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Shallow crustal structure in Kuwait based on gravity anomalies

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ABSTRACT

Interpretation of free air and Bouguer gravity anomaly maps provide new information about the crustal structure of Kuwait and surrounding areas. Using stratigraphic data constrained by deep boreholes drilled for oil exploration and the modeling of gravity data led to the construction of five cross sections (Fig. 1). The cross sections extend to depths of about 6,000 m, which are sufficient to portray the various Phanerozoic structural units throughout Kuwait. They provide definition of north to northwest trending anticlinal structures. Examples are the prominent gravity highs associated with the Kuwait and the Dibdibba Arches, which indicate their formation by simple uplift. These types of flexures had major influence on the accumulation of petroleum in the Arabian Gulf area. Most of the observed Bouguer anomalies are interpreted in terms of major subsurface structures (arches) and local troughs in the form of small basins. The Bouguer anomalies show no evidence of anomalous mass beneath Wadi al Batin, which suggests that either this valley is not controlled by structure, or that, if a fault is present, it juxtaposes lithologies of little or no density contrast.

INTRODUCTION

Objectives of this study are to interpret the gravity anomaly data in Kuwait to provide qualitative and quantitative information on crustal structure and subsurface geology. The data include Free-air anomaly map and Bouguer anomaly maps reduced at densities of 2.20 g/cm^3, 2.67 g/cm^3. The subsurface structure has been modeled along five profiles across Kuwait. In modeling of these profiles information from several previous gravity studies (Bou-Rabee 1986; Warsi 1990 and Bou-Rabee & Blakely 1993) have been used as a supporting evidence.

The gravity models extend to nearly 6,000 m below the surface and allow estimates of depths of Cenozoic, Mesozoic and Paleozoic sequences throughout Kuwait. The models provide estimates of depths to key stratigraphic units and a perspective of the structures penetrated by deep boreholes drilled for oil exploration. Shallow wells provided depth information on the Dammam Formation, a limestone formation of late Eocene-Oligocene age, which was used as a reference for modeling of the gravity profiles. The modeling further elucidated major geologic structures in the form of elongated anticlines and brachy-anticlines associated with north to northwest trends of the Kuwait and Dibdibba arches respectively. These flexures and other similar well-known arches, such as the Ghawar arch in Saudi Arabia and the Qatar arch in

Qatar, had major influence on the distribution of oil fields in the Arabian Gulf region. The structures may have originated from movement of the Hormuz salt of Infracambrian age coupled with reactivation of basement faults (Bou-Rabee 1986; Warsi 1990).

GENERAL GEOLOGY AND STRATIGRAPHY

The State of Kuwait located at the northern end of the Arabian Gulf, extends over an area of approximately 17,181 km^2. It is bordered on the north and west by Iraq and by Saudi Arabia on the southwest (Fig. 1). Kuwait has a low topography with a gently undulating topographic surface rising gradually from the shore of the Arabian Gulf toward the southwest and reaching to about 300 m at the extreme southwestern corner of the State. The Jal az Zor escarpment is the most significant topographic feature of the country. Other features include the Ahmadi ridge paralleling the east coast of Kuwait, and Wadi al Batin, a valley along the western border. The Jal az Zor escarpment has a remarkably straight trend. Its maximum local relief is 130 m and is covered by loose sediments sloping uniformly toward the Kuwait Bay (Milton 1967). It appears to reflect a subsurface structure and its straightness suggests an origin related to faulting. The linear depression of Wadi al Batin, with an average width of 8 to 11 km and relief as great as 70 m, also may reflect deep-seated faulting.

The regional gradient of about 2m/km (Bou-Rabee 1986) is to the northeast. It is interrupted by the Kuwait and Dibdibba arches and other smaller structures, that are present at the Raudhatain, Umm Gudair and Minagish oil fields (Fig. 1). Subsurface information indicates that these structures have been developing almost steadily since Middle Cretaceous time, and may be as old as late Jurassic. Evidence also indicates that such structures have been uplifted due to horizontal compression, especially during pre-Miocene times (Bou-Rabee 1986). Bou-Rabee (1986) suggests, for instance, that the Kuwait Arch in the vicinity of Ahmadi Ridge appears to be the result of horizontal compression in post-Eocene times and is probably related to the Zagros Orogeny.

Since Triassic time the Kuwait region appears to have occupied an intermediate position between the Arabian Gulf geosyncline, to the northeast, and the Arabian massif, to the southwest, with rocks ranging in age from Eocene to Recent exposed within the boundaries of Kuwait. Drilling conducted in Burgan area proved that the region is underlain by about 6,000 m of sedimentary rocks ranging in age from Permian to Pleistocene, including up to 1,500 m of Jurassic strata, up to 3,300 m of Cretaceous strata and as much as 1,500 m of Eocene strata.

The stratigraphic column shown in Fig. 2. indicates that the Miocene-Pleistocene sedimentary section is represented by arenaceous beds with an areally localized and vertically limited sequence of evaporite beds of middle Miocene age, which thin to the southwest toward the desert of Iraq and pinches out in north Kuwait. The Eocene section is represented by a limestone sequence broken by a thin but very widespread anhydrite interval. The top of the Oligocene Dammam limestone has been used as a reliable horizon for use as a reference to gravity modeling (Fig. 3).

Upper Cretaceous rocks are predominately limestone with subsidiary marls and thin shales. This lithology continues into the upper part of the Middle Cretaceous section. The lower part of the Middle Cretaceous and most of the Lower Cretaceous is predominately sandstone, with intervening shale horizons, and at least two well-developed limestones. The sand content of this sequence increases substantially south-

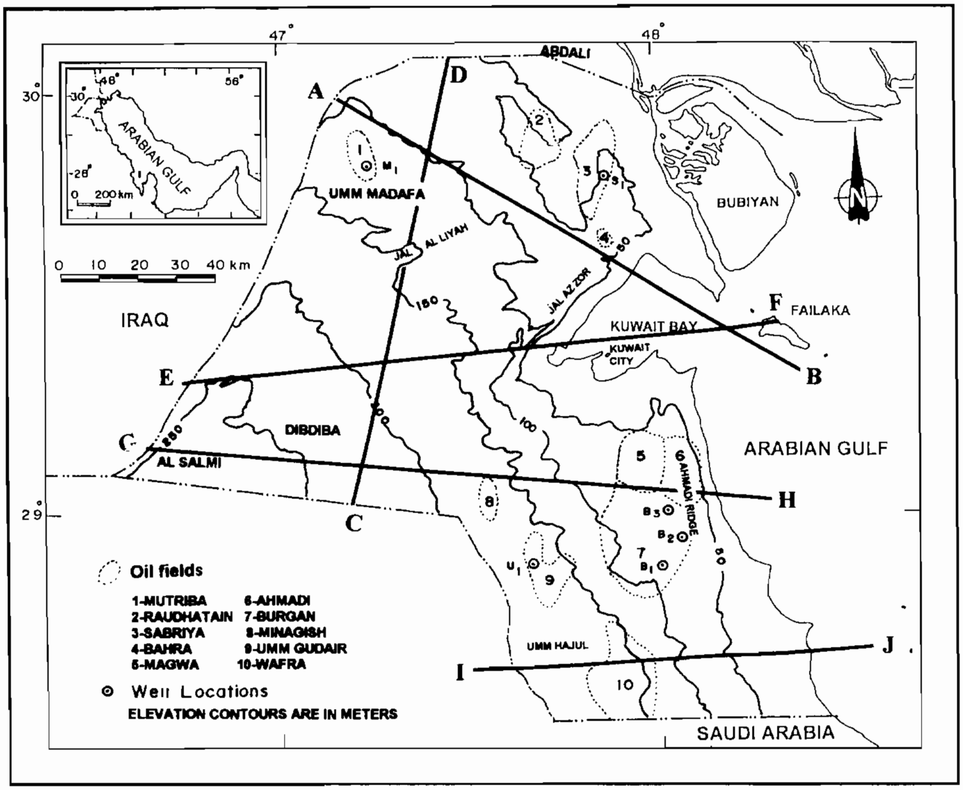

Fig. 1. Regional location and topography of Kuwait within the Arabian Peninsula (after Bou-Rabee, 1986).

