

# The relationship between the geology and the groundwater quality of the Great Fish River catchment north of Kommadagga

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## Abstract

The Great Fish River Basin is underlain mainly by sedimentary rocks of the Karoo Sequence. About two thirds of the area is underlain by rocks of the Beaufort Group whilst rocks of the Koonap Formation, Ecca Group and Dwyka Formation occur in the south. Dolerite in the form of sills and dykes has intruded the sedimentary strata of the Beaufort Group. Although the interaction of several factors is responsible for the quality of the groundwater in the area, only the relationship between the different geological units and the groundwater quality is discussed.

High salinities caused mainly by high concentrations of  $\text{Na}^+$  and  $\text{Cl}^-$  are encountered in the groundwater of the lower stratigraphic units of the sequence. These conditions are believed to have been caused by diagenetic processes together with the normal processes involved when percolating groundwater reaches stagnation. The groundwater in the upper units of the sequence is relatively fresh and contains mainly  $\text{Mg}^{++}$ ,  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$ . It is inferred that rock weathering played a greater role here than in the lower units.

## Introduction

The chemical quality of groundwater in an area is influenced by several factors which mainly include the geology, topography and climate. Where an area such as that under discussion is underlain by different geological strata, one may expect some variation in the groundwater quality as a result thereof. An attempt is made in the paper to outline some of the chemical features of the groundwater occurring in the different strata.

The locality of the area in review is presented in Fig. 1. This area is underlain by rocks of the Karoo Sequence of which the Beaufort Group is represented over more than two thirds of the total area. A semi arid climate prevails here with an average annual precipitation of 440 mm, whilst the evaporation rate exceeds the rate of precipitation throughout the year.

## Geology and groundwater quality – a general background

The various chemical and physical factors influencing the quality of groundwater in the area have been discussed extensively by Tordiffe (1978). Rock weathering as a result of the chemical reaction between circulating groundwater and the minerals constituting the surrounding rocks, may be regarded as one of the main geological factors influencing the quality of the water. During such reactions some of the elements contained in the rock-forming minerals are released to solution, thereby changing the chemical composition of the water. Chebotarev (1955a) is of the opinion that the proportion and type of soluble matter which is taken up from the rock-material depends on –

- the type of geological formation;
- the structural features of the area;
- the temperature of the water;
- the salinity concentration and the abundance of particular ions and compounds in the water;

- the amount of water moving through the particular rock-type; and
- the velocity with which the water flows through the rock.

Hem (1970) points out that the main cations which occur in groundwater are derived mainly from the solution of minerals during chemical weathering, whilst the anions may be derived mainly from non-lithologic sources. The dolerite in the study area is more susceptible to chemical attack by the prevailing atmospheric agents than the sedimentary rocks. Cations such as  $\text{Ca}^{++}$ ,  $\text{Na}^+$  and  $\text{Mg}^{++}$  are released into solution as a result of the weathering of plagioclase and pyroxene, which constitute the main mineral assemblage of the dolerite.

The sedimentary rocks contain resistant primary minerals

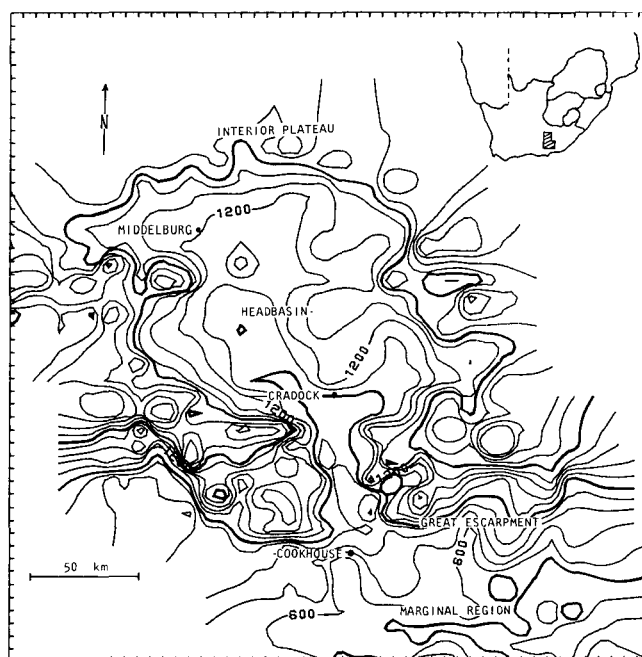


Figure 1  
Locality map of the Great Fish River Catchment, illustrating the four main topographic regions.

