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Groundwater flow in the southern part of the Etosha basin indicated by the chemical composition of water

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ABSTRACT

The objective of this paper is to identify the pattern of groundwater flow in the southern part of the Etosha Basin in northern Namibia by using the comprehensive knowledge of the chemical composition of groundwater (spatial distribution of alkali- $[Na^+, K^+]$ and alkaline-earth ions $[Ca^{2+}, Mg^{2+}]$) in the Etosha National Park. The Etosha Basin, which extends from northern Namibia into southern Angola, is the northwestern outlier of the large inland depocentre of the Kalahari Basin. For the characterization of the groundwater chemistry, the unit referred to is the equivalent percent concentration (meq%/l).

From the Otavi Mountains with parent dolomitic rocks and calcrete in the south and west towards the center of the Etosha Basin (with saline-alkaline clastics of the Andoni Formation), a zonal decrease of alkaline-earth metals combined with a zonal increase of alkali metals is recognized. The gradual (long-distance) shift from the calcium-magnesium bicarbonate type groundwater (*Damara carbonate aquifer*) to sodium chloride type groundwater (confined portion of the *Kalahari aquifer*) is thought to reflect the groundwater flow towards northerly directions in the southern part of the Etosha Basin. Consequences for the water management in the Etosha National Park and the adjacent Owambo region are highlighted.

INTRODUCTION AND HYDROGEOLOGICAL SETTING

Water is certainly the most prominent natural resource in Namibia. Increasing expectations of an expanding local population as well as of foreign tourists in the National Parks of northern Namibia have resulted in an increasing demand on current water supply. Consequently, there is a need to locate further sources of water to satisfy future requirements (Hoad 1992).

Although detailed knowledge of the groundwater potential in northern Namibia is of particular national interest, the collection of data in a systematic fashion started in 1989. Prior to the studies of Hoad (1992), Auer (1993) and Gammer (1993), evidence of groundwater potential (and especially the groundwater quality) in the area under discussion was limited in general and evaluations were concentrated on selected aspects (Huyser 1979, 1980a, 1980b; Winter 1975, 1976, 1978; Winter & Venter 1978; Winter & Huyser 1979; Winter *et al.* 1976).

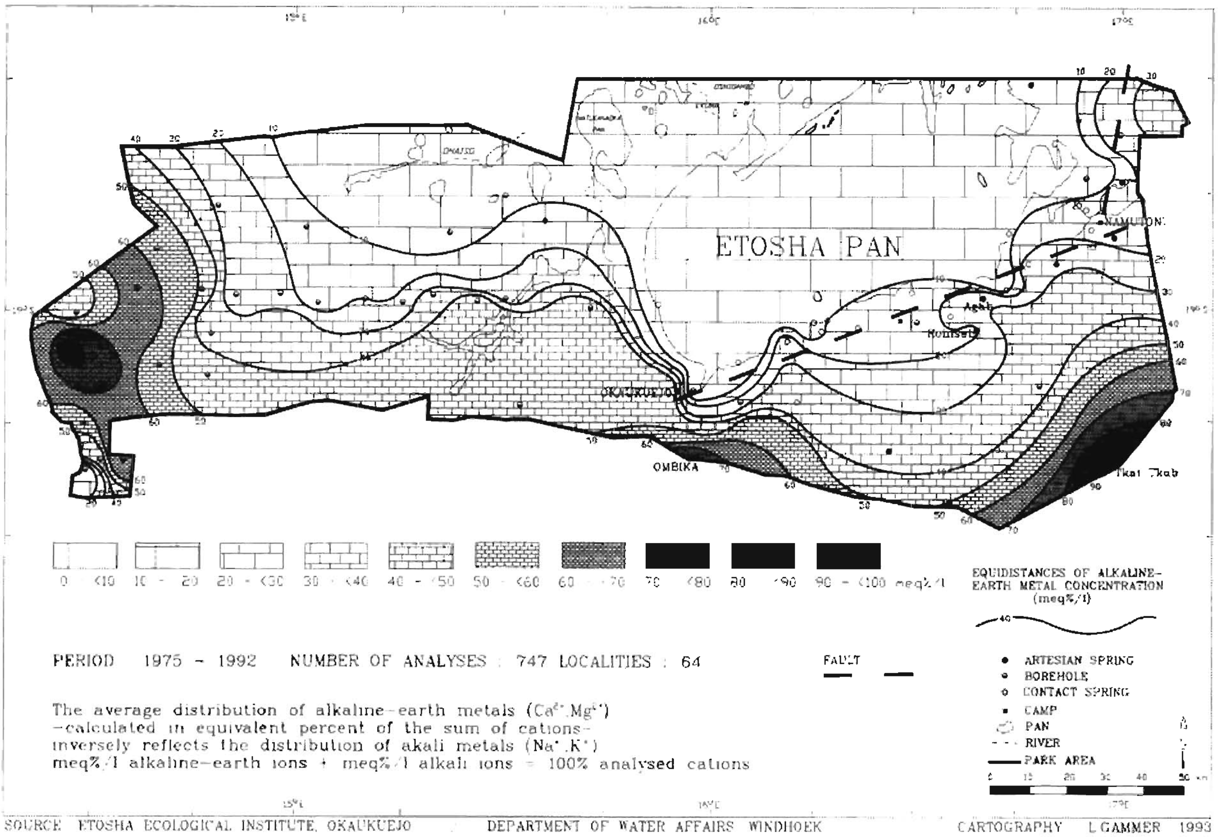
Nevertheless, a large number of water samples from more than 100 localities in the Etosha National Park have been collected and analysed since 1964. Unfortunately, these data were not evaluated systematically. Within the framework of a Research-Cooperation Project between the University of Regensburg/Federal Republic of Germany and the Etosha Ecological Institute/Republic of Namibia, these data, together with additional chemical water analyses from 1980 to 1992, have been computerized, and thus provided a reasonable basis for evaluations of the chemical water quality and the chemical water composition (Auer 1993, Gammer 1993).

