below 44 m.
9 000 l/h of muddy water were pumped for about 2 hours before bore-hole caved in completely.

Bh. 43 - Elandsfontein (Table 3)

The Cango Fault zone, between Bokkeveld shale and upper T.M.S. quartzite, was intersected at 43 m depth. Casing was inserted to this depth to prevent caving-in of the shale. Drilling was continued into the quartzite, but at 44 m depth, the drill bit dropped for 5 m into black shaly material which could not be prevented from caving in except by reaming through the quartzite and continuing to insert casing to depth unknown.
The prescence of this shaly material in the quartzite is explained as follows. In the quartzite, along the line of this fault (a normal fault here), cavities develop in the quartzite. These have become impregnated with shaly material derived from Bokkeveld shale which has disintegrated along the fault line. This bore-hole yielded only 900 l/h of fresh water. The owner was unwilling to continue drilling without the guarantee of a sufficiently strong water supply to justify the expense of drilling and lining the bore-hole.
In this context, it may be noted that bore-hole 42 at Balmoral, drilled for 153 m into brecciated T.M.S. quartzite, yielding 55 000 l/h, also encountered black shaly material from about 30-32 m. This borehole was earlier thought to

be situated on the fault line. Recent drilling of bore-hole 42a, 40 m to the south, has shown that this is not the case. Bore-hole 42 a still encountered T.M.S. quartzite showing that it is also north of the fault line, but black shaly rock was encountered between 36 and 45 m depth, showing that difficulties of drilling are likely to increase nearer to the fault line.

Bore-holes 87 and 88 (Kweekraal Table 4) were both drilled close to an S-W striking outcrop of brecciated T.M.S. quartzite following the Cango Fault line. Both these bore-holes encountered soft clay, the latter also with brecciated quartzite, and both bore-holes caved in. Yields of water were negligible. The soft clay in presumably disintegrated shale of the 'Q' and 'S' formation. Similar results were obtained in bore-holes 90 and 91 drilled on Rietfontein (Table 4).

Bore-hole 171a (Buffelsboschrivier, Table 4) encountered the Cango Fault, between 'Q' formation and T.M.S. quartzite at 80 m depth. Here, the fault plane appears to dip 50°S. The bore-hole was continued to 107 m depth in the quartzite. Casing was inserted to 80 m to prevent caving in. The bore-hole yielded 540 l/h.

At Schoemanshoek, bore-holes 201a (G. 23512) and 202, (G. 23511) inclined at 45° northwards, crossed the line of the Cango fault at depths of about 87 m and 26 m respectively below ground level, passing through basal Enon conglomerates into T.M.S. quartzite. From drilling records, it appears that no water was struck on the fault itself but by drilling further into T.M.S. quartzite, artesian flow of 140 and 45 l/h respectively were obtained. The vertical bore-hole on site G. 23512 (201) south of the fault, also obtained an artesian flow of 140 l/h when drilled into T.M.S. quartzite but when tested, yielded not more than 900 l/h. The depths at which the T.M.S. quartzite was encountered in these two bore-holes indicate that the fault is almost vertical.

Bore-holes 401 and 401a at Slypsteenkop, 2 m apart, appear to be situated close to the Cango Fault. The former, passed from shale into T.M.S. quartzite at 50 m depth, probably penetrating the fault on this junction. Also, bore-holes 423 (Posthouderskloof) and 437 (Misgunst) are similarly situated on the fault. While 401 and 423 have small artesian flow, their pumping yield has not been tested. As results of pumping of Bh. 201 at Schoemanshoek have shown, an artesian flow is not necessarily an indication of a strong potential yield Bh 435, it may be noted, was dry.

Of the bore-holes drilled at Wanhoop, (Ref. Table 6a) it would appear that more, with the possible exception of No. 446 (G. 14931), actually crossed the Cango Fault but several of them are close on the north or south side of the fault (438, 439, 443, 447, 450 and 451).