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which may undergo weathering under the present environmental conditions. It must, however, be borne in mind that such minerals have already endured at least one and in some case two cycles of weathering and will therefore not be readily decomposed by the weathering agents. The precipitation of cementing materials or the solution thereof in the sedimentary rocks cause a marked change in the quality of the groundwater. Such cementing materials may include calcium carbonate, silica and ferric hydroxide or ferrous carbonate.

Ion-exchange is another factor which may be responsible for a major change in the chemical quality of the groundwater in the area. Argillaceous sediments in particular, which are deposited in a marine environment will naturally have  $\text{Na}^+$  as the main adsorbed cation. Once such sediments are exposed to the atmosphere where meteoric water rich in  $\text{Ca}^{++}$  can percolate through them, the adsorbed  $\text{Na}^+$  is readily exchanged for  $\text{Ca}^{++}$ , thus rendering the remaining groundwater rich in  $\text{Na}^+$ .

Disseminated pyrite may occur within sedimentary rocks deposited under reducing conditions, but will on exposure to the atmosphere oxidise to hematite or other ferric hydroxides, whilst sulphate is released into solution. Many oxidised remnants of pyrite are found in such sediments in the study area. Biological reactions responsible for the reduction of the sulphate concentration in groundwater are discussed by Lawrence (1975).

Water is not easily transmitted through the sedimentary rocks of the study area because of their low porosity and permeability. Especially in the case of the fine-grained mudrock, connate water, which was entrapped during the deposition of the sediment, is able to remain there for a considerable length of time. Such waters are found to be highly saline (Hem, 1970) and may have a great influence on the groundwater quality of the area. This is especially true where marine deposits are encountered.

Chebotarev (1955b) points out that while groundwater is not fully saturated, it cannot remain unchanged in chemical composition as long as it is in contact with rocks containing soluble material.

## Geology of the area

The geology of the area has been described by Tordiffe (1978). The stratigraphic subdivision of the Karoo Sequence, which underlies the area under discussion is presented in Fig. 2. Sills and dykes of dolerite which are not presented in the above figure have, however, intruded the sedimentary strata.

### Dwyka Formation

The base of the Karoo Sequence in the area is represented by 680 m of tillite and associated shale of the Dwyka Formation. All indications show that this material was deposited from floating ice in deep marine water. As a result of the Cape Orogeny these strata are extremely folded and dips of up to  $60^\circ$  are encountered.

### The Ecca Group

Resting conformably on the tillite, is a sequence of 2 340 m of shale and dark grey to grey sandstone of the Ecca Group. Kingsley (1977) is of the opinion that most of the material of this group was deposited as turbidite fan complexes on the basin floor, on the slope and on the "shelf" of the Karoo Basin.

		MEMBER	FORMATION	GROUP	
ENVIRONMENT OF DEPOSITION	CONTINENTAL		Burgersdorp	BEAUFORT	KAROO SEQUENCE
			Katberg		
		Elandsberg	Balfour		
		Barberskrans			
		Daggaboersnek			
	Oudeberg	Middleton			
	TRANSITIONAL (DELTAIC)		Koonap	ECCA	
MARINE		Dwyka			

Figure 2  
The stratigraphic subdivision of the Karoo Sequence in the Great Fish River Catchment.

### Koonap Formation

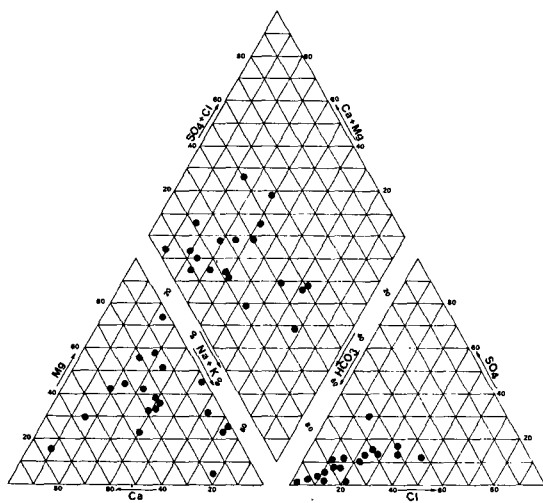
Above the deposits of the Ecca Group follows a 980 m sequence of sedimentary rocks which represents a transition from marine sediments to fluvial sediments. This Koonap Formation is distinguished from the underlying Ecca Group by the conspicuous number of sandstone beds which grade upwards into fine-grained siltstone and mudstone.

