# FISSURE ZONES AND UNDERGROUND-WATER

# IN PARTS OF CAPE PROVINCE.

## A REVIEW

by

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## A. Hydrology

### 1. General concepts

Fissures may be defined as fractures of partings (bedding planes, joints, faults, clearages) in consolidated or semi-consolidated rocks which are permanently open, thereby facilitating the passage of fluids through the rock formation in which they occur.

The fissures may follow special structural features, such as highly fractured or brecciated zones in hard rocks (e.g. T.M. quartzite) or contacts of minor intrusive bodies (dykes or sills), but this is not necessarily, and very often not, so. The prime requisite for the occurrence of fissures or fissure zones is a state of low compression or, locally, tension, within the rock formations in which they occur (Olivier 1970).

Normal fractures are, to a greater or lesser degree, open up to a certain critical depth, below which they become tightly closed due to:-

(i) static pressure of overburden and/or

(ii) non-infiltration of surface weathering agents.

In the case of dolerite dyke margins (following pre-existing fractures), the critical depth is estimated to be of the order 100 m, and fractures such as these may be opened up by weathering to depths of the order 60 m. (Van Wyk, 1963, Vegter and Ellis 1968).

Fissures, on the other hand, are open to considerably greater depths than 100 m allowing deep percolation and circulation of underground-water in them. Evidence for existence of deep open fissures are -

(i) high temperatures of water from thermal springs (See )

(ii) metallic oxide deposits associated with water emanating from fissures, derived from rock formations at depth, (see p. )

(iii) striking of strong ground-water supplies in certain boreholes at depths well below 100 m ( sometimes 300 m or more), which may be well above normal ground-water temperature (see p. )

At Shaft 2 headings in the Orange—Fish Tunnel 120 m below ground-level, Olivier (1970) observed steeply dipping fissures 1 - 3 cm in width and (at the point from which the headings were flooded) a horizontal fissure, following a bedding plane above tunnel soffit, about 15 cm in width. Olivier also observed that in the Shaft 2 headings, dolerite dyke contacts were highly permeable at 120 m below ground-level but not elsewhere in Inlet and Shaft 1 headings which are at shallower depth. The fissures appear to be restricted to Shaft 2 headings (along the line of the Roodewal—Bapsfontein—Aliwal North hot springs) and occur, not only along dolerite dyke contacts but also in the normally impermeable mudstones and sandstones of the Beaufort Group.

The Shaft 2 headings is one of the few places, perhaps the only place, in the Cape and Karoo regions where open fissures can be observed at depth. Further, there is no place known to the writer where fissures can be observed at the surface. Their existence can, however, be inferred from the occurrence of:-

(i) constant-flowing springs and seepages which appear to flow independantly of rainfall. (Springs may be thermal or of normal groundwater temperature). (See p. )

(ii) strong, consistently-yielding water boreholes, often drilled into rock formations which would normally be regarded as poor aquifers. (See pp. )

(iii) Fe/Mn oxide and lime deposits, believed to be deposited from colloidal solution, and derived from rock formations at depths. (See p. ). Also pseudocoal with lime in Karoo terrain (Haughton *et al* 1953).

(iv) elongate patches or lines of evergreen bushes in arid country such as the Great Karoo. (Rossouw, personal communication)

(Fringing vegatation along seasonal water-course excluded).

Cavern systems in the Cango Valley, Oudtshoorn District, (Ref. Rossouw *et al*, 1964, Taljaard and De Wet, 1961, pp. 78-82), appear to be related to fracture zones in limestone striking south of east and dipping 40 - 50°S. These cavern systems are commonly regarded as joint systems which have been opened up by solution in circulation of ground-water, but it could be suggested that the "joints" may have been open fissures.

