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A 3D Geophysical Model of Baggara Basin, Darfur Sudan

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Abstract

Integration of gravity and resistivity methods were used to characterize the geological structures and the hydrogeological conditions in Baggara Basin.

Baggara Basin is structural depression as a pull-apart basin produced by displacements along a system of faults. Five stratigraphic units occupy the depression; the superficial deposits, volcanic lavas (Eocene/Miocene), the Umm Ruwaba formation, Nubian sandstone formation, and the basement complex.

Gravity measurements give a sense of that the Baggara Basin was dissected by different fault trends with down throws towards the center of the basin resulting in formation of many sub-basins. The thickness of the sediments occupying these sub-basins vary from few meters at the periphery of the basin to more than 3000 meters at the central part. However, the study area comprises five main sub basins, in which the inversed model shows that most of the sub basins (troughs) are formed in graben structure as many faults were detected and showed a domino style. These sub-basins are; Om Alkhiyrat sub-basin, Solowng/Umm Dursoh sub-basin, Ghibeibish/Tulus sub-basin, Abu Sufian sub-basin, Rakuba sub-basin.

Resistivity inversion showed that the Baggara Basin consists of various sedimentary sequences including sandstone, and mudstone, that characterize the cretaceous sedimentary formation (Nubian sandstone), in addition to the unconsolidated sediments of Umm Ruwaba formation.

The Nubian sandstone formation is dominated in the western, southwestern and southern part of the basin, while in the eastern and central part of the basin the Umm Ruwaba formation prevails, and overlies in some areas directly the basement complex rocks. The Basin contains two main groundwater aquifers: the Umm Ruwaba aquifer and the Nubian aquifer, where Nubian prevails in the western and southwestern parts, while Umm Ruwaba is in the eastern and southeastern parts, and in the center both of them is existed.

Keywords: Gravity; Integration; Gravity measurements; Groundwater aquifers

Introduction

The Baggara sedimentary basin is located in southern Darfur and covers about 150,000 sq km extending in a WSW to ENE direction approximately located between 10°-12° N and longitudes 23°-26° E (Figure 1). The region has witnessed in the last few decades conflicts between nomads and farmers due to lack of sufficient water, desertification and displacement of inhabitants etc. The understanding of the geological constituents of this basin specially its dimensions and lithological constituents will help a lot in developing and utilizing its resources; mainly groundwater availability, its quantity and quality and possible occurrences of oil reservoirs. To achieve this goal, several studies were conducted [1-5,21].

The previous researches were only of regional nature and in most cases two dimensional geological or geophysical models were provided. However, in this paper an attempt is made to give a three-dimensional geophysical model based on *in situ* gravity data collected data and analysis of areal gravity data constituting of more than 4000 points covering most of the Baggara Basin region in addition to interpretation of 65 geoelectrical soundings conducted in the area of interest using ABEM, SAS 1000 instrument. The massive satellite data, the EIGEN-6C4 gravity field model released in 2014, whose accuracy is up to 2.73 mGal is used.

During this work, the locations of the vertical electrical sounding points were determined by using the Global Positioning System (GPS).

Materials and Methods

Geology and structural setting

The following geological units are recognized (Table 1) arranged in chronological order from top to bottom.

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Table 1: The geological units in chronological order from top to bottom.

Unit	Age
Superficial deposits	Quaternary
Umm Ruwaba formations	Tertiary-Quaternary
Volcanic lavas	Tertiary
Mesozoic sandstone formation	Cretaceous
Basement complex	Precambrian

The basement complex: Consists of Precambrian rocks which include metamorphic rocks of both igneous and sedimentary origin and younger intrusive. Strojexport [6] subdivided the basement complex, with reference to western Sudan, into:

- Older metamorphic rocks which include gneisses, migmatites and amphibolitic shales.
- Younger rocks which include granites, granodiorites and pegmatites.

However, Hunting Technical Services [7] subdivided the basement rocks in Darfur region into:

- Meta-igneous rocks.
- Metasediments such as pelites and coarse psammites.
- Younger intrusive group, which includes granites, granodiorites and syenite.
- Minor intrusive dykes, pegmatites and quartz veins (Pre-Cambrian to Cambrian).