### Beaufort Group

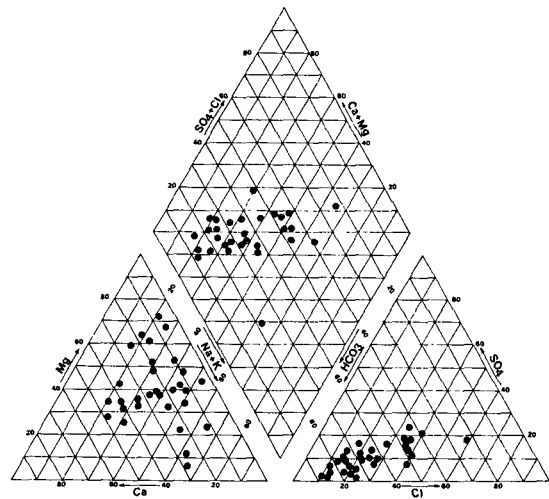
A sequence of 4 500 m of alternating fine-grained lithofeldspathic sandstone and mudrock lithosomes of varying thickness follows conformably on the Koonap Formation. The sandstone/mudrock cycles have a fining-upward trend and display features which are generally considered to be characteristic of fluvial deposits. This Beaufort Group, which represents the largest part of the area, may on lithological grounds be subdivided from bottom to top into the Middleton, Balfour, Katberg and Burgersdorp Formations.

The predominantly grey and bluish rocks of the Middleton and especially the Balfour Formations due to the relative absence of red mudstone, are believed to have been deposited under reducing conditions whilst red mudstones in the Katberg and Burgersdorp Formations indicate oxidizing conditions.

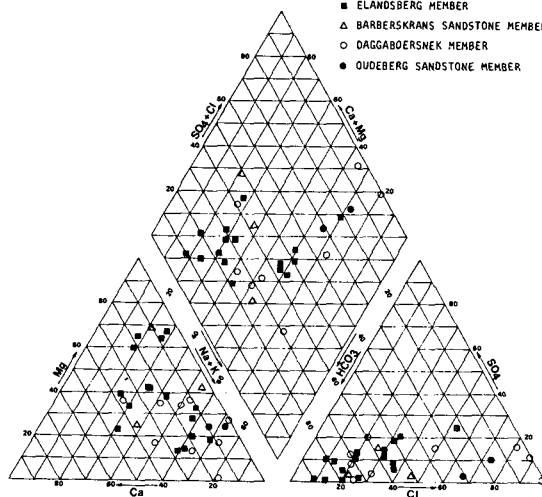
The Balfour Formation is subdivided into the Oudeberg Sandstone, Daggaboersnek, Barberskrans Sandstone and Elands-



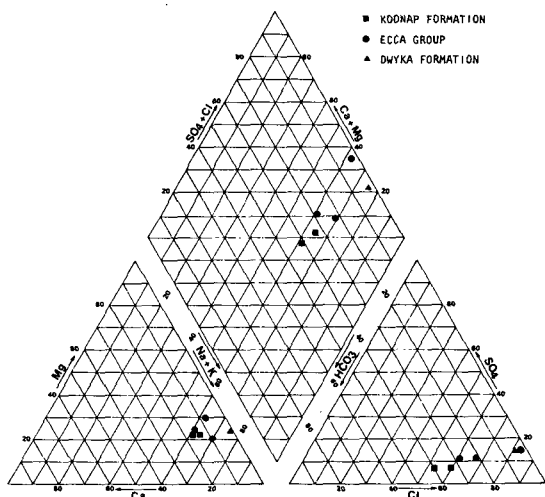
**A**  
BURGERSDORP FORMATION



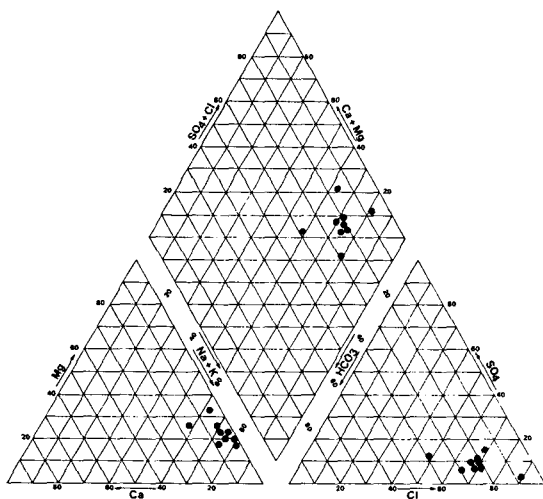
**B**  
KATBERG FORMATION



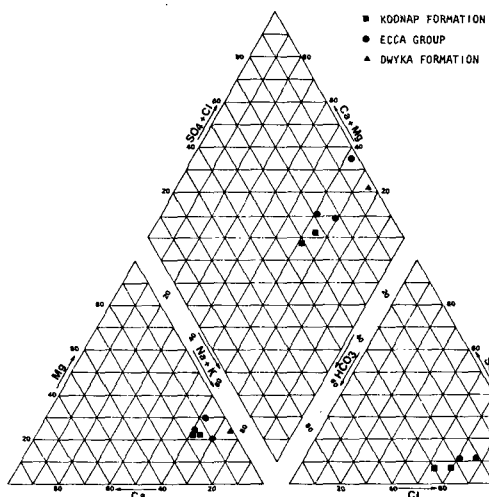
**C**  
BALFOUR FORMATION



**E**



**D**  
MIDDLETON FORMATION



*Figure 3*  
*Piper-Palmer trilinear diagrams of the cation and anion percentages in the groundwater of the various stratigraphic units in the Great Fish River Catchment.*

