CHAPTER TWO
REGIONAL SETTING

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Regional Setting

2.1 Surface

2.1.1 Tectonic setting

The Sinai Peninsula is wedged between the African and Arabian plates, the boundaries of which are defined by the Gulf of Suez and Gulf of Aqaba-Dead Sea rift systems. In the south, exposed Precambrian igneous and metamorphic rocks form the Arabo-Nubian shield. The shield consists of a series of island arcs which were cratonized during the late Proterozoic-early Paleozoic (1200 to 500 my BP) Pan-African orogeny (Gass, 1981). The peneplaned paleosurface of the shield dips gently northward with the overlying sediments, ranging from Cambrian to Recent, thickening northward. In Central Sinai the Gebel El Tih-Egma plateaux, 914 m above sea level, represent a thin sedimentary cover, which is affected only by faulting (Shata, 1956; Said, 1962). Northward from the Raqabet El Naam dextral wrench fault, the style of deformation becomes increasingly complex and consists predominantly of 65° N to 85° E oriented anticlinal folds and monoclinal flexures expressed mainly in the Cretaceous strata. This belt of folds extends offshore into the southeast Mediterranean Sea. The individual anticlines, which increase both in size and in amplitude northward, culminate in the extremely large, overturned, thrusted structures such as Gebel Maghara and Gebel Halal. The Syrian Arc structures attain a more northerly trend aligning themselves with the sinistral Dead Sea fault system and the Pelusium line, to the east and northeast of Sinai. In these regions, the folds appear to be reminiscent of fault plane drag (Jenkins, 1990).

2.1.2 Structural setting

The general structural pattern of the studied area, which lies on the eastern side of the Gulf of Suez, is mainly determined by a swarm of faults that dissect the area into several blocks. The main structural trend is NW-SE parallel to the axis of the Gulf of Suez. Compressional forces which may lead to either true folds or thrust faults, are of minor importance. The Gulf of Suez is an active rifted basin that originated early in the Early Miocene. It is bounded on the east by the Sinai Massif and on the west by the Red Sea Hills of the Eastern Desert (Fig. 2.1). The Suez rift is considered to be the right lateral component of the two complementary shear fractures of Suez and Aqaba that resulted from a northwesterly horizontal compression (Fig. 2.2). This compressive force is believed to have started in Eocene times as a result of the northward motion of Africa towards Laurasia which destroyed Tethys II and resulted in the Mediterranian (Meshref, 1990). Rifting occurred after a phase of Eocene shallowing and a prolonged phase of exposure during the Oligocene, a time of supposedly lowered global sea-level (Sellwood and Netherwood, 1984). The Gulf of Suez is dominated by four major fault trends recognized by many researchers (e.g. Colletta et al., 1988). The dominant fault system is the so called NW-SE "clysmic" trend which is the orientation of the major basin bounding extensional faults in the Gulf. The second major fault orientation is that of the Aqaba trend (N 10°-20° E) found predominantly in the southern Gulf where the influence of the Gulf of Aqaba-Dead Sea strike-slip system becomes apparent. In particular the NNE trending faults commonly form the linkages between the NW rift faults producing the characteristic rhomboidal fault pattern seen at the rift border fault systems. Two other relatively minor cross-

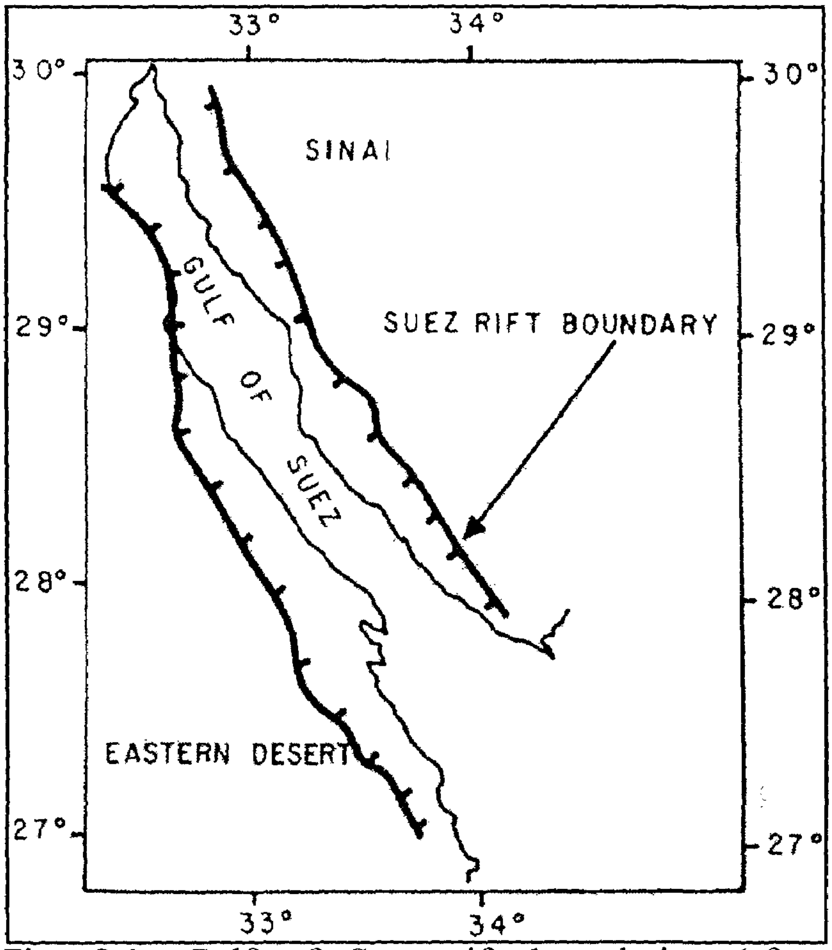

Fig. 2.1: Gulf of Suez rift boundaries (after Meshref, 1990).

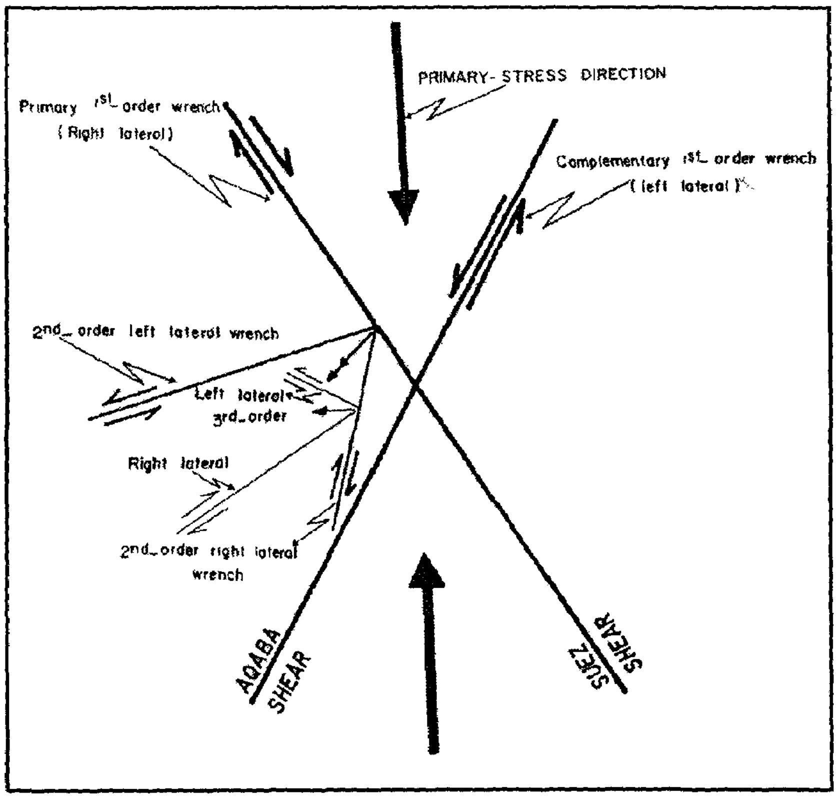

Fig. 2.2: Stress model for Suez and Aqaba shears (Oligocene time) (after Meshref, 1990).

fault trends, the Duwi and Cross trends are also developed and these appear to be at least partly controlled by the basement structural grains.

The distribution of the major troughs in the Suez rift, as deduced and mapped from subsurface data, shows that there are three tectonic provinces (northern, central and southern) separated by two accommodation zones (Meshref, 1990). In the northern province are the Darag and Lagia troughs, in the central province are the October, Belayim and Gharib troughs, and in the southern province are the West Zeit, Gemsa, East Zeit, South Central and South Ghara troughs. The Suez rift can be looked upon as having two major rift axes, a westerly axis and an easterly axis. The western axis of the rift represents the initial rifting phase in both the northern and southern parts of the rift and the later active subsidence phases in the central portion. The eastern axis of the rift coincides with the later active subsidence phase in the northern and southern parts of the Gulf and the initial phase of rifting in the central portion (Meshref, 1990).

In southwestern Sinai, the major tectonic trend that runs NW-SE brings the Paleozoic rocks together with the Precambrian basement opposite to the Cretaceous-Eocene rocks with a downthrow of about 2000 m. Here, a series of normal faults of varying lengths and displacement observed in the vicinity of Gebel Nukhul (Um Bogma area) are found to be oriented in a NW-SE direction and border the west Sinai rift area from the east (Shata, 1956). However, the isopach map of the total Paleozoic section in the Gulf of Suez shows a strong east-west tectonic trend that seems to have controlled the deposition of the Paleozoic rocks (Beleity et al., 1986). The vertical extension and lateral distribution of the Paleozoic rock units in the Gulf of Suez region have also revealed the existence of an east-west tectonic belt located between latitudes 28° 30` and 28° 38`

North. The southern limit of this belt represents an Early Paleozoic, down to south fault system, and the northern limit on the other hand represents a Late Paleozoic down to north fault system. These faults form two dislocated successive basins: (a) Early Paleozoic basin located south of the horsted belt, and (b) Late Paleozoic basin to its north. The former is associated with the Caledonian orogeny and the later with the Hercynian (Beleity et al., 1986). This east-west tectonic trend was also evidenced from the regional magnetic map of the Gulf of Suez proposed by Meshref (1990). The thrusting or uplifting of the African continent against the main block of the earth's crust in the Paleozoic time might have been the cause of the formation of this east-west trending swells and thrusts across the northern parts of the African continent, including Egypt (Meshref, 1990).