At the mouth of Welbedacht Kloof (Ref. Folder 1) a brecciated zone of T.M.S. quartzite is well developed and the bore-holes drilled there close to the fault, even the more successful ones, have encountered difficulties with caving in of shaly horizons in the quartzite which must, in the writers opinion, be disintegrated Bokkeveld shale impregnated into cavities in the quartzite as at Seven Weeks Poort. According to the driller, Van Tonder, the main water is often struck in these horizons but the tendency of the material to cave in presents a serious difficulty of drilling through them if they attain any appreciable thickness. Three of the bore-holes drilled at Wanhoop close to the Cango Fault (438, 443 and 445) give reasonably good yields, which are a useful contribution to the Municipal Water Supply for Willowmore, but such yields do not compare so favourably with yields of bore-holes drilled at a greater distance from, or right away from, the Cango Fault elsewhere.

As will become clear by reference to Sheets 1 to 3, in the case of all bore-holes mentioned above except those at Shoemanshoek and Van Zylsdamme, the sites have been chosen in places where there are shales and sandstones of the Bokkeveld or 'Q' formation are faulted directly against the upper Cango formation. In most places Enon conglomerates overly the 'Q' formation. West of Hoeks, Witteberg on Bokkeveld formation are down-faulted against uppermost T.M.S. or lower Bokkeveld shales. Along these sections of the fault, there is an impervious formation on one or both sides of the fault and results have shown that success cannot be expected by drilling for water on the fault itself.

Conditions along the section of the fault between Opsoek and Calitzdorp where T.M.S. quartzites are down-faulted against upper Cango formation, ground-water conditions are not known. Sites G. 26301 and 26302 were marked on this section of the fault, the latter being indicated to Calitzdorp Municipality as a possible site for a bore-hole water supply in May 1971. In such places, it is possible to drill from the surface in T.M.S. quartzites with a view to intersecting the Cango Fault on the south side. It must be borne in mind, however, that there is still an incompetent formation to the north of the fault.

Summarising, it may be concluded that drilling to intersect the Cango fault along the whole of its length is not to be recommended for the following reasons:-

1. Except, possibly, at Schoemanshoek, there is an incompetent formation (Bokkeveld or 'Q' formation) on one or both sides of the fault. Such rock is likely to cave in on the fault itself. Disintegrated material from the incompetent formation may impregnate fractures in the competent quartzite formation, tending to seal off the flow of water and may itself cave in if encountered in drilling.

2. Between Seven Weeks Poort and Barandas, as stated above (pp. 20-21), in the writers opinion, the last movement along the Cango Fault was thrust movement under compressive forces. In this case, unless there is reason to believe that tensional forces have been operative since, it is to be expected that fractures in quartzite will be tightly closed and ground-water movement therein very sluggish.

Possibilities may be better for drilling along the Baviaanskloof fault where, in many places, T.M.S. quartzite occurs on both sides of the fault. In the writer's opinion, here too, there was thrust movement under compression at the beginning of Cretaceous times and the results of drilling at Schoemanshoek must be borne in mind. The last movement, however, was normal and this may have allowed re-opening of fractures to some extent. No information apart from the results of drilling bore-holes 526, 527, 534 and 545 is available as yet. Those bore-holes are low yielding and would suggest that conditions along the Baviaanskloof Fault are not dissimilar from those along the Cango Fault.

In view of the foregoing considerations, several sites selected at an early stage of the present investigation to intersect the Cango Fault are no longer recommended. These include G. 26245, 46, 48, 85, 86, 87, 89, 97, 98, 26303, 06, 07, 08, 09, 10, 11.

(b) Drilling adjacent to the Cango Fault and Baviaanskloof Fault Zones

Drilling in formations adjacent to the Cango Fault zone, chiefly in T.M.S. quartzites or uppermost T.M.S. sandstones and shales, has met with considerable success as is shown by data in in Tables 3 to 6 and on sheets 1 to 3. Almost all these bore-holes have been drilled on the north side of the Cango Fault.