berg Members. Both the Daggaboersnek and Elandsberg Members are distinguished from the other two on account of their argillaceous nature. Johnson (1976) is of the opinion that certain features of the Daggaboersnek Member indicate the deposition of this unit in a fairly extensive inland sea or lake.

### Karoo Dolerite

Intrusive in the sedimentary strata of the Beaufort Group are numerous dykes and sills of Karoo dolerite. This rock-type varies from fine to medium grained and consists of minerals such as pyroxene, plagioclase and olivine.

### Groundwater

The sampling procedure and chemical analysis of the groundwater samples for this investigation are described by Tordiffe and Botha (1981). The results presented in Fig. 3 have been arranged in such a manner that they represent the various rock units as discussed above.

### Groundwater quality of the Dwyka Formation, Ecça Group and Koonap Formation

Due to the very steep dip of the Dwyka Formation outcrops are limited to only a narrow zone in the south of the study area, with the result that only one groundwater sample on the selected sampling grid was obtained. Boreholes in this formation are furthermore relatively sparse, because of the high salinity of the groundwater encountered therein. For similar reasons very few groundwater samples were obtained from the Ecça Group and the Koonap Formation.

Although no meaningful conclusions can be drawn from such sparse data (particularly from the individual units), it was, however, felt that for comparative purposes the chemical data of the groundwater samples from the above three units be discussed here (Fig. 3 E).

The total dissolved solids in the sample from the Dwyka Formation are extremely high in comparison with the rest of the groundwater in the area, while  $\text{Na}^+$  and  $\text{Cl}^-$  constitute the main ions. Groundwater quality of this nature may, however, be attributed to several factors such as the mobility of the chemical elements, the hydrodynamic conditions in the subsurface reservoir, as well as the local geochemical environment of the area (Chebotarev, 1955b). It is therefore deduced that the following factors are the main cause of the high salinity of the groundwater in the Dwyka Formation of the area:

- The influence of saline connate water of marine origin.
- The poor groundwater drainage in the tillite due to its low porosity and permeability and to the fact that this unit occurs in the Marginal Region which has low relief.
- The weathering of rock fragments in the tillite.
- Possible atmospheric fall-out.

Bond (1946) points out that the Dwyka tillite contains more fresh and decomposable primary rock material than any other rock unit in the Karoo Sequence.

Barret *et al.* (1976) also point out that pore water in tillite from Antarctica is as saline and in places more saline than present day sea water.

The salinity of the three samples from the Ecça Group is

generally slightly lower than in the previous one, although  $\text{Na}^+$  and  $\text{Cl}^-$  still remain the dominant ions. According to Fig. 3E the groundwater of the Ecça Group has a higher  $\text{HCO}_3^-$  percentage than the groundwater of the underlying Dwyka Formation.

Because of the insufficient samples from these strata, this trend cannot be accepted with absolute certainty. By comparing these results with data from the overlying Koonap Formation there is no doubt that the chloride-content decreases in the groundwater toward the upper strata. Fig. 4 shows that the increase in  $\text{HCO}_3^-$  percentage is not necessarily due to an increase in the  $\text{HCO}_3^-$ -concentration, but rather due to a decrease in the  $\text{Cl}^-$  concentration.