2.1.3 Stratigraphic setting

The Sinai is covered by sediments, which were deposited on a predominantly shallow platform and range in age from Cambrian to Holocene. The Paleozoic sediments are only exposed in the southern central parts of the Sinai, primarily in the Um Bogma area east of Abu Zenima and in Wadi Feiran – El Tor area, particularly at Abu Durba (Fig. 1.1).

In Wadi Feiran – El Tor area, the Paleozoic sediments are exposed at the base of the steep west facing the slope of Gebel Qabeliat, east of Gebel Abu Durba, Gebel Araba and Gebel Naqus. These sediments cover the eastern floor of Wadi Araba, then the outcrop is offset to the west, and extends to Abu Durba. The succession continues to be exposed on a relatively wide belt on the eastern side of Gebel Abu Durba until it is abruptly cut by a fault along the northern end of the basement rocks of Gebel Abu Durba. The sediments form a narrow strip at the base of the western slope of Gebel Egma and strikes to the northwest for a few kilometers until it is downthrown beneath the surface.

In southwestern Sinai, Paleozoic sedimentary rocks are exposed resting unconformably on the Precambrian basement rocks. Exposures are typically recorded at Gebel Abu Durba, Gebel Araba and Gebel Naqus. In these localities, the contact between the basement rocks and the overlying sedimentary rocks is highly corrugated. The sedimentary exposures include Pre-Carboniferous (Early Paleozoic) rocks which have been assigned to the Cambrian, and Carboniferous (Late Paleozoic) rocks. A brief description of these exposures is given below.

2.1.3.1 The Early Paleozoic Rocks

These deposits crop out in the southern part of the studied area unconformably overlie the basement rocks of Gebel Abu Durba, Gebel Araba and Gebel Naqus. The contact between the basement and the overlying rocks is highly corrugated and is best observed in Abu Durba area.

The Early Paleozoic rocks constitute a thick succession of sandstones which were subdivided by Hassan (1967) and Said (1971) into two rock units; namely: the Araba Formation at base (Lower Cambrian) and the Naqus Formation at top (Upper Cambrian). A brief description of each unit is given below:

2.1.3.1.1 Araba Formation

The term Araba Formation was given by Said (1971) for the 120 meters thick Lower Paleozoic sandstones previously described by Hassan (1967) in Abu Durba area. This formation unconformably overlies the basement rocks and conformably underlies the Naqus Formation. Lithologically, the formation is made of a varicolored and laminated sandstones which are easily differentiated by virtue of their colors from the overlying white sandstone of the Naqus Formation. Sandy clay and ferruginous bands are common.

Different ages are assigned to this formation: Early Cambrian based on the *Stromatolites* and *Archeocyathids* (Omara, 1972) and the trace fossil collection of Seilacher (1990) such as *Cruziana cf. nabatacica, C. aegyptica, C. salomonis, Bergauneria scuta and Dimorphichnus cf. quadafidus* (Klitzsch, 1990), Cambro-Ordovician by trace fossils including: *Skolithos Coensis, Cruziana sp., Allocotichnus sp., Dimorphicunus sp.,* and *Diplichnites sp.* (Issawi and Jux, 1982). This belief was confirmed recently by Magwood and Pemberton (1990), who reported a discovery of several ichnospecies of *Cruziana* (*C. furcifera, C goldfussi, and C. rugosa*) from the Lower Cambrian Gog Group in Canada. Their *Cruziana* species were previously though to be restricted to the Lower and Middle Ordovician. Although these ichnofossils may be used, in some situations, for time correlation, their stratigraphic distribution is not sufficiently understood to use them as global index fossils.

Regardless the age, Araba Formation is equivalent to many series and successions in Sinai such as: a) the lower sandstone series of Barron (1907) and Ball (1916), b) the lower Um Bogma series of Kostandi (1959), c) the lower Um Bogma Group of Soliman and El-Fetouh (Sarabit El Khadim, Abu Hamata and Adedia formations) (1969 a,b), and d) Sarabit El Khadim, Abu Hamata, Nasib and Adedia formations of El Shahat and Kora (1986). It is informally distinguished as Nubia "D" (Beets, 1948) by oil companies in the Gulf of Suez. Araba Formation is believed to represent a shallow marine depositional environment (Allam, 1989).

2.1.3.1.2 Naqus Formation

The term Naqus Formation was given by Said (1971) to the thick succession of sandstones (410 m thick in the type section), previously described by Hassan (1967) in Abu Durba area. The formation conformably overlies Araba Formation and unconformably underlies Abu Durba Formation. The lower contact with the underlying Araba Formation is sharp as far as the colors of the two units are concerned. The upper boundary with the overlying Lower Carboniferous Abu Durba Formation is marked by the presence of a thin conglomerate bed made up of subrounded quartz gravels. Lithologically, the formation is composed of almost white to pale brownish sandstone beds. Some are generally medium to coarse grained, subangular to subrounded, moderately to well sorted, massive, laminated and cross-bedded. Others contain randomly distributed quartz pebbles to cobbles. A few conglomerate lenses are sometimes recorded.

Naqus Formation is generally barren of any organic remains. So the age of the formation is not precisely determined, though Hassan (1967) considered it to be of carboniferous or older age. Said (1971) assigned it to the Early Paleozoic. Issawi and Jux (1982) suggested either Late Cambrian or Early Ordovician-Silurian age based on the genetic interpretation of the deposits. Based on its stratigraphic position, Beleity et al. (1986) considered Naqus Formation to be of questionable Lower Paleozoic age, while Allam (1989) suggested a Late Cambrian age. On the other hand, Klitzsch (1990) assigned Early Cambrian age to the formation.

Regardless the age, Naqus Formation coincides with: a) The middle Um Bogma series of Kostandi (1959), and b) Adedia Formation of

Soliman and El-Fetouh (1969). Informally it corresponds the Nubia "C" of Beets (1948).

Allam (1989) believed that the sediments of Naqus Formation have a non-marine mode of deposition, probably a meandering fluvial system. Issawi and Jux (1982), on the other hand, believed that the presence of quartz pebbles in Naqus Sandstone can not be explained as due to normal hydrodynamic effects and suggested a fluvio-glacial environment caused by the Sahara glaciation which covered most parts of northwest Africa at that time. This assumption was followed by Ahmed and Osman (1998) who believed that the haphazardly distributed quartz gravels and cobbles in Naqus Sandstone can not be explained by normal hydromechanical processes but reflects mainly the activity of fluvio-glacial process.

2.1.3.2 The Late Paleozoic Rocks

These rocks are characterized by their fossiliferous horizons, which distinguish them from the underlying poorly fossiliferous early Paleozoic rocks. A long hiatus separates the Cambrian sandstones from the overlying Carboniferous strata, but there is no discrenable angular unconformity between these two sequences in the exposures along the east side of the Gulf of Suez. The Late Paleozoic rocks in Wadi Feiran – El Tor area are differentiated into three rock units. Abu Durba Formation, forming the base of the Carboniferous section, followed upward by Aheimer Formation, which is followed by Qiseib Formation. The general specifications of each of these units are described in the following paragraphs.

2.1.3.2.1 Abu Durba Formation

The name Abu Durba Formation was first given by Said (1971) for the fossiliferous black shale sequence described by Hassan (1967) in Abu Durba area. The Abu Durba clastic section passes gradually into the overlying Aheimer Formation whereas at base it unconformably overlies

Naqus Formation. Lithologically, the formation is composed of interbedded shales and sandstones. At the base of this formation there is a conglomerate bed which ranges in thickness between 50 and 150 cm.

The formation was considered by many workers (Hassan, 1967; Omara, 1972; Issawi et al., 1981; Brenckle and Marchant, 1982) to be Early Carboniferous (Mississippian) in age due to the presence of the index fossils *Spirifer striatus, Productus semireticulatus, Neospirifer fascicostatus* together with planktonic foraminifers. Allam (1989) pointed out that the presence of brachiopods *Spirifer striatus* and *Productus semireticulatus* is a proof of a shallow marine depositional environment. He also considered the formation to be equivalent to: a) the "Carboniferous Limestone Series" of Barron (1907) and Ball (1916), b) the upper part of the "Um Bogma Series" of Kostandi (1959), and c) the upper Um Bogma Group (Khaboba Formation) of Soliman and El Fetouh (1970). It is informally equivalent to the Nubia "B" of Beets (1948).

2.1.3.2.2 Aheimer Formation

The term Aheimer Formation was first given by Abdallah and Adindani (1963) to the clastic succession at Wadi Aheimer on the northwestern bank of the Gulf of Suez. They considered the formation to be Upper Carboniferous–Lower Permian in age. Based on the similarity between the lithology and faunal content of the Upper Carboniferous beds in Abu Durba area and their equivalents at Wadi Aheimer, Issawi et al. (1981) applied that term to Abu Durba area. Aheimer Formation is a well developed unit exposed throughout the area between Gebel Araba in the south and Wadi Feiran in the north. It is easily differentiated from the sandy section of the overlying and the underlying units by its greenish gray color, which forms a prominent horizon along its stretch. Lithologically, the formation is made of greenish grey, sometimes yellow, shale section with pale brown sandstone interbeds. Highly fossiliferous dolomitic limestone bands are present within the sequence. The formation measures about 60 m in the area of Gebel Araba whereas northward it diminishes to 35 m recorded north of Gebel Egma. The boundary between Aheimer Formation and the overlying Qiseib Formation is sharp and is well distinguished for the clear difference in colors between the red or brownish colors of the Qiseib and the greenish grey color of this unit (Issawi et al., 1981).

