Kalahari aquifers in the Gam area of north-eastern Namibia

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Groundwater exploration in the Gam area of eastern Namibia has largely been aimed at fractured bedrock aquifers. An extensive cover of thick Kalahari Sequence sediments makes the location of bedrock structures notoriously difficult. In a number of localities boreholes drilled by air percussion indicate a piezometric surface situated above the Kalahari-bedrock contact although water strikes were only recorded below the contact, suggesting confinement. The absence of a clear, semi-regional aquitard in the Kalahari Sequence tends to discount such a possibility. To the south of Gam, the existence of the 'Eiseb Graben' aquifer, hosted in Kalahari Sequence strata, has been proved by drilling. During exploration of this aquifer it was demonstrated that conventional rotary air percussion drilling, as was used elsewhere in the Gam area, commonly fails to detect low-yield water strikes in Kalahari strata. This is concluded to be the result of the sealing off of the low-permeability strata by the invasive nature of this drilling technique. Development of boreholes by application of passive plunger methods and installation of appropriately designed casing results in low but dependable yields in many areas previously thought to be 'dry'. Re-interpretation of the 'piezometric' surface within Kalahari strata leads to the conclusion that in parts of the Gam area this is in fact a phreatic surface which was not detected during air percussion drilling. For groundwater exploration to be more successful in these areas of saturated Kalahari cover, a revision of the approach to groundwater exploration and the use of appropriate drilling and borehole completion techniques is required.

Introduction

The study area includes what have been referred to as the "Gam Block" and the "Eiseb Block" in eastern Namibia. It is bounded approximately by latitudes 20°S and 20°50'S and longitudes 20°E and 21°E, the latter corresponding to the Namibia-Botswana border (Fig. 1).

Historically a perennial spring at Gam provided water to small bands of nomadic Bushmen. Later, Herero speaking pastoralists settled at the spring with their livestock. The consequent increase in demand for water exceeded the natural rate of flow of the spring, prompting excavation of a well at the site. Prior to 1970, when the first boreholes were drilled, no other permanent water source existed in the Gam Block.

Early groundwater exploration efforts met with limited success and resulted in the area remaining relatively undeveloped. In the late 1970's and early 1980's, the Council for Scientific and Industrial Research (CSIR) conducted a comprehensive exploration programme aimed at understanding the controls on groundwater occurrence in the area. This programme was based mainly on the application of electrical resistivity methods and met with limited success during subsequent drilling by the Department of Water Affairs. The area remained sparsely inhabited until the mid 1990's when a concerted exploration effort resulted in the establishment of several new water points which facilitated organised settlement in the area.

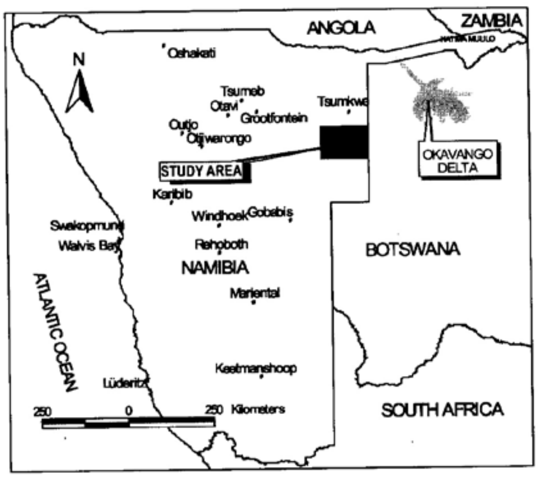

Figure 1: Location of the study area

Difficulties experienced in locating groundwater in the area are explained in terms of the prevailing hydrogeological regime. A thick blanket of Phanerozoic and Recent sediments, collectively referred to as the Kalahari Sequence, covers most of northeastern Namibia and effectively masks older crystalline and sedimentary bedrock formations. In the Gam area, groundwater exploration using rotary air percussion methods has indicated that the Kalahari is generally dry and the focus has therefore turned to fracture aquifers in the crystalline bedrock. Locating such aquifers in bedrock beneath 30-200 m of cover has proven a difficult, sometimes impossible task despite the application of increasingly more sophisticated geophysical techniques.