The Mesozoic sandstone formation (Nubian sandstone): The Nubian sandstone formation occupies about 28 (percent) of the total surface area of the Sudan. Most of this formation is situated North of latitude 10 N. The formation is usually flat lying or very gently dipping. The thickness of the Nubian sandstone formation may reach more than 2000 m [8]. Karakanis [10] divided the Nubian sandstone group in Western Kordofan and Darfur into a basal, middle and upper series. The basal series consists of coarse silicified sandstone and conglomerates. The middle series is composed of mudstone and sandstone (mudstones dominate over sandstones). The upper series is composed of poorly sorted sandstone. Mukhtar [9] attributed the lens-shaped occurrence of the conglomeratic sandstone in north Darfur to channel deposition (Figure 1).

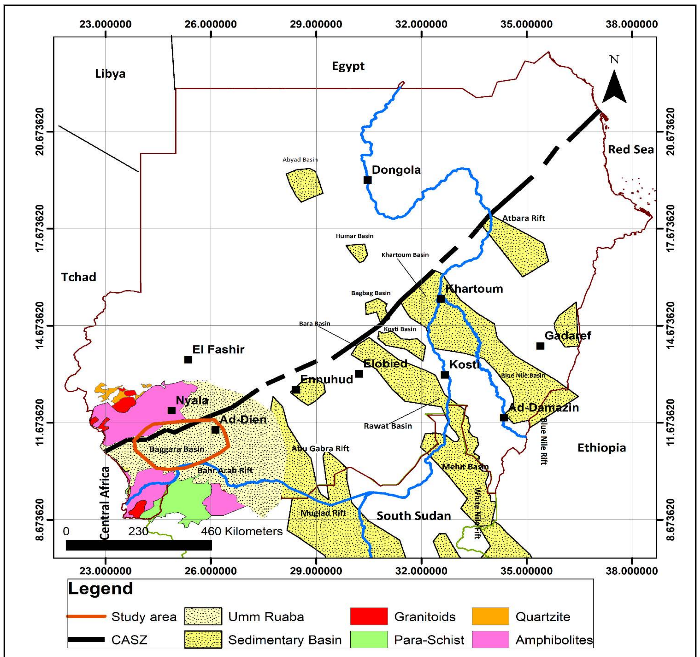

Figure 1: Structural and geological map of Baggara Basin [11].

Volcanic lavas (Eocene/Miocene): Consist mainly of hard dark grey basalt, basaltic tuffs and volcanic ashes, which cover most of the previously mentioned formations. J Marra covering a large area of western Darfur is an example of this tertiary formation.

The Umm Ruwaba formation: Covers all Upper Nile province and the most, Lakes Provinces and parts of Bahr El Arab, Northern and Southern Kordofan and Darfur provinces. It covers about 20 percent of the Sudan. It rests largely on an irregular surface in the basement rock or Nubian sandstone formation. The sediments consist of unconsolidated to semi-consolidated gravels, sands, clayey sands, and clays. Abd Abd El-shafi [12] recognized three thicknesses in Umm Ruwaba formation according to the distribution of the heavy minerals content collected from 100 to 160 m depth.

The superficial deposits: These are unconsolidated sediments consist of gravels, sands and sandy clays deposited during Pleistocene to recent time and can be classified into wind-blown sands (Qoz) and stream deposits (wadi fills). These sediments overlie unconformably the Umm Ruwaba Formation or Nubian sandstone in some places.

Baggara graben covers the area between the Nuba Mountains in the East and the Central African Republic in the west. In the north it is defined by the faulted Mesozoic deposits south of the Darfur dome. North of this line the Mesozoic deposits crop out in the form of a

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chain of low-lying, flat-topped hills, covered by lateritic deposits, and extends for a distance of more than 200 km. South of the faulted zone, the Mesozoic sediments are found below the surface and are known from borehole records and remnants of sandstone and laterites cropping out along Bahr El Arab [5].