Between Seven Weeks Poort and Vlakteplaas, drilling has not been successful. This may be attributed to two factors:-

1. There is usually insufficient thickness of T.M.S. quartzite on the north side of the fault to penetrate this formation to any great depth.

2. The fractures in the formation remain tightly closed due to compression at the beginning of the Cretaceous period.

West of Seven Weeks Poort, many bore-holes have been successfully drilled over T.M.S. quartzite, uppermost T.M.S. sandstones and shales, and basal Bokkeveld shales to the north of the Cango Fault. Those on farm Van Zylsdamme (nos. 8 to 14) have been described by the writer in a separate report (1970a).

Many of the successful bore-holes have been drilled where there are clear indications of fracturing or brecciation in the T.M.S. quartzite or uppermost sandstones of the T.M.S. include 12, 14, 33, 34 and 35. These bore-holes, together with Bh 42 drilled on brecciated T.M.S. quartzite at least 40 m north of the Cango Fault are the most successful drilled along the southern foot of the Swartberg Mountains in Ladismith District. It must be noted that bore-holes 12 and 14 have greatly decreased in yielding capacity over the 20 years which they have been pumped and the rest water level has dropped 10-20 m in bore-holes 35 and 42 which were artesian when first drilled. Some yields are also reported to have decreased owing to the earthquake of 26.9.69.

Bore-holes 19, 22, 23 and 24 on Voorbaat have been drilled in basal Bokkeveld shale and still give strong yields of water. At Van Zylsdamme, Byvangerskloof and Voorbaat the basal Bokkeveld shale is vertically cleared but banding observed in certain places indicate that the true dip of the formation there is 10-30°S, so that the T.M.S. formation lies at no great depth below.

Of the bore-holes mentioned above, only 12 and 14, which are situated on the same brecciated zone in uppermost T.M.S. sandstones are known to affect each other when pumped.

It may be noted too, that bore-holes 4 and 5 at Die Poort are only 20 m apart across the strike and do not affect each other.

It would seem, from the results of drilling on Van Zylsdamme and Voorbaat to date that bore-holes drilled anywhere on the basal Bokkeveld and uppermost T.M.S. outcrops may reasonably be expected to give useful supplies of water provided that:-

(i) They are drilled to a sufficient depth (say 120 to 150 m).

(ii) They are drilled at sufficient distance (say 70 m or more) north of the Cango Fault to avoid the zone in which the shale has disintegrated, and tooverly the T.M.S. at depths of the order not more than 300 m.

(iii) they are not spaced too closely together along the E-W strike of the formation.

Yields of water to be expected may be of the order of 15-200 000 l/h, and not the minimum of 35 000 l/h which some farmers desire.

It is not known whether such conditions could be expected at Die Poort and Knuyswagensdrif or not (similar geological structures are observed on these farms). The failure of bore-hole 7, drilled on basal Bokkeveld shale at Die Poort, may be due to insufficient depth of drilling. Bore-holes drilled north of the Cango Fault on these formations on Elandsvlei for Ladismith Municipality (28, 29 and 30) have not been successful. The exact position of the Cango Fault in the immediate vicinity of bore-holes 29 and 30 is not clear.

Bore-holes drilled at Hoeks have not been successful to date. Again, the position of the Cango Fault is not clear except near the eastern boundary of the farm where bore-holes 38 and 41 have been drilled close (probably too close) to the north side of the fault. It is suggested here that drilling over the T.M.S. outcrops, which are brecciated locally, be attempted. (Sites G. 26294, 95 and 96). It should, however, be borne in mind that bore-hole 36, drilled to 53 m depth, yielded only 9000 l/h.

On the eastern side of Hoeks valley, it is noted that when bore-hole 40 is pumped, the siphoned flow at Bh 39 is temporarily stopped and the water level at Bh 38 is lowered. The two latter bore-holes are situated 70 and 100 m respectively south of Bh 40 which is close on the north side of the Cango Fault.

