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Preliminary sequence stratigraphy and tectonic evolution of the Tokar Delta, (Southern Sudanese Red Sea)

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دراسة استنتاج التتابعات الترسيبية في دلتا طوكر (جنوب البحر الأحمر – السودان)

عباس موسى يعقوب

جامعة العلوم والتكنولوجيا السودانية

كلية هندسة البترول والتكنولوجيا

قسم هندسة البترول

يعتبر البحر الأحمر صدع أخدودي يفصل بين الجزيرة العربية و قارة أفريقيا. يمتد هذا الأخدود من خليج عدن جنوباً عند خط عرض $40^{\circ} 12'$ شمالاً إلى خليج السويس في الشمال عند خط عرض $50^{\circ} 27'$ شمالاً). تم اختيار عدد اثنين وثلاثين خط زلزالي في منطقة الدراسة من المعلومات الزلزالية التي تم جمعها بواسطة شركات البترول التي عملت في منطقة البحر الأحمر (شيفرون 75-1976م , توتال 1980 , الشركة العالمية للبترول 1992). وتقدر المساحة الكلية لهذا الدراسة بحوالي 2500 كلم مربع. تم استخدام السيزموغرافات الاصطناعية (synthetic seismograms) لأبار سواكن-1, بشانر-1أ , وبشانر-2أ. تم توزيع التتابع الطبقي و الترسيبية لهذه المنطقة علي خلفية الحركات الأرضية إلي أربعة مراحل وهي:

- 1- التتابع الترسيبية لما قبل الحركات التكتونية.
 - 2- التتابع الترسيبية خلال فترة حدوث الحركات التكتونية.
 - 3- التتابع الترسيبية الملحي.
 - 4- التتابع الترسيبية خلال فترة حدوث الحركات التكتونية وما بعد التكوينات الملحية.
- لإستنتاج التتابعات الترسيبية في منطقة الدراسة تم استخدام أساسيات الزلزالية الطبقيية حيث وجد أن:
- 1- التتابع الأدنى: (مكار + حماميت + مجموعة مقرسم) تتوضع فوق صخور الأساس بصورة شبه منتظمة.
 - 2- التتابع الملحي: ترسب في فترات انحسار وتقدم البحر. وجود هذه الترسبات الملحية يشير إلي تغييرات مناخية وانقطاع الترسيب. هذا التتابع يشمل علي (تكوين بلاعيم وتكوين دونقناب). السطح الأعلى لدونقناب يعتبر سطحاً للفالق الزاحف في هذه المنطقة.
 - 3- التتابع الثالث: يحتوي علي ثلاث سحنات (التي تعبر عن تكوين زيت) أدناها يتراكب فوق السطح الأعلى لتكوين دونقناب. السحنات الترسيبية الوسطي تدل علي تقدم البحر والتي ترسبت خلال هذه الفترة (تم بمقارنة منحنيات التغيرات الاقليمية للبحر مع التغيرات المحلية لهذه المنطقة).
 - 4- التتابع الأعلى: رسوبيات سميكة تحتوي علي خليط من الصخور الرملية والجيرية والتي يطلق عليها أسم مجموعة أبوشجرة.
- تعتبر دلتا طوكر جزء من الصدع (الشمال غربي-الجنوب شرقي) الأخدودي الذي يتحكم في مجمل الحوض الرسوبي في هذا الاقليم.

Keywords: stratigraphy , tectonic evolution, synthetic seismograms, rifting, salt phase.

ABSTRACT

The study area comprises about 2500sq.Kms. From the seismic data acquired by the Oil Companies (Chevron 1975-76 Total 1980 and IPC 1992), thirty two seismic lines were selected Fig (2). Also synthetic seismograms of Suakin-1, Bashayer-1A and Bashayer-2A wells are used.

The stratigraphy and sedimentation of the Sudanese Red Sea can be placed into four major tectonic phases, Pre-rifting stratigraphy, Syn-Rift Pre-Salt Stratigraphy, Salt Phase and Syn-Rift Post Salt Stratigraphy. Basic concepts of seismic stratigraphy are applied, the lower most sequence (Mukawar, Hamamit and Mughersum group) overlies and onlaps the basement complex is relatively uniform throughout the area, the evaporite sequence deposited during the cycle of sea level rise and fall, indicating a change in climate and prolonged period of desiccation, this sequence is composed of Belayim and Dungunab Formation. The Dungunab Formation is a listric glide surface. The third sequence contains three system tracts, the lowermost is a low stand, the middle is a transgressive, and the upper is a high stand system tract. This sequence is known as the Zeit Formation. The uppermost sequence is a thick sedimentary unit which is composed mainly of a mixture of clastics and carbonates of Abu Shagara Group. The region witness extensive studies concerning the behavior of the tectonism and the evolution of the Red Sea and its adjoining. Tokar Delta is a part of a NW-SE trending fault-controlled sedimentary basin.