In places where the existence of fissures is inferred, it is observed that the rocks are not highly folded. Dips are frequently gentle and if, as in parts of Klein Swartberg Valley (Laingsburg District) steep flexures occur, they are usually monoclinal (Whittingham, 1972b). It would appear that zones of low compression or tension in which fissure zones occur lie within zones which underwent low tectonic compression during the last period of folding. (The Cape Folding in the Cape and Karoo regions).

## 2. Characteristics of fissure zone aquifers

Fissuring in rock formations which would, hydrogeologically, normally be regarded as poor aquifers, may render much formations highly permeable, capable of yielding strong, consistent water supplies from permanent springs or boreholes. Examples from the Western Cape Province include:-

| | Group/Formation | Rock types | Example/Localities |
| --- | --- | --- | --- |
| | Pre-Cape | Slates and arenaceous rocks | Breërivier<br>Brandwag (Worcester)<br>Matjiesrivier (Oudtshoorn) |
| Cape | Table Mountain | Unbrecciated and slightly fractured quartzite | South of Calitzdorp<br>East of Dysseldorp<br>Georgida (Ghwarriepoort) |
| | Bokkeveld | Shales and sandstones | South of Oudtshoorn<br>Klein Swartberg Valley<br>Koo & Keisies Valley<br>Buyspoort (Willowmore) |
| Karoo | Beaufort | Mudstones and sandstones (away from dyke contacts) | Orange—Fish Tunnel<br>(Shaft 2 headings) |
| | Cretaceous | Mudstones and sandstones | Oudtshoorn |

Strong water supplies from boreholes and from permanent springs (thermal or cold) commonly occur in the uppermost quartzite of the Table Mountain Group and lowest Bokkeveld Group, to the extent that this boundary zone is commonly regarded as a good potential aquifer. In this boundary zone, strong fracturing and, quite frequently, brecciation, are observed. On the other hand, strong water supplies may be strictly localised and strength may vary considerably from borehole to borehole. In other areas, this boundary zone, sometimes even where it is highly fractured or brecciated may, for no clear hydrogeological reason, give disappointingly low yields of water.

Water Supplies from T.M./Bokkeveld Boundary Zone

| Example<br>High-yielding localities | Example<br>Low-yielding localites |
|---|---|
| Brandvlei - Goudini (Worcester) | Klein Swartberg Valley (Laingsburg) |
| Hex River Valley - northern side (Worcester) | (especially on Koueveld Not Seven Weeks Poort) |
| Barrydale - Warmwaterberg (Swellendam) | Opsoek (E of Ladismith) |
| Montagu | S & SW of Oudtshoorn |
| Fountains (E of Ladismith) | Boerbonefontein (SE of Ladismith) |
| Van Wyksdorp (Ladismith) | |
| Warmwater (Calitzdorp) | |
| E of Dysseldorp (Oudtshoorn) | |
| Die Tuine (Uniondale) | |
| Van Zylsdamme - Voorbaat (Ladismith) | |
| Georgida - Ghwarriepoort (Willowmore) | |
| Napier (Bredasdorp) | |

It seems that the localisation of strong ground-water supplies is controlled by a factor which cannot be discerned readily by geological examination, namely, the degree of fissuring, determined by the size and frequency of occurrence of the fissures in a given locality.

In Klein Swartberg Valley, for instance, it is inferred that the degree of fissuring is higher in the 3rd/4th Bokkeveld shale outcrops then in the lowest Bokkeveld formations since the strongest water supplies are obtained in the former formations.

Strength of ground-water supplies may also be diminished if fissures become constricted by excessive deposition of metallic oxides or lime. Deposition of these oxides may depend on the acidity of the water which, in the southern Cape, is very variable.

In areas where artesian water is struck, e.g. Georgida, it is probable that fissures were completely closed by deposition of metallic oxides near the surface, thereby forming a confining layer.

## 3. Vertical and horizontal extent of fissure zones

Deposits of oxides, usually of iron or manganese, together with calcium carbonate, commonly occur in the vicinity of springs and in areas where strong boreholes have been drilled. These oxides occur as veins within the consolidated rocks or veneers over the rock surface, occasionally as layered surface deposits. Sometimes, they may be impregnated into superficial sand, silt and gravel deposits.