ward toward the Burgan field (Fig. 1), where it constitutes approximately 75 percent of the section. In northern Kuwait, sandstone comprises only 30 percent of the Middle Cretaceous rocks. The lowermost part of the Lower Cretaceous is represented by a limestone and shale sequence. The Jurassic rocks in southeastern Kuwait are predominantly limestone with a thick (400 m) anhydrite-salt-evaporite unit. Sedimentary rocks of probable Triassic age are composed of shales and sandstones.

A major break in the above succession occurred during late Eocene and Oligocene times, with a possible minor break in Early Cretaceous (pre-Maestrichtian), and another clearly recognized break at the end of the Middle Cretaceous (post-Cenomanian-Turonian). All intervals above Middle Cretaceous rocks show a progressive thinning across the crest of drilled structures in Kuwait, indicating that nascent folding and uplift has persisted since that time. Because only one well B1 (Fig.1.) has penetrated in to the Paleozoic in Kuwait, Paleozoic stratigraphy is poorly understood. Below the Sudair Formation (Triassic age), the Khuff Formation of Permian age (Fig. 2) consists of 460-610 m of limestone with some clastic to carbonate shelf deposits (Murris, 1980). The following is a brief description of Triassic through Cenozoic aged rocks from the point of view of parameters influencing the normal distribution of the earth's gravitational field in Kuwait.

Triassic System

A complete section of Triassic rocks has been penetrated by a few wells in northern and southern Kuwait. The section is represented from bottom to top by three formations namely the Sudair, Jilh and Minjur Formations (Fig. 2).

Sudair formation: ranges in thickness from about 150 m in the north to about 200 m in the south. It is composed of gray to brown, moderately hard, dolomitic limestone, with shale.

Jilh formation: includes two units, a lower unit of argillaceous dolomite, with soft chalky white anhydrite, calcareous gray-green fissile to sub-fissile shale, and a thick bed of anhydrite and an upper unit similar to the lower but without the thick layer of anhydrite. The thickness of the Jilh Formation ranges from about 350 m in the south to about 500 m in northern Kuwait.

Minjur formation: which ranges in thickness from about 250 m in southern Kuwait to about 340 m in northern Kuwait, is found to consist of littoral continental sandstone with relatively thin layers of conglomerates and shales representing a major regression at the end of the Triassic.

Jurassic System

Five formations of Jurassic age have been penetrated by wells (Fig. 2) with a total thickness varying from 1,215 m to 1,730 m. This variation in thickness is attributed to the presence of evaporites within the Upper Jurassic Gotnia Formation. The general thickening of this sequence is toward the east-north-east.

Marrat formation: This Formation overlies the Triassic section with a thickness ranging from about 580 m in southern Kuwait to about 910 m in northern Kuwait. It consists mainly of limestone and dolomite.

Sargelu formation: This Formation which ranges in thickness from 260 m in the south to 290 m in the north consists of calcareous, carbonaceous shale with occasional plant remains. Intercalation of oolitic limestone occur in the lower and upper part of the formation.

Najmah formation: The Najmah Formation consists of argillaceous limestone with interbedded, locally bituminous, calcareous black shales, containing well preserved fossils. The thickness of this formation ranges from about 60 m in the southern part to about 105 m in northern Kuwait.

Gotnia formation: The Gotnia Formation consists mainly of anhydrite, with halite layers, interbedded with fossiliferous, argillaceous anhydrite, soft shale, and limestone. The thickness ranges from about 240 m in the south to about 425 m in the north.

Hith formation: The Hith Formation consists mainly of anhydrite interbedded with some limestone and shale. It has a thickness ranging from 70 m in southern Kuwait to about 295 m in northern Kuwait.

Cretaceous System

Cretaceous sedimentary rocks are generally considered to be the main oil reservoirs of Kuwait. They range in thickness from about 1,455 m in the southwest to about 3,800 m