Introduction

The (Tokar Delata) study area (of about 2500 km^2) is located in the Southern Sudanese Red Sea Fig (1) (lat 18° 30' N to 18° 59' N and long 37° 50' E to 38° 20' E). Tokar Delta is most prospective area in the Sudanese Red Sea, fig (9) is a schematic cross-section through the delta toward seawards through Bashayer Suakin area and South Suakin this cross-section shows why the delta is so prospective. It constitutes three separated syn-rifting clastic wedges, the lower of Middle Miocene age, separated from the next oldest of Middle-Upper Miocene age by the Dungunab Formation halites and with the youngest of Plio-Pleistocene age lying unconformably on the Middle-Upper Miocene clastic wedge

The region is characterized by high fringing Red Sea hills; these hills are composed of Precambrian Basement Complex, with peaks rising to an altitude of about 2000m, parallel to which exist an almost continuous coastal plain, with bands of reef terraces (of recent age) having a width ranging between 0.5 and 10km. The coastal plain is covered by sparse vegetation and dominated by young alluvial deposits. The Sudanese Red Sea was studied by many authors. Swartz D.H., and Arden, D.D.[1], described the geological history of the Red Sea. Carella and Scarpa, [2] described the lithostratigraphy and the biostratigraphy of the Sudanese Red Sea coastal planes. Sestini, [3] was the first to recognize the Miocene/Pliocene-unconformity.

The Department of Mineral Resources of Sudan in collaboration with the Soviet Technical Aid Program [4], Qureshi, [5] with a team of Khartoum University carried out gravity survey from Atbara to Port Sudan. Chevron Oil Company (1975-1976), carried out gravity survey, which resulted in the production of Bouguer anomaly map of Tokar Delta. Texas Eastern (1980) acquired gravity data in the onshore area contiguous to their offshore Halaib-1 well, which is located close to the Egyptian border.

Robertson Research International (RRI) [6]; Bunter and Abdel Magid, [7]; United Nation Development Program (UNDP 1988), revealed the presence of good to fair quality Miocene reservoirs and source rocks within Middle Miocene evaporates. In 1992 IPC

acquired the seaward portion of the former Chevron Tokar Delta acreage. Izzedin, A. Y., [8] interpreted and compiled seismic and potential field surveys in the central part of the Red Sea for the structures and evolution of the Red Sea. Girdler [9]. Makris and Henke [10] in their pull-apart model have suggested left –lateral strike-slip faults extending roughly in a north-south direction in the region. A regional basin analysis with special emphasis on Tokar Delta was completed by Geiger, [11].

Geological Setting

Stratigraphy and sedimentation of the Sudanese Red Sea can be divided into four major tectonic phases (Roberston Research International) [5]. These are:

1- Pre-rifting stratigraphy

During the late Precambrian/Eocambrian, the Afro-Arabian craton was penplained and tilted to the north and east. Through the Paleozoic time, marine clastics were deposited in the north, onto the eroded Precambrian/Eocambrian Basement. Due to the transgression of the Tethys Sea during the Jurassic time marine sediments were deposited onto the northern part of the African continent (Mitchell, et al) [12].

A marine Jurassic sequence extended along both eastern and western margins of the shield to latitude 17° N. At the end of the early Cretaceous, there was an abrupt regression, Fig (3), and then there was a Cenomanian marine transgression onto the Afro-Arabian craton, which effectively halted the deposition of Malha Formation (Upper Palaeozoic to lower Cretaceous age). During this period of transgression, sediments of Mukawar Formation (Upper Cretaceous age) were deposited onto the northern part of the Red Sea. The end of Cretaceous was marked by uplift and erosion.

The Eocene sea transgressed the Afro-Arabian craton from the north and south. At the end of Eocene there was again a pronounced regression and a further widespread period of erosion and non-deposition.

2-Syn-Rift Pre-Salt Stratigraphy

At the end of Eocene times, pre-rift doming resulted in the deposition of coarse continental clastics. The initiation of rifting followed the Eocene- Oligocene boundary, so that the Hamamit Formation straddle the pre-and post rifting events. The deposition of Hamamit Formation was followed by lower Miocene clastics sediment (Rudeis Formation) and lower-middle Miocene (Kareem Formation). A period of desiccation was initiated during the Middle Miocene, represented by the mixed clastics, carbonates and evaporitic of the Belayim Formation.

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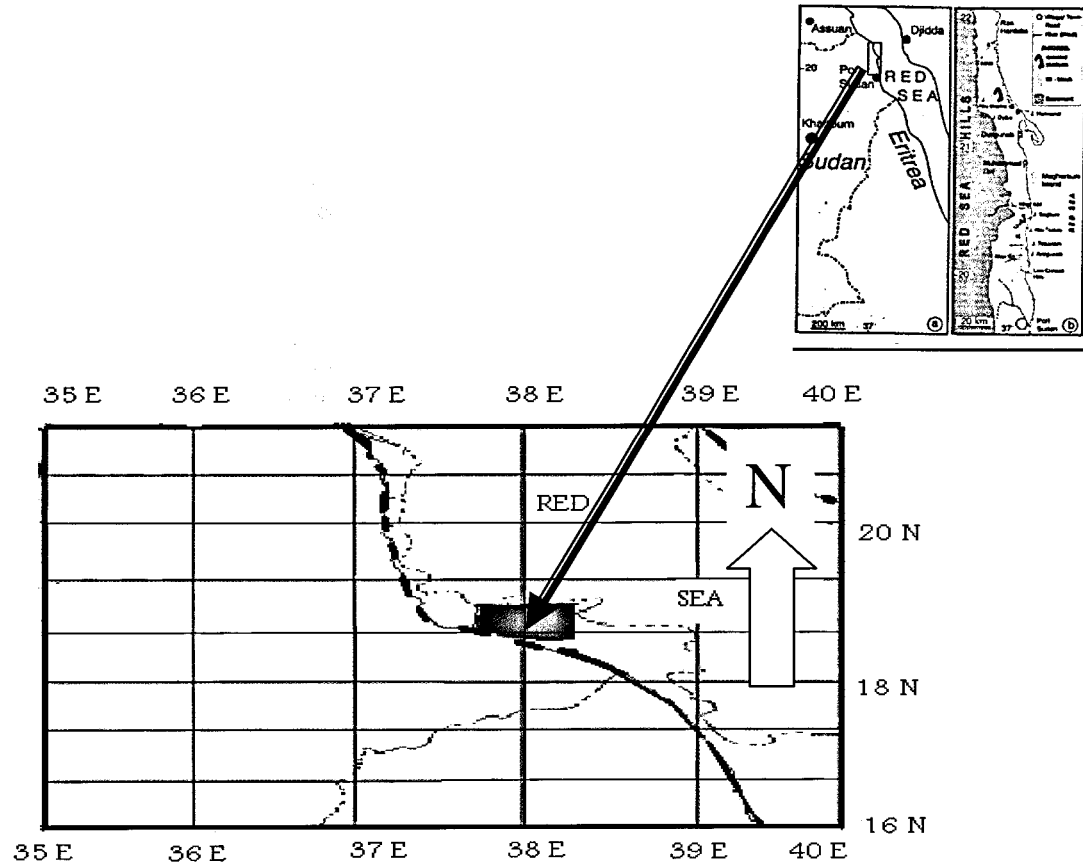