Structurally, the Bagarra basin is one of the Sudanese interior basins described by Schull [13] to be of Mesozoic to Tertiary in age and are generally controlled by major NW to WNW trending pre-existing faults. The basins are terminated from the northwest by major SW-ENE trending curvilinear structures lineament termed Central African Shear Zone [14]. These basins are located within two NW and NNW trending rift systems referred to as Muglad Rift and Melut Rift, respectively (Figure 1). Elhassan et al. [15] The Baggara Basin of Sudan is an ENE-WSW trending basin located within the West and Central Africa Rift System (WCARS) and NW of the Muglad Basin. The trend of the Baggara Basin is similar to other basins in eastern Chad, where oil has been discovered.

Results and Discussion

Interpretation of geophysical data: Gravity measurements

Qualitative interpretation: The satellite gravity data together with the data acquired in the field has been processed, transformed and gridded by Kriging interpolation, and contouring with spacing of (10 mGal) to make Bouguer anomaly map (Figure 2). It shows several zones; high gravity anomalies, intermediate, low gravity and very low gravity anomalies. These variations in anomaly are controlled by the density contrast between subsurface rocks and the gradients indicate presences of geological structure (faults).

- The high gravity anomaly contour closures are between (-56 to more than -40 mGal). These anomalies are occurred in several areas in the map with different geometric shapes and dimensions. This pattern indicates shallow basement Complex as in Buram, Suleia, Assalaya, Abu Ajoura, Ghazala Gawazat, Abu Matarig, and southwest of the area.
- The intermediate gravity anomaly closures are between -56 and -62 mGal. These anomalies are present in many scattered areas on the Bouguer map and indicate a reasonable thickness of sediments, such areas as Ed Elfirsan, Tulus, Abu Sallala, Kateela, Gedi, Al Bayada, Gandol, Al Tomat, and others.
- The low gravity anomaly closures are ranging in the gravity values from -62 to -72 mGal. These anomalies indicate shallow sedimentary basins as in Elsarig and Git where the values decreased toward the center forming an elliptical shape. Also, this clear in the southwest of the map, Al Deain, Alfirdos, Sargaila, Ummari, Gerieda, Al-Nakhara and others.
- The very low gravity anomaly closures are present in five areas in the map with almost elliptical shapes and different dimensions. The gravity values range from -72 to less than -94 mGal. Very Low anomaly closures normally represent bodies with a lower density than the basement, in this case, these closures indicate deep sedimentary sub-basins such as Ghibeibish/Tulus Sub-Basin, Solowng and Umm Dursoh sub basin, Om Alkhiyrat Sub-Basin, and Rakuba and Abu Sufian sub-Basins southeast and northeast of Al Deain.

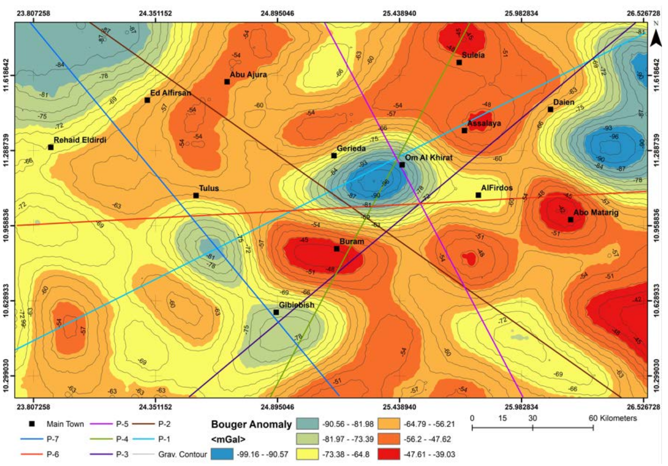

Figure 2: Profiles along the Bouguer map in study area.

The analysis is based on selected profiles across some structure (Figure 2) and graphical method is used to separate regional from residual by smoothing profiles (Figure 3).