Regional Geology

Stratigraphy

The stratigraphy of the Gam area is described in terms of the four major geological units present. Figure 2 shows the limited distribution of outcrops of pre-Kalahari strata in the region.

Grootfontein Metamorphic Complex

Granitic gneiss, hornblende rich in places, has been intersected in boreholes in the north and northwest. These rocks are correlated with gneisses exposed southeast of Tsumkwe and south and east of Grootfontein (Interconsult, 1996a).

Damara Sequence

Minor outcrops of white limestone with thin intercalations of weathered phyllite occur immediately north and northeast of Gam. These rocks are correlated with

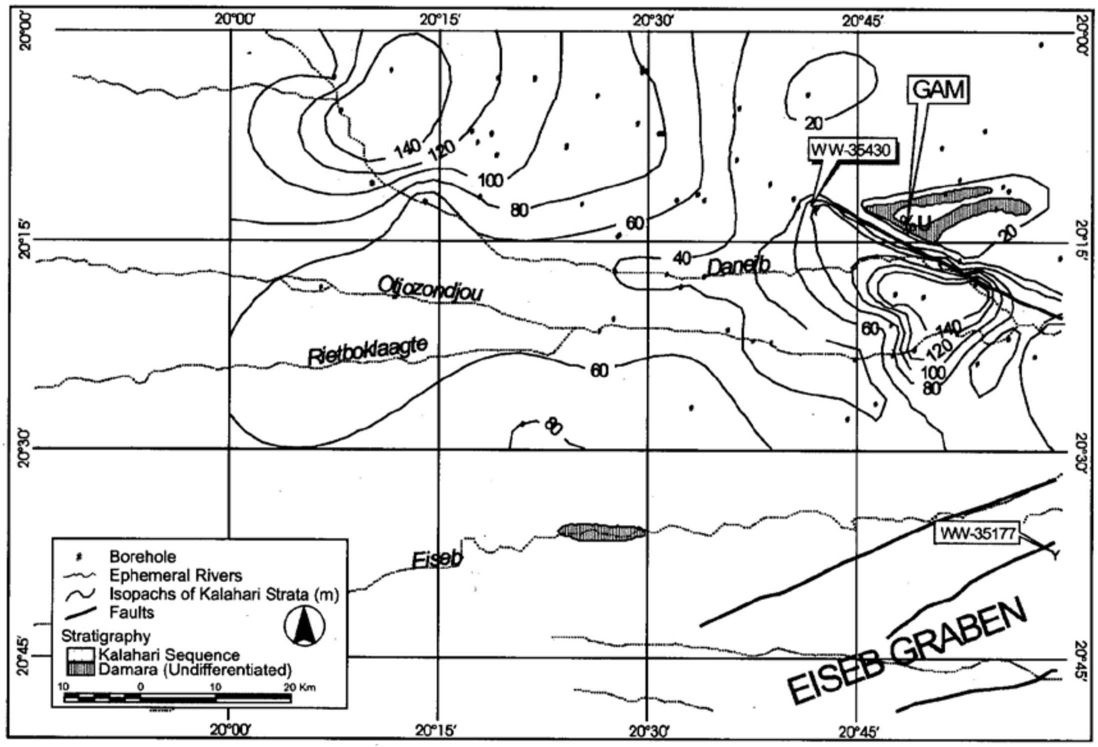

Figure 2: Regional geology and structure

the Northern Damara platform carbonate sequence which occurs in the Tsumeb area. The nearest similar carbonate outcrops are found in the Aha Hills area, 60 km to the north of Gam.

Damara rocks intersected in boreholes include grey phyllite, various carbonates (limestone and dolomite) and mica schist (Interconsult, 1996a).