Fig (1) Location map of the study area

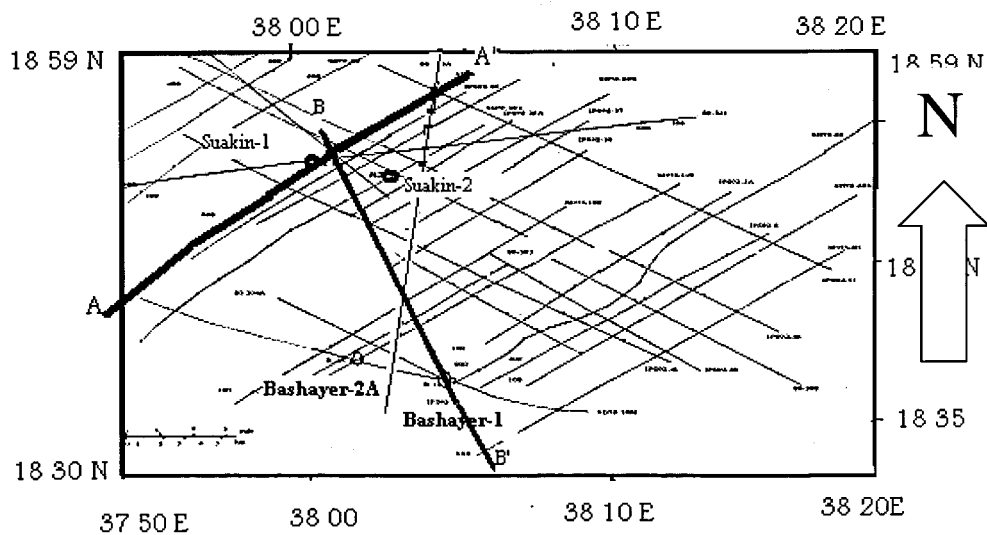


Fig (2) Base map of seismic lines

3- Salt Phase

In the Middle Miocene, the Red Sea graben became restricted in the northern extremity, where vast thicknesses of evaporates were deposited. Eventually the Gulf of Suez-Red Sea graben was desiccated and thick halites were deposited, forming the South Gharib Formation of Gulf of Suez and its Sudanese equivalent, Dungunab Formation. Rifting continued until the latest Miocene, accompanied by horst-graben faulting and consequent fault block rotation.

4- Syn-Rift Post Salt Stratigraphy

During the Middle Miocene the Red Sea has been split via floor spreading, almost to the present day configuration, but the Bab-el Mandab was still closed. At the end of the Miocene and during earliest Pliocene a renewed phase of uplift took place and the Bab-el Mandab was breached, leading to the widespread unconformity and erosion of most of the upper most Miocene deposits.

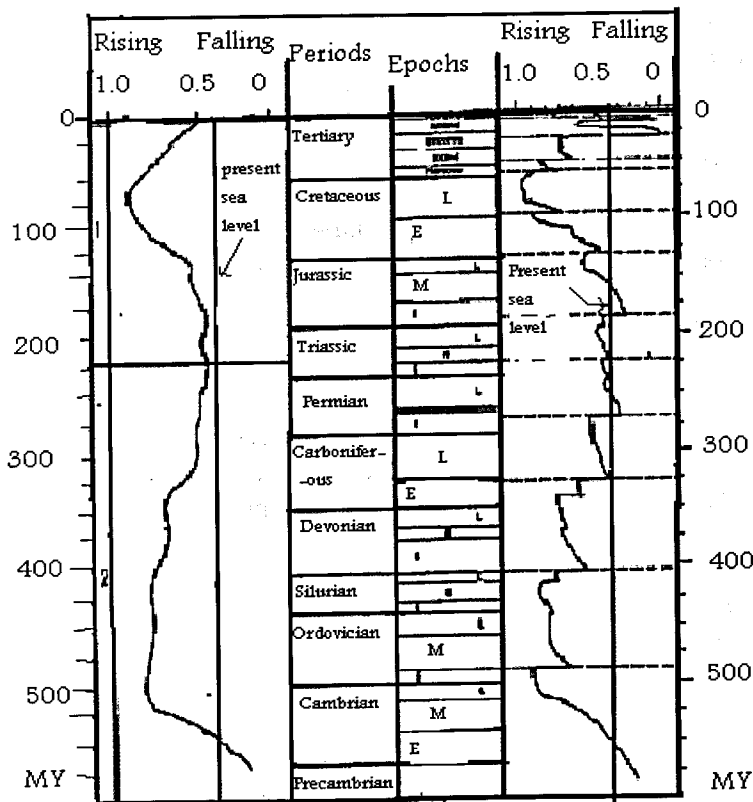


Fig (3) Cycles of relative changes of sea level during Phanerozoic time (After Vail et al, 1977) a modern version of this figure can be found in Sharland et al 2001