This material would appear to have been brought up in colloidal solution by ground-water emanating from formations at depth. Taljaard and De Wet (1961, p. 76) have noted the occurrence of these oxides and consider that the iron/manganese oxides have formed by oxidation of iron pyrites which is commonly disseminated in brecciated and fractured zones in the Cape formations. Such oxidation releases sulphur to combine and dissolve in ground-water as $SO_2$ and $H_2S$. This would account for the occurrence of some of the iron oxides and sulphuretted waters and to this extent, this explanation is accepted. The occurrence of manganese oxides and calcium carbonate is not, however, explained and it would seem that these are more likely to be derived from primary sources in the sedimentary formations. Likely sources of these oxides are:-

(i) Fe/Mn oxides - from lowest members of the upper quartzites of the Table Mountain Group, above the upper shale horizon, in which the oxides are disseminated. (Suggested by Toerien).

These oxides occur in slates of the Klipheuwel formation north of Worcester.

(ii) Calcium carbonate - a likely source is somewhat speculative but limestones and basic eruptive rocks of Pre-Cape Formations are suggested. It seems unlikely that this material is of surface derivation since driller Hayes of Oudtshoorn has reported calcium carbonate in Bokkeveld shale at depths of 100 m or more. (Ref. Whittingham, 1971, 1972a).

If these sources are correct, it would indicate that fissures must extend deep into the rock formations of the Cape and upper Precambrian groups.

The lateral and longitudinal extent of fissure zones is not determined but there is evidence that zones in which rocks are fissured to a greater or lesser degree are many kilometers in length. The fissure zone of Klein Swartberg Valley is at least 35 km in length from east to west and at least 4 km broad from north to south - the zone of intense fissuring, following the outcrops of 3rd and 4th Bokkeveld shale is 1 - 2 km broad. The fissure zone of Roodewal—Badsfontein—Aliwal North, in which water at all the major springs and in the Orange—Fish Tunnel at shaft 2 stands at an altitude of about 1310 m A.M.S.L., is at least 110 km in length from east to west.

All fissure zones in the Great and Little Karoo appear to be elongated east-west, parallel to the Cape Fold Belt.

The depth to which fissures penetrate is less certain but in the writer's view, <u>fractures</u> may be expected to extend for the same order of depth into the earth as they can be traced lengthwise at the earth's surface i.e. fractures which are appreciably more than 30 km in length may be expected to extend right through the earth's crust (30 km depth). In the case of open fissures and fissure zones, it can only be suggested that, provided conditions of low tectonic compression or tension persist at depth, there is no reason why fissure zones should not extend deep into, or right through the earth's crust.

## 4. Fissure pattern

The attitude of fissures within the fissure zones can only be determined by tunnelling, shaft sinking or careful core-drilling.

In Orange—Fish Tunnel, steep dipping E-W striking, and horizontal fissures were observed in Shaft 2 headings.

From information given on 2 boreholes situated 1 m apart at Georgida, by the owner Mr. J.C. Loock, it was estimated, from depths at which strong water was struck in these boreholes, that the fissures there dip 80 to 85 degrees south.

From present information, it is suggested that the fissures form a complex boxwork pattern with a preponderance of steeply dipping fissures running parallel to the fissure zone. There are indications also, as at Shaft 2 headings in Orange—Fish Tunnel, that low-dipping fissures parallel to bedding planes, although less numerous than steep dipping fissures, may be broader.

Boxwork patterns of iron oxide mineralisation in highly fractured quartzites, such as observed along the sea shore at Onrust River (Caledon) may be illustrative of the postulated boxwork pattern of fissures.