Karoo Sequence

Drilling has shown that basalt and basic intrusive bodies of probable late Karoo age underlie the Kalahari Sequence in the eastern and central northern areas. In the east, two discrete basalt fields south and north of Gam have been intersected by drilling. Several dyke- and sill-like intrusions are present which are thought to be feeders to the basalt fields. Rare, pipe-like, gabbroic bodies, which occur in the central parts, may also be of Karoo age (Interconsult, 1996a).

Kalahari Sequence

The Kalahari Sequence forms a stratigraphic blanket over the entire area with only minor, isolated exposures of Damara Sequence bedrock, one northeast of Gam and another to the southwest along the Eiseb Omuramba (ephemeral water course). Lithologies encountered during drilling comprise minor, semi-consolidated to consolidated coarse gravel at the base, clay-rich siltstone, minor silcrete and calcrete, and sandstone near the top. Recent deposits of loose aeolian sand form the upper unit of the sequence. On the basis of extensive geophysical investigations de Beer and Blume (1983) proposed three stratigraphic units for the Kalahari but this subdivision was not clearly seen in borehole logs.

In the northeastern part of the area, Kalahari Sequence sediments are less than 20 m thick. These thicken towards the south and west where drilled depths of up to 200 m (Interconsult, 1996a) are recorded. Due to an increase in new borehole data, isopachs of Kalahari thickness shown in Fig. 2 bear little relationship to the isopachs given in the 1: 1 000 000 Geological Map of Namibia (Geological Survey, 1980). In the Eiseb Graben (Fig. 5) the Kalahari Sequence reaches 250 m in thickness.

Structure

A number of major linear structures are apparent in the area (Fig. 2). Of these the southeast-trending Gam Lineament, passing through Gam itself, is the most prominent feature and is clearly visible on aerial photos and satellite images. Work carried out by the CSIR during the late 1970's and early 1980's showed that the Gam Lineament is a major, long-lived fault (de Beer *et al.*, 1982).

Evidence pointing to the magnitude of throw and longevity of this fault include the following:

- A borehole, drilled immediately south of the fault near Gam, terminated in Kalahari at a depth of 200m;
- Damara carbonates are exposed immediately north of the fault suggesting a southern down-throw of Damara bedrock greater than 200 m;

- Aeromagnetic data indicate basalt (Karoo) underlying the Kalahari south of the fault;
- Dolerite has intruded the Gam Lineament in places, as suggested by the aeromagnetic data (Corner, 1994) and confirmed in a borehole drilled on the lineament northwest of Gam (borehole WW35430; Interconsult, 1996a).

A number of other structures have been inferred from interpretation of recent high-resolution airborne magnetic survey data (Corner, 1994). These are not apparent through the thick Kalahari cover.

South of the Eiseb Omuramba, four northeast-trending faults coincide with the displacement of dune crests and influence present-day drainage patterns (the northernmost three of these are shown in Fig. 2). These features are interpreted as recent faults forming the southwestern extension of the Okavango Delta graben structure, which occurs further east in Botswana (Scholz *et al.*, 1976). In Namibia, this structure has been referred to as the "Eiseb Graben" (Interconsult, 1996b).

A thickness of Kalahari sediments exceeding 250m has been confirmed by drilling in the centre of the Eiseb Graben adjacent to the Botswana border (Interconsult, 1996b).

It is therefore clear that recent tectonism relates to the occurrence of significantly thick accumulations of Kalahari sediments in certain areas. There is insufficient evidence to indicate whether tectonism caused the deposition of thick Kalahari sediments or merely preserved them.

Hydrogeology

Aquifers

The distinction between Kalahari sediments and bedrock formations (i.e. all pre-Kalahari strata) is essential to develop an understanding of the groundwater of the region, particularly in terms of defining aquifer type and thus the appropriate exploration approach.