During the last six years research on the groundwater potential in northern Namibia concentrated on the location of aquifers, including informations on recharge characteristics, groundwater flow directions and resulting water quality. The objective of this paper is to use the comprehensive knowledge of the chemical composition of groundwater in order to identify the pattern of groundwater flow in the southern part of the Etosha Basin. The Etosha Basin, which extends from northern Namibia into southern Angola, is the northwestern outlier of the large inland depocentre of the Kalahari Basin (for details on the geological history of the Etosha Basin, see Buch & Trippner 1997 and Buch 1997).

THE PERCENTAGE IONIC COMPOSITION AS AN INDICATION OF THE FLOW OF GROUNDWATER

The equivalent percent concentration (meq%/l) is regarded as an adequate way of representing water analysis results across the Etosha area, especially with regard to the type of water in hydrogeological terms (Hölting 1974). Water samples from specific localities have often been taken from different sampling points like borehole outlet, trough or mudhole, which are affected in various degrees by animals, evaporation and soil. In some cases there are drastic variations in the amount of dissolved solids. Evaporation affects the absolute mass-, molar-, and equivalent concentration, but does not change the relative ionic composition.

Variations in water composition occurs over a relatively narrow range, so that in general, data of the equivalent percent concentration (meq%/l) are quite reliable (Auer



PERIOD 1975 - 1992 NUMBER OF ANALYSES : 747 LOCALITIES : 64

The average distribution of alkaline-earth metals (Ca^{2+}, Mg^{2+}) -calculated in equivalent percent of the sum of cations- inversely reflects the distribution of akali metals (Na^{+}, K^{+})
meq%/l alkaline-earth ions + meq%/l alkali ions = 100% analysed cations

SOURCE ETOSHA ECOLOGICAL INSTITUTE, OKAUKUEJO DEPARTMENT OF WATER AFFAIRS WINDHOEK CARTOGRAPHY L.GAMMER 1993

FIGURE 1: Mean percentage distribution of alkaline-earth metals in the Etosha National Park.

1993, Gammer 1993). Across all localities, the average standard deviation of *alkali* (*Na^+ and K^+*) and *alkaline-earth metal* (*Ca^{2+} and Mg^{2+}*) concentration is 4,6 meq%/l, with the median at 3,0 meq%/l.