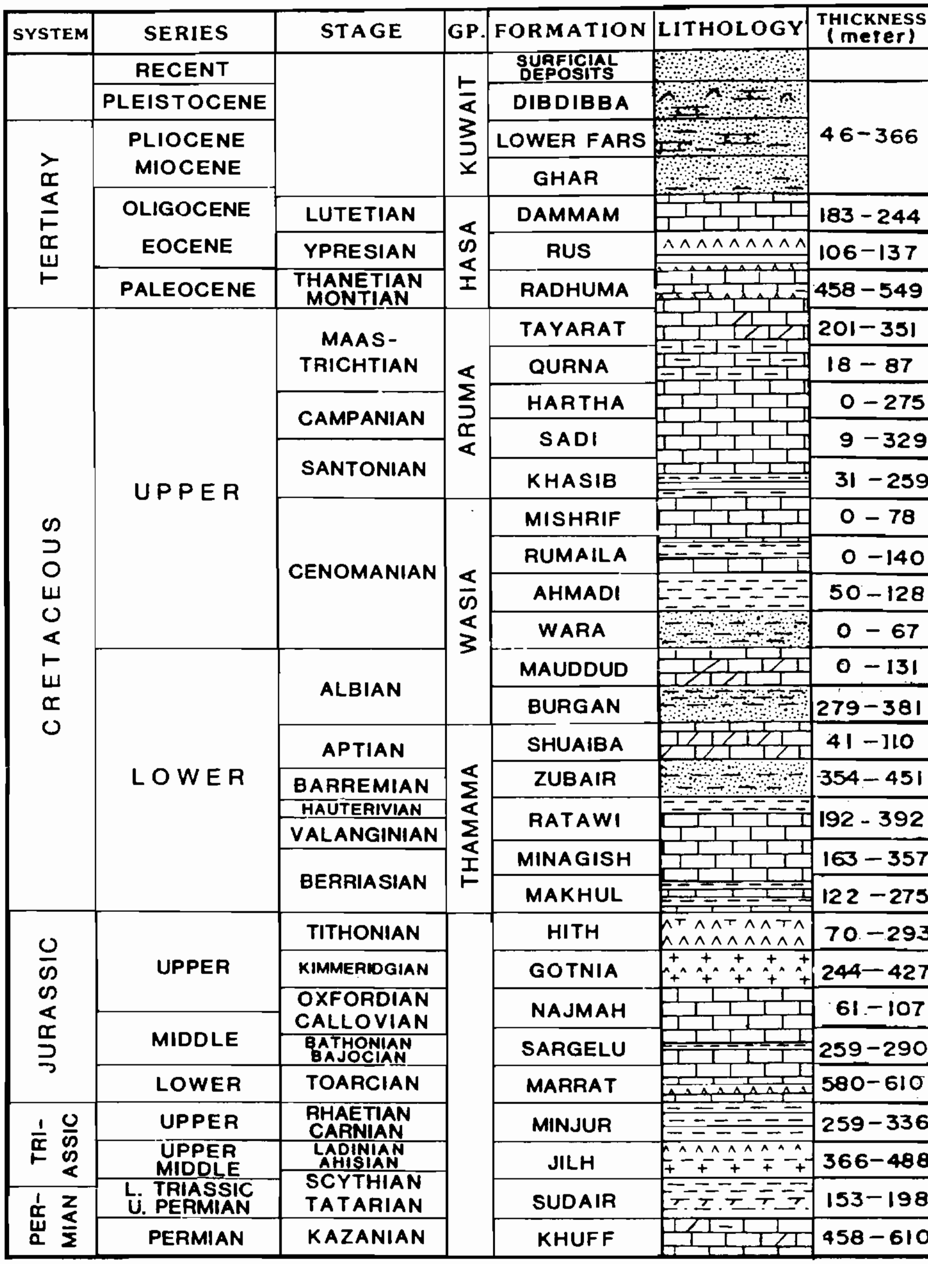

Fig. 2. A stratigraphic column of Kuwait, section showing lithologies relevant to gravity anomalies (after Bou-Rabee, 1986).

in the northeast and are differentiated in three main rock groups (Thamama, Wasia and Aruma, Fig. 2).

1. *Thamama group:*

This Group is the lowest group in the Cretaceous section and is divided into five formations: the Makhul, Minagish, Ratawi, Zubair, and Shuaiba formations.

Makhul formation: The Makhul Formation is the lowest formation in the Thamama Group and ranges in thickness from about 120 m in northern Kuwait to about 275 m in southern Kuwait. It consists of hard, cryptocrystalline limestone, occasionally dolomitic, and interbedded with marl and silt in the lower part of the section.

Minagish formation: The type-section of the Minagish Formation is located in Burgan well-113 in the Burgan field of south-eastern Kuwait where it is about 305 m thick. Lithologically, it is similar to the Makhul Formation and range from about 160 m thick in southern Kuwait up to about 355 m in northern Kuwait.

Ratawi formation: The Ratawi formation, which is composed mainly of interbedded shale and limestone, ranges from about 190 m thick in southern Kuwait to about 390 m in northern Kuwait.

Zubair formation: The Zubair Formation ranges from about 350 m thick in the south to about 450 m thick in the north. The lithology is mainly sandstone, with some intercalation of a shale sequence with minor limestone.

Shuaiba formation: The thickness of the Shuaiba Formation ranges from about 40 m in southern Kuwait to about 110 m in northern Kuwait. Lithologically it consists of coarsely crystalline, highly dolomitized, porous and cavernous limestone. Rare thin shale beds occur locally.

2. *Wasia Group:*

This middle Cretaceous Wasia Group which has a minimum thickness of 330 m and a maximum of 950 m has been also divided into five formations in southern Kuwait, and into six formations in northern Kuwait (Fig. 2).

These Formation – from bottom to top – are Burgan (mainly sandstones), Mauddud (limestones), Wara (sandstones intercalated with shale), Ahmadi (impervious shale, forming cap rock over most of Kuwait oil fields), Rumaila (shale intercalated with limestones) and Mishrif Formation which consists mainly of limestones.

It is indicated here that most of the production from the Greater Burgan field has been developed from this Wasia Group.

3. *Aruma Group:*

The Aruma Group is divided into the five following formations: Khasib (Mutriba), Sadi, Hartha, Qurna, and Tayarat. The group consists mainly of limestones and dolomites intercalated with shales, with a minimum thickness of about 250 m thick in southern Kuwait and a maximum of 1,300 m in northern Kuwait.

Tertiary System

Rocks of Cenozoic age are composed of the Hasa and Kuwait Groups which range in age from Paleocene to Recent.

1. *The Hasa Group:*

is composed of three formations: the Dammam, the Rus, and the Radhuma formations.

Radhuma Formation: Radhuma formation was named for the Umm-er-Radhuma water well in Saudi Arabia. The formation consists mostly of anhydrite and dolomitic and marly limestone. Thickness ranges from about 450 m in the south to about 550 m in the north.

Rus Formation: The Rus Formation consists of alternating beds of anhydrite and limestone. Regionally, the Rus Formation in Kuwait varies in thickness from about 105 m in the south to about 135 m in the north.

Dammam Formation: The type section of the Dammam Formation for Kuwait is in Burgan well number 10 in southern Kuwait. It consists of 180 to 245 m of porous, dolomitized limestones, and nummulitic limestones. This formation, which ranges in thickness from about 180 m in southwestern Kuwait to about 245 m in north-eastern Kuwait, has been locally subdivided into three members on the basis of lithology; from top to bottom, these are:

Member 1. dense, dolomitic limestone with a lower fossiliferous (numulitic) dolomitic limestone, thin anhydrite beds and green shale in the lower part.

Member 2. chalky, locally shaly limestone with thin siliceous limestone with beds at the base.

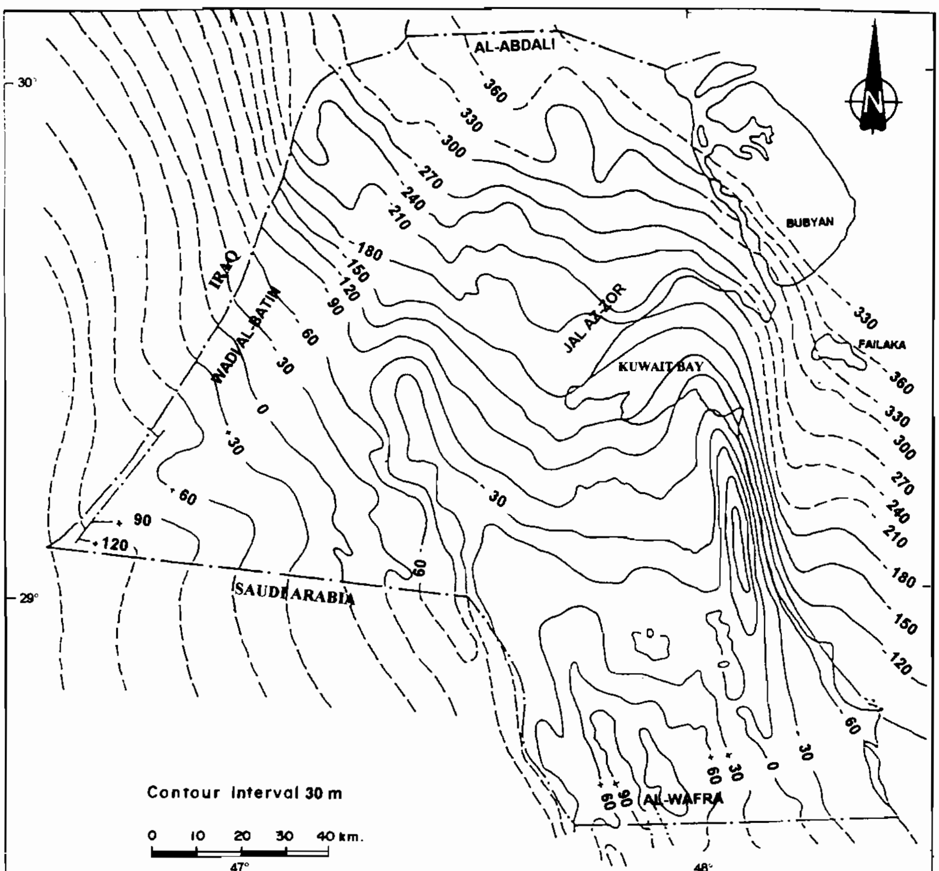

Fig. 3. Topography of the mid-Tertiary limestone Dammam Formation taken as a reference for gravity modeling (after Omar *et. al.*, 1981).