The Red Sea and the surrounding regions exposed to extensive research, which deals Concerning the regional geology and tectonics of the area, the succession of the numerous igneous, sedimentary and metamorphic rocks that crops out in the Sudanese Red Sea region was summarized by several authors (Carella and Scarpa, [2], Sestini [3], Beydoun [13], Bunter and Abdel Magid [7] and Crossley et al,[14].

1- Basement Complex

The Basement Complex comprises rocks of "pre-Nubian sandstone" age. Three sequences have been recognized, arranged from the youngest to the oldest, Awat Series [15], Nafirdeib Group (Gabert et al) [16] and Kashabib Group (Gabert et al) [16].

2- The Coastal plain deposits

Carella and Scarpa, [2] classified the stratigraphy (lat 19° N and 22° N) as:

-Mukawar Formation: A clastic sequences of shallow marine origin. The fossil assemblage indicate shallow-marine environment of upper Cretaceous to Paleocene (Whiteman) [17].

-Hamamit Formation: A clastic sequence and volcanics below the Maghersum Group which unconformably overlies Mukawar Formation. It is probably Paleocene?-Lower? Miocene age. The depositional environment is terrestrial-lacustrine-estuarine-shallow-inner neritic.

-Maghersum Group: It is a Middle-Lower Miocene sequence,(Bunter and /Magid) [7], two distinct rock units have been identified, these are Rudeis Formation (with the upper and lower members) and Kareem Formation (with Shagara and Markha Members)

-Belayim Formation and its equivalent sediments: Represents the beginning of the main evaporate cycle of the Miocene. It is Middle Miocene age, which is subdivided into four members, (from oldest Baba, Sidri, Feiran and Hammam Faruan Members). The depositional environment indicates alternating conditions of normal salinity and hypersalinity.

- Dungunab Formation: An evaporitic which is overlying a clastic unit. It is comprises all massive Miocene halite and anhydrite beds with minor interbedded clastics and carbonates.

- Zeit Formation: The term "Upper Clastic Group" was introduced to define the clastics above the massive Miocene salt and below post-Miocene reefal limestone (Sestini) [3]. The Zeit is conformably overlies Dungunab. It is a Middle-Upper? Miocene.

- Abu Shagara Group: The term "Abu Shagara Group" describe the Quaternary carbonates and clastic units, this group can be subdivided into a clastic (Wardan Formation) underlying a distinct carbonate (Abu Shagara Formation).

Methodology

Thirty two seismic lines were selected Fig (2) From the seismic data acquired by the Oil Companies (Chevron 1975-76 Total 1980 and IPC 1992), synthetic seismograms of Suakin-1, Bashayer-1A and Bashayer-2A wells were calibrated with these seismic lines, four horizons (Abu Shagara Group, Zeit, Dungunab and Belayem Formation) were traced, using loop-tying techniques. Depths to these horizons were calculated and posted obtaining sets of structural maps. This study is oriented to solve the problems of the complicated subsurface geological structures of the Tokar Delta, by locating certain depositional sequences in the area.

To pursue the objectives of this study the following methods are attempted

- 1- Re-interpretation of seismic sections obtained by the international oil companies e.g. Chevron, (1975), Total, (1980) and IPC (1992). Picking the interesting horizons
- 2- Interpretation of the logging records using available synthetic seismograms of Suakin-1, Bashayer-1A, and Bashayer-2A wells
- 3- Determination of two way times and calculations of depths to the reflectors, so as to construct time and depth structural maps and as well as isopach maps.

Results:

Four strong reflectors are encountered in most of the seismic sections in the study area, seismic sections have been interpreted and contour maps of two-way-time for these horizons were constructed, faults locations, trends and throws were determined in the time values in the maps.

All seismic sections are provided with velocities in different forms, the depth to a marker, is then calculated, using the equation

$$Z = \frac{VT}{2}$$

Isopachs are constructed by subtracting the time or depth values to two different horizons at each shot point. (Figs 4; 5; 6) show Abu Shagara Group depth map, Zeit Formation depth map and isopach map of the Zeit Formation respectively.

The geoseismic sections along lines SD76-16M (cross section AA' in the base map), IPS92-19 (cross section BB' in the base map), are shown on (Figs. 7 & 8) respectively.

The sequence stratigraphy of the Red Sea is similar to any other shelf slope system, which shows a considerable preservation of sequence patterns and boundary relations Fig (9 a and b) (through AA').

The lowermost sequence (Mukawar, Hamamit and Mughersum Group) which overlies and onlaps the Basement Complex, is relatively uniform throughout the study area. Evaporite sequence which was deposited during a cycle of sea level rise and fall indicates a change in climate and a prolonged period of desiccation.

The third sequence (Zeit Formation) contains three system tracts, which were deposited during one cycle of sea level rise and fall. The uppermost sequence (Abu Shagara Group) is a thick sedimentary unit that gradually becomes thinner towards the basin. The onlap relation at its lower boundary signifies a relative rise of sea level.

