GRAVITY AND SEISMIC REFRACTION MEASUREMENTS FOR DEEP GROUND WATER SEARCH IN SOUTHERN DARFUR REGION, SUDAN

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ABSTRACT

In Northern Darfur Region (Sudan) the search for ground water from deep sources has greatly intensified especially in Southern Darfur, where appreciable thickness of Tertiary-Cretaceous sediments exist. To determine the lateral and the vertical extents of these sediments gravity measurements were made along profiles oriented perpendicular to the general structural trend of the area. Gravity measurements were supplemented by seismic refraction profiles to provide depths at specific control points. These depths were used to interpolate the regional-residual gravity components along the profiles to allow for accurate quantitative interpretation.

The measurements have revealed a deep sedimentary basin that attains a maximum depth of 4.0 km and is bounded by steep sides.

The result of this study has highlighted the suitability of combing gravity and seismic refraction techniques for regional ground water exploration in arid and semi arid zones similar to Darfur Region.

INTRODUCTION

The period 1968-1973 was characterized by drought all over arid and semi arid regions in the Sudan. Among these the northern part of Darfur region (Fig. 1) has suffered greatly from drought disasters whose impacts are clearly reflected on enhancement of desertification, loss of livestock, recession of water resources and tribal clashes (Ali,1982). Due to this degradation in the ecosystem large parts in the region have failed to provide subsistance for their inhabitants who were forced to migrate towards the southern part of the region (Southern Darfur) where

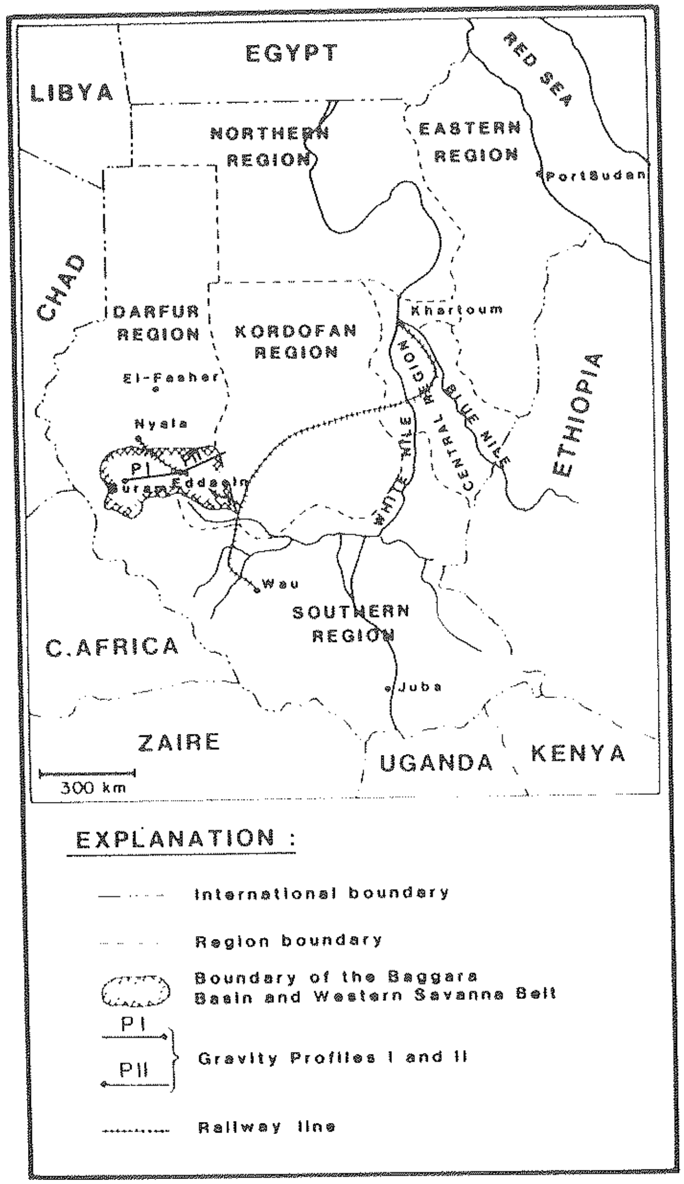

Figure 1. Location map.

favourable savanna climatic conditions exist (Fig.1). The savanna belt in southern Darfur is characterised by great numbers of tree species and taller grasses. The terrain is dominated by sandy soils and sand dunes, but it changes to sandy clay soils towards the south. The rainfall varies from 350-660 mm annually and occurs during the period June-October. The long term record of the rainfall has revealed a downward trend in the annual rainfall below the long term mean (Fig. 2). Annual evaporation mounts to 2500 mm and the mean daily temperature is about 35°C.