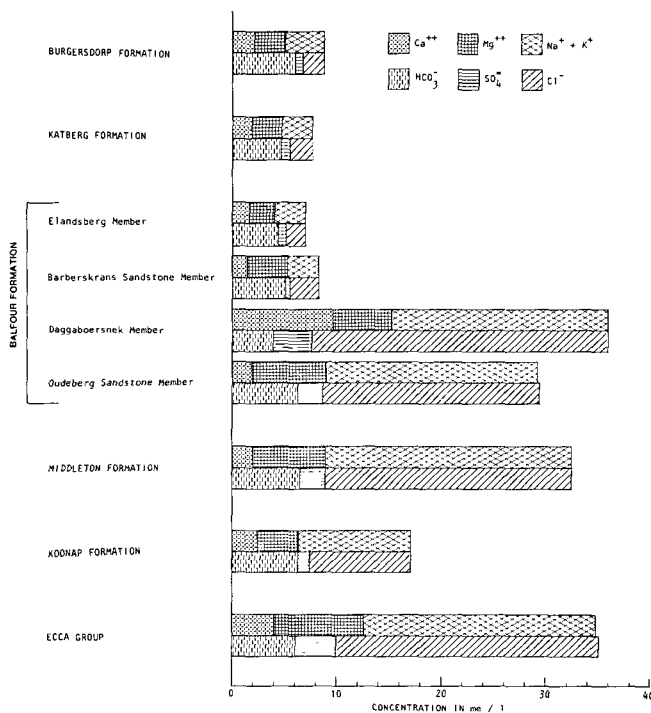


Figure 4  
Mean concentrations of the various ions in the groundwater from the different stratigraphic units in the Great Fish River Catchment (1 me = 1 mmol charge)

Such a trend would suggest that  $\text{Cl}^-$  filtration occurred during the upward migration of the connate water as a result of the compaction of the underlying sediments (Tordiffe, 1978).

According to Fig. 4 the mean concentration of total dissolved substances in the groundwater of the Koonap Formation is considerably lower than that in the groundwater of the underlying Ecça Group. Should connate water be regarded as the main factor influencing the quality of the groundwater in all three the stratigraphic units mentioned, the lower salinity concentrations in the Koonap Formation must then indicate a different depositional environment. This conclusion corresponds with geological observations which were discussed previously.

The relative ratios of the major cations in the groundwater of the Dwyka Formation, the Ecça Group and the Koonap Formation remain constant between the limits:  $\text{Na}^+ + \text{K}^+ = 60$  to 80 per cent,  $\text{Ca}^{++} = 0$  to 20 per cent and  $\text{Mg}^{++} = 20$  to 30 per cent (Fig. 3E), although the actual concentration of these ions varies greatly. This indicates that chemical weathering which is mainly responsible for the concentration of cations in the groundwater, is

probably not the main factor influencing the groundwater quality in these units.

The influence of topography on the quality of this water must never be ruled out completely, as outcrops of this group occur within the Marginal Region (Fig. 1) where drainage is poor and stagnant conditions may prevail (Tordiffe and Botha, 1981).

### Groundwater quality of the Middleton Formation

The mean salinity concentration of the groundwater in the Middleton Formation is much higher than that in the underlying Koonap Formation (Fig. 4). This increase is due mainly to an increase in the  $\text{Na}^+$  and  $\text{Cl}^-$ -concentrations and compares well with the concentrations in the groundwater of the Eccla Group.

It must be noted that due to insufficient samples from the Koonap Formation no accurate comparison between the two formations can be made. According to Fig. 3D the groundwater in the Middleton Formation is dominated by  $\text{Na}^+$  and  $\text{Cl}^-$ , which

coincides with the "stagnant waters" described by Johnson (1974). These samples differ from those of the underlying strata in that slightly higher values of  $\text{Na}^+$  (70 to 80 per cent), together with lower values of  $\text{Ca}^{++}$  (0 to 10 per cent) are encountered. The  $\text{Mg}^{++}$  percentages remain the same. This phenomenon is attributed to the exchange of  $\text{Na}^+$ , (adsorbed by the sediment) for  $\text{Ca}^{++}$  in the groundwater which is preferentially adsorbed.

The anion percentages of the groundwater in this formation do not vary greatly. There is, however, a higher percentage of  $\text{Cl}^-$  in these waters than in those of the underlying Koonap Formation.

It is therefore deduced that factors other than the upwards migration and anion filtration of the connate water, which is assumed for the underlying strata, were responsible for the groundwater quality of this unit. Should the process of  $\text{Cl}^-$  filtration have continued from the Koonap to the Middleton Formation, lower chloride percentages than those observed in Fig. 3D would be encountered. This does not imply that the upward migration of connate water did not continue into the Middleton Formation, but rather that other factors responsible for the con-