Bedrock Aquifers

In the bedrock formations, fractures and faults host groundwater. Where Kalahari cover exceeds 30 metres, the identification of these potential water-bearing features is difficult.

West and south of Gam this situation is illustrated by the historical 20 - 30% borehole success rate reported by Dijkstra (1993) and maintained during more recent drilling programmes (Interconsult, 1996a).

In the ubiquitous deep sandy soils of the area, surface water flow is both infrequent and short lived. The result is a rapid infiltration of rainfall. In areas where the Kalahari cover exceeds several metres, most of this water is lost through evapo-transpiration during the dry season (Martin, 1961) with negligible recharge taking place. Direct recharge to bedrock aquifers from local rains or indirect recharge from riverbeds is only likely in cases where thick, permeable calcrete layers occur (J. Kirchner, *pers. comm.*). Fracture aquifers probably rely mainly on very slow flow through bedrock fracture systems from outside the area for replenishment.

Kalahari Aquifers

In the Kavango and Caprivi Regions of Namibia, to the north and northeast of the Gam area, Kalahari sediments have a characteristically low primary porosity and form an almost continuous saturated layer (Namibian Groundwater Development Consultants, 1991 and 1993; Interconsult, 1993). Generally low yields (1-5 m^3/h) may be achieved from boreholes and wells intersecting these aquifers.

In the region around the study area, known Kalahari groundwater is rare (Interconsult, 1996a). Immediately south of the Gam Lineament, down-faulting has displaced the bedrock contact below the regional groundwater table resulting in saturation of the lower part of the Kalahari strata (i.e. forming a Kalahari Aquifer) (Namib Hydro Search, 1992). Further south, in the Eiseb Graben, the base of the Kalahari is similarly deeper than the regional groundwater table with saturated lower Kalahari sediments providing a source of abstractable groundwater (Interconsult, 1996b).

Water Levels

Figure 3 is a contoured plot of rest water levels, measured from surface, across the region. Such a plot gives an indication of the depths targeted by groundwater exploration in the area which helps explain some of the difficulties experienced in locating fracture aquifers in deeply buried bedrock. Rest water level depth may also be considered as the thickness of the unsaturated zone through which infiltration must take place for direct recharge to occur.

The piezometric surface in Figure 4 shows a general fall southwards and eastwards across the Gam area suggesting recharge from shallow bedrock areas to the north as well as from through flow from the west. The lowest point lies adjacent to the Botswana border, immediately south of the Eiseb Omuramba and coinciding with the Eiseb Graben.

Water strikes recorded in the Gam area (Interconsult, 1996a and b) are grouped as follows:

a) Within shallow fractured Damara bedrock, such as in the northeast parts;
b) At or near the Kalahari-bedrock contact, in areas to the west;
c) 'Seepage' or 'moisture' within Kalahari sediments of 80-180m thickness, in areas to the west;
d) Entirely within Kalahari sediments, such as to the south, in the Eiseb Graben where bedrock was not encountered in any of the boreholes.

In some areas of relatively thick Kalahari cover (apparently containing no significant groundwater), water strikes corresponding to groups b) and c) above were