During the last decade, the savanna belt in southern Darfur received great attention and integrated plans for conservation, development and utilization of its natural resources were formulated. Availability of permanent sources of water has been put as a pre-requisite condition for any development plan in the savanna belt of Southern Darfur. Due to unstable climatic conditions, and the anticipated decrease in rainfall versus high evaporation rate, it is apparent that ground water from deep sources (aquifers) is the only plausible solution for future water demand in the region. Since little was known about deep geological formations favourable for ground water accumulation in the region, this geophysical investigation was initiated (Hunting Geology and Geophysics, 1973).

GEOLOGY OF THE AREA

The general geology of the area can be summarized into the following items (Hunting Technical Services, 1974):

i. The Basement Complex: These are Precambrian rocks and include the younger intrusives and the metamorphic rocks. The younger intrusives are mainly synites, quartizite veins and granitic rocks. The metamorphic complex comprises acidic gneisses and chlorite echists. The formation was subjected to faulting during post-Nubian times (Whiteman, 1971).

ii. The Nubian Sandstone Formation: This formation is Jurassic-Cretaceous in age and consists of pebbly and siliceous sandstone, sandy mudstone and conglomerate. Generally the sub-Nubian topography is uneven and forms sub-basins which are separated by basement ridges. The sediments of the Nubian sandstone were deposited rapidly by river systems onto delta fans across flood plains (Vail, 1978).

iii. The Umm-Ruwaba Formation: This consists of fine unconsolidated sediments probably of Tertiary Pleistocene in age. The sediments consist of silts, clay and sandy clays and are characterized by sudden facies changes. Vail (1978) attributed the origin of the Umm Ruwaba sediments to the early Nile drainage system.

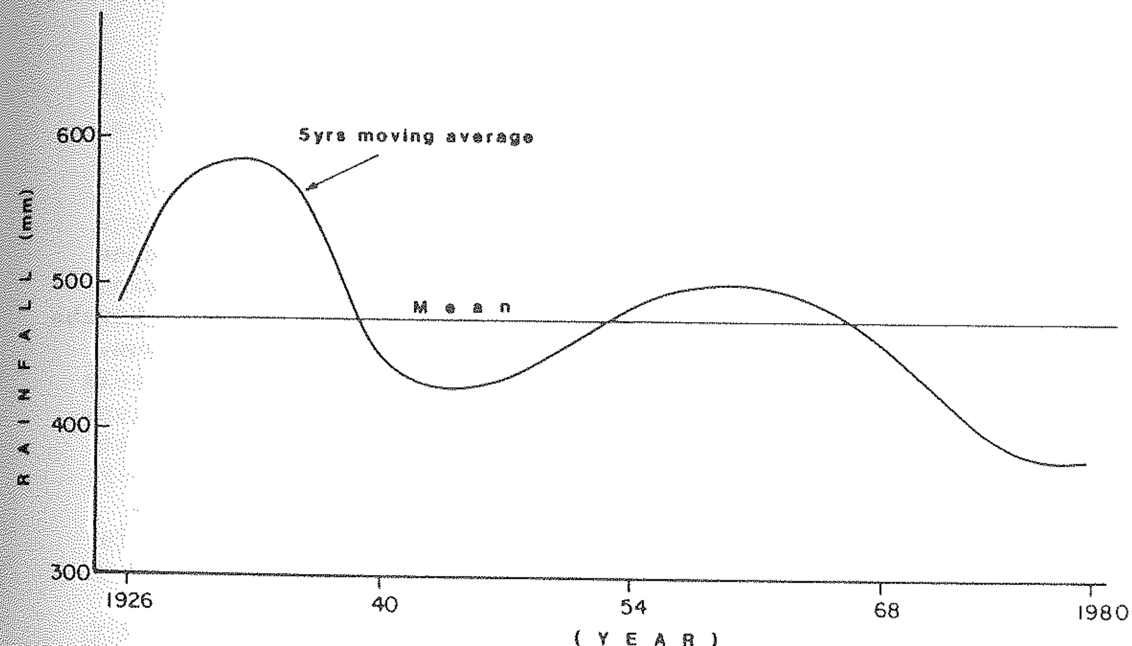

Figure 2. Rainfall record in Western Savanna area.

iv. The Superficial Deposits: These are unconsolidated sediments deposited during Pleistocene to recent time and can be classified into wind blown sands (Qoz) and stream deposits (Wadi fills). The wind blown sands consist of quartz grains while the stream deposits consist of gravels, sands and sandy clays. The thickness of the superficial deposits range between two and 35 m.