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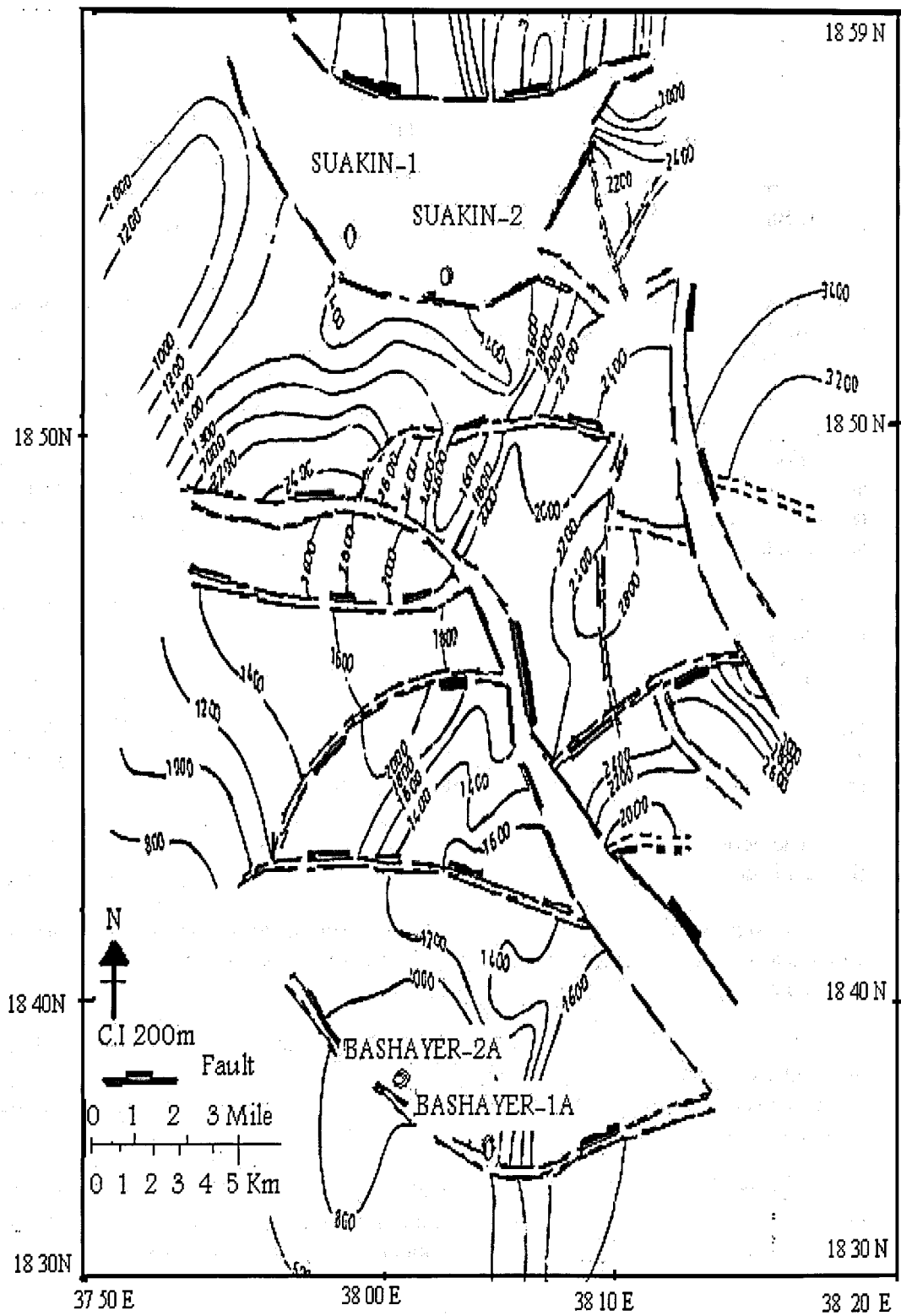