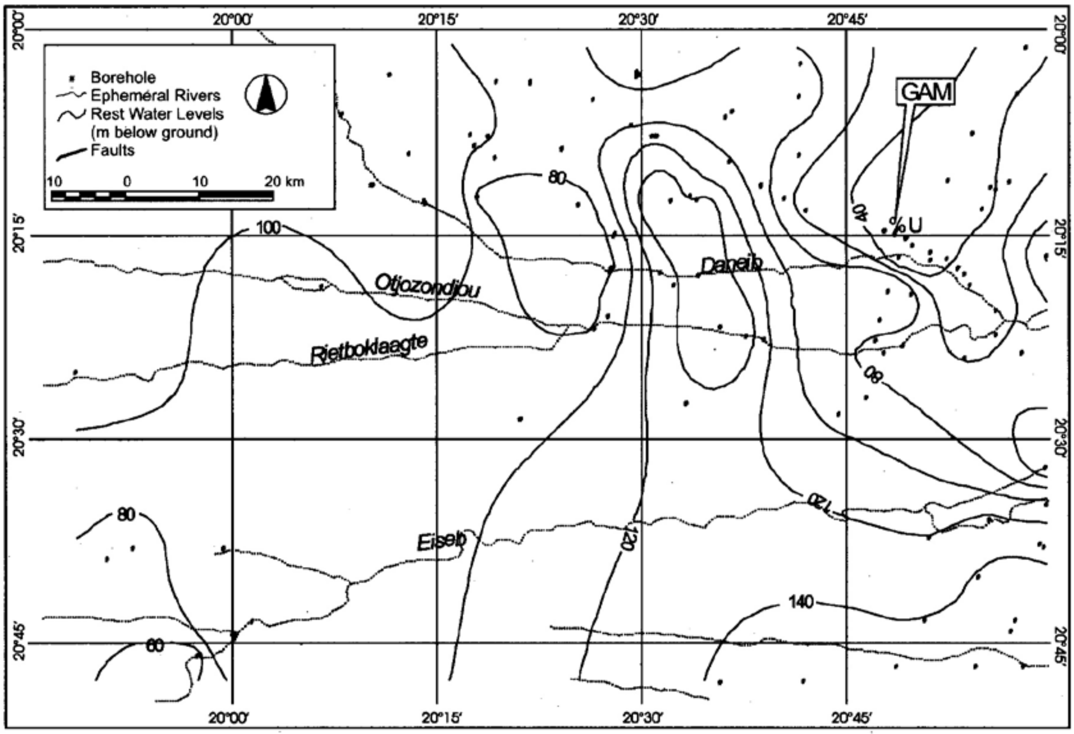

Figure 3: Rest water level contours

recorded. In many instances these corresponded to a pronounced piezometric rise (i.e. from water strike depth to rest water level) (Interconsult, 1996a). Leo Hatz (1991) considered this a function of confinement of groundwater by overlying impermeable Kalahari layers. Interconsult (1996a) concluded that this implies potential saturated Kalahari sediments. Figure 5 shows the difference in elevation of the water table, above (+) and below (-) the pre-Kalahari surface. Three areas of positive water table elevation, i.e. saturated Kalahari