GROUND WATER RESOURCES

The Savanna area in southern Darfur region is hydrogeologically known as the Baggara Basin (Salama, 1977). The basin covers an area of 140,000 km^2 and trends NW-SE (Fig.1). The main water bearing formations are the Nubian sandstone and the Umm Ruwaba formations. Distinction between these formations on the basis of their hydrologic characteristics can hardly be possible, therefore they are considered as one hydrogeological unit. However, the Nubian sandstone formation yields higher amounts and less saline water compared with the Umm Rawaba formation. The aquifer thickness of the Umm Ruwaba/Nubian sandstone formation varies from 150 m to 650 m (Salama, 1977). The water levels in the basin vary from 75-120 m and occur under water table conditions, though it is believed that the clay layers could cause confinement to deeper aquifer(s). Although water levels in the basin are relatively shallow, good productive zones (aquifers) may occur at much greater depths. Ali (1983) has shown that certainty of finding aquifer(s) in the Umm Ruwaba formation is only possible at depths that exceed 400 m. In the eastern and the western parts of the basin, where the Nubian sandstone is the main aquifer, the water salinity ranges from 100-400 ppm while in the central part, where the Umm Ruwaba formation is the main aquifer, the salinity is about 850 ppm.

THE GEOPHYSICAL SURVEY

The sediments of the Umm Ruwaba and the Nubian sandstone were the prime target of this geophysical investigaton for deep ground water sources. The term 'deep' in this respect is quantitatively defined as depths that exceed 400 m.

A combination of gravity and seismic refraction technique was used in the survey. The gravity was selected as the main method of investigation because:

i. The marked density contrast between the sedimentary formations (2.1 g/cc) and the basement complex (2.7 g/cc) together with the expected thickness of the sediments could lead to measurable gravity anomaly.

ii. Gravity measurements are reasonably fast and simple, therefore the area could be studied in a short time and with minimal cost.

iii. Recent applications (e.g. Wallace and Spangler, 1970, Van Overmeen, 1975 and Ali and Whiteley, 1981) have proved that the method is versatile for ground water exploration in sedimentary basins especially in arid and semi arid regions.

The seismic refraction was used as an auxiliary method to:

i. Calibrate the gravity measurements by providing depth control-points for separation of regional/residual gravity components graphically (Dobrin, 1976).

ii. Differentiate between sedimentary formations in the basis of their seismic velocities.

Though the seismic refraction method has a great resolving power and is less ambiguous than gravity, its field operation for deep investigations is relatively laborious and costly. These drawbacks hinder the use of the technique in a wide scale especially in ground water projects.

FIELD MEASUREMENTS

Gravity measurements were taken at 0.5 km intervals along 2 profiles of total length 250 km oriented perpendicular to the general trend of the Baggara Basin (Fig. 1). To increase the productivity of the survey, profile (1) (Eddaeinm Buram) was modified to follow existing tracks. Heights at gravity stations were determined by levelling and gravity readings were taken using a La Coste and Romberg gravimeter. A system of running base stations (Nettleton, 1977) was adopted in the survey. The observed gravity readings were corrected for drift, latitude elevation and tied to a gravity base station whose absolute value is 978102.5 mgal and located at Eddaein Raily station (Fig. 1). The base station is fully described by Isaev and Mitwali (1974).

On the basis of qualitative results of the Bouguer gravity, suitable sites for seismic refraction measurements were chosen along the profiles. A 24 channel seismic refraction system was used in the survey. Long spread (1610 m) with geophone separations of 70 m was the common lay out. Also, weathering spreads of 460 m (20 m geophone spacings) were conducted at some specific points. Normally six shot holes with depth varied from 4-9 m were fired at each spread. Figure (3) shows spread layouts and positions of the shotholes.