Between Seven Weeks Poort and Vlakteplaas a few bore-holes have been drilled on the formations adjacent to the Cango Fault.

The most successful bore-hole drilled on the north side of the fault on this section is No. 85 (Kweekraal) drilled in limestone and shale of the Cango Formation. Bh 84 was stopped due to technical difficulties. Apart from these two bore-holes, the ground-water potential of this outcrop of Cango limestone is undetermined. Since successful bore-holes have been drilled in limestones of the lower Cango Formation in Matjies Rivier and upper Grobbelaars Valley, it is recommended that further drilling at Kweekraal could profitably be attempted.

Bore-holes drilled on the grits and slates of the upper Cango Formation and on the rocks of the 'Q' formation have not been successful, with the exception of Bh. 170 (Buffelsbosrivier).

In general, these formations and the Cretaceous deposits which may overly them are poor aquifers - bore-holes are dry or low yieldings, often with brackish water. The success of certain bore-holes at Schoemanshoek can be attributed to infiltration from gravels of the Grobbelaars River (e.g. Bhs 199 & 200) or in other cases to infiltration of rainwater or furrow water into superficial deposits overlying the impervious Enon conglomerate where the former attain sufficient thickness (e.g. Bhs 196, 197, 198, 213, 215 and 220 - 225). Similarly, the more successful bore-holes at Ou Muragie and Doringkloof are all situated near to stream courses and their success can be most reasonably attributed to percolation of water from superficial gravels.

Between Valkteplaas and Barandas, bore-holes drilled in T.M.S. quartzite on the north side of the Cango Fault (nos. 272, 379 and 391) have proved more successful than any others drilled between Seven Weeks Poort and Barandas. These bore-holes are still in the "high-angle thrust" section but it is possible that later movement may have allowed partial reopening of fractures in the quartzite here.

Sites G. 26314, 15, 19, 20 have been marked as possible sites for drilling on this section of the fault and, being situated over T.M.S. quartzite on the north side, are recommended as sites for drilling with a view to obtaining yields of 5000 - 10 000 l/h. Such quantities, although inadequate for irrigation purposes, could provide a useful augmentation to the water supplies on the respective farms.

The chief difficulty of drilling north of the Cango Fault east of Vlakteplaas is the lack of access to sites on which to drill. The lower part of the Swartberg escarpment is steep and the kloofs are narrow and steep sided, often floored with large boulders. This same difficulty occurs along the Cango Fault Zone east of Barandas, except between Slypsteenkop and Georgida (Ghwarriepoort area) where the Cango Fault Zone swings south-eastwards sway from the southern foot of the Swartberg (Slypsteenberg) Mountains across the mouth of Ghwarriepoort to the southern foot of Antoniesberg.

East of Barandas, many bore-holes have been drilled on the north side of the Cango Fault in T.M.S. quartzite with varying degrees of success. Between Barandas and Slypsteenkop the escarpment is a very steep fault scarp and bore-holes have necessarily been drilled very close to the fault itself. The same applies to farms Misgunst and Wanhoop, though on these farms, the bore-hole sites are restricted due to narrowness of the kloofs.

Between Slypsteenkop and Misgunst, it has been possible to drill over T.M.S. quartzite in places further north of the Cango Fault either because the Cango Fault is situated away from the foot of the escarpment as between Slypsteenkop and Georgida, or because certain kloofs are flat-floored and sites are accessible 100 - 200 m north of the fault line, as at Posthoudersklcof, Vaaldraai, and Rooiklip.

Many of the bore-holes successfully drilled are artesian and in others, the water level stands high enough to allow water to be siphosed. When these bore-holes were drilled, it was noted by farmers that when the artesian flow commenced or when water was siphosed from the bore-holes, nearby springs and seepages ceased to flow or, as at Brits se Vlakte (Bh 404) weakened and flowed out from a lower outlet. Water levels in neighbouring existing bore-holes were also affected in some cases as at Toorwater (Bhs 398 and 399) and Wanhoop (Bhs 443, 445 and 446).