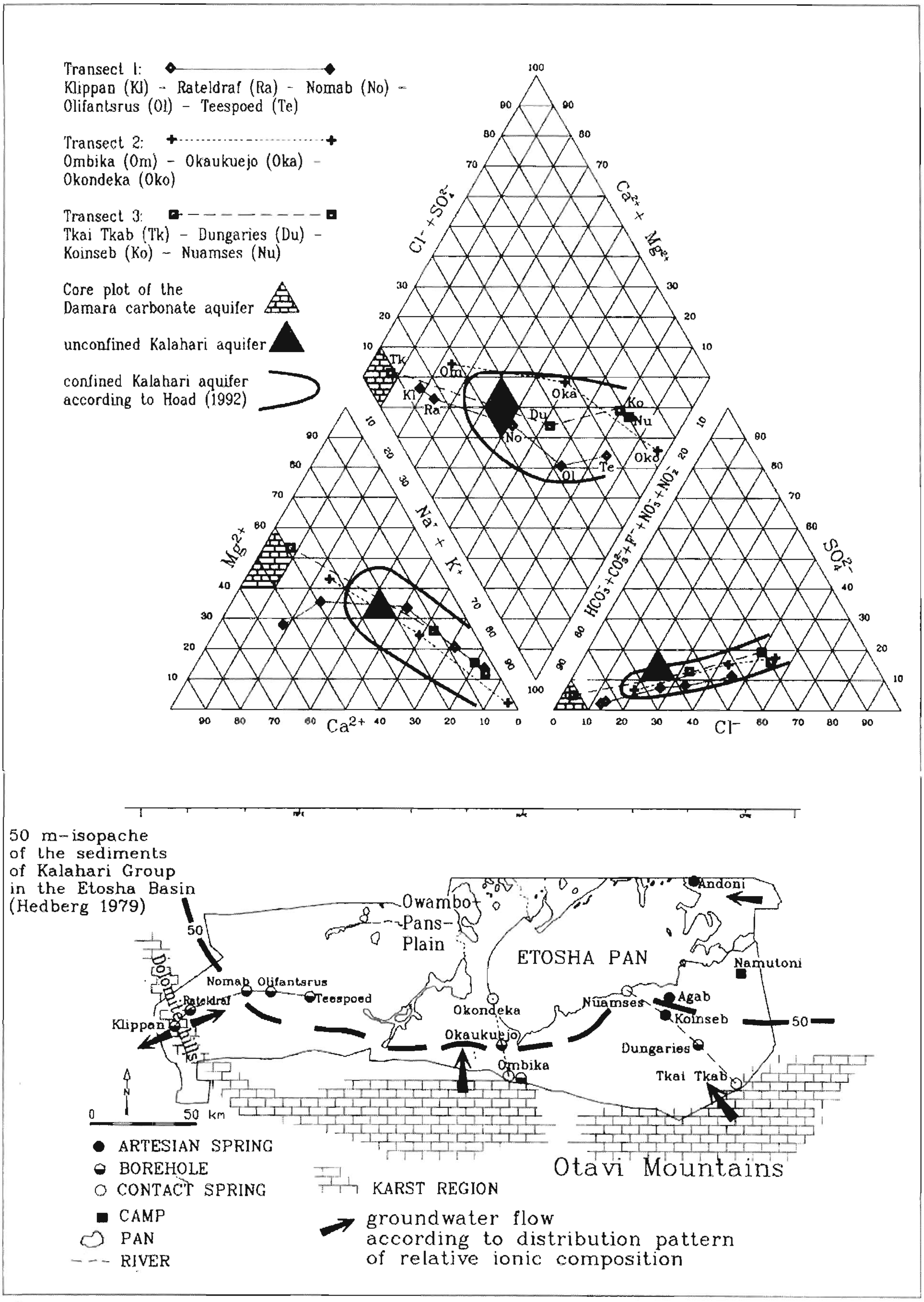
For the generalized presentation of the hydrochemical constitution of groundwater within the present boundaries of the Etosha National Park (Figure 1), the results of 747 water analyses from 64 localities were used. These samples comprise about 72% of the total data set. More detailed informations are available as computerized maps in areas with a high density of waterholes, like in the Namutoni area in the east of the Etosha National Park. Isolines of equal percentage concentrations were constructed by interpolation between the average values of individual localities. Spatial precision is limited in those areas where the spatial distribution of sampling points is erratic. These are areas such as the south-east where the interpolation is not supported by further locations of water sampling.