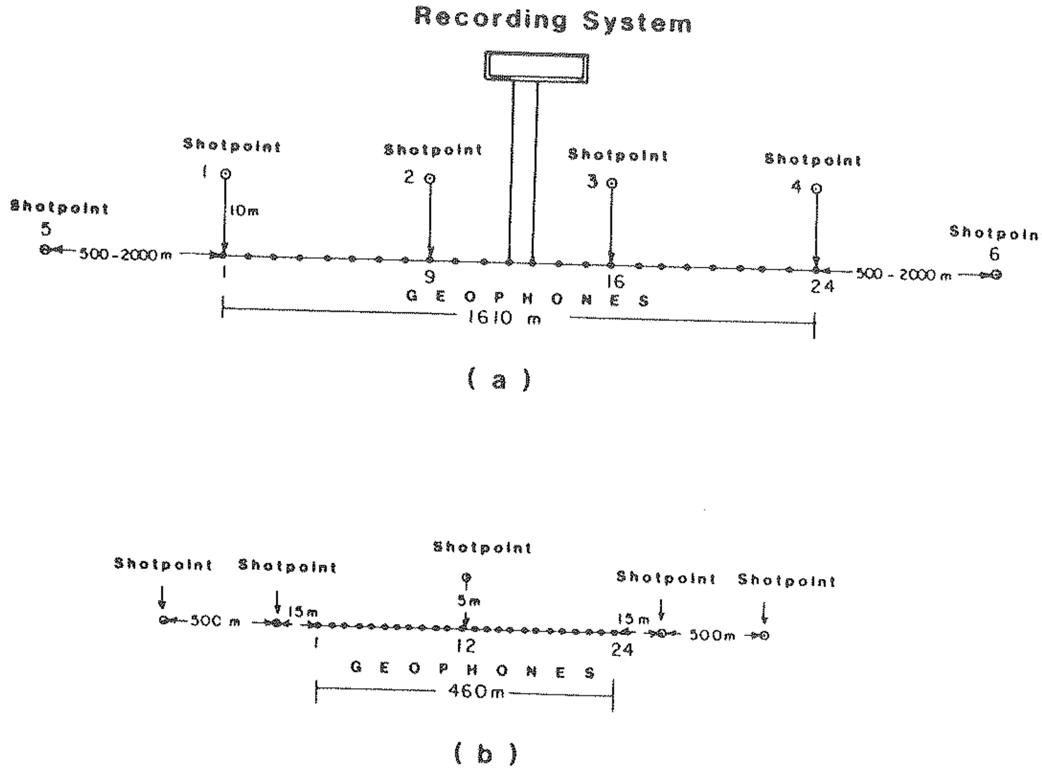

Figure 3. Seismic spread layouts
(a) Long spread (b) Weathering spread

INTERPRETATION OF THE DATA

The reciprocal method (Hawkins, 1961) and its modification (O'dins, 1976) were used for calculation of layer thicknesses and their corresponding velocities from time distance graphs. The calculated thicknesses together with seismic velocities were reasonably adjusted to agree with nearby boreholes (Fig. 4).

The calculated thickness of the sediments was used to compute the residual gravity at specific control points along the profiles by calculating the gravitational attraction of an infinite horizontal slab (Dobrin, 1976), then regional gravity was established at the control points and smooth regional as well as residual gravity trends along the profiles were produced. This procedure of regional/residual separation has the advantage of reducing the bias inherent in the graphical separation method (Ibrahim and Hinze, 1972).

Inversion of the observed residual gravity values into a 2-D geologic model has been achieved iteratively by computer using the methods described by Qureshi and Mula (1971) and Qureshi and Kumar (1976). The agreement between the calculated and the observed residual gravity is within ± 0.5 mgal at the centre and ± 0.1 mgal at the edges of the model. Although the correspondence between calculated and observed residual values is relatively close the model has certain limitations because:

i. The computer solution assumes a horizontal top for the model, whereas the superficial deposits (top of the model) are, in fact, irregular and vary considerably within a short distance. Attempts were made to reduce this limitation by incorporating the version described by Qureshi and Kumar (1976).

ii. The solution assumed an infinite extent of the model in the Y-plane, but the sedimentary formations do not extend infinitely perpendicular to the gravity profiles.

iii. Within the same formation, constant density value was assumed, but due to rapid facies changes in the sedimentary formations (especially in Umm Ruwaba), the density changes accordingly.