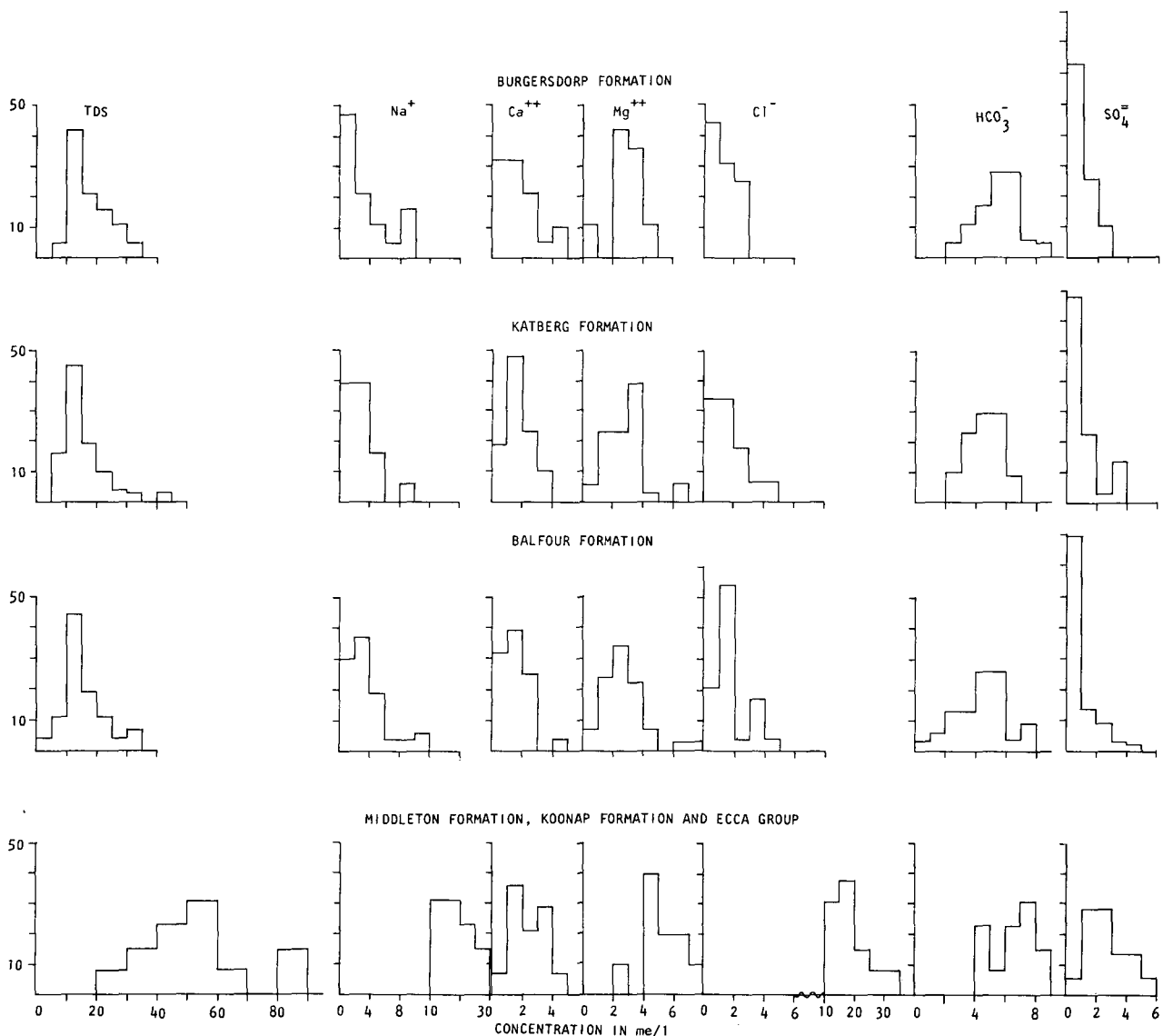


Figure 5  
Histograms of the concentration (me/l) of the various ions in the groundwater from the different stratigraphic units in the Great Fish River Catchment (1 me = 1 mmol charge)

centration of  $\text{Cl}^-$  become more dominant in this unit.

The higher  $\text{Cl}^-$  content of the groundwater of this formation is therefore attributed merely to a change from a bicarbonate character to a chloride character (Johnson, 1974) as the water gradually progresses through the basin. Further indications of this is the decrease in the  $\text{Ca}^{++}$  in relation to the  $\text{Na}^+$  percentages, as discussed previously.

The influence of topography on the groundwater quality is expected to be uniform throughout the strata which has thus far been discussed, because of the fact that outcrops of the various units occur within the Marginal Region (Fig. 1) (Tordiffe and Botha, 1981).

All differences encountered in this area may therefore be attributed largely to various geological factors. The exception, however, is the Middleton Formation which lies closest to the Great Escarpment (Fig. 1) from which percolating groundwaters change in chemical composition as they reach the low-lying parts towards the south.

Data obtained from the chemical analyses of the groundwater samples from the Ecca Group and from the Koonap and Middleton Formation were grouped together in order to compile the histograms presented in Fig. 5. This was done because no sensible pattern could be obtained for each individual unit (because of the few samples available). According to this figure the salinity concentration of the groundwater of these lower units is much higher than that of the units higher up in the sequence. This is due mainly to higher  $\text{Na}^+$  and  $\text{Cl}^-$  concentrations of which the equivalent concentrations fall within the same range. Magnesium concentrations remain relatively constant. The higher  $\text{SO}_4^{--}$  concentrations encountered in these strata may be attributed to the oxidation of pyrite.