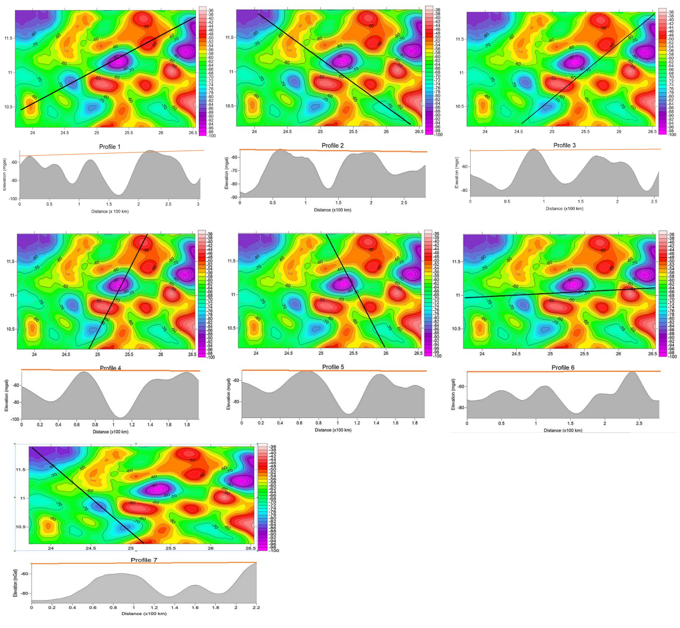

Figure 3: Regional separation along profiles in gravity map.

Gravity inversion (2D): For the quantitative interpretation, a two-dimensional model is executed using 2D modeling program (Gravmod) which uses vertical prisms as an inversion method.

For the modeling, seven profiles are selected (Figure 2), which approximately cover the area of study.

From the previous studies by Strojexport [6], Hunting Geology and Geophysics [16], Mitwalli [17], Mula [8], Faraw [18], and Ali and Whiteley [19] and Ali [4], the bulk densities for the basement complex around the study area vary from 2.54 to 2.90 g/cm^3, with mean value of 2.66 g/cm^3, and matrix densities vary from 2.56 to 2.97 g/cm^3, with mean of 2.76 g/cm (Table 2). In the basement complex rocks, generally low densities are caused by weathering. The mean bulk densities for sedimentary sequences vary from 1.8 to 2.5 g/cm^3, with mean of 2.15 g/cm^3, and mean matrix densities vary from 2.56 to 2.72 g/cm^3, with mean of 2.64 g/cm^3. High densities characterize silicified

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sedimentary rocks of low porosity. Argillaceous sediments of the recent Formations show the lowest value of the bulk densities.

For creating of the gravity models for each profile, density contrast of (-0.5 g/cm^3) between Basement rocks and the overlying sediments, and associated structures are assumed which is suitable for the models. Density variation within the basement rocks is not considered, because they are undifferentiated where they are mapped or recorded in boreholes.

Table 2: Some physical properties of rocks.

		Density gm/cc				
Formation	**Rock type**	**Bulk**	**Mean**	**Matrix**	**Mean**	**Porosity**
Basement complex rocks	Granite	2.55-2.76	2.65	2.56-2.66	2.61	1
	Amphibolite	2.89-2.92	2.9	2.96-2.97	2.97	2
	Schist	2.44-2.65	2.54	2.64-2.68	2.66	7
Nubian Sandstone	Silicified sandstone	2.4-2.6	2.5	2.58-2.73	2.72	9
	Medium/Coarse sandstone	2.26-2.34	2.3	2.53-2.62	2.56	10-15
	Mudstone	1.76-2.36	2.06	1.43-2.76	2.62	21
UmRuwaba formation	Unconsolidated sediments	2.2-2.3	2.1			25
Superficial deposits		1.10-2.98	1.8			-

The gravity inversion (2D) analysis of the Baggara Basin through the proposed profiles (Figure 4) showed that there are many sub-basins filled with a reasonable thickness of sediments, and this was confirmed by the boreholes data. The thickness of the sediments in these basins is vary and may reach more than 3000 meters in some areas.