Based on the presence of thin limestone and dolomite beds as well as the roundness of the quartz grains in the sandstone beds, Allam (1989) suggested a transgressive-regressive sea, which was adjacent to aeolian sand dunes, as the depositing agent. He believed that the sand dunes could be the main factor, which caused the roundness of the quartz grains, and a lagoonal system could be responsible for the deposition of the marine shales.

2.1.3.2.3 Qiseib Formation

The term Qiseib Formation was given by Abdallah and Adindani (1963) for the red beds exposed northwest of the Gulf of Suez. It is equivalent to: a) the Qiseib Red Beds of Awad and Said (1965), b) the uppermost part of Rod El-Hamal Formation of Beleity et al. (1986), and c) "amended" Ataqa Formation of Beleity et al. (1986). Qiseib Formation, in Wadi Feiran – El Tor area, unconformably overlies the Carboniferous Aheimer Formation. Lithologically, the formation is composed of varicolored sandstones, alternated with shales. The sandstones are mainly reddish-brown and cross-bedded. The shale interbeds vary in color between red-brown and bluish grey. They are massive, sandy and contain large amount of iron oxides.

Qiseib Formation is believed to be deposited through shallow braided streams in a wide braid plain. The plant remains in this formation point to its continental origin. The cross-bedded sandstones represent, therefore, fluviatile channel deposits. The reddish fine-grained sediments are overbank deposits and / or underclays (Allam 1989).

Qiseib Formation is non fossiliferous, however Issawi et al. (1981) and Issawi and Jux (1982) described some arenaceous foraminiferal species from the Qiseib shales and mudstones (such as *Ammodiscus* cf. *priscus* Rauser Ceronussova, *Paratikhivella sp.*, *Bathysiphon sp.*, *Ammovertella sp.*, *Tolypammina sp., and Hyperammina sp.*), which have strong similarities to those of the Late Carboniferous recognized by Abdallah and Adindani (1963) and Said and Eissa (1969). Moreover, Beleity et al. (1986) indicates that Qiseib Formation includes pollens and spores which assign it to the Permian. Therefore, it is believed that the top of the Qiseib red sandstones in Wadi Feiran – El Tor area marks the upper boundary of the Paleozoic Era (Allam 1989).

2.2 Subsurface

2.2.1 Tectonic setting

Ras Budran field lies on a nearly northeast-southwest aligned broad platform like feature near the east coast of Gulf of Suez (Fig. 1.2). This trend, which aligned nearly at right angles to the main Gulf of Suez trend, is anomalous. Most of the vicinity fields are of northwest-southeast geometrical shape (Fig. 1.2). As a regional view, the field lies in the northeast dipping central tectonic province (dip provinces of Moustafa, 1976).

The Ras Budran feature (Fig. 2.3) is flanked to the northwest by a northeast-southwest trending synclinal depression separating it from Abu Zenima structure. Towards southwest, it is separated from October trend,

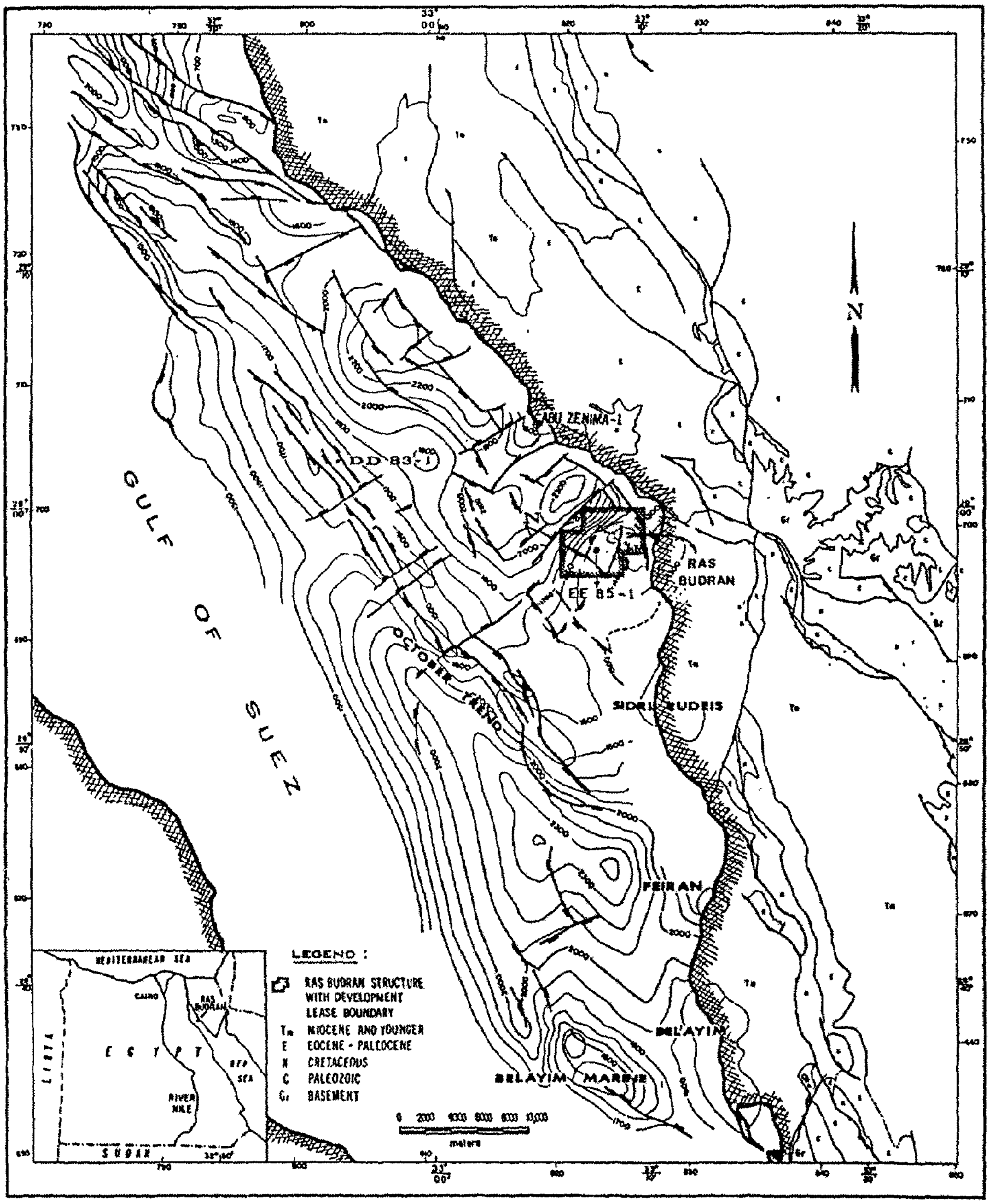

Fig. 2.3: Tectonic setting of Ras Budran structure, Gulf of Suez, Egypt (after Chowdhary et al., 1986).

which contains a string of oil discoveries, by a syncline aligned NW-SE (Clysmic trend). To the south, it is separated from the Rudeis structure by a structural saddle. To the northeast, it is separated from the pre-Miocene outcrops by a major coastal fault system, with a cumulative throw exceeding 10,000 ft in less than 4 kms distance.

Ras Budran field was subjected to three distinct phases of tectonism of different timing and magnitudes, those are the pre-rift (pre-Miocene) phase, the syn-rift phase and the post-rift phase. There is little doubt that rifting tectonism played a dominant role in the evolution of Ras Budran field and its influence is clearly seen in the field structure.

2.2.2 Stratigraphic setting

The stratigraphic sequence of Ras Budran field as revealed by the wells drilled on the structure is broadly similar to the strata present else where in the Gulf of Suez. A sedimentary sequence ranging in age from Paleozoic to Recent with several non-depositional and erosional hiatuses is recorded in the field (Fig. 2.4). The general specifications of each of these units are described in the following paragraphs.

2.2.2.1 Precambrian Basement

The Precambrian basement, penetrated only in one well (RB-A2) possibly in fault contact with pre-Miocene sediments and intruded by younger Oligocene intrusives along the fault plane, is composed of fine to coarse crystalline biotite granite.