Although the artesian bore-holes have artesian flows ranging from seepages to flows of 32 000 l/h, it may be noted that only 396, 398, 420 and 445 have been pump tested. In each case, a tested yield of the order 4 times the artesian flow was obtained, and the artesian flow was reported to return to normal after up to a few days recovery. No artesian bore-holes in this area have ever been pressure tested. It is clear, however, that there is not necessarily any close correspondence in water levels between the artesian bore-holes and neighbouring springs and bore-holes.

At the sites of several of these artesian bore-holes, especially the stronger ones (e.g. 404, 419 and 420) there are indications of fracturing of brecciation in the T.M.S. quartzite and of black Fe/Mn oxide deposits. Bh 432 at Rooiklip is drilled on a brecciated zone in white quartzite dipping steeply southwards.

The reason why there is so much variation in the strength in the yield of these bore-holes, for instance, why drilling at Posthoudersklоof and Vaaldraai has failed to meet with the same degree of success as at Georgida and Rooiklip, is not clear. It can only be suggested that water bearing fractures and fissures have been opened up more widely in certain places then in others. At Posthoudersklоof, water is highly acid and precipitates much iron oxide material - possibly such excessive iron oxide deposition may cause clogging of the fractures and fissures at depth.

On farms Modderfontein in Ghwarriepoort, it is noted that while the fractured quartzite in the vicinity of artesian bore-hole 409 is white and only slightly ferruginised, as also near bore-holes 413 and 414 at Keurfontein, the quartzite in the vicinity of bore-hole 405 is highly brecciated and ferruginised. This brecciated quartzite is not unlike that observed adjacent to the Cango Fault at Wanhoop and it is possible that there has, in the vicinity of Bh 405, been considerable fault displacement, possibly with impregnation of disintegrated shale material.

In most of the artesian bore-holes drilled, artesian flow has been shown to increase with depth. During the drilling of bore-hole 419 at Georgida, the owner, Mr. H.S. Loock kept a record of artesian flows from the bore-hole at various stages of drilling. This is shown on figure 2. Figure 2 also shows results of drilling at bore-hole 420, and illustrates the different ground-water conditions which may be encountered by drilling in T.M.S. quartzite in places only 1,3 m (4 feet) apart.

The artesian flow from all the bore-holes in this area is reported to have remained constant since the bore-holes were drilled, in some cases for periods exceeding 10 years. Siphoned flows are also reported to be constant except in so far as the flow may be reduced due to dogging of pipes with iron oxide deposits, necessitating cleaning out from time to time.

Quality of water struck at different depths may vary. This has been noted by Mr. D.E. Barkhuysen of farm Rooiklip. At bore-hole 432, he noted that water struck at higher levels was acid, bitter to taste and highly corrosive, while the water struck at 140 m depth was fresh and the flow was stronger. He remedied this by inserting 138 m of casing and separating the fresh water from the acid water struck at higher levels. (Ref. figure 3).

Bore-holes drilled in 'Q' or Bokkeveld formations or Enon Conglomerate close on the south side of the Cango Fault east of Vlakteplaas have been unsuccessful.

In Baviaanskloof, bore-hole 523, drilled on the north side of the Baviaanskloof Fault, is the only one which has been successful. Other similarly situated bore-holes, (527, 528, 530 and 534) gave small yields only.

(c) <u>Drilling in T.M.S. boundary and fault zones south of the Cango Fault and Baviaanskloof Fault</u>

Investigation of ground water conditions in areas well to the south of the Cango Fault zone was not a primary object of the present survey and is far from complete. In view of the fact that results of drilling along the Cango Fault zone between Hooks and Toorwaterpoort have proved disappointing and reports of successful drilling in certain areas further south, mainly in T.M.S. boundary and fault zones, were obtained, certain localities were investigated. Results of drilling, where obtained, are given in the latter sections of Tables 3 to 6. Only a very general description is attempted here.