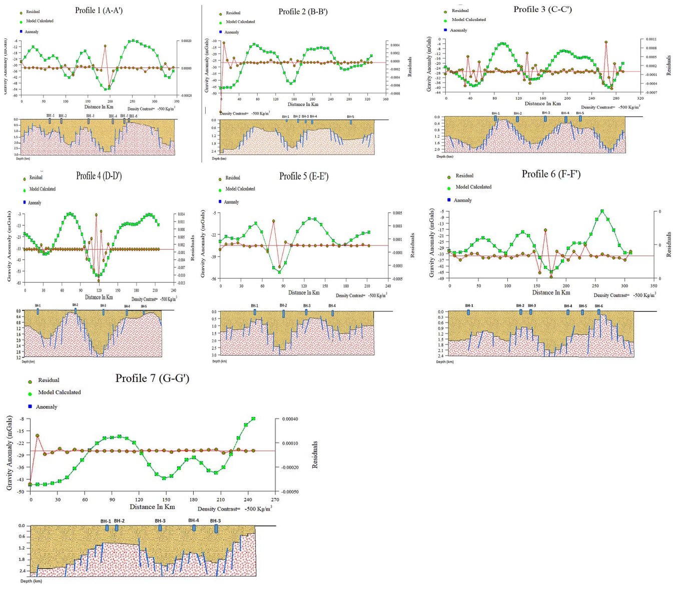

Figure 4: Gravity inversion (2D) along the proposed profile.

3D gravity model: The Three-Dimensional (3D) inversion is carried out for the Baggara Basin (study area) through 3D gravity modeling program, which uses Talwani's [20,24] (approach to model arbitrary 3D shape, used of the initial slab model as contour sides then used inversion to calculate final 3D model of the data sets. Final 3D models are shown on (Figure 5) for gravity map with their comparison with the initial slab model.

From the 3D models the study area depths ranges from less than 200 meters to about 3.0 km in Talwani's inversed models.

The study area comprises five main sub basins, in which the inversed model shows that most of the sub basins (troughs) are formed in graben structure as many faults were detected and showed a domino style, these sub basins are:

- Om Alkhiyrat Sub-Basin, the sediments thickness is 2800-3000 m.
- Solowng/Umm Dursoh Sub Basin in the NW part of the Baggara Basin. The maximum calculated depth is 2500-2600m.
- Ghibeibish/Tulus Sub-Basin with maximum sedimentary rocks thickness of 1800 m.
- Northeast of Al Deain (Abu Sufian sub-Basin). Because the profile is passed through the NW side of the basin, 2000 m of sediments were calculated.
- Southeast of Al Deain (Rakuba Sub-Basin), the calculated sediments thickness is 2500 m.

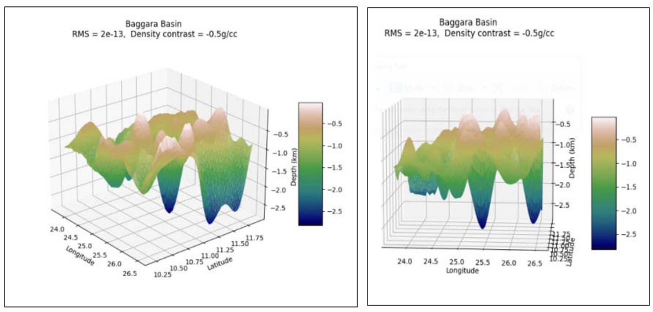

Figure 5: 3D gravity model of Baggara basin.

Electrical resistivity inversion: The quantitative interpretation of Vertical Electrical Sounding (VES) data that acquired in the area

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lacking borehole data is interpreted with the help of automatic inversion computer program referred to as IPI2WIN.

The calibration is made by interpreting the VES curves with help of the lithological logs of the corresponding borehole depth, the calculated layers model has been converted into geo-electric sections for a meaningful picture along eight profiles (Figure 6).

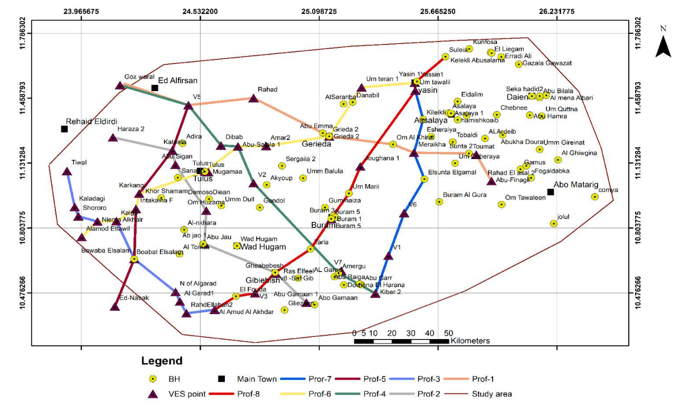

Figure 6: The VES points, BH and the profiles of the geo-electric sections.