Figure 1 displays a clear zonal configuration of the hydrochemical constitutions of the groundwater in the southern part of Etosha Basin. Two centers of high alkaline-earth concentrations are situated in the south (Ombika) and in the south-east (Tkai Tkab) at the edges of the Otavi Mountains; a third center is identified in the west of the Etosha National Park (Klippan). The composition of groundwater thus reflects the character of the associated geological situation in this part of the study area with parent dolomitic and calcitic rocks of the Damara Sequence (see also Buch & Trippner 1997). Calcite and dolomite are dissolved by rainwater and Ca^{2+} and Mg^{2+} become dominant cations, HCO_3^- the dominant anion.

The hydrochemistry indicates the groundwater to be of the calcium-mangesium bicarbonate type as was already described for the so-called *Damara carbonate aquifer* in the Tsumeb-Otavi-Grootfontein karst region by Hoad (1992) (Fig. 2). Thus, the groundwater in the south-east and the west of the Etosha National Park proves to be in contact to the fissured, inhomogeneous and leaky to unconfined karst water system of the Otavi Mountains (Hoad 1992, Schneider 1989, Van Der Merwe 1983). This means that water withdrawal in the latter area might affect the groundwater availability in the Etosha National Park.

In the west (Klippan area), the watershed between the endorheic Etosha Basin drainage system and the exorheic drainage system to the Atlantic coast is also reflected in groundwater composition. The alkaline-earth metal concentration decreases with increasing distance from the watershed, to the north-east as well as to the south and south-west. The surface watershed and the groundwater divide both seem to follow the same pattern.

The spatial pattern of the alkaline-earth ions (Ca^{2+} and Mg^{2+}) inversely reflects the distribution of the alkali metals (Na^+ and K^+), i.e. a decrease of the percentual share of alkaline-earth metals implies an increase of alkali metals. Northwards from the alkaline-earth metal dominated centers along the southern border of the Etosha Basin and the Etosha National Park, the percentual share of Ca^{2+} and Mg^{2+} decreases. The lowest relative concen-



SOURCE: ETOSHA ECOLOGICAL INSTITUTE / VAN DER MERWE (1983) CARTOGRAPHY · L.RAHM 1995

FIGURE 2: Piper Trilinear Diagram of selected groundwater samples from the Etosha National Park (above). Three transects situated in the west, south and southeast of the study area show a characteristic change of water chemistry in the direction of the assumed groundwater flow (below).

trations of alkaline-earth metals are found around the Etosha Pan and in the central northern area of the Park. At most of the localities, alkaline-earth metals occur in concentrations less than 50 meq%/l. Thus, groundwater in vast areas of the Etosha National Park is mainly dominated by alkali metals, especially sodium (Na^+). Plots of these samples in the Piper Trilinear Diagram (Fig. 2) illustrate a good correspondance with either the confined or the unconfined portion of the so-called sodium chloride type *Kalahari aquifer* according to Hoad (1992). The high absolute and relative concentrations of Na^+ at the Andoni locality in the east of the Etosha National Park fits well in the depicted pattern.

The contribution of potassium to the sum of alkali cations is of secondary importance, as K^+ is less soluble than the other cations and has a strong tendency to be reincorporated into solid weathering products like clay minerals and soils (Hem 1985). For example, it is known from the eastern side of the Etosha Pan that analcim is chemically transformed to potassium feldspar by a seasonal surface water inundation rich in K^+ (Buch & Rose in press). In fact, 75% of the groundwater data show potassium concentrations below 1.2 meq%/l. On the other hand, in the center and central north of the Etosha National Park sodium constitutes 80 to 100% of the total cations.

The gradual (long-distance) shift from the calcium-magnesium bicarbonate type groundwater to sodium chloride type groundwater in general is replaced by a short-distance change south of the Etosha Pan between Okaukuejo and Namutoni. The samples from two artesian springs (Agab, Koinseb) distinctly influence the course of the 20 meq%/l-isoline in Figure 1. This irregularity in the general pattern of the hydrochemistry of the study region is thought to be associated with a well-known SW-NE stretching fault (Fig. 1). In addition a quite abrupt change of the hydrochemical conditions also occurs along with a SSW-NNE stretching fault in the eastern part of the Etosha National Park with saline waters identified west of the 17°E longitude (see Andoni spring for reference) (Buch 1993; Hoad 1992).