2.2.2.2 Paleozoic

Paleozoic sandstones with thin shale layers comprise the oldest section partially penetrated by wells, which in turn overlain by a thick shale unit and sandstones in Nubian facies (Nubian A of Lower Cretaceous age). As there are no fossils within the shale unit, its age is not well defined. Based on regional considerations, the massive sandstone sequence is correlatable

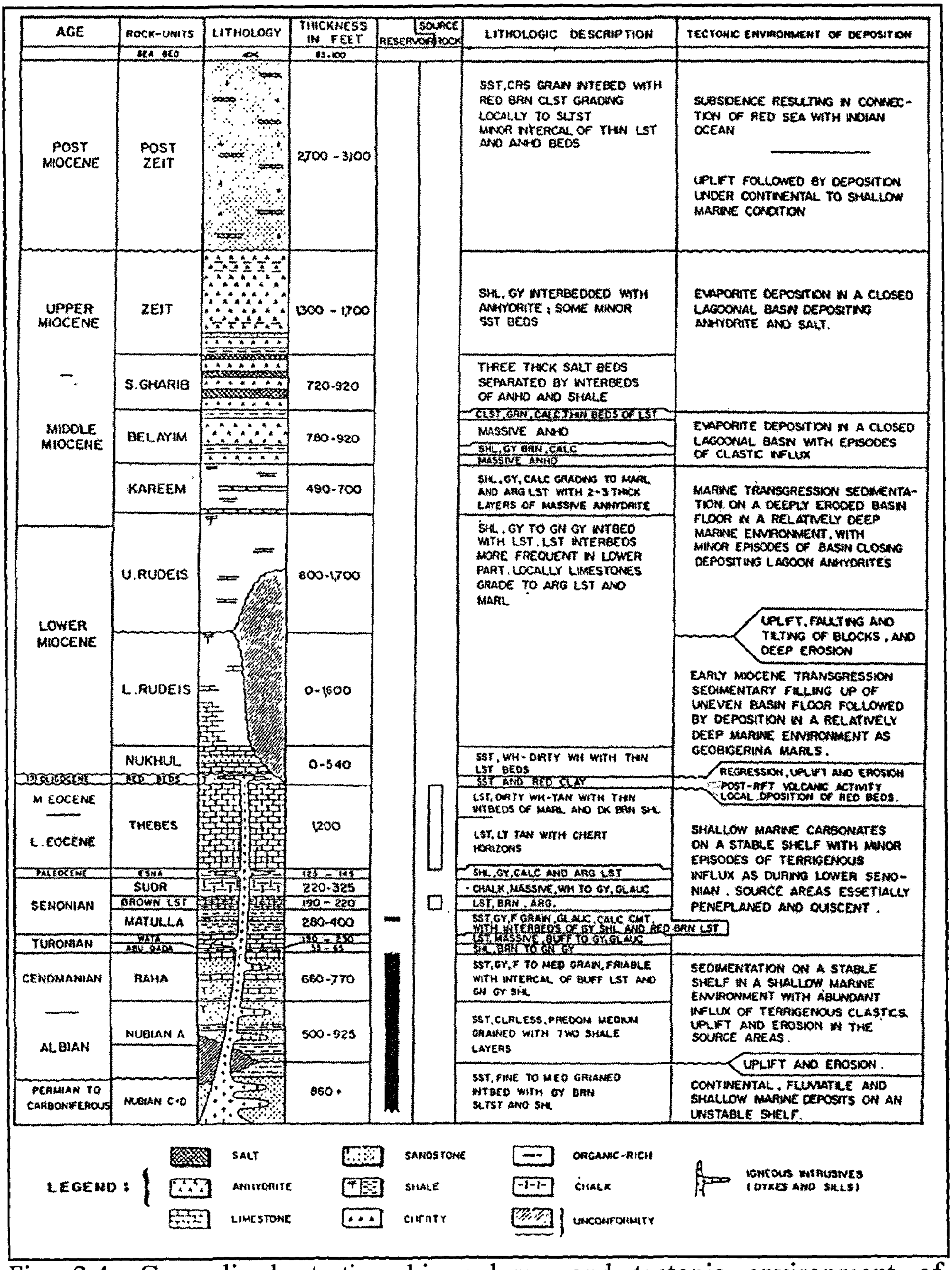

Fig. 2.4: Generalised stratigraphic column and tectonic environment of deposition- Ras Budran (after Chowdhary et al., 1986).

to the well known Paleozoic Nubian C and D, and the overlying thick shale unit to Nubian B (Naggar and El Hilaly, 1985). Within this sequence thus occurs an unconformity between Paleozoic and Cretaceous sediments which represents at least 150 million years. This unconformity is generally believed to be within the shale unit (Chowdhary and Taha, 1986), Naggar and El Hilaly (1985), however, believe it to be at the base of the shale unit which they thought to be of Permian or even Cretaceous age. This shale unit gradually increases in thickness towards east and northeast suggesting a gentle easterly paleoslope during its deposition. However, in the absence of correlation markers within the Paleozoic Nubian sandstones, the amount of erosion and tectonic intensity during this long span of time could not be deciphered. There is no evidence for an unconformity between the shale unit and the overlying sandstone interval of Lower Cretaceous age (Nubian A).

2.2.2.3 Mesozoic

The well-dated oldest Cretaceous sediments of Albian to Cenomanian age, designated as Nubian A Formation, were the first fossiliferous strata laid down on the shale unit. Based on peak-to-peak correlation of log markers within the Nubian A Sandstone, it is concluded that these sediments were deposited as sheet-like sands (Naggar and El Hilaly, 1985).

The Nubian A Sandstone is conformably overlain by a complete sequence of transgresive strata ranging in age from Cenomanian to Middle Eocene. These are subdivided into eight rock units namely, Raha (Cenomanian), Abu Qada, Wata (Turonian), Matulla (Coniacian-Santonian), Brown Limestone (Early Campanian), Sudr (Late Campanian-Maastrichtian), Esna (Paleocene) and Thebes (Lower to Middle Eocene) formations (Brown, 1980). Log correlations of these units show that, in general, they slightly increase in thickness towards northeast, and that no unconformities are recognizable within the section. The missing stratigraphic sections in different wells are thus considered to be fault cut-outs (Naggar and El Hilaly, 1985).

2.2.2.4 Cenozoic

Two major unconformities are recognized within the Cenozoic succession, one between Eocene and Lower Miocene and the second within Lower Miocene.

2.2.2.4.1 Paleocene – Middle Eocene

The Esna Shale of Paleocene age conformably overlies Sudr Formation and is conformably overlain by Thebes Formation of Early to Middle Eocene age.

2.2.2.4.2 Late Eocene – Oligocene

Strata of Late Eocene age are absent in Ras Budran area probably as a result of non-deposition, following uplift and tilt of the Gulf of Suez basin to the north, accompanied by Late Eocene regression (Naggar and El Hilaly, 1985). During pre-Clysmic phase (Oligocene), the Gulf of Suez underwent intense tectonic activity resulting in uplift and faulting followed by volcanic activity because of rifting. In Ras Budran structure, mild tectonic activity and insignificant erosion during this period is indicated by the presence of almost uniform thickness of Thebes Formation above the Thebes Marker - a marker near the top of the unit.

The pre-Miocene sedimentary section, in places, is interrupted by younger Oligocene igneous intrusions using the fault planes as conduits. These igneous intrusives, localized in the eastern part of the structure and associated with the eastern fault system delimiting the structure, are interpreted, either as sills or dykes, based on their thicknesses, their contact with sedimentaries and finally their preferred geometric interpretation in the geologic framework (Naggar and El Hilaly, 1985).

2.2.2.4.3 Miocene

The Miocene succession comprises a lower shale-marl section and an upper evaporite section. The lower section of Early to Middle Miocene age is divisible into three units namely Nukhul, Rudeis and Kareem formations with an intervening evaporitic phase at base Kareem. Some sandstones are also developed within Nukhul Formation. Nukhul and Rudeis formations are subdivided, based on log correlation, into four and eighteen units respectively, and unconformably overlay the Middle Eocene erosional surface (Ali and Khairy, 1996). Detailed log correlation and paleontologic studies indicate the presence of a major erosional and non-depositional phase within Rudeis Formation (intra-Rudeis unconformity) in Ras Budran structure. This intra-Rudeis tectonic phase of late Lower Miocene age involves major faulting and tilting, followed by erosion of up to 2,000 ft strata belonging to Nukhul and Lower Rudeis formations from the high block of Ras Budran structure. The overlying Kareem Formation was deposited in a relatively deep marine environment with minor episodes of basin closing.

The upper evaporite sequence of Middle to Late Miocene age comprises three formations namely Belayim (with two cycles of clastic deposition), South Gharib and Zeit. These formations were essentially deposited in a closed lagoonal basin. Influx of clastic sediments, which alternated with the precipitation of evaporites during deposition of Belayim Formation, reduced with time and was negligible during the deposition of South Gharib and Zeit formations (Naggar and El Hilaly, 1985).

2.2.2.4.4 Post-Miocene

Separated by a major hiatus, post-Zeit sediments in Ras Budran field were deposited under continental and paralic environments and are mainly represented by a sandstone sequence.

2.2.2.5 Reservoir units

Nubian sandstones of Paleozoic to Cretaceous age form the main reservoirs in Ras Budran field. Based on geologic aspects (correlation, layering, continuity of shale and sand units, resistivity characteristics and NGT logs) and reservoir behavior (pressure, production potential), the Nubian can be generally subdivided into four mappable reservoir units. They are from below upwards: Unit I, IIA, IIB and III. There are also some additional reservoir units of secondary importance within the Raha and Matulla formations.

Paleozoic Sandstone with shale layers (Nubian C and D) comprise the oldest section penetrated in wells and represents the first reservoir unit, Unit I, with an average porosity of 11 %. A shale unit and sandstone in Nubian facies (Nubian A of Lower Cretaceous age) overlie this sandstone. At the base of the shale unit, there is an unconformity between the Paleozoic and Cretaceous sediments. This shale unit represents the second reservoir unit, Unit IIA, and consists mainly of shale intercalated with sandstone. The rest of the Nubian A is subdivided into reservoir Unit IIB and Unit III. These are sandstones with shales at the bottom of Unit III and a higher porosity than Unit I at around 15 %. There are two reservoirs in Raha Formation, which overlays Unit III, the Lower Raha with massive sandstones and the Upper Raha with a separate sandstone body. The Lower Raha Sandstone occurs in gradational contact with the sandstones of the Unit III. However, it is recognized as a separate reservoir unit based on lithologic differences and the absence of cross flow between the two reservoirs due to the presence of continuous thin shale layers within Lower Raha. In addition, there are thin discontinuous sandstone layers present in the lower clastic part of Matulla Formation near its base.