The results of the interpreted VESes data (thickness and resistivity's) together with the boreholes lithologic data have been used to construct the geo-electric sections along eight profiles (Figure 7).

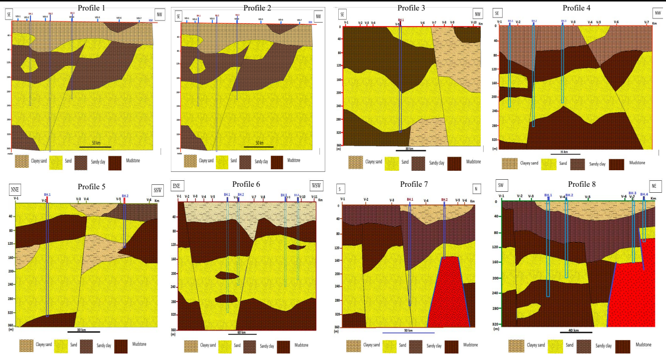

Figure 7: Geo-electrical sections along profiles in Baggara Basin.

The resistivity limits of the rock units which are used in the interpretation of the study area are represented in Table 3. The VES values and the boreholes description in combined geological -geo-electrical sections along profiles (1-8) show the differences in the thickness of the lithological units.

Table 3: The resistivity values and the corresponding lithologies which are used in the interpretation and construction of the geo-eclectric sections.

Resistivity in ohm-m	Rock units
1-14	Mudstone
15-30	Sandy clay
31-75	Clayey sand
76-99	Fine sandstone
100-400	Medium sandstone
300-2000	Coarse sandstone
>2000	Silicified sandstone

The basement complex is not usually showed in VES measurements due to the thick sedimentary sequence and limitation of the resistivity method. Nevertheless, Basement Complex was tapped in some boreholes due to some geological structure control.

Resistivity inversion of these profiles showed that the Baggara Basin consists of various sedimentary sequences including sandstone, and mudstone, that characterize the Cretaceous sedimentary formation (Nubian sandstone), in addition to the unconsolidated sediments of Umm Rawaba formation.

These profiles showed that the Western, Southwestern and Southern part of the basin is dominated by Nubian sandstone formation, and the Umm Rawaba formation is almost non-existent or of less thickness, while in the eastern and central part of the basin the Umm Rawaba formation prevails, and overlies in some areas directly the basement rocks, such as in Ghazala Gawazat, Keliekile, and Suliea. Nevertheless, the Baggara Basin contains two main groundwater aquifers: The Umm Rawaba aquifer and the Nubian aquifer, where Nubian prevails in the western and southwestern parts, while Umm Rawaba is in the eastern and southeastern parts. In the center of the basin both of Nubian and Umm Ruwaba aquifers are existed.

Resistivity inversion model also showed that the Baggara Basin is complex in terms of geological structures, as there are several faults separating the various sedimentary sequences and basement rocks.

Conclusion

Interpretation of the integrated geophysical data indicates that Baggara Basin is structural depression as a pull-apart basin produced by displacements along the Central African Shear Zone and a system of faults. Five stratigraphic units occupy the depression; the superficial deposits, volcanic lavas (Eocene/Miocene), the Umm Ruwaba Formation, Nubian Sandstone Formation, and the Basement Complex.

Based on the massive satellite gravity data and in situ gravity data collected, gravity Bouguer anomaly map has been constructed. This map is divided and described into four closures: High gravity anomalies, intermediate, low gravity and very low gravity anomalies. Accordingly, 2D inversion model for seven proposed profiles were constructed using density contrast of (-0.5 g/cm^3) between basement rocks and the overlying sediments, and associated structures are assumed which is suitable for the models. From the 2D inversion model of all the profiles many troughs and sub-basin have been designated with the maximum calculated sediments thickness is greater than 3000 m. The deepest trough is in the center of the basin.

From the 3D models the study area depths ranges from less than 200 meters to about 3.0 km. The study area comprises five main sub basins, in which the inversed model shows that most of the sub basins are formed in graben structure as many faults were detected and showed a domino style. These sub-basins are; Om Alkhiyrat sub-basin, Solowng/ Umm Dursoh sub-basin, Ghibeibish/Tulus sub-basin, Abu Sufian sub-basin, and Rakuba sub-basin.