RESULTS AND DISCUSSION

Interpretation of seismic data has revealed insufficient velocity contrast between the Nubian sandstone and the saturated Umm Ruwaba formations to mark the boundary between them. Also a clear distinction between the superficial deposits and the dry sediments of Umm Ruwaba is rather difficult due to overlaps in their velocities. From correlation of seismic velocities with lithology of nearby boreholes, the following ranges of velocities have been determined:

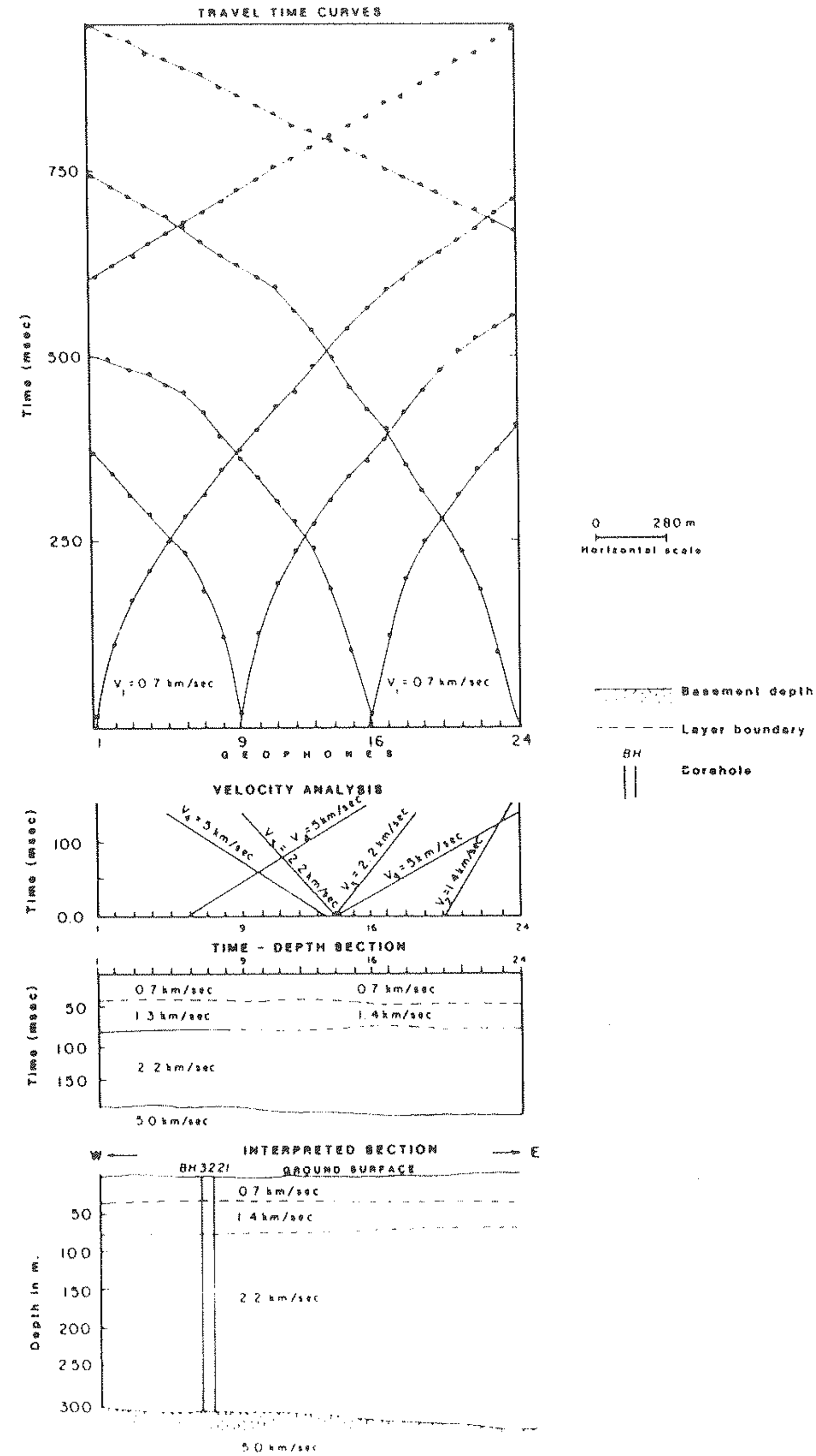

Figure 4. Interpreted seismic refraction section near borehole BH3221 (Eddaein town).