## 5. Criteria for borehole site selection in fissure zones

Since fissures are not normally exposed at the ground surface and there is no geophysical method which can be envisaged to detect their presence, there is always an element of chance in selection of borehole sites for water in fissure zones.

There is no guarantee that a borehole drilled, say, to 120 m will strike water-bearing fissures, but areas can be delineated where it can be advised that chances of encountering water-bearing fissures by drilling to a certain depth are good.

The following criteria may be used as guides to the possibilities for drilling for water-bearing fissures in a given area:-

(i) Constant flowing springs or seepages (hot or cold). The quality of water at such springs may also be taken as a guide to the quality of water to be expected from boreholes drilled in the vicinity.

(ii) Existing strong-yielding boreholes which may or may not be artesian.

(iii) Veins, veneers, or surface deposits of oxides of iron and manganese or calcium carbonate. Such deposits indicate that water has infiltrated through fissures in the rocks but give no indication of the strength or quality of the water, or the depth at which it would be encountered.

(iv) Underground disappearence of strong flowing surface waters over abnormally short distances.

(v) Underground leakage of storage dams which are founded on solid shale formation. This leakage may be reflected by fluctuation of water-levels in neighbouring boreholes according to the level of water in the dam.

(vi) Mutual effect on water-levels and yields of boreholes in a given vicinity, especially where the rock formation is one which would normally be considered a poor aquifer (e.g. Bokkeveld shale, Malmesbury slate).

## B. Geohidrology

### 1. Groundwater-level

Ground-water fills the fissures in the fissure zones up to or near the ground surface and, presumably extends downwards into the earth's crust to the full depth of the fissures.

The former fact is illustrated by:-

(i) the occurrence of constant-flowing springs (hot or cold) which usually emerge at low-lying places - or plains, at the base of escarpments, or in valleys,

(ii) the fact that in boreholes drilled into fissure zones in places of relatively low elevation, the natural rest water-level usually lies within 20 m of the surface, in some boreholes, there is artesian flow.

While the groundwater-level generally reflects the topography, lying deeper in elevated places than in depression, this is not always the case. In some instances, it appears that valleys have been incised below the groundwater-level without encountering fissures in the valley floor, so that springs may emerge at elevated places on the valley flanks at points where fissures do reach the ground surface. Examples include -

(i) Buffelsfontein, 4 km north of Van Wyksdorp (80 $m^3/h$).
(ii) Aristata spring, Seven Weeks Poort, Ladismith (8 $m^3/h$).
(iii) Badsfontein springs near Venterstad (45 $m^3/h$).

While it is unusual for major fissures to be missed by valley incision in this way, such a phenomenon is quite common in the case of minor fissures so that minor springs and seepages may occur at elevated positions on valley flanks or escarpments maintaining a small, but nevertheless constant, flow, e.g. southern flank of Bosluiskloof north of Seven Weeks Poort.

## 2. Springs

Springs represent the natural overflow of water stored in fissure zones and emerge at points where the ground surface intersects the groundwater-level.

Their rate of flow would depend on -

(i) the ground-water gradient in the vicinity of the spring.

(ii) the size and concentration of fissures in the vicinity.

The flow of these springs is reported to be constant, apparently independant of rainfall.

Natural fluctuations in the rate of low, permanently or temporarily, due to earth disturbance, e.g. the Boland earthquake of 1969. In the case of most of the strong springs and all the thermal springs known, such a fluctuation was temporary and springs reverted to their normal flow after 2 to 3 months. Since water-levels in boreholes drilled in fissure zones commonly show semi-diurnal (tidal) fluctuations, usually very slight, it is to be expected that flow of springs in fissure zones would be subject to very slight, if even discernable, semi-diurnal fluctuations also (see section B. 3 below).

Flow of springs may be artificially reduced or stopped by pumping from boreholes in the vicinity which encounter the same fissures. Flow recovers strength when pumping is stopped and may return to natural strength if pumping is suspended for a sufficiently long period.