2.2.3 Structural setting

The Ras Budran structure, as seen on top Kareem (the deepest and consistently mappable seismic reflector), is a nearly northeast-southwest trending anticlinal feature. The structure is broken into several parallel panels by a set of nearly northwest-southeast trending faults. Interestingly, none of these faults mapped on seismic affecting top Kareem have, however, been penetrated in the well sections at or near top Kareem level. On the other hand, these faults are seen to be present in the well sections mostly at pre-Miocene levels or within lower Rudeis (Naggar and El Hilaly, 1985).

The pre-Miocene structure of Ras Budran is very complex as it is severely disturbed by faults at different levels and aligned in various directions (NW-SE, NNE-SSW and ENE-WSW). Further, the structural complexity is enhanced by the presence of two major erosional unconformities in the stratigraphic section: one post-Eocene and second intra-Rudeis. In addition to these, a post-Paleozoic unconformity is also recognized. Based on the interpretation of faults regarding their alignment, throw and hade from well data and dipmeter analysis, the limits of Ras Budran field can be considered as fairly well defined. Three main blocks are delineated: the northern main block (block A), the intermediate block (block B) and the southern smallest block (Block C).

Ras Budran structure is illustrated by four structural sections: three northeast-southwest (Figs. 2.5-2.7) and one southwest-northeast (Fig. 2.8), and by a structural contour map on top of Lower Raha (Fig. 2.9).

2.2.4 Origin of Ras Budran structure

Based on the study of isopach maps and paleostructural sections, it is concluded that the Ras Budran structure was formed during intra-Rudeis tectonic phase (Chowdhary and Taha, 1986). The pre-Miocene sedimentaries comprise a typical plateform cover and are of nearly uniform thickness in Ras Budran structure (approximately 5,000 ft from top Thebes to Paleozoic Nubian sandstones). Following Late Eocene regression, these pre-Miocene strata in Ras Budran were probably faulted and uplifted, however, they were neither tilted nor deeply eroded, as is suggested by the presence of an almost uniform thickness (130-420 ft) of the Thebes Formation above the Thebes marker (Fig. 2.10). The amount of erosion can be estimated as not exceeding 300 ft or so. Thus, the Ras Budran structure was not differentiated during this Oligocene tectonic phase (Chowdhary et al., 1986).

Mildly uneven topography of the basin floor created during Oligocene was filled as a result of deposition of Nukhul Formation during early Miocene transgression. The overlying units of Lower Rudeis were deposited in a nearly uniform thickness (about 1500 ft) throughout the Ras Budran area, as revealed by the preserved thickness of this formation in various wells.

During intra-Rudeis tectonic phase, the Ras Budran structure, tilted to the northeast, was differentiated into a fault-bounded high block surrounded by low blocks to the west and south. The Lower Rudeis strata are preserved in these low-lying blocks, where they are severely eroded (exposing Eocene Thebes Formation) in the high block (Fig. 2.11). This topographic relief feature has since been preserved by filling up of the topographic low areas to the south and west by the lower units of Upper Rudeis and finally by the successive deposition of the upper units of Upper Rudeis throughout the area (Figs. 2.12-2.13). Subsequent post-Rudeis sedimentation in Ras Budran was nearly uniform, the difference in structural elevation being less than 300 ft both at top Rudeis and top Kareem formations. This difference in elevation is mainly attributed to the effect of sedimentary drape over the pre-existing relief feature (Chowdhary et al., 1986).

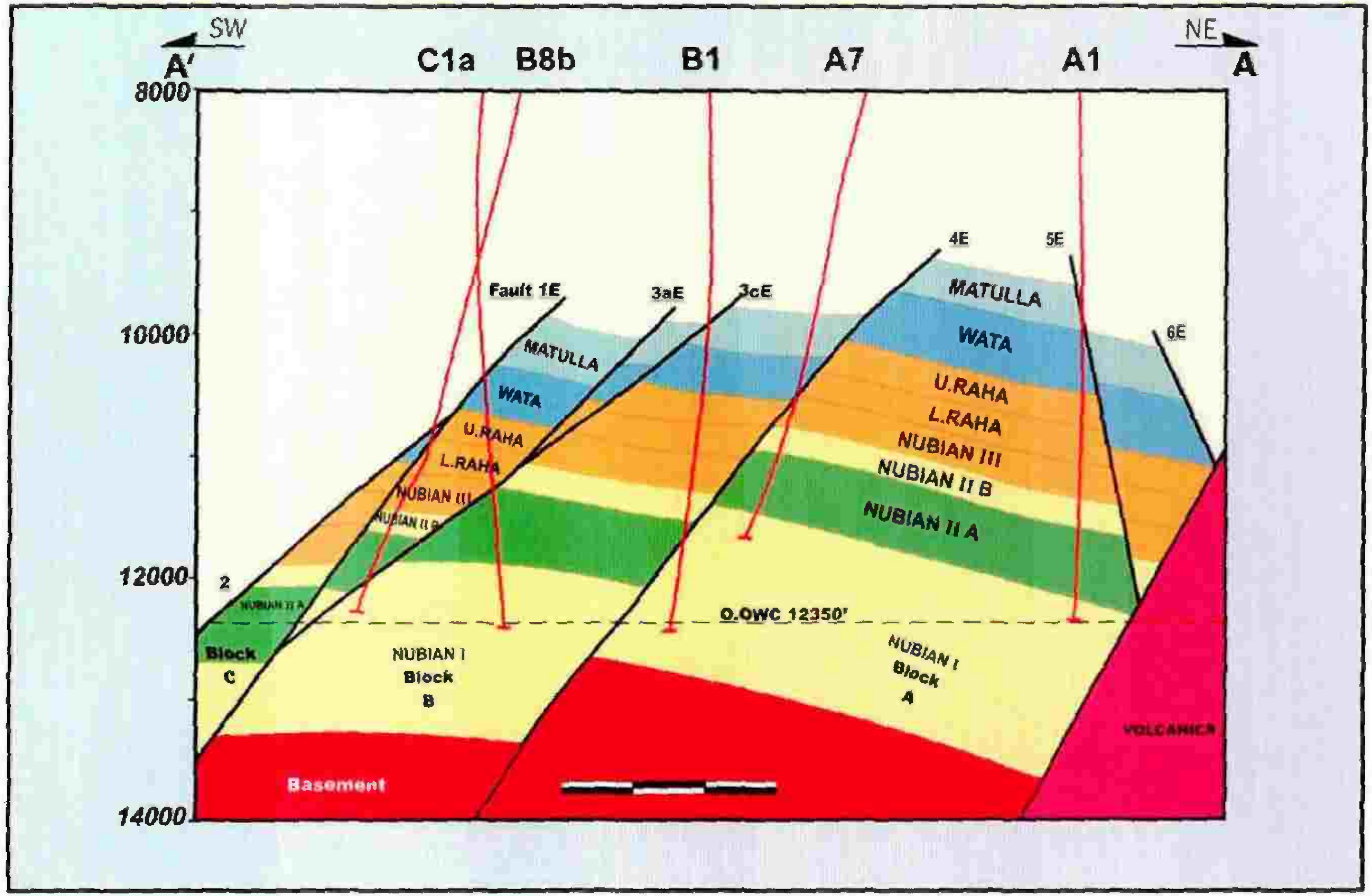

Fig. 2.5: Structural cross-section through RB-C1a, B8b, B1, A1 and A7 wells (after Suco Oil Company).