0.5-0.9 Km/sec for superficial deposits.
1.0-1.8 Km/sec for dry Umm Ruwaba formation.
2.0-2.2 Km/sec for saturated Umm Ruwaba and/or Nubian sandstone.
2.3-2.6 Km/sec for cemented Nubian sandstone.
4.0 Km/sec for the basement complex.

The average seismic velocity (V Km/sec) can be related to the average density (P g/cc) of the same sedimentary formation by the formula:

$$P = 1.9\ V^{0.25}$$

Where: P : average sedimentary formation density (g/cc).
V : average seismic velocity in sedimentary formation (Km/sec).

This relation holds only for sedimentary formations in this area and its generalization elsewhere should be used with caution.

Fig.5 shows the regional gravity, Bouguer gravity, residual gravity and the interpreted 2-D geological section for profile 1 (Eddaein-Buram). The profile shows irregular low Bouguer gravity values that reach about 25 mgal at 50 km from Eddaein town and decrease gradually towards Buram town (SW). The adjusted regional trend is of low order and apparently does not unduly influence Bouguer gravity data, however a gradient of 0.08 mgal/km decreasing in SW direction can be predicted. This low order trend may indicate that the source of the regional is deep. The irregular negative residual gravity profile (Bouguer gravity-regional gravity) reveals variable thicknesses of low density sediments infilling this part of the basin. The quantitative 2-D geological model, derived from residual gravity values, shows irregular basement topography. The sediments reach a maximum depth of 1500 at the central part, then the depth decreases southwestwards where, it reaches 400 m near Buram town. From the values of seismic velocities (2.3 km/sec) it could be concluded that this part of the basin is composed mainly of Nubian sandstone which is considered as the main aquifer in this part. The Umm Ruwaba formation is relatively shallow (less than 190 m) and stands above the regional water level in the area.

Fig.6 also shows the regional gravity, Bouguer gravity, residual gravity and the interpreted 2-D geological section for profile 11 which extends 125 km NE from Eddaein town. The profile shows a large gravity low at the central part. The gravity low is bounded from both sides by steep gradients gravity values. The negative residual gravity values can be interpreted as a low density two-dimensional sedimentary section and bounded by steep sides which may suggest normal faulting (Ali and Whiteley, 1981). The sediments reach a depth of 4.0 km at 50 km from Eddaein town. This remarkable thickness together with steep slopes on both sides of the section form a typical graben structure. The graben represents the NW continuation of Abu Gabra rift, which trends SE-NW, 150 km wide and filled with Cretaceous-Tertiary sediments (Browne and Fairhead, 1983). According to Medani and Vail (1973) the post-cretaceous faulting in Sudan is contemporaneous with East Africa Rift system. However Browne and Fairhead (1983) and Bermingham et al. (1983) relate Abu Gabra rift to the Central Africa Rift System and regard it as similar to early stage development of Red Sea and Gulf of Aden rifts.