Fig (4) Abu Shagara Group Depth Map

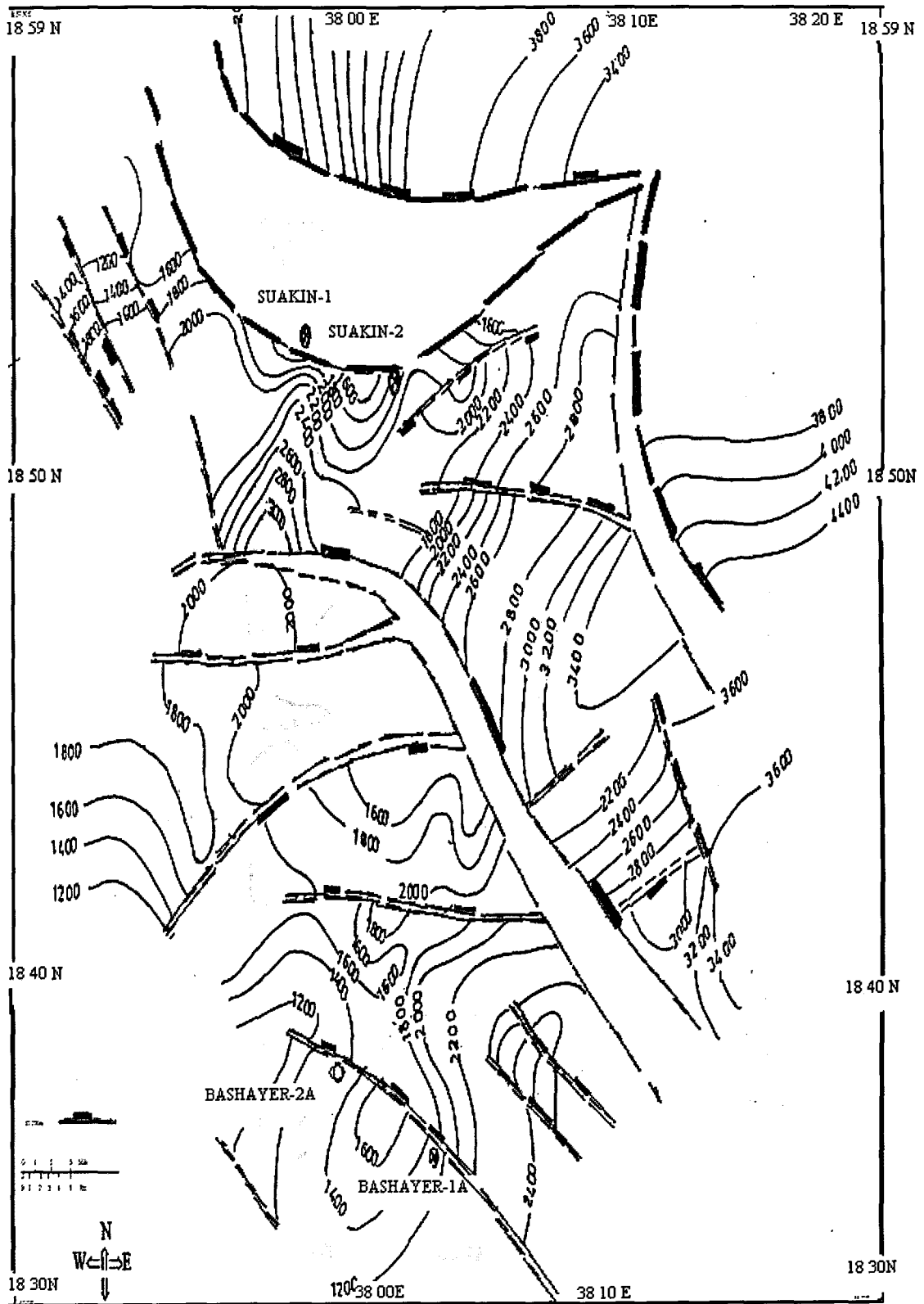


Fig (5) Zeit Formation Depth Map

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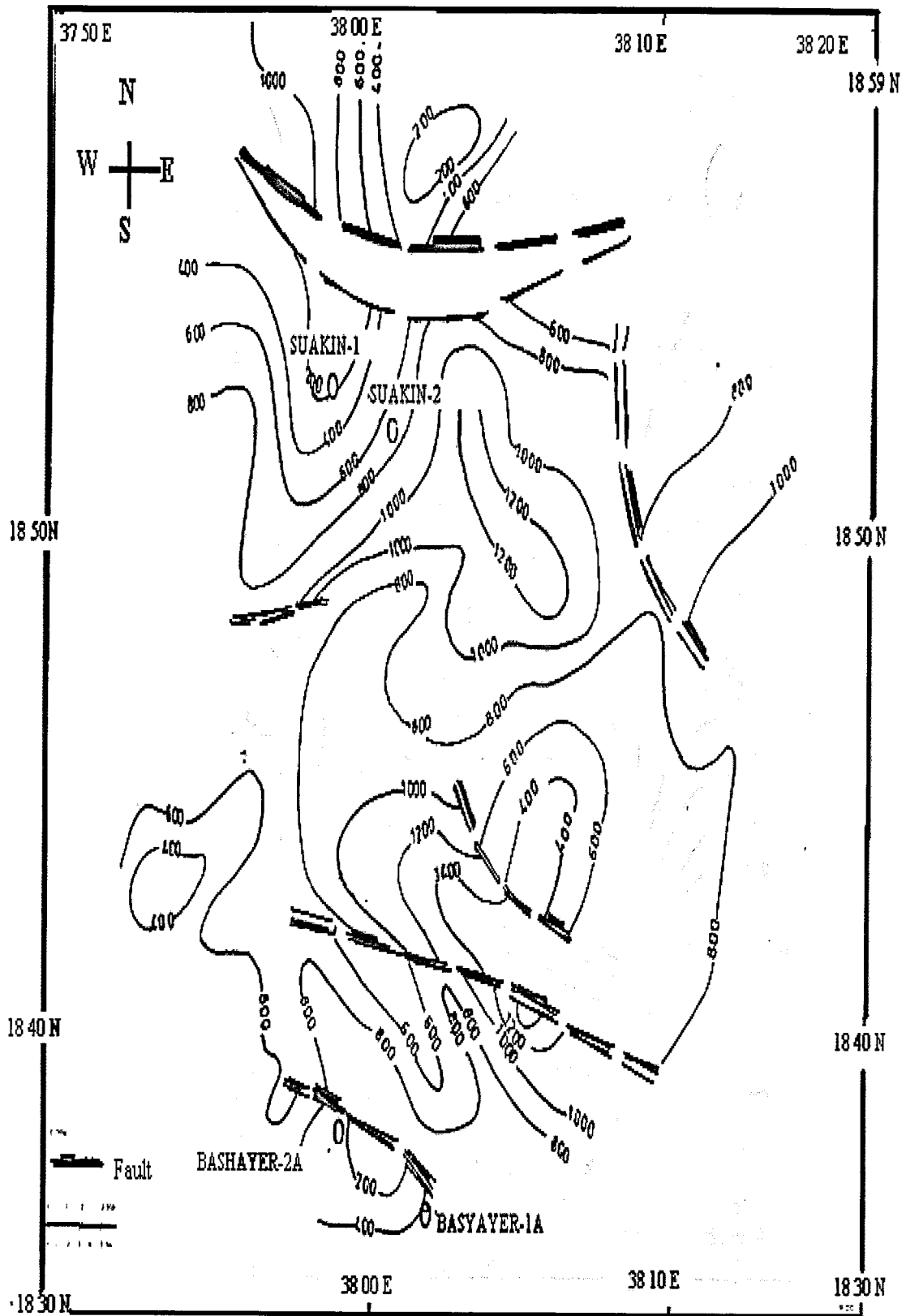