Member 3. shaly, chalky, porous limestone with hard, siliceous limestone at top.

2. *The Kuwait Group:*
forms the surface outcrop over the entire country, except where overlain by unconsolidated Recent sediments ranging from gravel and sands to fine-grained coastal deposits. The exposed stratigraphic sequence includes conglomerates, sandstones, sandy limestones, claystones, marls, sands, and gravel and ranges in age from Miocene to Holocene. It shows marked increase in thickness, from a few meters at Ahmadi to about 365 m in northeastern Kuwait. In northern Kuwait, this group is divided into three formations based on the presence of an intermediate evaporite horizon: 1) the Ghar Formation (sand and gravel), 2) the Lower Fars Formation (evaporites), and 3) the Dibdibba Formation (sand and gravel).

Recent

Surficial rocks of Recent age consist of eolian sand, residual deposits, playa deposits, desert plain deposits, and Sabkha deposits.

INTERPRETATION OF GRAVITY ANOMALY DATA QUALITATIVE INTERPRETATION

Information about crustal structure and subsurface geology of Kuwait was obtained from interpretation of Bouguer and free-air gravity anomaly maps and geologic cross sections derived from modeling of five gravity profiles that extend across the State (Fig. 1).

Bouguer Anomaly Maps

Two Bouguer gravity anomaly maps of Kuwait were prepared using reduction densities of 2.20 g/cm^3 and 2.67 g/cm^3 (Figs. 4 & 5). Because of the relatively low topographic relief, no terrain corrections were made. For this study, I selected the map reduced at a 2.67 g/cm^3 density (Fig. 5) as most representative of the average crustal density. For detailed studies of near surface sources, it can be argued that a lower reduction density is more appropriate since the surface sedimentary rocks (i.e., the Kuwait Group) have densities of about 2.20 g/cm^3. However, a comparison of the two maps reduced at 2.67 g/cm^3 and 2.20 g/cm^3 shows that the location and shapes of Bouguer anomalies are more or less identical since most of the topography of Kuwait is subdued.

Intensities of the Bouguer anomalies reduced at 2.67 g/cm^3 are found to vary from –46 mGal in the northern part of the State, near the Iraq border, to –16 mGal in eastern Kuwait. The gravity field in the maps (Fig. 5) shows two elongated positive anomalies (A & B) separated by a deep gravity depression (D).

The most significant feature of the gravity 'high' belt (labeled A) appears to be related to an asymmetrical north-south brachyanticline or perhaps a series of anticlinal structures which make up the Kuwait arch. This anomaly, which generally strikes north-south and broadens to the north, extends for about 175 km across Kuwait Bay and into north-eastern Kuwait, where its source plunges beneath increasing thickness of sedimentary rocks. An important characteristic of this positive anomaly is that its maximum axis, although nearly parallel, does not

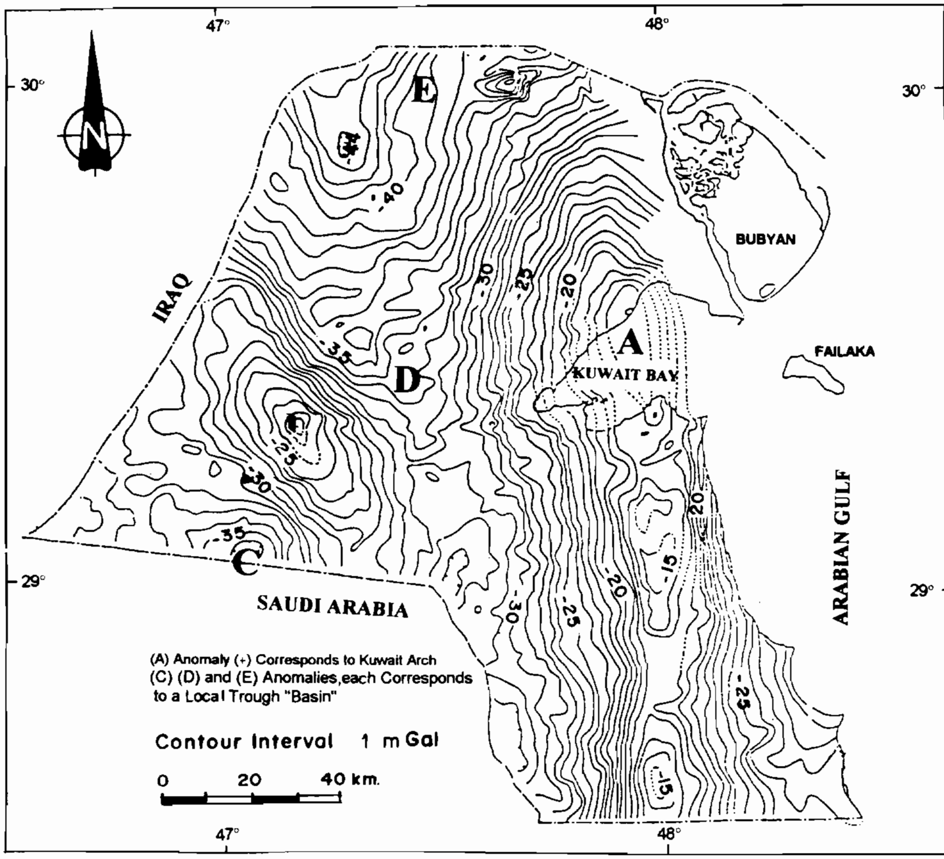

Fig. 4. Bouguer anomaly map (density 2.20 g/cm^3).

follow the topographic relief of Ahmadi ridge, but is shifted nearly 10 km to the west of it.

The second prominent positive anomaly, labeled (B) and extending over the southwestern part of Kuwait, seems to be related to a structure referred to as the Dibdibba Arch (Warsi 1990). The anomaly has a maximum value of –27 mGal and a lateral extent of about 75 km. From previous modeling, this anomaly was attributed to a major brachyanticline elongated northwest-southeast (Bou-Rabee 1986). South-southwest of the northwest-trending Dibdibba positive anomaly, a gravity low (labeled C) in southwest Kuwait suggests the presence of a small basin of low-density sedimentary rocks that may extend into Saudi Arabia.