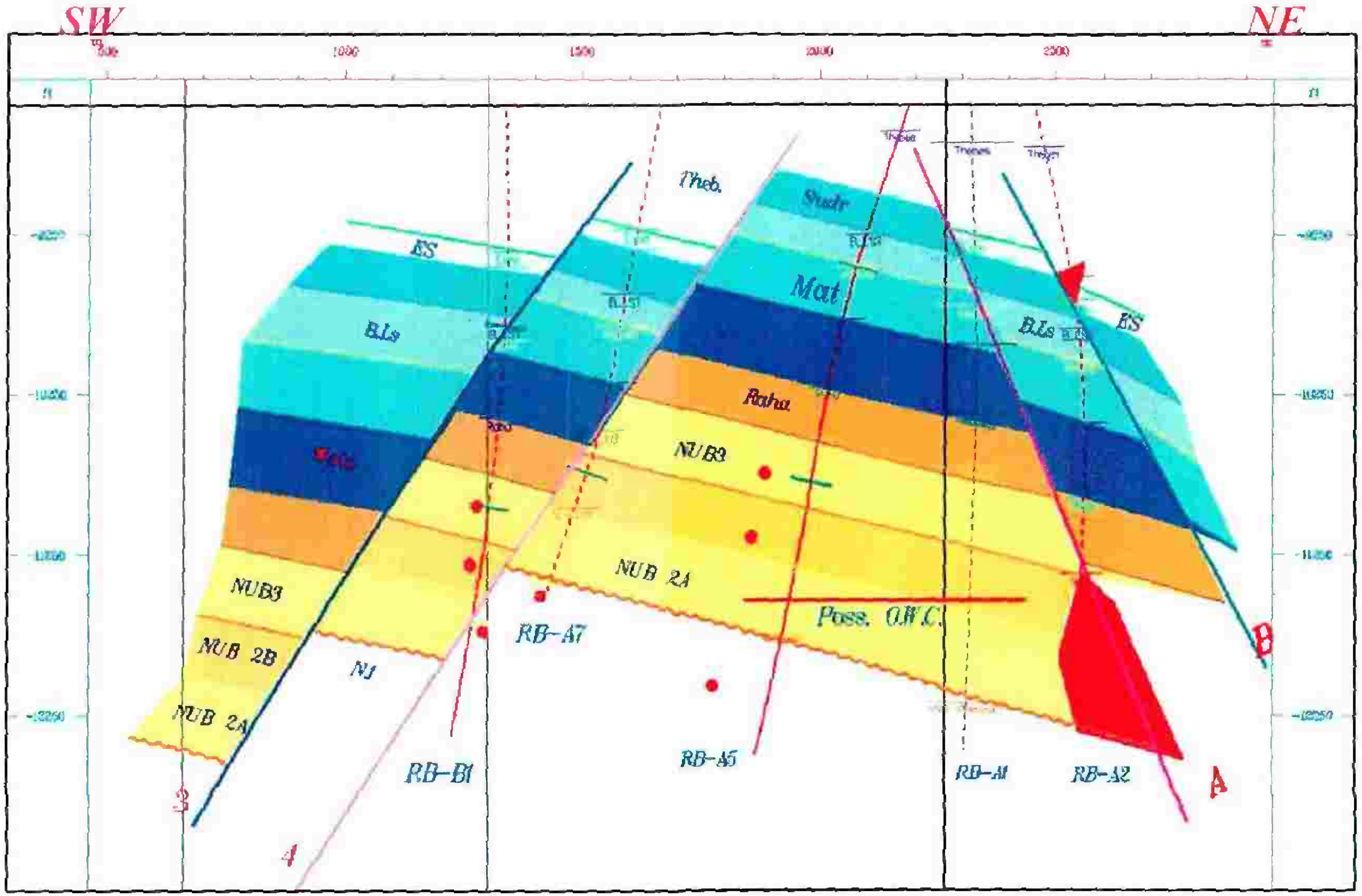

Fig. 2.6: Structural cross-section through RB-A1, A2, A5, A7 and B1 wells (Dip 4°) (after Suco Oil Company).

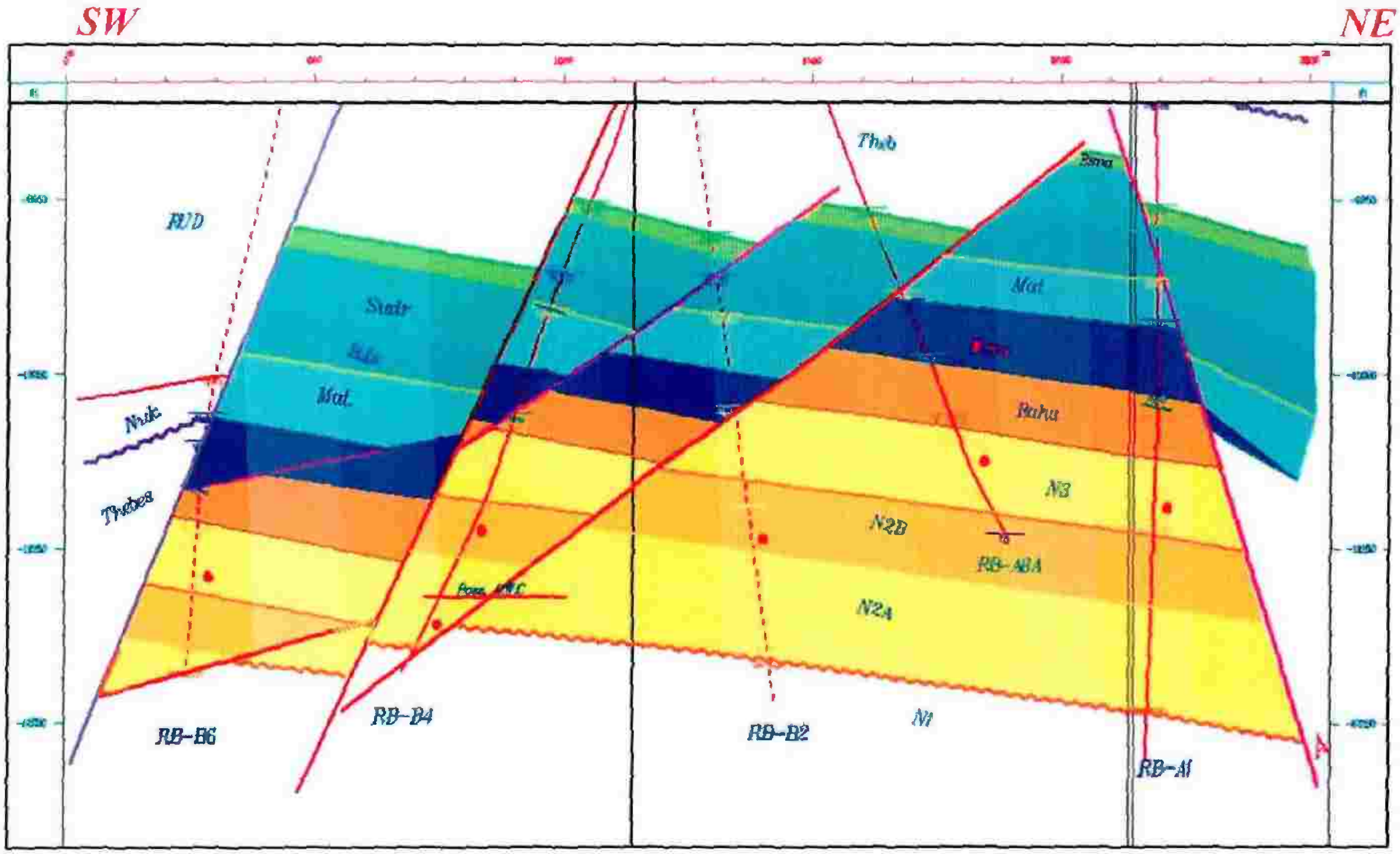

Fig. 2.7: Structural cross-section through RB-A1, B2, B4 and B6 wells (Dip 6°) (after Suco Oil Company).

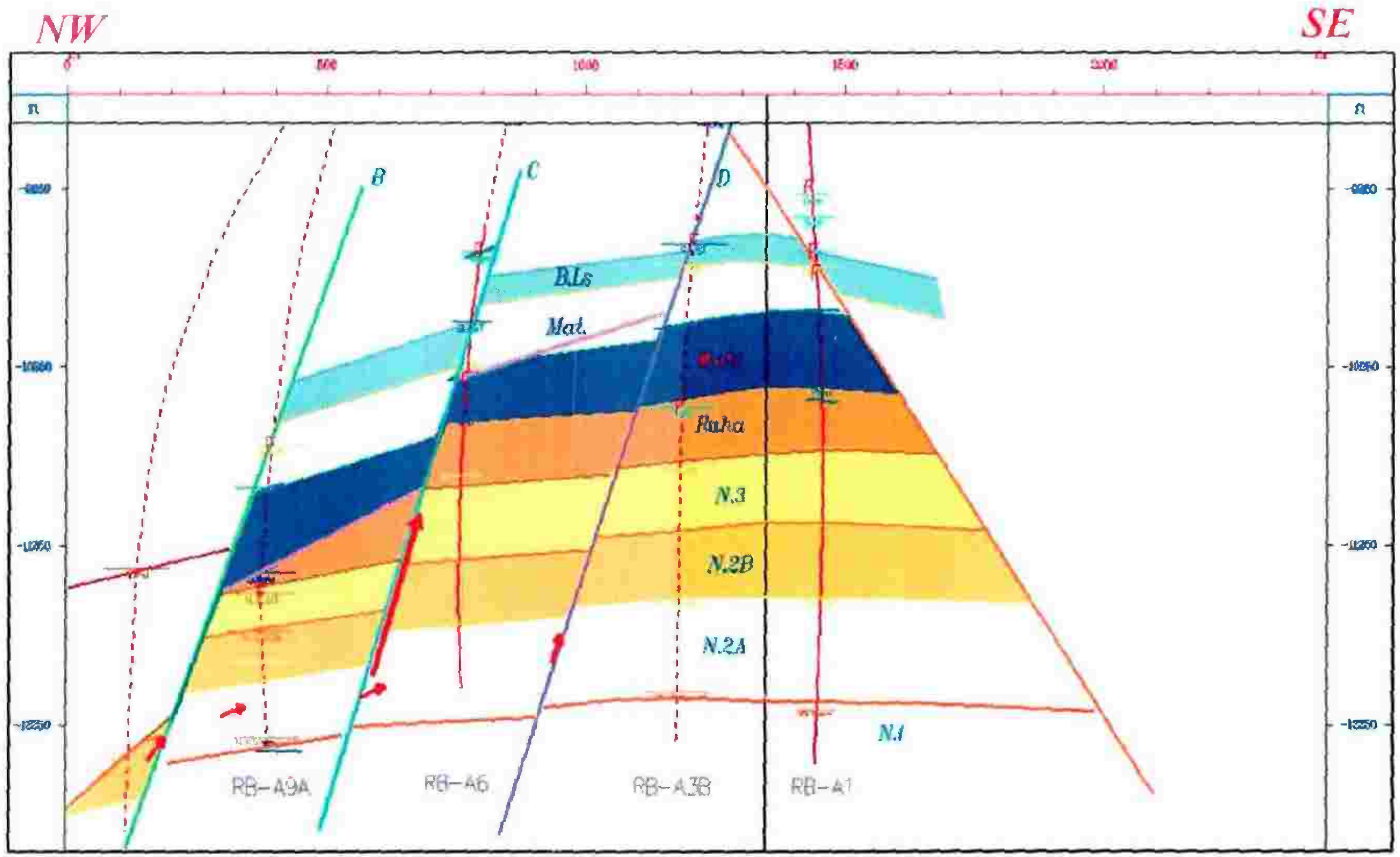

Fig. 2.8: Structural cross-section through RB-A1, A3B, A6 and A9A wells (after Suco Oil Company).