Fig (6) Isopach Map of the Zeit Formation

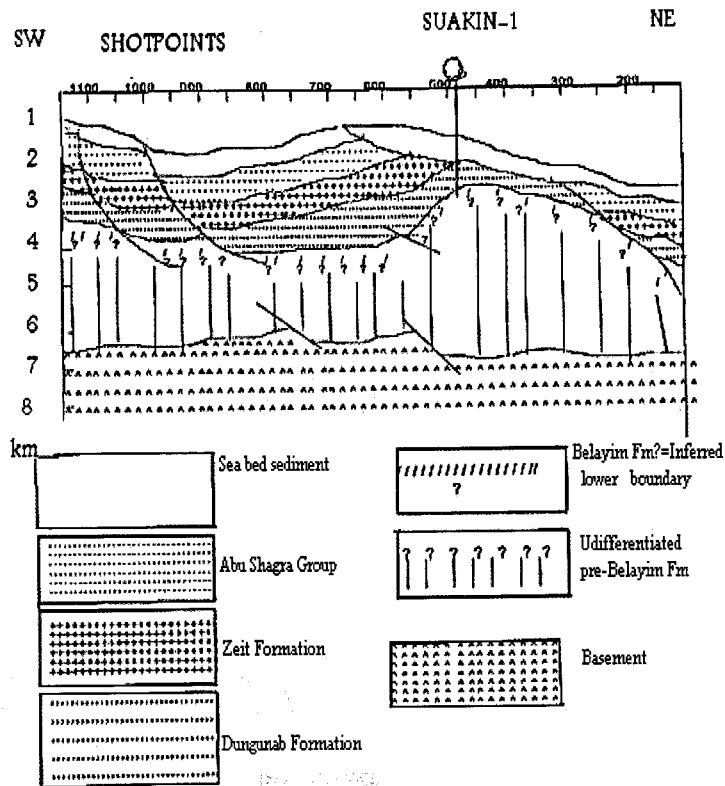


Fig (7) Geological section along profile SD76-16M (cross section AA' through area)

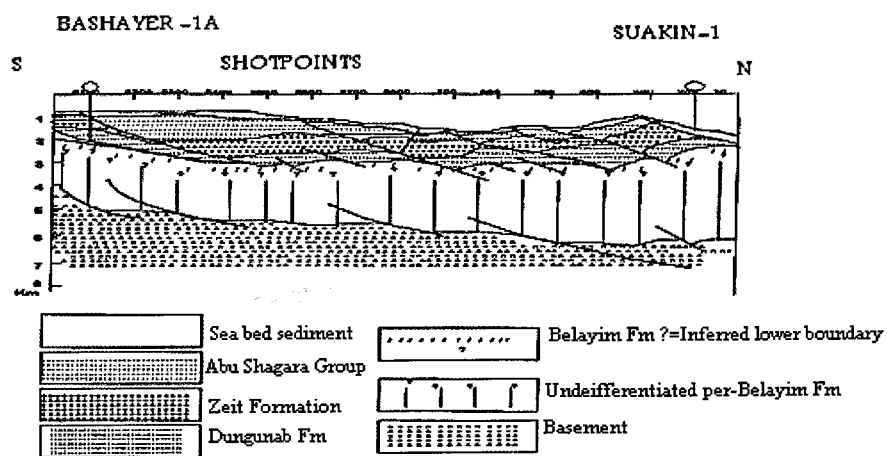


Fig (8) Geological section along profile IPS92-19 (cross section BB' through area)

Preliminary sequence stratigraphy and tectonic evolution of the Tokar Delta, (Southern Sudanese Red Sea)