To the east, the Dibdibba anomaly is separated from the larger positive anomaly associated with the Kuwait arch by a gravity trough (labeled D). This wedge-shaped north-northwest-trending trough is caused by an intervening sedimentary basin. The basin widens and deepens to the north, with gravity intensities generally decreasing from south to north in response to a combination of the effect of the gentle north-easterly-dipping crystalline basement and the northeasterly thickening of low-density sedimentary rocks of the Kuwait Group.

In northern Kuwait, just southwest of Abdali, a distinctive negative anomaly (labeled E) with a closure is also present.

The above discussions enables the following conclusions:

1. Most of the observed Bouguer anomalies are interpreted in terms of major subsurface structures (arches) or local troughs in the form of small basins.
2. Wadi al Batin and Jal az Zor escarpment are prominently reflected in the free-air anomaly map (Fig. 6).
3. The Bouguer anomalies show no evidence of anomalous mass beneath Wadi al Batin, which suggests that either this valley is not controlled by structure, or that, if a fault is present, it juxtaposes lithologies of little or no density contrast.
4. The Ahmadi ridge is expressed as a steep gradient along its eastern flank. Near Wafra, a gravity high may reflect a small anticline on the west flank of the Kuwait arch.
5. Both the Kuwait and Dibdibba Arches must have been formed by a simple uplift, with no regard for the requirements of isostasy, since they appear to be associated

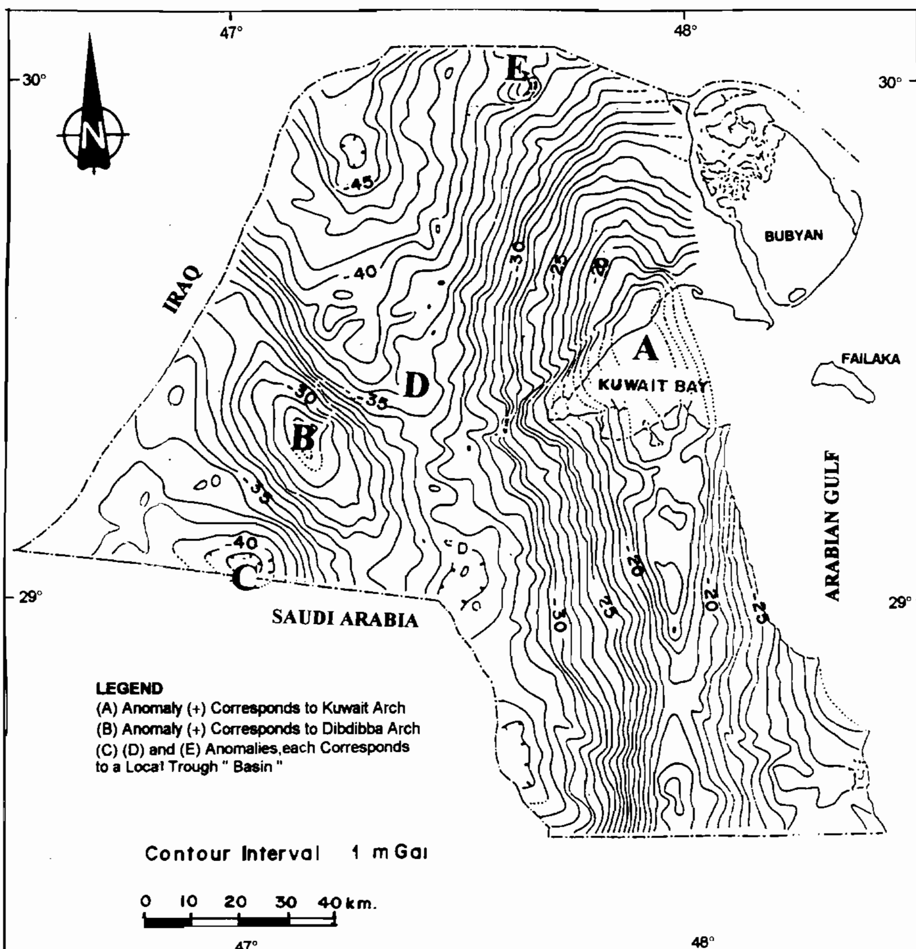

Fig. 5. Bouguer anomaly map (density 2.67 g/cm^3).

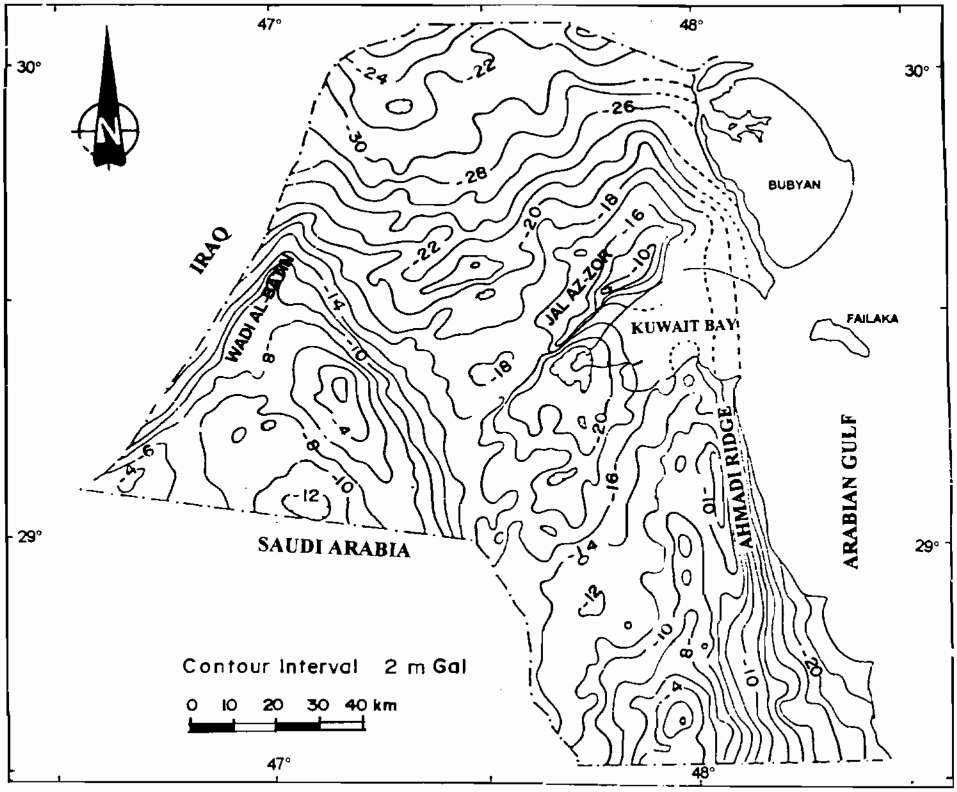

Fig. 6. Free-air anomaly map.

with well-defined relatively positive Bouguer anomalies (A and B in Fig. 5), probably related to the uplift of heavier, deep-seated rocks below these arches.