DISCUSSION AND CONCLUSIONS

Free movement of groundwater across long distances, relative to the geological environmment and time for chemical reactions, leads to a zonal distribution of dissolved ions in the water during its flow. According to Hölting (1989), the anion-sequence is: $HCO_3^- \Rightarrow HCO_3^- + SO_4^{2-} \Rightarrow SO_4^{2-} \Rightarrow SO_4^{2-} + Cl^- \Rightarrow Cl^-$, while the sequence of the cations is: $Ca^{2+} \Rightarrow Ca^{2+} + Mg^{2+} \Rightarrow Na^+$.

Keeping this principle in mind, it is most likely that the zonal configuration of the hydrochemical data indicates that the groundwater flow is directed towards the center of the Etosha Basin, with the Otavi Mountains and dolomite hills as a semicircular geological and morphological frame in the south and the west (Fig. 2). With increasing distance from the southern and western recharge regions in the Otavi Mountains and the related dolomitic ridges, alkali ion concentrations increase, while the percent concentration of Ca^{2+} and Mg^{2+} decrease.

The Piper Diagram of ionic composition of groundwater from wells and boreholes following three transects (Fig. 2) clearly shows a characteristic change of water chemistry in the direction of the assumed groundwater flow. The transects are situated in the west, south and south-east of the Etosha National Park and extend from the surrounding dolomite hills towards the center of the Etosha National Park. At the starting points the water generally is dominated by alkaline-earth metals and hydrogen carbonate. Sodium, sulphate and cloride increase continuously and form the main components at the end of the transects.

Three mechanisms can be proposed for this observation:

1. Early precipitation of alkaline-earth metal compounds like calcit and dolomite from groundwater could lead to a decrease of alkaline-earth metal concentration (and consequently to an increase of alkali metal concentration) distal to the recharge region. Fractional precipitation would thus contribute to the genesis of the deep calcretes or to the genesis of the *Etosha Limestone* during the Tertiary history of the Etosha Basin, with a depth of the limestone of up to 52 m at Bitterwater.

2. The solution of sodium-rich minerals would lead to an increase of alkali metal concentration and consequently to a decrease of the percentage concentration of alkaline-earth metals. With increasing distance, groundwater would contain more of the comparatively easily soluble sodium compounds. In fact, the green-coloured clastic sediments of the Andoni Formation in the Etosha Basin (Fig. 3) are rich in Analcim-(Na [$AlSi_2O_6$] x H_2O), indicating a saline-alkaline environment in the Etosha Basin during the Tertiary (see for details Buch & Rose in press; Buch this volume).

3. A combination of the two above mentioned mechanisms could account for the centers of high percent concentration as well as high mass concentration of alkaline-earth ions. The relative and absolute concentrations of alkaline-earth metals decrease in relation to the distance from the marginal calcitic-dolomitic frame. In the same direction, from the edges to the center, the total ion content also increases (Auer 1993, Gammer 1993).

Hoad (1992) describes this third mechanism as cationic exchange and mixing, which is typical for the confined portion of the Kalahari aquifer. In order to discuss the possible input of groundwater recharge into the Etosha Basin from Owambo and southern Angola in more detail, the same spatial density of hydrochemical data would be needed from the regions north of Etosha. Nevertheless recharge from these northern regions are very unlikely to have an influence in the southern part of the Etosha Basin.

Within the area of the Kalahari aquifer, Hoad (1992) differentiated an unconfined aquifer (above a confining clay layer within the sequence of the Kalahari sediments) and a confined aquifer (below this clay layer). Keeping in mind the lithological diversity of the Andoni Formation along the southern margin of the Etosha Basin (Fig. 3 and see Buch 1997) and faulting occuring in this region, a clear differentiation between both types of the Kalahari aquifer is not always possible. Considering climatic and