The T.M.S. boundary zones are located on the flanks of subsidiary anticlinoria south of the Cango and Baviaanskloof fault zones which bring the T.M.S. formation to the surface. (See p. 16). On the northern side of these anticlinoria, the sequence appears to be normal and unfaulted, though, especially from Calitzdorp eastwards, the strata may be overturned, (e.g. N side of Kammanassieberg). On the southern side of these anticlinoria, faulting even if of a minor nature, along E-W fractures is often observed or suspected, e.g. at Studtis (Baviaanskloof), Caledons Kloof (W of Calitzdorp), and Rietfontein (S side of Touwsberg).

In general, success in drilling can be said to be more consistent than along the Cango Fault zone but this may be due to the fact that the T.M.S. boundary zone south of the Olifants River is more extensive between Calitzdorp and Vlakteplaas and is often more easily accessible for drilling. It is noted too, that water from bore-holes is commonly warmer in these T.M.S. boundary zones (20-25°C) than in the Cango Fault zone and Swartberg Mountains (17-19°C).

Localities where abundant supplies of ground water are available appear to be somewhat limited in extent. These localities include:-

1. The Fountains - E of Ladismith.
2. Doringkloof - Opsoek, N of Van Wyksdorp.
   (Other localities also reported E of Van Wyksdorp).
3. Danielskraal - SW of Calitzdorp.
4. Warmwater - SE of Calitzdorp.
5. Jan Fourieskraal - E of Warmwater.
6. Kandelaars River area - S of Oudtshoorn - (details being obtained on independent investigation).
7. E of Dysseldorp - strong water supplies obtained from Enon conglomerates overlying T.M.S. and lower Bokkeveld formations.
8. Kleinplaas - Buffelsklip - N side of Kammanasieberg.
9. Keurfontein - Die Tuine - S of Barandas.
10. Studtis - Baviaanskloof (on minor fault).

Moderately successful bore-holes have been drilled along intervening areas in the T.M.S. boundary zones, but it may be noted that, for instance at Opsoek (E of Zoar), bore-hole 59 was dry and Bh 60 yielded only 4500 l/h, also that on farm Boerbonefontein, N.W. of Van Wyksdorp, 80 bore-holes were drilled unsuccessfully (details not investigated).

At Warmwater, the owner, Mr. H.E. Meiring, pointed out that drilling east of the hot spring had been unsuccessful while on the west side, several successful bore-holes have been drilled, though it seems to be purely a matter of chance as to whether the bore-holes so drilled will strike water which is strong or weak, warm or cold, fresh or brack, or even dry. Since most of these bore-holes are drilled in lower Bokkeveld shale, there are no clear geological criteria for selection of sites. It would seem that success depends on striking water bearing fissure in the formations penetrated. (See above pp. 28-29).

At many of these localites, black Fe/Mn oxide deposits, similar to those observed near to the hot springs, occur. These deposits, as mentioned above, (pp. 26-28) are believed by the writer to be indicative of mineralised water at depth, the Fe/Mn oxides being brought up in solution from rocks of the upper T.M.S. quartzites immediately overlying the upper shale band. The prescence of these deposits is, however, no indication of the strength of flow of underground water below or of the depth which it would be necessary to drill. These deposits are observed veining rocks as high as the 4th shale in the Bokkeveld formation. It may be noted, though, that bore-holes drilled in the 4th shale where Fe/Mn deposits occur, e.g. south of Barandas, often give better yields of water of better quality than in normally obtained from this horizon.

In Kandelaars River area, where strong, though sometimes slightly brackish water is encountered, Bokkeveld shales are impregnated with calcareous veins.

In places where there are several bore-holes drilled close together in localities 1 to 10, data in the tables shows that there is often no close correspondence of water levels in bore-holes or levels of springs in the vicinity, though there is some indication of a gradient corresponding broadly to the ground topography.