QUANTITATIVE INTERPRETATION

Gravity Modeling

An interactive program for IBM compatible personal computers (PCs) was used to model the five gravity profiles. Geologic cross sections were made from computer modeling of gravity profiles that extend across Kuwait (Fig. 1). The cross-sections are modeled to depths of nearly 6,000 m, which is sufficient to portray Middle to Upper Paleozoic and Mesozoic sequences throughout Kuwait. Due to a lack of density measurements, estimated density values were assigned in the modeling and are considered only as a first approximation. Density values used for this study were estimated on the basis of rock types, probable pressure and temperature, and depth of burial. Future investigations will include compilation of rock densities obtained from measurements of drill hole core samples and from borehole density logs. Furthermore, unpublished bore-hole information (from KOC) was utilized in constraining the models (Fig. 1)

The modeling was done using a 2.5-dimensional gravity computer program based on the formulation of Rassmusen & Pedersen (1979). Since the stratigraphic units are sub-horizontal for long distances, the models are essentially two-dimensional. Unfortunately little is known about the rocks below 2 km. One proprietary borehole drilled (well number B2, Fig. 1) in the Burgan area reportedly reached the contact between Cretaceous and Jurassic beds at a depth of 2,910 m, the top of Triassic at 4,410 m, and bottomed at 4,620 m. The contact between the Kuwait Group and the Dammam Formation was established on the basis of well data and structure on top of Dammam Formation (Fig. 3) (Omar *et al.* 1981). Other depth information used to adjust the sections was taken from reports that discuss the crustal geology of Kuwait (Owen & Nasr 1958; Milton 1964).

Calculated Geologic Cross-sections

The geologic cross-sections were derived from modeling five gravity profiles, A–B, C–D, E–F, G–H, and I–J (Figs. 7–11). The results provide qualitative and quantitative information such as dimensions of structures and depths to key beds found in anticlines or brachyanticlines, such as those associated with the Kuwait arch and Dibdibba Arch. Approximate depths picked to marker horizons at specified spacing along each geologic cross section are indicated in the text.

Profile A–B: This profile extends for 130 km from the northwest part of Kuwait south-eastward across Kuwait Bay to Failaka Island (Fig. 7). Bouguer anomalies along this profile increase from –46 mGal at its northwestern end to a maximum of –16 mGal over Kuwait Bay. The geologic cross-section shows a gently wrapping stratigraphy.

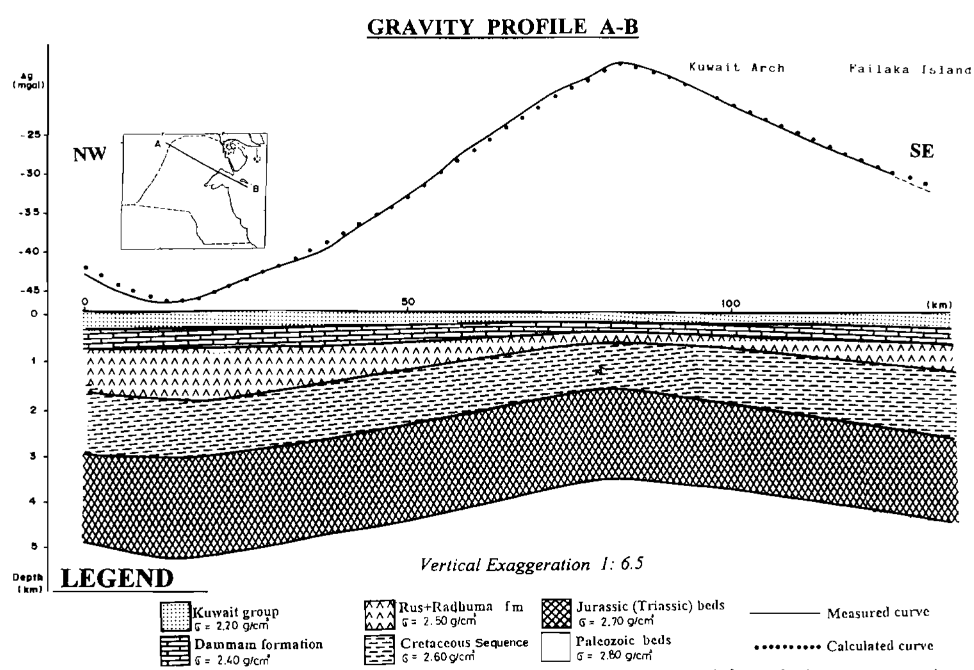

Fig. 7. Bouguer gravity profile A–B and modeled geologic cross section.

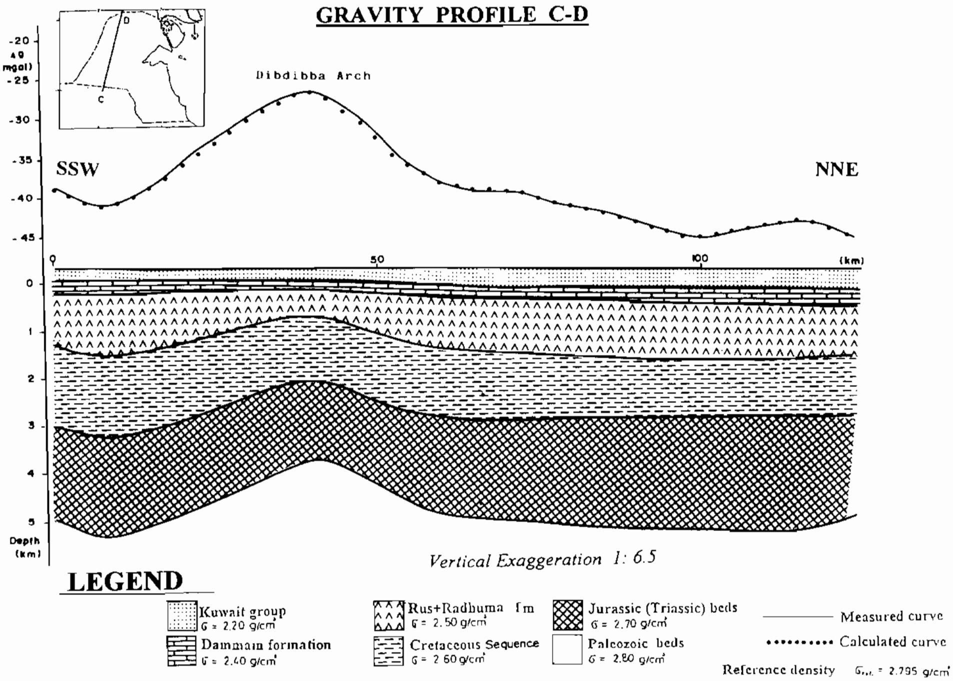

Fig. 8. Bouguer gravity profile C–D and modeled geologic cross section.

Maximum sedimentary rock thickness occurs at a distance of 15 km from the starting point A, along the profile. Here the Kuwait Group has a thickness of about 300 m, the base of the Dammam Formation was modeled at 800 m, the base of the Rus and Radhuma Formations is at 1,850 m, the Cretaceous beds bottom at 3,050 m and Jurassic-Triassic beds extend to depths of 5,300 m.

Continuing to the southeast along the profile at 80 km, the thicknesses decreases over the Kuwait arch. Depth values modeled are 120 m for the Kuwait Group, 300 m for the Dammam Formation, 550 m for the Rus and Radhuma Formations, 1550 m for Cretaceous beds and 3,600 m for the Jurassic-Triassic beds.