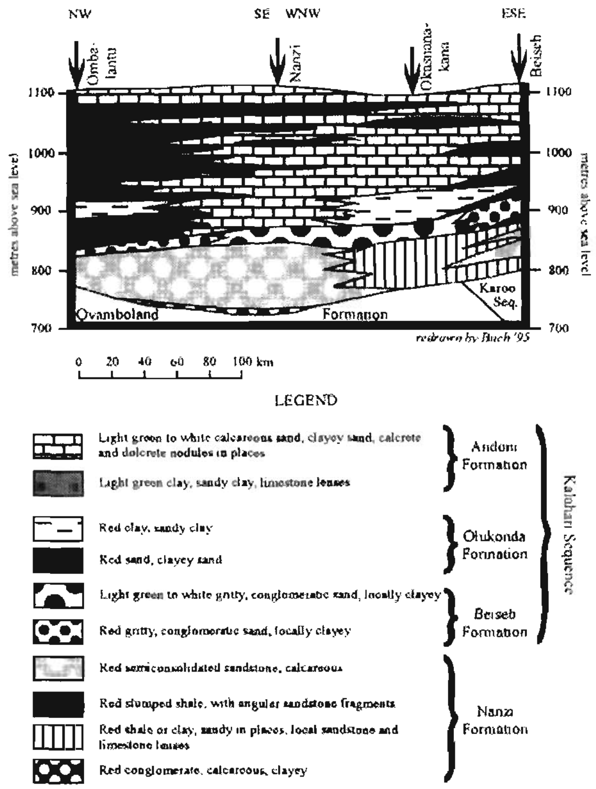


FIGURE 3: Geological cross section through the Mesozoic and Tertiary sediments in the Etosha Basin, showing the various lithological units of the area and their relationship with one another (after McG Miller 1990; redrawn).

geomorphologic characteristics, high rates of groundwater recharge to the unconfined aquifer cannot be expected. In the Etosha region, the evaporation is about 5 to 6 times higher than the precipitation (Van der Merwe 1983), which is disadvantage for the recharge of groundwater recources. In plain and flat areas with a rather thin layer of permeable substrata (e.g. fluvial and/or aeolian sands) even more of the near-surface water evaporates or is lost to the atmosphere by transpiration processes of the vegetation. Direct diffuse recharge is thought to be the dominant recharge mechanism within the unconfined portion of the Kalahari aquifer (Hoad 1992) and in accordance to regional observations, flood events in the ephemeral streams contribute to a major extent to a shallow, near-surface recharge within these drainage lines expecially in the oshana region of Owambo (Marsh & Seely 1992: 15).

In the karst region of the Otavi Mountains (Damara carbonate aquifer), water penetrates the surface dolomites and calcretes comparatively rapidly. Hoad (1992) considers an average groundwater recharge rate of 2% of rainfall, with a maximum recharge of 4% in years of over-average rainfall and no groundwater recharge in years of drought. There is consequently strong evidence that fossil (i.e. not recently replenished) water is used at many of the artificial water holes in the southern part of the Etosha National Park to provide water for people and game. This is in particular true for the tourist camps like Okaukuejo, Halali and Namutoni.

Future research in northern Namibia should focus on water management in relation to factors like groundwater recharge, groundwater abstraction and the age of the abstracted groundwater. Preliminary results from an isotope hydrological survey (Geyh 1994) already indicate that the groundwater ^{14}C-ages are increasing from the Otavi Mountains in a north-west direction towards the Etosha Pan. Along the SW-NE stretching fault from Okaukuejo to Halali and Namutoni (see above) groundwater discharging from springs have similar ^{14}C values of about 55 pMC. This might indicate a groundwater flow from the Otvai Mountains towards the nort-west. δ^{18}O values, however, are less negative than the values of the Otavi Mountains, leading to the conclusion, that the north-west directed groundwater flow is replenished by local recharge on the footslopes and the pediment zone of the Otavi Mountains rather than in the Otavi Mountains itself (Dierkes 1995).

The hydrochemical data presented here suggest that the northern footslopes and the pediment zone of the Otavi Mountains with parent dolomitic rocks and calcretes in the south and west of the Etosha National Park are the most important areas for groundwater recharge and the distance from the recharge region is controlling the chemical quality of the groundwater. The groundwater flow in the Etosha Basin in general is directed to the north, resp. to the north-west and the north-east. Even more important for the water management of the Etosha National Park, only the alkaline-earth bicarbonate dominated waters provide excellent or good quality water (classes 'A' and 'B' of the guidelines of the Department of Water Affairs) for human consumption (Hoad 1992, Auer 1993, Gammer 1993). The sodium enriched groundwater of the confined Kalahari aquifer, which is found in vast areas of the Etosha National Park (and adjacent Owambo), is unfavourable for human consumption (classes 'D' and 'E' of the guidelines of the Department of Water Affairs). Although wildlife might show some adaptation to these hydrochemical conditions (Auer, pers. comm.), future exploitations of the groundwater potential in the areas mentioned are limited and furthermore, the groundwater in general in unsuitable for irrigation (Trippner 1997).

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