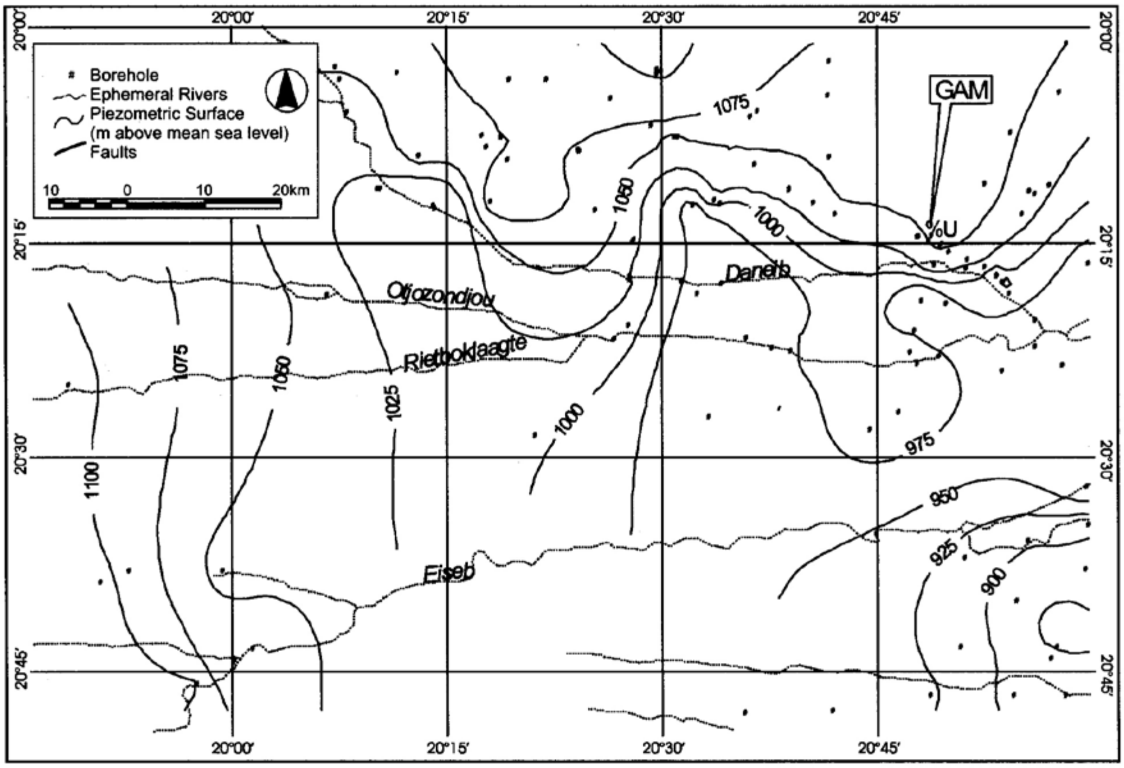

Figure 4: Piezometric surface elevation

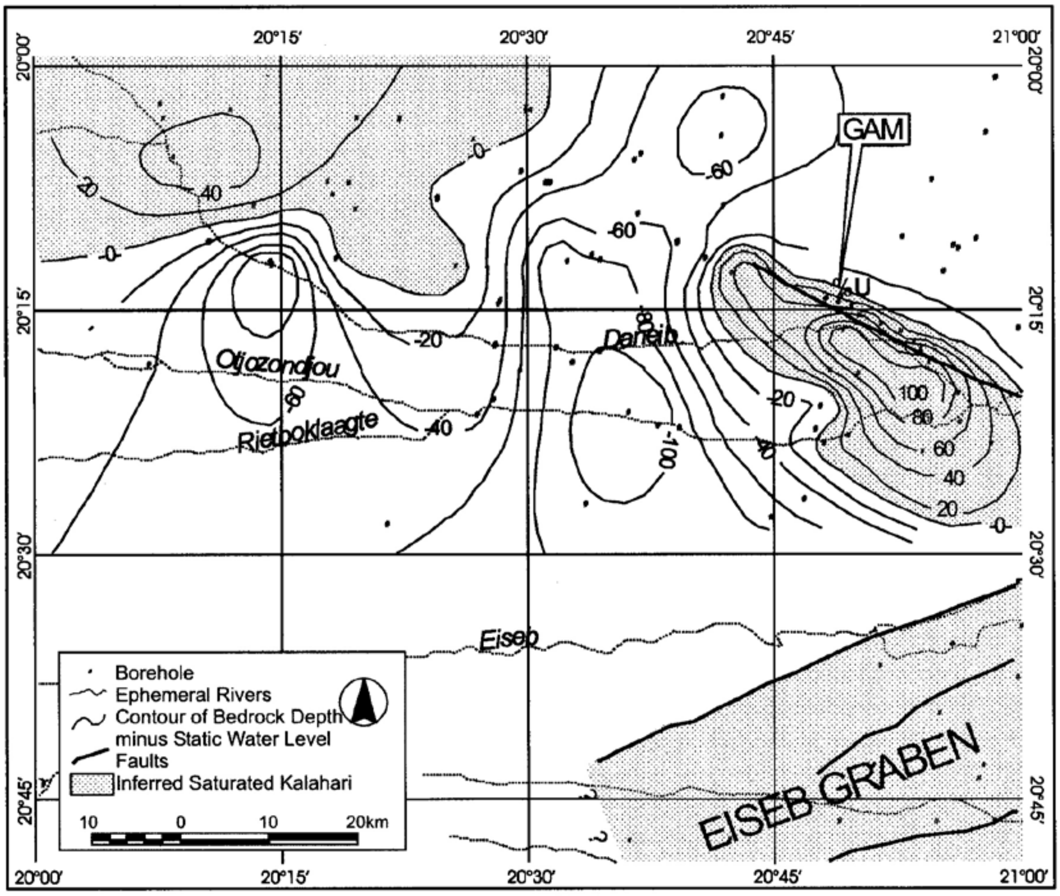

Figure 5: Inferred Kalahari aquifers

sequence, are inferred;

- an area immediately south of the Gam lineament (Namib Hydro Search, 1992);
- a large area in the extreme northwest of the study area;
- the Eiseb Graben (Interconsult, 1996a and b).

Drilling Technique

In the Gam area, many boreholes drilled by conventional rotary air percussion techniques recorded no water strikes in the Kalahari strata, yet a rest water level was subsequently measured several tens of metres above the bedrock contact. Elsewhere in this part of Namibia, Leo Hatz (1993) interpreted this phenomenon as due to a confining layer of regional extent. In the Gam area, no clear regional aquitard (or aquiclude) was recorded in borehole logs and such an explanation can therefore not be confirmed.

During more recent drilling operations, it was noted that, where the piezometric surface was above the bedrock contact, moist patches were present in the lower part of the Kalahari. In some cases such zones were sufficiently moist to reduce intergranular cohesion, causing collapse within boreholes and hampering drilling operations (Interconsult, 1996a).

South of the Eiseb Omuramba, a borehole drilled with a cable-tool rig into a Kalahari aquifer was in production for more than a decade. Increased demand for water at this locality and a consequent increase in pumping rate, caused ingress of fine sediment into the borehole through the perforated casing, which rendered the borehole useless. Clear illustration of the need for applying appropriate drilling methods was given when a failed attempt was made to replace this borehole (WW3 5177) using conventional air percussion methods (Fig. 2). During a subsequent attempt, a successful borehole was piloted using air percussion methods, and completed using a cable-tool rig. The borehole was developed by plunging, using the cable-tool rig. Further boreholes drilled into thick Kalahari strata in the Eiseb Graben area, which were treated in a similar manner, resulted in a high success rate (90% of the boreholes drilled had blow-yields 1.5-3.5 m^3/h).