Profile C–D: This profile extends approximately NNE-SSW with a length of 120 km (Fig. 8). Bouguer anomalies along the profile include a negative anomaly of –40 mGal near the Saudi Arabia border, a relatively positive anomaly associated with the Dibdibba arch (–28 mGal), and a negative anomaly near the Iraq border (–46 mGal). The depths modeled at the base of key stratigraphic horizons of the Dibdibba arch, at 40 km distance along the profile, are as follows: Kuwait Group 150 m, Dammam Formation, 400 m, Rus and Radhuma Formations, 900 m, Cretaceous beds, 2,350 m and Jurassic-Triassic beds, 4,050 m. To the north at 100 km along the profile, these values increase to 400 m, 700 m, 1,900 m, 3,600 m and 5,450 m respectively.

Profile E–F: The longest profile E–F, extends approximately 155 km in an east-northeast (Fig. 9). It starts at Wadi al Batin, crosses the positive anomaly associated with the Dibdibba arch, the gravity trough to the east of the arch, the positive anomaly associated with the Kuwait arch beneath Kuwait Bay, and ends near Failaka Island.

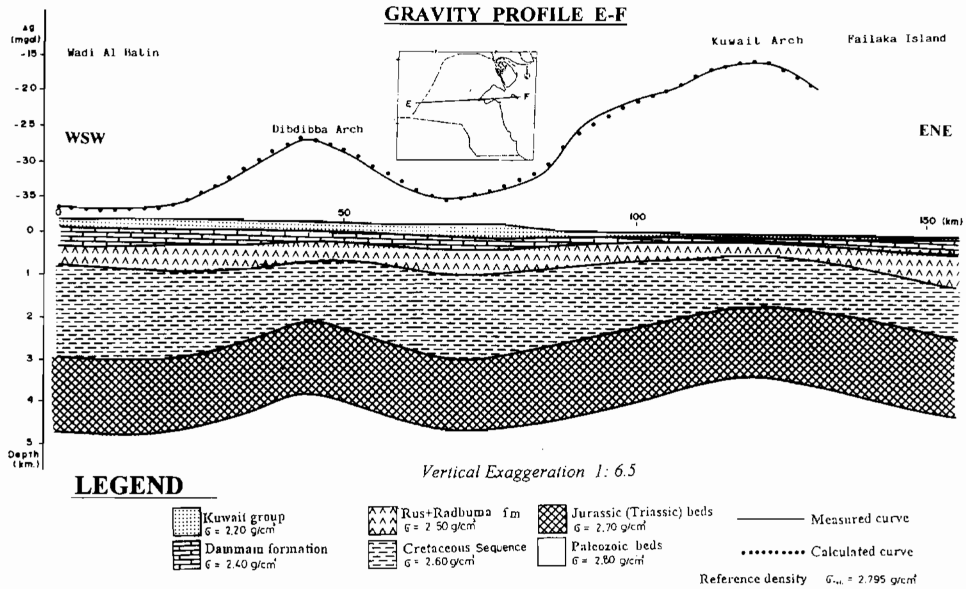

Fig. 9. Bouguer gravity profile E–F and modeled geologic cross section.

Intensity values range from −37 mGal at the beginning of the profile (E) to −16 mGal over Kuwait Bay. The depth of the Dammam formation decreases from 600 m near the Iraq border to 400 m beneath the positive anomaly associated with the Dibdibba arch at about 45 km along the profile (Bou-Rabee 1986). The depth again increases to 700 m at the gravity trough in the central part of the profile (70 km distance). Beneath

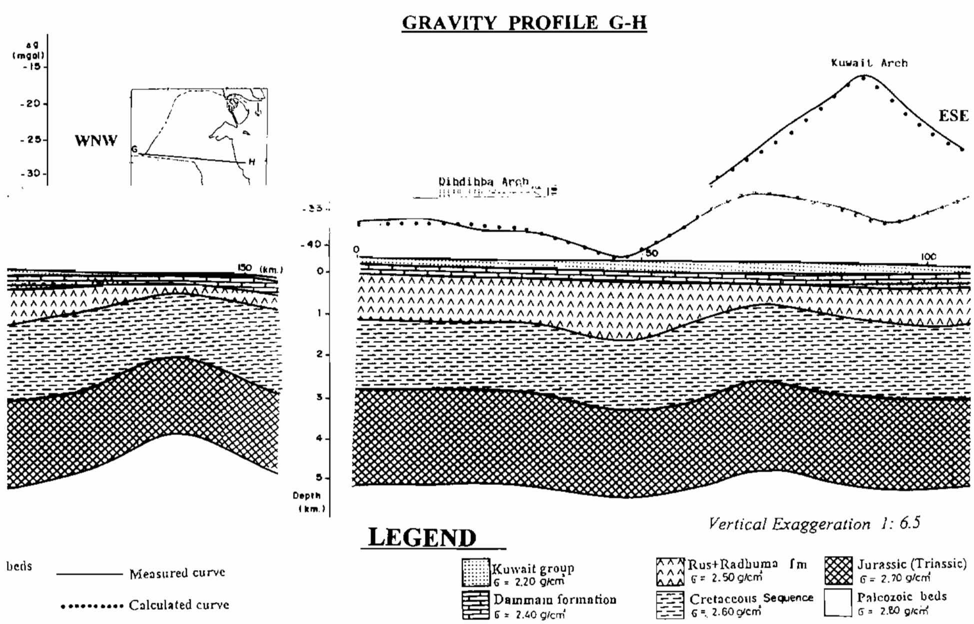

Fig. 10. Bouguer gravity profile G–H and modeled geologic cross section.

the maximum values of gravity, the depth of the Dammam Formation decreases to 220 m. The top of Cretaceous beds occur at 1,000 m, 850 m, 1,200 m, and 500 m, at distances along the profile of 0, 45, 70 and 120 from the Iraq border. The depth values of the base of the Cretaceous are 3,200 m, 2,250 m, 3,150 m, and 1,800 m. The depth values of the base of Jurassic-Triassic beds are 5,000 m, 3,950 m, 4,900 m, and 3300 m, at the above distances along the profile.

Profile G–H: This profile is 155 km long and trends east-west across Kuwait (Fig. 10). It extends from an area of low gravity near the Saudi-Iraqi border, across the southeast end of the gravity high associated with the Dibdibba arch at 70 km, and to a maximum of −15 mGal over the Kuwait Arch. The depth of the Kuwait Group from west to east along the geologic section is, 150 m at 50 km, 270 m at 70 km and 215 m at 90 km. Kuwait Group rocks have been eroded away at the top of Ahmadi ridge where the underlying Dammam Formation is exposed. At the east end of the section,