Flow of springs may be reduced or stopped by the drilling of boreholes in the vicinity, and such changes will be permanent as long as the artesian boreholes flow.

Several reportedly constant-flowing springs emerge from near the junction between Neogene deposits and older consolidated formations, e.g. Stanford (Caledon), Die Kelders (Caledon), Silwerstroom (Malmesbury). Such springs, if they do indeed maintain a constant flow independent of rainfall, may well originate from fissures in the older consolidated formation (usually Cape or pre-Cape). The water would in this event flow along the base of the Neogene deposits, which are not fissured, to emerge from the nearest available outlet.

Natural disappearence of surface water underground, along abnormally short stretches of a water-course, may also indicate fissuring. Such disappearences could be compared to those which occur much more markedly in cavernous limestone (karst) or lava terrain. Such disappearences would normally occur:-

(i) where there are irregularities in the gradient of the water-course.

(ii) at the foot of a hill range where the gradient of the water-course is relatively steep but groundwater-level would correspond to the topographical plain level at the foot of the hills.

These disappearences may or may not re-emerge as springs at a lower level of the water-course.

## 3. Boreholes

As mentioned in section 1, boreholes drilled in any consolidated rock formation which strike water in fissures may be strong yielding and, whatever depth the fissures are struck, the water-level will tend to rise close to usually within 20 m of the ground surface, and are sometimes artesian.

The following general characters of boreholes drilled in fissure zones are noteworthy:-

(i) Boreholes in close proximity may strike fissures at greatly differing depths but the RWL is the sam (e.g. at Georgida).

(ii) In an immediate locality, some boreholes encountering fissures may be strong yielding, others mediocre, and others (which do not happen to encounter fissures, dry (e.g. grout boreholes drilled near Shaft 2 inflow, Orange—Fish Tunnel).

(iii) Boreholes at a given locality may not only vary in strength (as in (ii)) but water may vary in temperature or quality according to which fissures are struck in the formation (e.g. Warmwater, Calitzdorp).

(iv) At a given locality, while water-levels in boreholes generally correspond to the topography, water-levels in strong yielding boreholes usually (but not always) stand higher than in the mediocre boreholes.

(v) As a borehole is drilled deeper and encounters fresh fissures, the rest water-level usually rises and may become artesian. In some cases, but far less commonly, the rest water-level may fall when new fissures are struck at depth - this may indicate that certain fissures are isolated from the water-bearing fissures and remain void until connected to the latter by drilling.

(vi) When a number of boreholes are drilled in fissure zones in the same vicinity, some may intersect the same fissures and there may be a mutual effect on the water-level and yielding capacity. This effect would vary:-

(a) directly, according to the degree of fissuring in the locality,

(b) inversely, according to the strength of the groundwater supplies in the fissure zone.

Thus the mutual effect of pumping neighbouring boreholes would be most marked in fissure zones of medium water supply potential (see p.      below).

Artesian flow occurs in boreholes in fissure zones where -

(i) the borehole encounters fissures which do not reach the surface (usually in deep boreholes).

(ii) the borehole encounters fissures which are sealed near the surface, usually by Fe/Mn oxides, thereby confining the water therein,

The normal "water-level" in an artesian borehole may be indicated by springs or seepages situated above the borehole elevation, which cease to flow when the artesian flow from the borehole commences. (e.g. Slypsteenberg, Toorwater, Georgida, Uniondale District). This shows that the springs and seepages are connected to the same fissures as are encountered by the artesian borehole.

Strength of water in boreholes and consistency of yield would depend on the size and concentration of fissures struck e.g. in Klein Swartberg Valley, greater strength of boreholes on the 3rd/4th Bokkeveld shale is attributed to a higher degree of fissuring than on the 1st/2nd shale and T.M. quartzite where boreholes are generally of mediocre strength.