#### Groundwater quality of the Balfour Formation

Bond (1946) remarked on the high salinity of the groundwater arising in the lower beds of the Beaufort Group and also on the chloride character of these waters. He states, however, that no appreciable difference in quality between the groundwater of the Ecca Group and the Lower Beaufort is present.

According to Fig. 4 the chloride-rich water with high salinity occurs only as high as the Daggaboersnek Member. The high percentages of sodium and chloride in the groundwater of the Oudeberg Sandstone and Daggaboersnek Members are also illustrated in Fig. 3C. The fact that the samples from the Oudeberg Sandstone Member and the Middleton Formation plot in the same area on the diamond of Figs. 3C and 3D proves that the same factors were responsible for the groundwater quality of these waters.

The variation in groundwater quality of the Daggaboersnek Member requires some discussion. According to Fig. 3C the samples vary from groundwater rich in  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{HCO}_3^-$  to water containing mainly  $\text{Na}^+$  and  $\text{HCO}_3^-$  and finally to water with a sodium chloride character. This trend corresponds with the normal chemical cycle of groundwater as described by Johnson (1974). It therefore appears that the Daggaboersnek Member contains recently recharged, dynamic underflow, as well as stagnant groundwater. The high salinity of some of these samples, may, however, suggest saline connate water entrapped in the sedimentary rocks of this member. This is in accordance with deposition in a brackish lacustrine environment.

In the Barberskrans Sandstone Member the groundwater is much less saline than in the underlying strata and contains mainly  $\text{Mg}^{++}$ ,  $\text{Ca}^{++}$  and  $\text{HCO}_3^-$  as the major ions (Fig. 3C and 4). Such characteristics, according to Johnson (1974), represent

recently recharged groundwater. Another observation (Fig. 4) is that the mean  $\text{SO}_4^{--}$  concentration in this water is much lower than that of the underlying strata. This suggests that the reducing conditions, which are responsible for producing pyrite in the sediments, were not as prevalent during the deposition of this unit.

The groundwater of the Elandsberg Member is mainly of the magnesium-calcium-bicarbonate type, although a few samples reveal a sodium-bicarbonate character (Fig. 3C). According to Fig. 4 the mean salinity of this water is relatively low and one may consider it also to represent recently recharged meteoric water.

The groundwater of the Balfour Formation may therefore be subdivided into two groups, *viz.*

- the highly saline water of the Oudeberg Sandstone and Daggaboersnek Members, with a predominantly sodium-chloride character and corresponding well with the stagnant groundwater of the underlying Middleton Formation; and
- the relatively fresh water of the Barberskrans Sandstone and Elandsberg members, with a predominantly magnesium-calcium-bicarbonate character.

Apart from the main division between  $\text{Cl}^-$  and  $\text{HCO}_3^-$  water (Fig. 3C), there appears to be very little variation in the anion percentages in the groundwater of the Balfour Formation. The cation percentages, however, vary considerably i.e. from  $\text{Na}^+$  to  $\text{Mg}^{++}$  rich water, while none of the samples contain more than 50 per cent  $\text{Ca}^{++}$  of the total cations. This observation is contrary to Bond's (1946) statement that there is almost invariably more calcium than magnesium in the groundwater of the Lower Beaufort Beds.

If the conclusion of Hem (1970) that the cation concentration in groundwater is controlled mainly by the solution of minerals in rocks is correct, then the great variation in the cation percentages of these waters must be attributed to chemical weathering of the rocks in the area. In the Great Escarpment and around the outer margin of the Headbasin (Fig. 1), where most of the outcrops of this formation occur, conditions are favourable for such chemical weathering.

#### Groundwater quality of the Katberg Formation

The groundwater of the Katberg Formation, like that of the underlying Barberskrans Sandstone and Elandsberg Members, has a low salinity, with magnesium, calcium and bicarbonate as the predominant ions (Fig. 3B and 4). The anion percentages in this water vary even less than in the underlying units and only two samples contain chloride in quantities exceeding 60 per cent of the total anions (Fig. 3B).

There is, however, a large variation in the cation percentages, although  $\text{Ca}^{++}$  never exceeds 50 per cent of the total. Chemical weathering of the rocks may therefore also be attributed to this phenomenon.

#### Groundwater quality of the Burgersdorp Formation

Although there is very little difference between the groundwater quality of this formation and that of the underlying Katberg Formation, Fig. 3A reveals slightly higher bicarbonate percentages. Most of the samples also plot in the lower triangle of the diamond which, according to Johnson (1974), suggests groundwater of a dynamic basin environment. Groundwater which plots in the upper triangle represents a static environment.