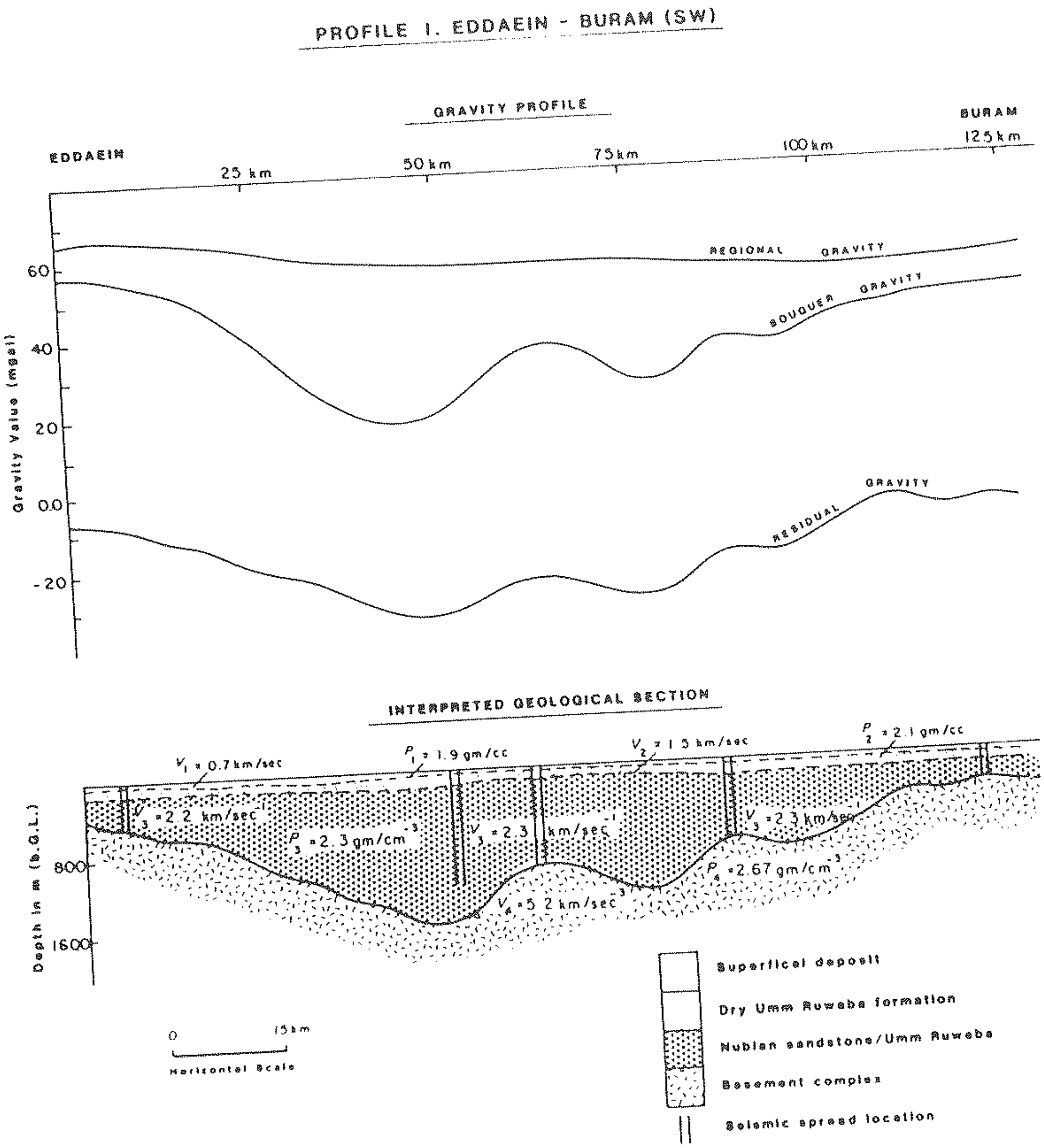

Figure 5. Quantitative interpretation of gravity measurements along profile 1 (Eddaein-Buram).