The resistivity inversion showed that the western, southwestern and southern part of the basin is dominated by the Mesozoic sedimentary formation (sandstone formation), and the Umm Rawaba formation is almost non-existent or of less thickness, while in the eastern and central part of the basin the Umm Rawaba formation prevails, and overlies in some areas directly the basement rocks.

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References

1. Salama RB (1978) Groundwater resources of the Sudan. University of New South Wales, USA.
2. Hunting Geology and Geophysics (1973) Savanna development project. Geophysical Survey Report. F.A.O. Sudan Project 71/525/3. Rome.
3. El Tohami MS (1978) Geology and hydrogeology of Baggara basin, Sudan. Unpublished Ph.D. Thesis, London University, England.
4. Ali HO (1985) Gravity and Seismic Refraction Measurements for Deep Ground Water Search in Southern Darfur Region, Sudan. In NWWA Conference on Surface and Borehole Geophysical Methods in Ground Water Investigations February 12-14, 1985, Fort Worth, Texas. pp. 106-120.
5. Salama RB (1986) The evolution of the river Nile in relation to buried saline rift lakes and water resources of Sudan (Doctoral dissertation, UNSW Sydney).
6. Strojexport (1972) Groundwater Research, SW part of Kordofan, Second Stage, Final Report, Praque. Sudan-a possible continental transform fault. Berline Geowiss Abh (A) 1: 31-44.
7. Hunting Technical Services (1974). Southern Darfur Landuse Planning Survey. Annex 2. Hydrogeology, Herts. England.
8. Mula HG (1972) A geophysical survey of Jebel Aulia region. Sudan Notes and Records, 164-168.
9. Mukhtar AR (1975) The hydrogeology of Shagara Basin, with reference to the water supply of the El- Fashir Town, western Sudan. M.Sc. Thesis, University of Khartoum, Sudan.
10. Karkanis BG (1966) Hydro chemical facies of ground water in the western provinces of Sudan.
11. Fairhead JD (1988) Mesozoic plate tectonic reconstructions of the central South Atlantic Ocean: the role of the West and Central African rift system. Tectonophysics 155: 181-191.
12. Abd El-shafi ME (1975) Environmental Isotopes as hydrogeological tool in Bara Basin, Sudan. IAEA, Report, Vienna, Austria.
13. Schull TJ (1988) Rift basins of interior Sudan: petroleum exploration and discovery. AAPG Bull. 72: 1128-1142.
14. Scandelmeier H, Pudlo D (1990) The Central African Fault Zone (CAFZ).
15. El Hassan WM, El Nadi AHH (2015) Impact of inversion tectonics on hydrocarbon entrapment in the Baggara Basin, Western Sudan. Mar Pet Geol 68: 492-497.
16. Hunting Geology and Geophysics L (1970) Water supply and development in "Darfur Province; Report No. 4.
17. Mitwalli MA (1970) Interpretation of some gravity profiles from estern Sudan. Pure Appl Geophys 80: 184-192.
18. Farwa AG (1978) Geology and structure of the Gezira area as deduced from gravity measurements (Doctoral dissertation, MSc thesis, University of Khartoum).
19. Ali HO, Whiteley RJ (1981) Gravity exploration for groundwater in the Bara Basin, Sudan. Geoexploration 19: 127-141.
20. Talwani M, Ewing WM (1960) Rapid computation of gravitational attraction of three-dimensional bodies of arbitrary shape. Geophys 25: 203-225.
21. Elkadi HH, Abd Elshafi ME (1985) Reevaluation of hydrogeological and hydrochemical aspects for Nubian aquifer in Sudan. IAHS-AISH Publication. 154: 92-101.
22. Browne SE, Fairhead JD (1983) Gravity study of the central African rift system: a model of continental disruption: 1. The ngaoundere and Abu Gabra rifts. Developments in Geotectonics 19: 187-203.
23. Strojoexport (1976) Geophysical investigations of groundwater structures, western part of Kordofan province and eastern part of Darfur province. Report submitted to Rural Water Corporation, Khartoum.
24. Talwani M, Worzel JL, Landisman M (1959) Rapid Computations for Tow-Dimensional Bodies with Application to the Mendocino Submarine Fracture Zone. J Geophys Res 64: 49-59.