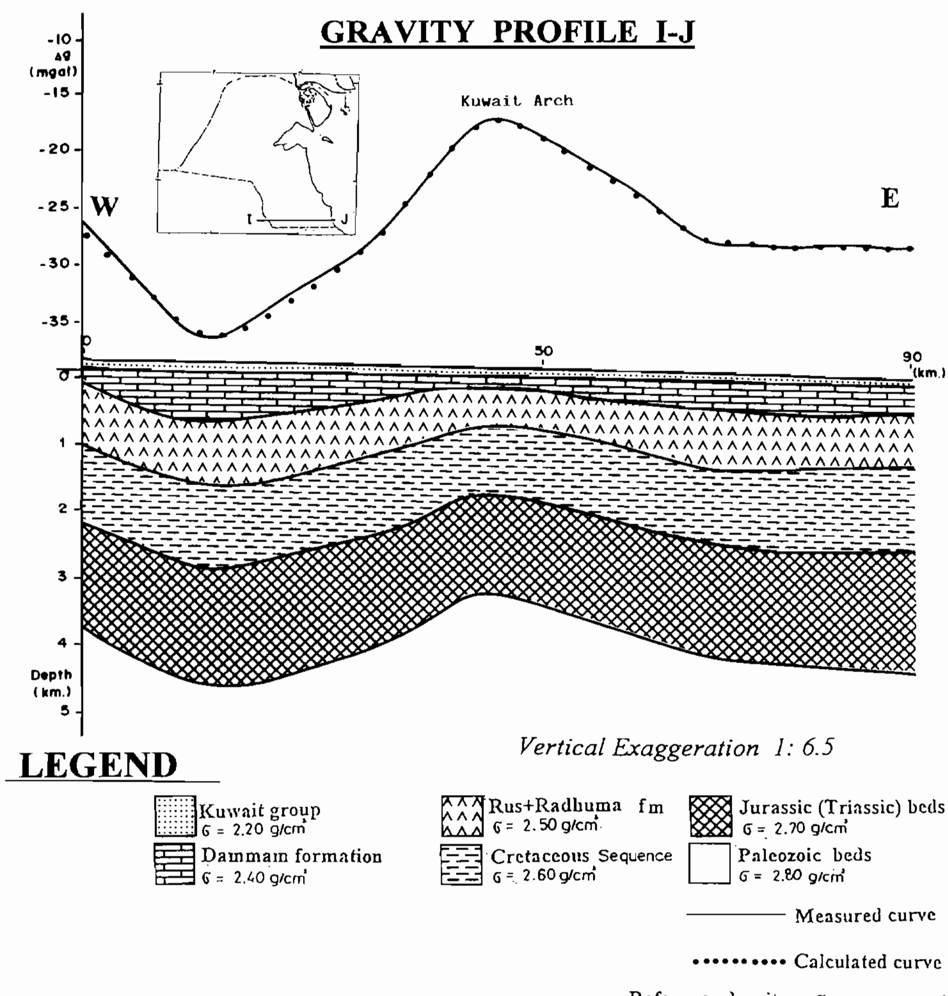

Fig. 11. Bouguer gravity profile I–J and modeled geologic cross section.

the thickness of the Kuwait Group is estimated to be 50 m. From the west-northwest end at distances of 0 km, 50 km, 70 km, 90 km, 135 km, and 150 km along the profile, the depths to the base of Dammam Formation were modeled to be 400 m, 530 m, 450 m, 600 m, 190 m, and 430 m. At the same locations along the profile, the top of the Cretaceous is estimated to be 1,530 m, 1,900 m, 930 m, 1,420 m, 330 m, and 700 m. The base of the Cretaceous picked at the same points along the profile were 50 m, 3,600 m, 2,730 m, 3,200 m, 1800 m, 2,700 m, and the base of Jurassic-Triassic is estimated to be at depths of 5,450 m, 5,730 m, 4,850 m, 5,430 m, 3,700 m, and 4,700 m.

Profile I–J: This profile is 90 km long and crosses the Wafra area from west to east across the southern part of Kuwait (Fig. 11). Bouguer gravity anomaly values range from –36 mGal on the west to –27 mGal at the coast. The main feature of this profile is the positive anomaly which is a part of the main south-north elongated positive anomaly associated with the Kuwait arch. The top of Dammam was modeled at a depth of about 150 m in the western part and its depth decreases eastward to 70 m near the coast. Depths were picked along the section from west to east at 0, 15, 45, and 90 km. The depth of the base of Dammam Formation taken at the above distances are as follows: 500 m, 1,000 m, 400 m, and 500 m. Depths to the top of the Cretaceous at the same locations are 1,200 m, 1,900 m, 900 m, and 1,300 m, depths to the base of the Cretaceous are 2,400 m, 3,150 m, 1,800 m, and 2,500 m and depths to the base of Jurassic-Triassic are 3,850 m, 4,950 m, 3,300 m and 4,300 m.

CONCLUSIONS

This paper gives qualitative and quantitative interpretations of gravity anomaly data for Kuwait, which adds to our knowledge of the crustal structure and regional geology of the country and its surroundings. For the first time, geologic cross sections across Kuwait have been calculated from gravity modeling. The result has been to enhance our interpretations of the stratigraphy and structure of the upper 5–6 km of the crust. Physical property data is not yet available and could only be approximated. Hence my interpretations should be considered as a first step. Most of the observed Bouguer anomalies are interpreted in terms of major subsurface structures (arches) and in terms of local troughs in the form of small basins.

The interpretations provide greater detail about the structure and stratigraphy of geologic features associated with the Kuwait and Dibdibba arches. These structures are primarily elongated anticlines with northern and northwestern trends and are typical of structures associated with important oil fields in the Arabian Gulf area. Both the Kuwait and Dibdibba Arches must have been formed by simple uplift. The structures seem to have been generated through the uplift of heavier, deep-seated rocks below these arches. Wadi al Batin and Jal az Zor escarpment are well expressed in the free-air anomaly map. The Ahmadi ridge shows steep gravity gradient along its eastern flank. The gravity high near Wafra may reflect a small anticline on the west flank of the Kuwait arch.

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تركيب القشرة الأرضية القليلة العمق في الكويت
على ضوء شواذ الجاذبية

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خلاصة

يقدم تفسير خرائط بوجير لتوزيع شواذ الجاذبية معلومات جديدة عن التركيب الجيولوجي للقشرة الأرضية في الكويت والمناطق المجاورة. وقد تم اعداد خمسة قطاعات جيولوجية من نماذج مجسمة لقطاعات جاذبية (مبنية على قياسات الجاذبية في عدة مواقع) باستخدام بيانات طباقية من آبار عميقة حفرت لاستكشاف النفط، وتمتد القطاعات الجيولوجية الى أعماق تصل الى حوالي (6000)متر وتكفي هذه الأعماق لتقييم التراكيب الاقليمية الفانيروزووية في اطار النطاق تحت السطحي لكل أراضي الكويت.

وتبين القطاعات الجيولوجية الخمسة وجود تراكيب تحدبية ذات الاتجاه الشمالي أو الشمالي الغربي. ومن أمثلة هذه التراكيب الشواذ الجاذبية الايجابية المرتبطة بقوسي الكويت والدبدبة. والتي تدل على تكوين هذين التركيبين لعمليات رفع بسيطة. ولهذه التراكيب تأثير كبير على تراكم النفط في منطقة الخليج العربي.

وقد فسرت معظم قياسات بوجير لشواذ الجاذبية على أساس أنها تمثل تراكيب تحت سطحية (أقواس) ضخمة ومنخفضات محلية في شكل أحواض ترسيب صغيرة. ولم تظهر هذه القياسات اي دليل على وجود قدر كبير من شواذ الجاذبية تحت وادي الباطن، مما يفترض معه أن الوادي لم يتحكم في تكوينه تركيب جيولوجي معين أو أن الوادي قد تكون نتيجة لحدوث صدع في صخور رسوبية متماثلة او أن الفرق بين كثافتها قليل جدا.