Natural fluctuations in water-level in boreholes occur due to:-

(i) lunar tidal effect - semi-diurnal fluctuations are commonly observed on water-level recorder charts and may vary, e.g. from 50 cm amplitude in Shaft 2 area, Orange—Fish Tunnel to 1 - 2 cm amplitude in Klein Swartberg Valley;

(ii) earths disturbance, e.g. the Boland earthquake of 1969. In Boland area and in the Little Karoo west of Ladismith, variations in water-level were observed and in some cases reported to be permanent. Rise in water-level is accompanied by a higher yielding capacity while a fall in water-level is accompanied by a reduced yield. Conversely, it may reasonably be suggested here that excessive disturbance of the groundwater regime by pumping may be a contributary, if not a prime cause of the earthquakes;

(iii) rainfall. This is discussed hereunder.

When boreholes are pumped, the drawdown for a given pumping rate will vary inversely according to the yielding capacity. Falls in water-level primarily due to lack of rainfall are not observed since during dry periods, boreholes are usually pumped. Recovery will take place due to -

(i) stoppage of pumping and replenishment from water stored in the fissure zone; (Subterranean recharge).

(ii) meteoric recharge due to rainfall and infiltration of surface water.

The relative importance of these two factors in recharge is often difficult to assess, though at Klein Swartberg Valley, in 1972, recovery during the dry winter appeared to be due mainly to the former. At Badsfontein, during the 1969 - 1970 drought, a virtually 100 per cent recovery due to subterranean recharge was noted. During the period of flooding in Shaft 2 headings (Orange—Fish Tunnel), water-level at the Badsfontein boreholes dropped 4 - 5 m and recovered to normal as the shaft filled up. These boreholes have been pumped (some with centrifugal pumps) through long drought periods for 15 years or more without any noticeable fall in water-level or drop in yield - this shows that recovery after pumping is immediate and virtually independant of rainfall. (Maximum drawdown during pumping is 3 - 4 m only). (Whittingham, 1970). This topic is discussed further below. (Section B4, pp. ).

### 4. Movement of ground-water in fissure zones

Following the evidence outlined in the foregoing sections, indicating that fissure zones may penetrate to great depth in the earth's crust and that water is stored in them to such depth, it is appropriate to consider how the fissures become filled with water and what happens subsequently.

Water in fissure zones could originate from -

(i) entirely meteoric sources. This would mean that the fissures were filled up from surface inflow during the period immediately after they were opened up. Such water would have remained stored in the fissure zones ever since. Some fissures which are sealed off from the ground surface would remain void;

(ii) partly meteoric and partly juvenile sources;

(iii) partly connate sources. This could occur if -

(a) water squeezed out of sediments during consolidation was stored at depth prior to the fissuring;

(b) fissuring took place penecontemporaneously with consolidation and water was squeezed out of the sediments directly into the fissures.

If, however, heating accompanied consolidation, the salts could feasibly remain disseminated in the sediments when water was squeezed out.

Since earth temperatures increase with depth, water perculating to great depth must become heated.

In the case of a free body of ground-water, such as might be stored in a large volcanic vent, free convection would take place and the water would reach the surface at a temperature of 100°C, and a geyser would result. In the case of fissure zones, it is here argued that either -

(i) the fissures, although open, are too constructed or too sparce to allow convection of water stored in the fissure zone; or

(ii) water tending to rise upwards under convection in fissures cannot rise rapidly enough, due to constriction or sparseness of the fissures, to maintain the heat gained at depth. Consequently the rising water would cool off but, at any given level in the fissure zone would have a temperature higher than the earth temperature at that level. Since circulation of ground-water must be maintained, some fissures must contain descending water where the water temperature would be lower than the corresponding earth temperature at any given depth.

Whichever of these concepts is preferred, the overall effect would be the same. The water in a fissure zone would become progressively warmer according to the geothermal gradient and at great depth, under high hydrostatic pressure, could become superheated above 100°C.