The lack of success of holes drilled into saturated Kalahari strata by air percussion may be ascribed to the effect of this method on the fine, clay-rich saturated siltstones, typical of the Kalahari Sequence in many parts of northeastern Omaheke (former Hereroland East).

It is concluded that during such drilling, the rotating hammer and bit may provide a smearing action of the moist clay fraction resulting in a lining of the borehole (commonly termed 'wall cake'). Attendant escaping hot air from the hammer partially dries the wall cake, effectively sealing off water that would otherwise seep into the borehole from low transmissivity Kalahari beds, and masking possible water strikes. In a number of these initially 'dry' boreholes water strikes were recorded at the bedrock contact.

Conclusions and implications for future Groundwater Development in the region

The Kalahari Sequence, which covers large areas of eastern Namibia, has the reputation for being a poor host to groundwater in useful amounts. In addition, this thick Kalahari Sequence cover inhibits the targeting of buried fracture aquifers within the underlying bedrock. This condition has led to poor success rates in drilling for groundwater and hence a poor potential for settlement within these areas. It is strongly suspected that this poor success rate was the result of:

- Lack of understanding of the hydrogeological regime;
- Inappropriate drilling techniques;
- Inappropriate borehole development.

Reinterpretation of drilling results shows the probable presence of previously unknown Kalahari aquifers in certain parts of eastern Namibia. These areas are generally within block faulted environments, which have down-thrown lower Kalahari strata below the ambient water table level.