It is interesting to note that a number of samples have a  $\text{NaHCO}_3$  character indicating groundwater of a dynamic underflow regime. Bond (1946) also found that many of the groundwater samples from the upper horizons of the Beaufort are rich in  $\text{Na}^+$  and  $\text{HCO}_3^-$  and attributes this fact either to the weathering of feldspar in the sandstone of this strata or to the weathering of dolerite in the area. He, however, eventually disregards the possibility of the weathering of dolerite as the cause of the high  $\text{NaHCO}_3$  content in the water, on the grounds that groundwater around such bodies contains much higher  $\text{Mg}^{++}$  than  $\text{Ca}^{++}$ . According to Bond's (1946) analyses the  $\text{Ca}^{++}$  in the groundwater is much higher than the  $\text{Mg}^{++}$  concentration. In the present study it was, however, found that in most cases magnesium prevailed over calcium and therefore the weathering of dolerite as a source of soluble  $\text{Na}^+$  cannot be ruled out. The lower calcium percentages may be attributed to the fact that this cation is more readily adsorbed by clay minerals in the sediments than are magnesium or sodium.

## Conclusion

One may conclude that the groundwater in the sequence below the Barberskrans Sandstone Member has a predominantly sodium chloride character together with a high salinity. This phenomenon is caused partly by the upward migration of saline connate water during the compaction of the sediments (the groundwaters of the Dwyka Formation, Ecca Group and Koonap Formation), while saline groundwater containing sodium and chloride as the major ions in the Middleton Formation and lower members of the Balfour Formation is the result of normal percolating meteoric waters reaching stagnant conditions. Chemical weathering of the sedimentary rocks in the lower stratigraphic units is at a minimum, hence the small variation in cation percentages.

In the upper parts of the sequence chemical weathering does occur to some extent and therefore produces the great variation in the cation percentages. The groundwater is relatively fresh and contains mainly magnesium, calcium and bicarbonate.

Although most of the above variations can be observed in Fig. 3, the decreasing trend of  $\text{SO}_4^-$  in the groundwater from the lower to the upper stratigraphic units needs special mention (Fig. 4). The stratigraphic units below the Katberg Formation were deposited mainly under reducing conditions, thus enabling pyrite to develop, which under present day oxidising conditions is able to produce  $\text{SO}_4^-$  upon weathering. The Katberg and Burgersdorp Formations were, however, deposited under oxidising conditions, which do not permit the formation of pyrite.

It must be stressed, however, that although the geology plays an important role in controlling the quality of the groundwater in the study area, this factor still remains subordinate to the influence of topography as discussed by Tordiffe and Botha (1981).

Although the influence of atmospheric fall-out cannot be ruled out completely, the distance from the coast and the existence of a relatively high mountain range between the study area and the coast make this a highly improbable factor.

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An original typed script in double spacing together with three copies should be submitted. Words normally italicized should be typed in italics or underlined. The **title** should be concise and followed by authors' names and complete addresses. A paper may be organized under main headings such as **Introduction, Experimental, Results, Discussion** (or **Results and Discussion**), **Conclusions, Acknowledgements** and **References**.

### Contents of manuscripts

The International System of Units (SI) applies. Technical and familiar abbreviations may be used, but must be defined if any doubt exists.

### Tables

Tables are numbered in arabic numerals (Table 1) and should bear a short but adequate descriptive caption. Their appropriate position in the text should be indicated.

### Illustrations and line drawings

One set of original figures and two sets of copies should accompany each submission. Photographs should be on glossy paper (half-tone illustrations should be kept to a minimum) and enlarged sufficiently to permit clear reproduction in half-tone. All illustrations, line-drawings and photographs must be fully identified on the back, numbered consecutively and be provided with descriptive captions typed on a separate sheet. Authors are requested to use proper drawing equipment for uniform lines and lettering of a size which will be clearly legible after reduction. Freehand or typewritten lettering and lines are not acceptable. The originals should be packed carefully, with cardboard backing, to avoid damage in transit.

### References

Authors are responsible for the accuracy of references. References to published literature should be quoted in the text as follows: Smith (1982) or (Smith, 1982). Where more than three authors are involved, the first author's name followed by *et al.* and the date should be used.

All references are listed alphabetically at the end of each paper and not given as footnotes. The names of all authors should be given in the list of references. Titles of journals or periodicals are abbreviated according to **Chemical Abstracts Service Source Index (Cassi)**.

Two examples of the presentation of references are the following:

Grabow, W.O.K., Coubrough, P., Nupen, E.M. and Bateman, B.W. (1984) Evaluation of coliphages as indicators of the virological quality of sewage-polluted water. *Water SA* 10(1) 7-14.

Wetzel, R.G. (1975) *Limnology*. W.B. Saunders Company, Philadelphia, p 324..