The inpairment of convection in fissure zones could conceivably cause a reactive upward pressure to be set up, which could in itself be sufficient to maintain the water-level near the surface.

If fissures become abnormally enlarged, convection may take place to a limited extent. Where such fissures reach the ground surface, a thermal spring would occur.

The Table Mountain quartzites, being a rigid formation are more amendable to local development of large fissures than the less competent associated formations. Thus it can be explained why thermal springs in western and southern Cape Province commonly occur at the foot of mountain ranges formed of T.M. quartzite. The enlarged fissures would deliver thermal water through the quartzite under the mountain, to emerge at the lowest point where they reach the ground surface, usually close to the foot of the mountain. (Where the mountains are anticlinal, these localities commonly coincide with the T.M./Bokkeveld boundary zone).

The groundwater-level in fissure zones may be maintained by -

(i) Hydrostatic adjustment - replenishment by infiltration of water of meteoric origin; (Water-table) and/or

(ii) subterranean pressure which is sufficient to hold the groundwater near surface level, kept more or less constant by outflow from constantly flowing springs, seepages, and artesian boreholes. (Piezometric surface). The subterranean pressure could be tectonic or, alternatively could be simply a reactive pressure set up due to heating of water at depth (see above).

Evidence in favour of subterranean pressure is as follows -

(i) Many springs in fissure zone areas, whether strong or weak, hot or cold, fresh or brackish, and even small seepages are reported to flow constantly whether under conditions of heavy rainfall or prolonged drought. Flows appear to be affected only by pumping from neighbouring boreholes, outflow from nearby artesian boreholes, or by earthquakes.

(ii) Water-levels in strong yielding boreholes appear to be higher than those in mediocre or low yielding boreholes in the same vicinity. This may indicate that in large fissures, water rises higher under the same pressure than in small fissures. (A good example is at Die Tuine north of Uniondale).

(iii) 100 per cent recovery of water-level took place in boreholes near Orange—Fish Tunnel Shaft 2 under severe drought conditions following the lowering of water-level connected with the flooding of Shaft 2. (See above).

Following the Boland earthquake of 1969, the yield of strong water sources (hot springs and strong boreholes) in the Boland and Western Karoo fluctuated noticeably but reverted to normal after a 2 - 3 month period. A similar effect was observed at Badsfontein spring (Venterstad) in 1956 following a local earthquake. In mediocre or low yielding sources, the change (for better or worse) was more prolonged, if not permanent.

This would indicate that narrow fissures can more readily be opened or closed up to produce a noticeable effect on the flow of water than the larger fissures.

Regarding the possibility of hydrostatic adjustment, it is observed that water-levels in boreholes in fissure zones recover following rainfall, when streams flow and dams are filled. It is difficult, however, to determine to what extent this recovery is due to meteoric recharge and how far it is due to reduction or stoppage of pumping.

It is suggested that the relative importance of meteoric and subterranean recharge depends on the readiness with which meteoric water can be distributed through the fissure zone. Where there is a low degree of fissuring or where fissure zones are of limited extent, distribution of meteoric water would be limited and recharge may be appreciable. Such recharge would quickly be lost after rain ceases and pumping recommences.

Where there is a high degree of fissuring or where a fissure zone is very extensive (e.g. the Roodewal—Badsfontein—Aliwal North zone), any meteoric water entering the zone would be rapidly distributed over the whole zone and meteoric recharge would appear negligible.

To give a more definite determination of the relative importance of meteoric and subterranean recharge, continued observations on fissure zone water supplies, e.g. at Klein Swartberg Valley would be necessary. It would also be advantageous to gauge some of the "constant" flowing springs and artesian boreholes by means of permanent, automatically recording gauging veins to find how constant these flows really are.

## 5. Water Quality

Water obtained from fissure zones in quartzites of the Table Mountain group is normally fresh.