To ensure the best chance of locating water in areas covered by thick Kalahari lithotypes in this part of the country, the following approach is recommended:

1. The regional structure of the area should be interpreted, with emphasis on the delineation of down-faulted blocks which may provide thick sequences of Kalahari strata;
2. The establishment of the position of the regional water table in relation to the Kalahari/bedrock contact;
3. The thickness of potentially saturated Kalahari strata and their areal extent must be estimated in order to assess volumes of water that may be present;
4. Boreholes should be drilled in areas of thickest saturated Kalahari;
5. Drilling should be directed as deep as possible to penetrate a maximum thickness of saturated Kalahari strata, regardless of the individual lithologies encountered;
6. Appropriate techniques, such as rotary fluid flush or cable-tool methods, should be used for drilling production boreholes.

References

Corner, B. 1994. Interpretation of the Aeromagnetic Survey Conducted over the Gam Block in the Otjozondjupa and Omaheke Districts. *Unpubl. Rep. Ministry of Lands, Resettlement and Rehabilitation, Namibia*.

De Beer, J.H., Blume, J., Du Plooy, A. and Kruidenier, J.H.B. 1982. Geoelectrical Survey in the Gam Area and Eiseb Omuramba. *Unpubl. Rep. Nat. phys. Res. Lab., CSIR, South Africa*.

De Beer, J.H. and Blume, J. 1983. Final Report on the 1982 Geoelectrical Survey in Gam and Eiseb Omuramba. *Unpubl. Rep. Nat. phys. Res. Lab., CSIR, South Africa*.

Dijkstra, T. 1993. Water supply potential for the repatriation ofBatswana of Namibian origin in Eastern Hereroland near Gam. *Unpubl. memo. Dept. Water Affairs, Namibia*.

Geological Survey. 1984. Geological Map of Namibia (1:1 000 000). Geol. Surv. Namibia. Interconsult Namibia (Pty) Ltd. 1993. Groundwater Investigation in Eastern Caprivi, Namibia (Phase 2). *Unpubl. Rep. Dept. Water Affairs, Namibia*.

Interconsult Namibia (Pty) Ltd. 1996a. Groundwater exploration in the Gam area of Eastern Namibia. *Unpubl. Rep. Ministry of Lands, Resettlement and Rehabilitation, Namibia*.

Interconsult Namibia (Pty) Ltd. 1996b. Groundwater exploration in the Eiseb area of Eastern Namibia. *Unpubl. Rep. Ministry of Lands, Resettlement and Rehabilitation, Namibia*.

Leo Hatz Consulting (Pty) Ltd. 1991. Report on phase 1 of the groundwater investigation in Eastern Hereroland. *Unpubl. Rep. Dept. Water Affairs, Namibia*.

Leo Hatz Consulting (Pty) Ltd. 1993. Groundwater Resource Evaluation of East Hereroland. *Unpubl. Rep. Dept. Water Affairs, Namibia*.

Martin, R. 1961. Hydrology and water balance of some regions covered by Kalahari sands in South West Africa. *Inter-African Conference on Hydrology, Nairobi*.

Namib Hydro Search (Pty) Ltd. 1992. Inception Report: Water supply for Gam Integrated Community Development Project, Eastern Hereroland. *Unpubl. Rep. Namibia Inst. Community Development*.

Namibia Groundwater Development Consultants. 1991. Groundwater Investigation-in Kavango and Bushmanland, Namibia (Phase 1). *Unpubl. Rep. Dept. Water Affairs, Namibia*.

Namibia Groundwater Development Consultants. 1993. Groundwater Investigation in Kavango and Bushmanland, Namibia (Phase 2). *Unpubl. Rep. Dept. Water Affairs, Namibia*.

Scholz, C.R., Koczynski, T.A. and Hutchins, D.G. 1976. Evidence for Incipient Rifting in Southern Africa. *Geophys. J. R. astr. Soc.*, **44**, 135-144.