(d) Bore-holes in Cretaceous Deposits

In general, bore-holes drilled in Cretaceous Deposits, whether of the Enon Stage or Wood Beds Stage, have been unsuccessful. Exceptions include:-

1. In Enon conglomerates east of Dysseldorp, where they overlie T.M.S. and lower Bokkeveld formations at shallow depth.
2. In Enon conglomerates and W.B.S. south of Oudtshoorn (Ref. Whittingham 1970c) where slightly brackish water is obtained from several strong yielding bore-holes. These

supplies may be associated with the strong water supplies obtained from Bokkeveld shales in Kandelaars River area to the south-west.

3. North of Oudtshoorn, in the vicinity of Riempie Motel and Caves Motel, in rocks of W.B.S. formation. The source of slightly brackish water in the strong yielding bore-holes here is uncertain but it is possible that the Cretaceous deposits may be directly underlain by T.M.S. quartzite as is implied in the interpretation of the seismic survey.

4. On the south side of Vlakteplaas farm, in W.B.S. formation. Bore-holes 274, 275 and 281, giving strong yields of slightly brackish water are situated in this area.

D. Conclusions and Recommendations

In view of results of drilling for water in the Cango and Baviaanskloof Fault zones (tabulated above) and considerations outlined in the foregoing sections, it is concluded that, except possibly in the immediate vicinity of Toorwater hot spring, drilling on these faults is most unlikely to give successful results. (i.e. steady yields of the order 20 000 l/h or more).

Success in drilling for ground water in the vicinity of these major fault zones has been achieved in places where it is possible to drill in suitably fractured, brecciated, or fissured rock formations (T.M.S. quartzite, uppermost T.M.S. sandstones, or basal Bokkeveld shales) at distances sufficiently north of the fault, away from where the incompetent formations (chiefly shales) have disintegrated in the fault zone. This is possible in parts of Ladismith District and Uniondale District but often, in these districts and Willowmore District, the steep topography immediately north of the fault prohibits access to suitable drilling sites. In Calitzdorp and Oudtshoorn District, except possibly at Kweekraal where limestones of the Cango Formation adjoin the Cango Fault on the north side, the formations on either side of the fault (upper Cango and Bokkeveld formation) are poor aquifers - T.M.S. quartzite, where it occurs, is insufficiently developed to be expected to hold large reserves of ground water.

A greater measure of success has been obtained in drilling in places well to the south of the Cango Fault zone. (Except in the case of Bh 543 south of Studtis, conditions in Baviaanskloof are virtually unknown since most successful bore-holes there are shallow ones drilled in alluvial gravels - not described in this report). This is especially noticeable in the area east of Seven Weeks Poort and may be due to the fact that T.M.S. boundary zones crop out more extensively and are more readily accessible for drilling than to the north of the Cango Fault. It is noted, however, that even in areas to the south of the Cango Fault, areas where strong supplies of ground water are obtainable appear to be limited and such supplies probably depend upon the extent to which the formations are fissured.

Strong water supplies have also been obtained by drilling in Cretaceous sediments in certain areas, notably in the vicinity of Oudtshoorn. The reason for occurrences, of strong water is not clear and may be attributable to sub-Cretaceous geological factors. Such water is usually brackish to varying degrees and while it can be used for irrigation (chiefly for lucerne), is not suitable for domestic use.

In order to investigate further the possibilities of obtaining quantities of ground water adequate for irrigation or domestic supplies, it is recommended that drilling be attempted in the following places:-

1. North of the Cango and Baviaanskloof Fault Zones -

   (a) Ladismith District - Farms Die Poort, Van Zylsdamme, Byvangerskloof and Voorbaat, in uppermost T.M.S. and basal Bokkeveld formations. Also possibilities at Knuyswagendrif and Hoeks might be further investigated.

   (b) Calitzdorp District - Farm Kweekraal, in limestones of the Cango Formation. It would be advisable not to be over-optimistic about possibilities here.