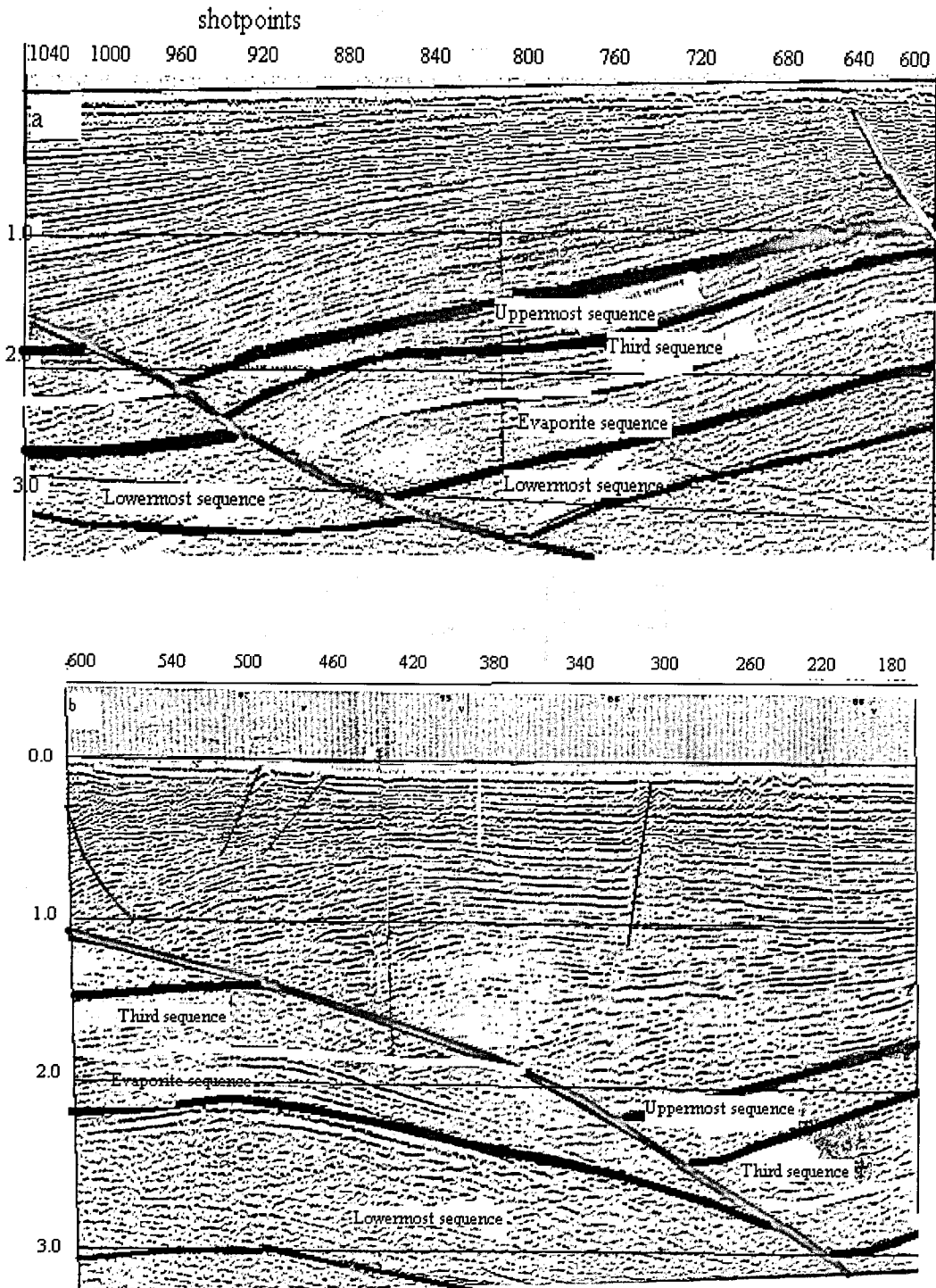


Fig (9) SD 76-16M Seismic section (coincide with AA' line in the base map) showing the main sequences and system tracts in the study area
 (a) Upper part (s.p 600 -1040).
 (b) Lower part (s.p 180 - 600)

Discussion

The results obtained from the structural maps and seismic cross sections in this study are integrated, to help understand the tectonism and to suggest model for the evolution of the Red Sea. The depths and thickness observed throughout the study area, from southern parts towards the further north, and also from western to eastern parts, shows that the top of Abu

Shagara group encountered in a depth of 600m in southern parts, but suddenly drops to a depth of 3400 in the northern and eastern parts, while the same formation ranges from 800m to 3200 from west to east. Near this level break horst and graben structures are observed, major listric faults with trend in the NW-SE direction, accompanied with other faults in different directions are traced. So we can say these changes in depths are probably attributed mainly to the presence of horst-graben systems, NW-SE listric faults with other fault systems in different directions.

The depth of Zeit Formation range from 1200m in the southern parts to 3800m in the northern parts, while this formation was encountered at 1000m in the west to 4400 in the extreme east Zeit thickness varies from 400m in the western parts to 1000m in the eastern parts, which is indicates thickening seaward. The area between Bashayer-1 and Bashayer-2 (refer to a figure 5) shows a synclinal closure, faulted with downthrown side to north-east direction. To the N-NE of Bashayer vicinity, Zeit Formation is affected by several normal faults, making sets of step faults, grabens and horsts structures. The Dungunab top Formation is dissected by a set of NW-SE trending faults, forming anticlinal closures along the shelf area. Most of the faults characterizing the top of Dungunab appear to have been active through the Miocene time as shown on the geoseismic sections. The subsidence history analysis indicates a high rate of total subsidence 2-4 feet per 1000year, because of sediments loading these sediments were derived from Red Sea hills, which drained towards the basin through conduits that followed sutures and zones of weaknesses (Makris and Henke) [10]. The top of the Belayim Formation top is affected by intensive NE-SW normal faulting. The Basement is encountered at a time interval of 2.7-3.85 sec, corresponding to a depth interval 5200-7400m. Once again the most prominent features are NW-SE trending fault, the configuration of the Basement exhibits systematic variations from south to north. the boundary separating the oceanic and the continental crust, is gently sloping and lies in the region of maximum sediments thickness, Izzeldin A. Y., [8].

Conclusions

The integration of the results derived from seismic data in the study area points to the following:

- The bulk thickness of the sediments increases towards the Red Sea.
- The emerging configuration of the basement shows that the boundary between the continental crust and the basement is not sharp, and it dips seaward from the coast.

The above results are evidences of tectonic activities, associated with vast sedimentation rate above the basement rocks, producing graben and horst structures. The active listric faults are the main structural features. The sediments slide along their planes towards the sea, where they are accommodated. These sediments create a load upon the underlying formations; the resultant subsidence is attributed mainly to this excess load.

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