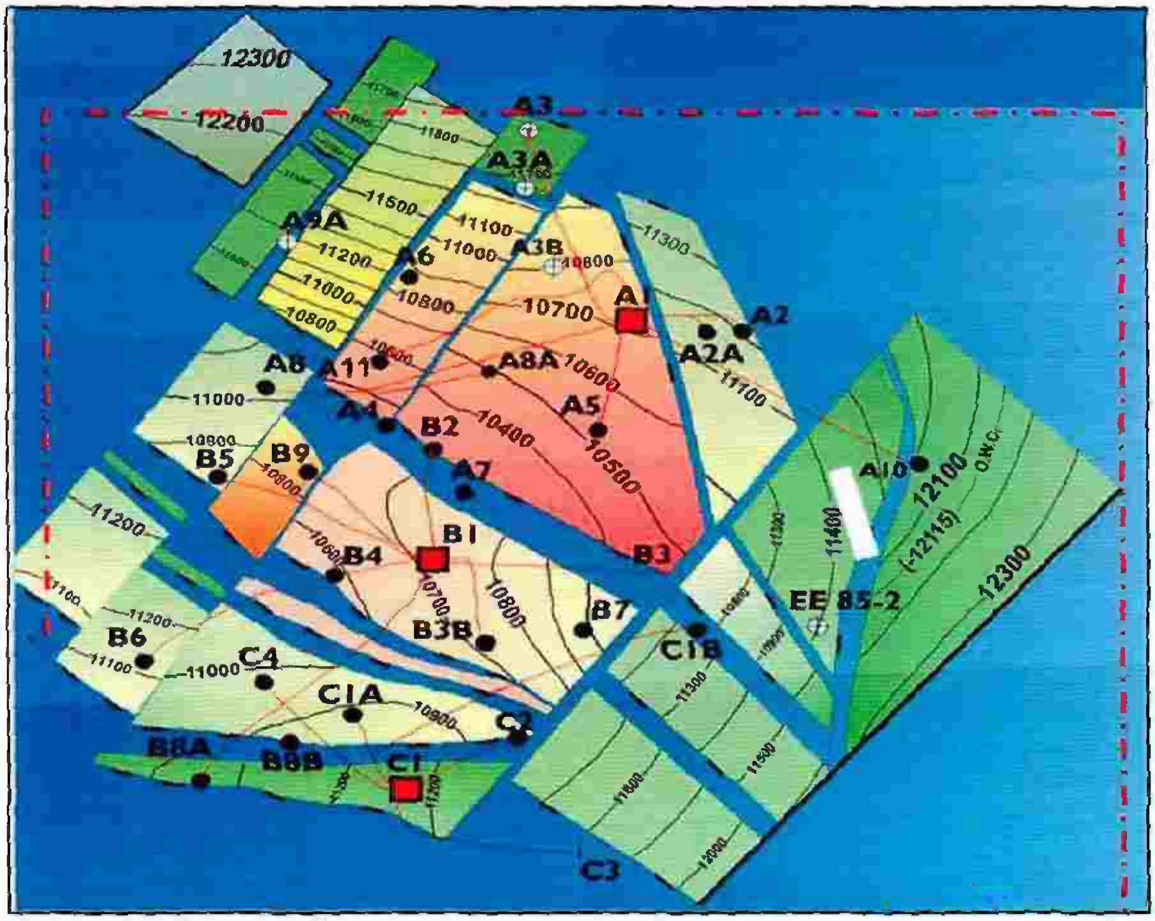

Fig. 2.9: Structural contour map, top Lower Raha (after Suco Oil Company).

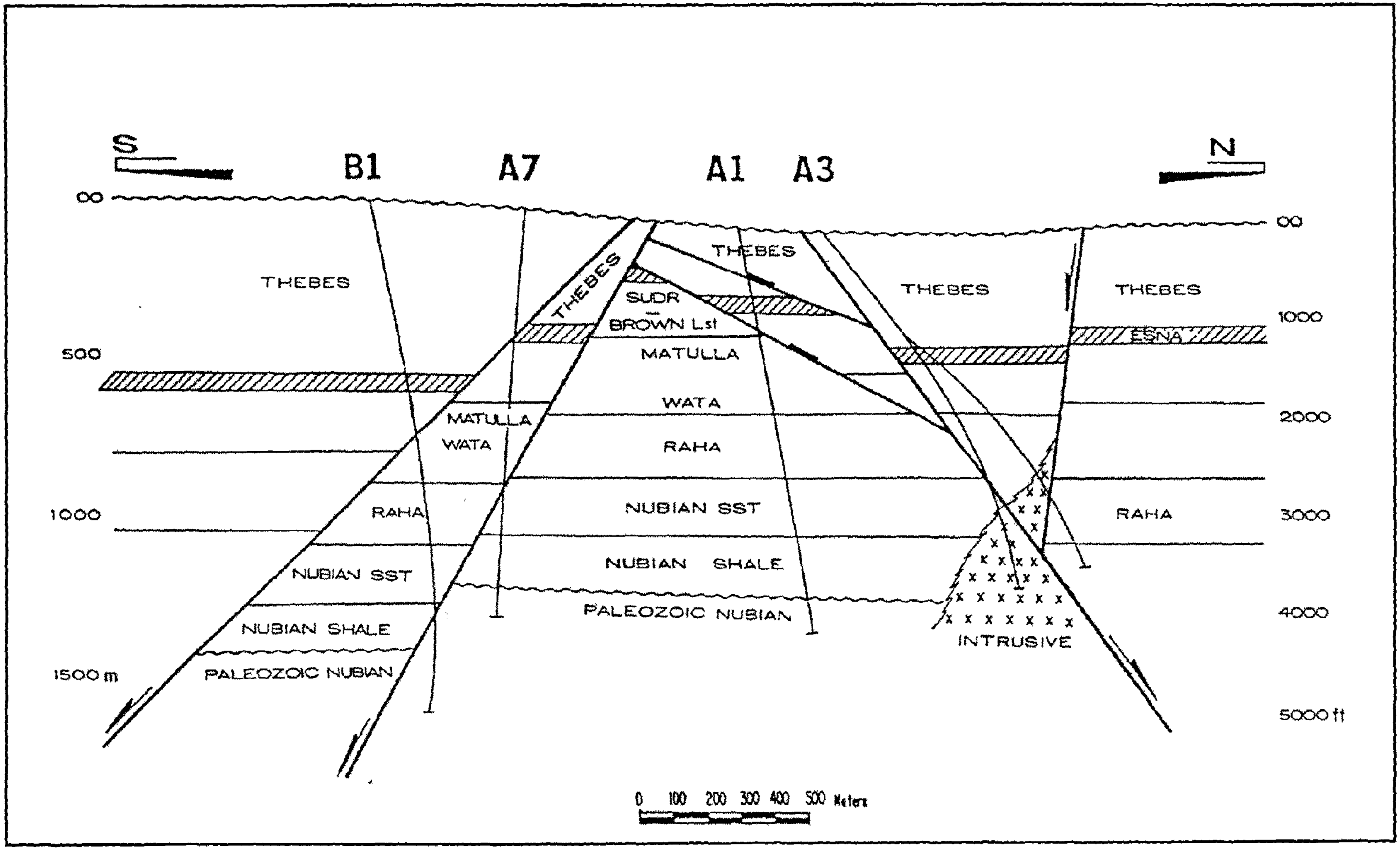

Fig. 2.10: Paleostructural section across Ras Budran structure at Upper Eocene – Oligocene unconformity (after Chowdhary et al., 1986).