In shale/sandstone formations of the Bokkeveld group or in pre-Cape groups, water is commonly brackish, salts being derived from the shale formations. Water from strong-yielding boreholes is usually of better quality than from low-yielding boreholes in the same vicinity.

Water is usually acid, often corrosive to steal piping. Water is also commonly sulphuretted, but this is not always noticeable.

Quality of water may deteriorate as a result of excessive pumping of boreholes.

## 6. Water Potential

The ground-water potential in fissure zones depends on -

(i) degree of fissuring - breadth, extent and density of fissures within the fissure zone;

(ii) extent of the fissure zone.

Continued observations on individual areas are necessary to enable any reasonable estimate of the water potential of fissure zones. For the time being, a threefold classification can be made with regard, to the effect of pumping over a prolonged drought period in the fissure zones.

(i) High Potential - Water-levels and yields appear to be completely unaffected by continued heavy, even excessive pumping. Recovery at the end of the drought period is complete and almost immediate. Quality of water does not noticeably deteriorate, e.g. Badsfontein (Venterstad), Kandelaars River (Oudtshoorn). High yielding boreholes situated in close proximity and encountering the same fissures may be pumped together without any considerable, if even noticeable, effect on each other's yielding capacity although a mutual drawdown in water-level is evident.

(ii) Medium Potential - Water-levels fall noticeably and yields may drop with heavy pumping, but after a period of, say, 3 - 4 months of normal rainfall, conditions return to normal. Quality of water may deteriorate but improves after the rest period (e.g. 3rd/4th shale zone in Klein Swartberg Valley. The Fountains near Ladismith). High yielding boreholes which encounter the same fissures cannot be pumped together without considerable adverse effect on each other's yielding capacity.

It is possible that excessive pumping may convert a zone of low potential. This may have already happened in some areas, (e.g. parts of Hex River Valley).

(iii) Low Potential - Water-levels fall rapidly after pumping commences and yields fall off perhaps to $\frac{1}{2}/\frac{1}{3}$ normal yield during a pumping season. Quality may noticeably deteriorate. Recovery after a 3 - 4 months period of normal rain may be incomplete.

If boreholes are pumped excessively, fall in water-level, yielding capacity, and deterioration in quality could be permanent, (e.g. 1st/2nd shale zones in Klein Swartbergs Valley).

It is not clear at this stage as to whether excessive pumping from zones of high/medium potential can affect neighbouring zones of medium/low potential but such possibilities should not be ruled out.

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# Appendix

## Possible means of illustrating heating of water in fissure zones

Referring to the accompanying diagram -

1. Fissured plastic block should be rigid, heat resistant, but not brittle. Fissures should be, on average, about $\frac{1}{8}$" in width and should form a boxwork pattern.

It would probably be necessary to construct the boxwork first from material which can be dissolved in water or melted by mild heating. The thermometers would be mounted in the boxwork.

The plastic material would them be moulded around the boxwork. The boxwork material would then be dissolved or melted out leaving voids with thermometers mounted therein.

One thermometer would be mounted in the space between the plastic block and the steel plate.

The steel plate is intended to hold the plastic block in position at the top of the concrete container and the metal cover to prevent gushing out of water exceeded under pressure.

2. The voids in the fissured plastic material and the space between the plastic block and the steel plate should be filled with cold water. To achieve the proper effect, it would probably be necessary to fill the apparatus slowly, maintaining a temperature approaching 100$^{o}$C in the space above the steel plate so that the water entering this space becomes heated while that passing through the fissures remains cool.

3. Strong heat should be applied to the steel plate, and experiment continued until it can be discerned -

(a) whether or not convection takes place freely in the fissures.

(b) whether or not the water below the fissured plastic block becomes superheated above 100°C.

This apparatus would allow only a very imperfect simulation of conditions actually pertaining in a natural fissure zone. In the first place, the initial "geothermal gradient" would be much higher.

Nevertheless, some indication of the effect of heating water, whose upward flow under convection becomes constricted, may be obtained.

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