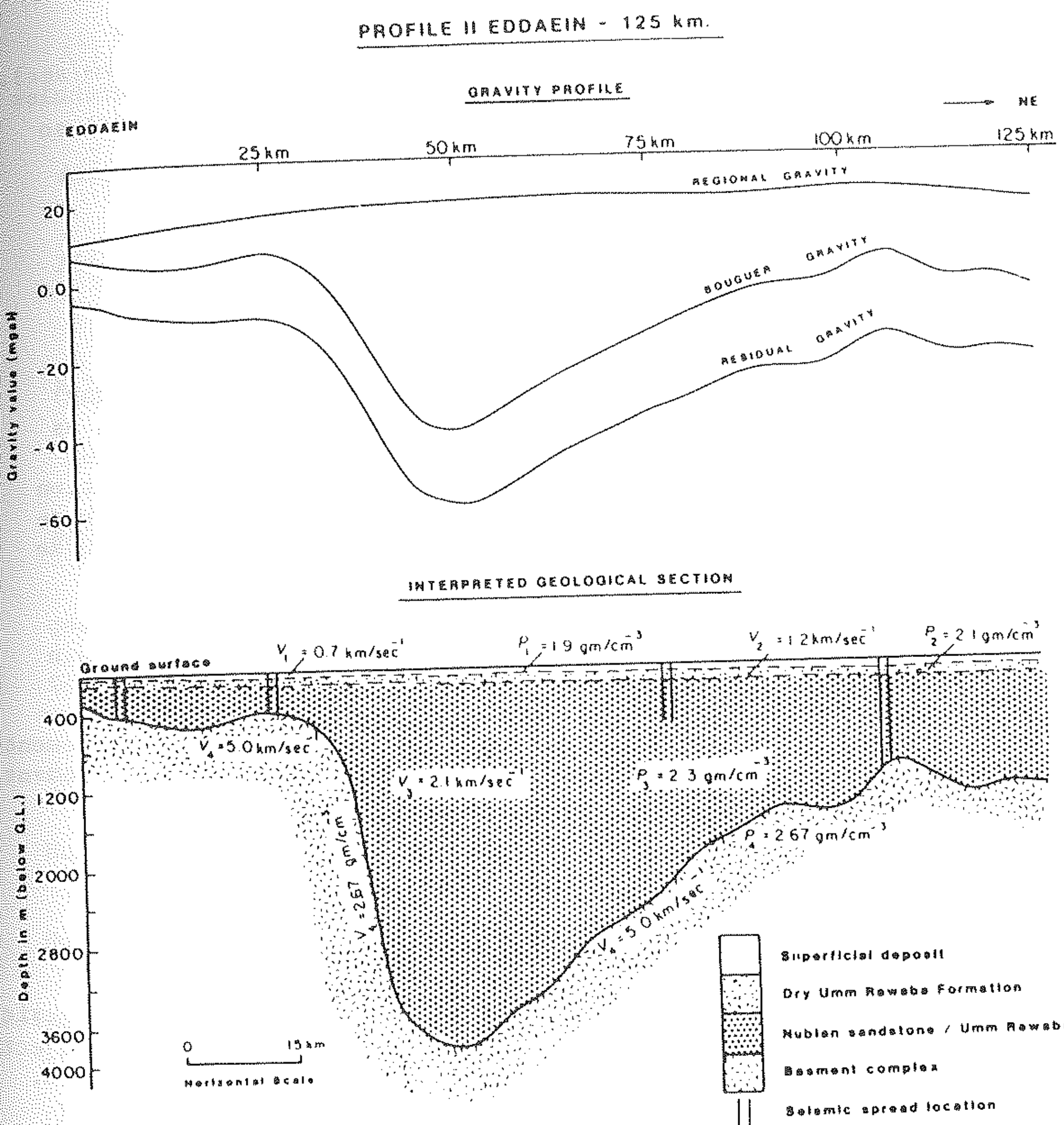

Figure 6. Quantitative interpretation of gravity measurements along profile 11 (Eddaein-NE 125 km).

In this part the bulk of the basin is filled with Umm Ruwaba sediments and/or less cemented Nubian sandstone formation (V=2.1 km/sec). Because Umm Ruwaba formation is the main aquifer in this part, boreholes are recommended to be drilled to depths that exceed 400 (Ali, 1983) so as to secure sufficient yields.

CONCLUSION

Gravity measurements were taken along two profiles (250 km long) to determine the lateral and the vertical extents of the sediments as a part of groundwater search in the Baggara Basin in southern Darfur Region (Sudan). Gravity measurements were aided by seismic refraction to provide depths at specific control points along the profiles. These depths were used to estimate the regional/residual gravity along these profiles.

Automatic inversion of gravity residual data has revealed a deep sedimentary basin that reaches 4.0 km at 50 km northeast from Eddaein town. The sediments are less cemented and possibly related to Umm Rawaba formation. The thickness of the basin decreases rapidly SW where it reaches 400 m near Buram town and the sediments are more cemented possibly related to Nubian sandstone and deposited on irregular basement topography.

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BIOGRAPHICAL SKETCH

Hamid O. Ali received B.Sc degree in geology from Khartoum University in 1972. In 1977 and 1979, he received Grad. Diploma in Hydrology and M.APP.Sc. in engineering geophysics respectively from University of New South Wales, Australia. Also holds Graduate Certificates in Ground Water geophysics from Italy, U.S.A. and Australia. He worked as a geophysicist with Rural Water Corporation, Sudan from 1972-1980 and with Chevron Oil Company from 1980-1981. He served as Director General for Water Corporation, Darfur Region, Sudan from 1981-1983. Presently, he is a teaching member at Department of Geology, Kuwait University, Kuwait. Fields of interest are ground water geophysics and evaluation of ground water resources.