   (c) Oudtshoorn District - Only drilling in limestones of the lower Cango Formation or along the T.M.S. boundary following the southern Swartberg escarpment can be suggested. Also, over-optimism is not recommended.

(d) Uniondale and Willowmore Districts - in T.M.S. or lower Bokkeveld formations. It would appear that most suitable sites which are accessible have already been drilled. There are possibilities for further development in Ghwarriepoort. Extensive drilling near Toorwater hot spring is not recommended since the flow of the spring would probably be adversely affected. (There is little demand for large supplies of ground water here).

In upper Baviaanskloof, only drilling on suitably fractured T.M.S. quartzite in Nuwekloof can be suggested.

2. South of Cango Fault zone.

There appears to be much wider scope for drilling in this area. T.M.S. quartzite outcrops and T.M.S. boundary zones are widely exposed in southern Ladismith District and in Calitzdorp, Oudtshoorn and Uniondale Districts south of the Olifants River. It is recommended that further geological and geohydrological survey work be carried out in this area and suitable sites selected for deep drilling. Such a survey is being commenced in the Kandelaars Rivier and Dysseldorp areas (Oudtshoorn District), Three sites (G. 26322, 23, 24) have been marked on farm Wanhoop (Ref. Whittingham 1971b)(Uniondale District). In Baviaanskloof, a similar survey might profitably be carried out south of Baviaanskloof River.

Deep drilling in Cretaceous sediments, even in areas where strong water supplies are known to exist, is not recommended. It is anticipated that it would be necessary to seal off brackish water encountered in these sediments and the cost of bore-hole casing would prove excessive.

Geological Survey,
Pretoria.

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Appendix

Formation of Enon Conglomerate by rock-break process as a result of Compression along the Cango Fault zone. (Ref. Folder 1)

This process is suggested as a possible means by which the fragmental material contained in the Enon Conglomerates formed, giving consideration to the writer's view that at the beginning of Cretaceous times, the Cango Fault plane (and possibly associated faults, such as the Baviaanskloof fault) was reversed in attitude and that compression caused high angle thrust movements along it at that time. Reasons for this are outlined in the main report to which this is appended. (pp. 20-22).

The rock break process is understood to be caused by internal stresses in the rock due to static pressures of overburden. When pressure is released on one face of the rock, as exposed by stoping in deep mine workings, rock may break off the face without external inducement.

It is argued that if tectonic compressive forces act upon consolidated rock, a similar process would be expected if stresses are not released by extensive horizontal movement as would be the case with a low angle thrust.

In the case of a high angle thrust, such as the Cango Fault is inferred to have been, any tendency for horizontal movement would be impeded and the internal stresses in the rock would remain so long as compression forces were operative. These stresses would be of a far higher order to those due to static overburden pressure in deep mines.

Rock break would tend to take place in the direction of least pressure. This would be off the ground surface. Hence in this process, rock fragments would tend to shoot vertically off the ground surface, landing under gravity more or less whence they came, but with different orientation.

The deposit so formed would, axcept in geological boundary zones, consist exclusively of fragments of the formation directly underneath.

Size of fragments would depend on the nature of the rock, i.e. hard rocks, such as quartzite, would tend to form a relatively small number of large fragments, whereas more fissile rocks, such as shale would tend to form a much vaster number of small chips.

As is indicated on Folder 1, erosion of the overthrust (northern) block took place contemperareously with compression and fragments would be transported over the lower (southern) block. Hence after the initial stage, rock break material over the lower block would be mixed with transported fragments from the overthrust block.

Over the lower block, fragmentary material may have reached such a thickness as to form a blanket over the consolidated formation underneath, preventing the rock break process from continuing even though compressive forces were still active.

Over the overthrust block, since fragmentary material was eroded away, the rock break process would have continued as long as compressive forces operated. Hence the later deposits over the lower block would consist exclusively of transported material derived from the overthrust block.

Provided the process or erosion continued, after compression forces had ceased to operate, any fragmentary material would be eroded away from the overthrust block and deposited over the lower block.