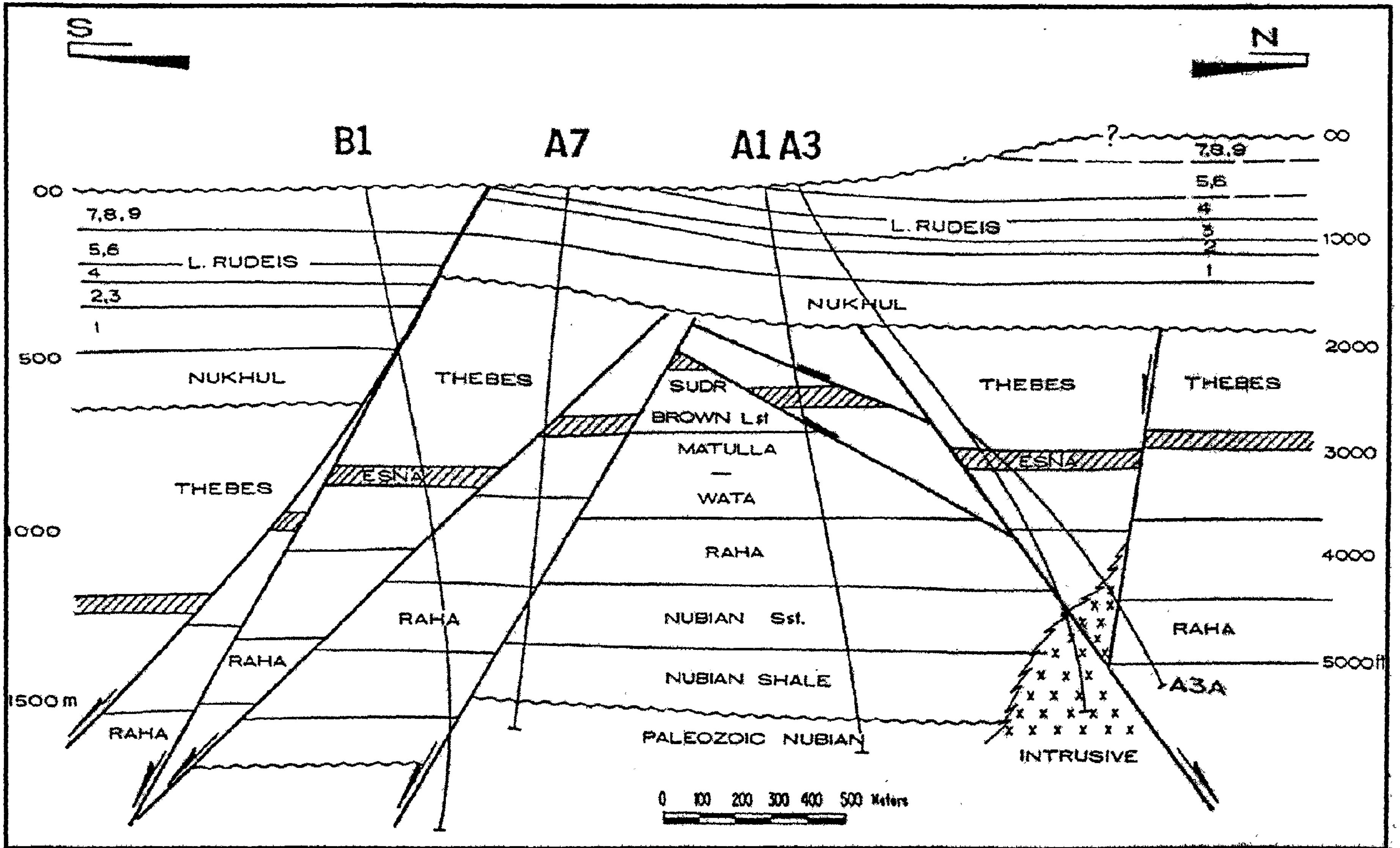

Fig. 2.11: Paleostructural section across Ras Budran structure during Intra-Rudeis unconformity (prior to onset of Upper Rudeis deposition) (after Chowdhary et al., 1986).

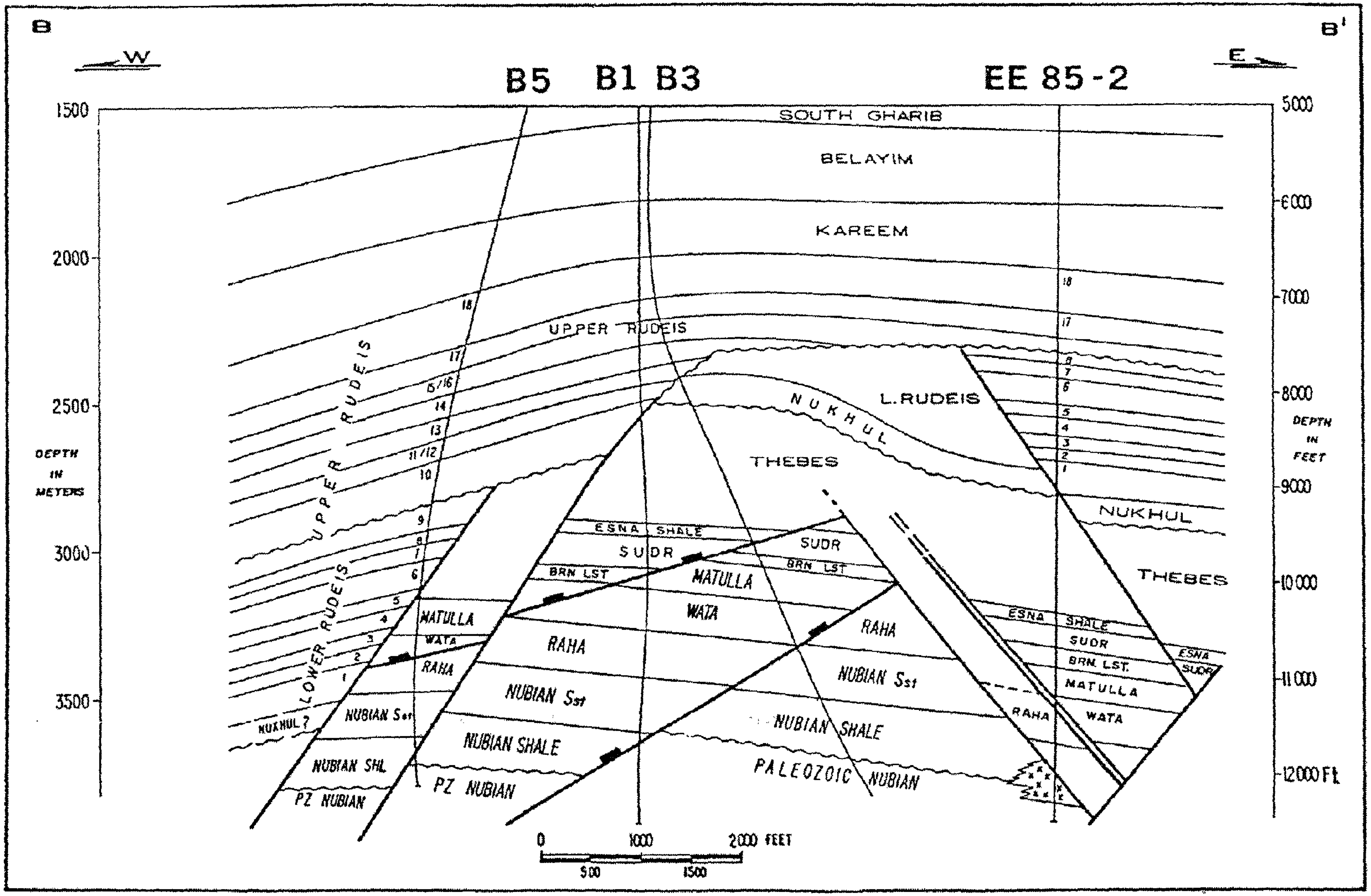

Fig. 2.12: Structural section aligned East-West, Ras Budran field (after Chowdhary et al., 1986).

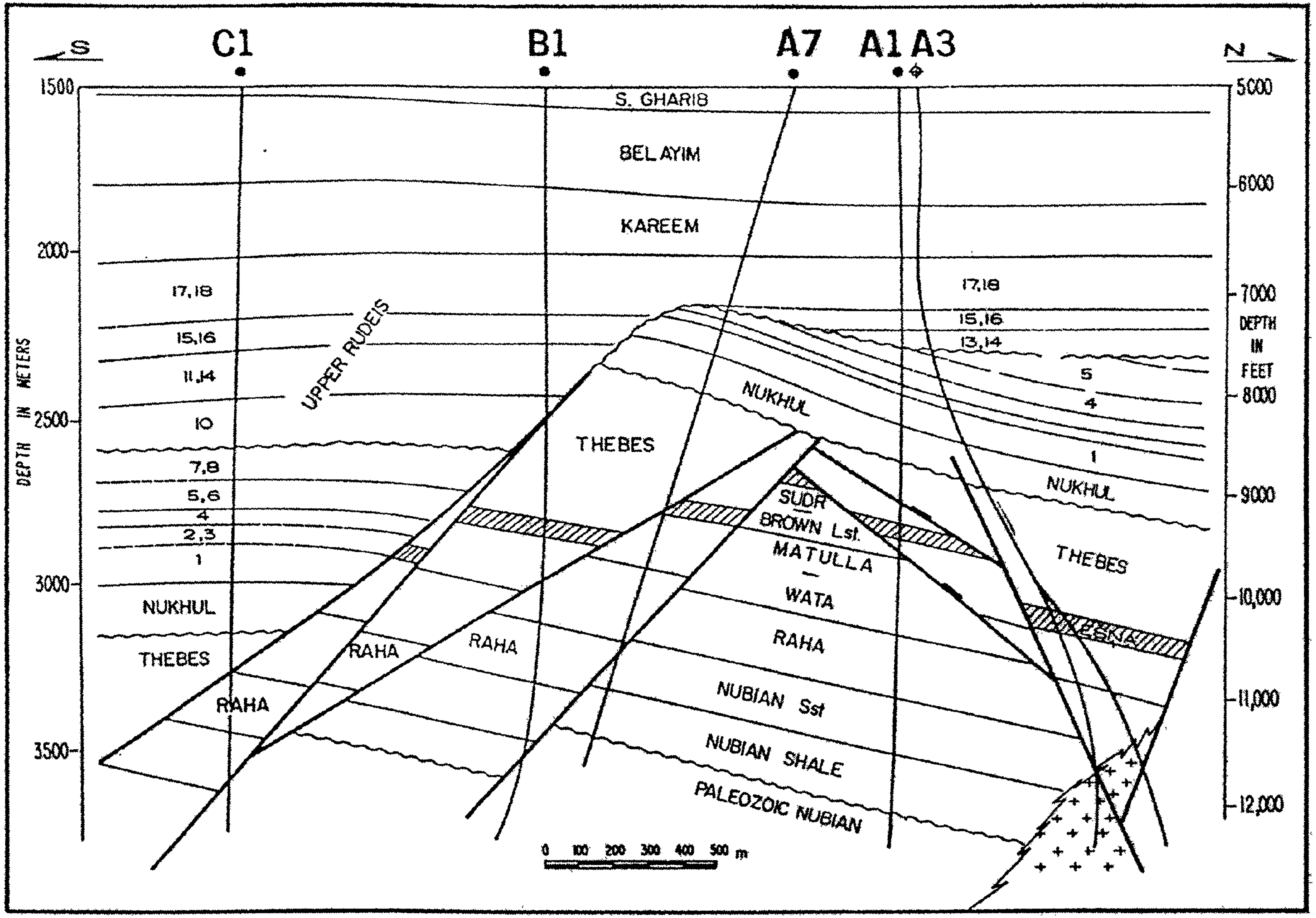

Fig. 2.13: Structural section aligned North- South, Ras Budran (after Chowdhary et al., 1986).