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The origin of the Jal-Az-Zor escarpment

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ABSTRACT

The Jal-Az-Zor escarpment is the most prominent geomorphic feature northwest of Kuwait Bay. It extends about 60 km on a SW–NE trend with a maximum elevation of 135 m. Stratigraphically, the sediments of the Jal-Az-Zor escarpment area have been divided into three units which vary from sandy shale to calcareous shale and calcareous pebbly sandstone. The uppermost sequence, comprising both the Dibdibba gravels and the Holocene sediments, is considered to be a result of the most recent pluvial period which has developed several fan surfaces. These lobate fans spread out from the foot of the escarpment toward Kuwait Bay. Seismic and electric logs as well as stratigraphic techniques permit recognition of several subsurface faults of Tertiary age in the Kuwait Bay and Bahra anticline areas. Structural development of the Jal-Az-Zor area indicates that the escarpment was located structurally in Kuwait Bay during Miocene times, and has since retreated landward to its present position.

INTRODUCTION

The bedrock of Jal-Az-Zor area consists of sedimentary rocks of Oligocene to Holocene age. The regional dip of the strata is less than 1% toward the northeast (Fig. 1). Superficial deposits consist of lag gravel, talus and alluvium. Alluvial deposits of coarse sands are limited to the Wadi floors. The purpose of this study is to establish the origin of Jal-Az-Zor by interpretation of electric log results obtained from oil exploration wells.

TECTONISM AND GEOLOGICAL HISTORY

In a regional sense, Kuwait lies at the edge of the Arabian Foreland where the northeast dipping monocline passes into the geosyncline of the Arabian Gulf and the Iraq Valley (Cox 1932). The regional dip in Kuwait is to the northeast at about 2·5 m/km, which is interrupted by very gentle structures (Milton 1967) (Fig. 1).

According to Kassler (1973), 'The topography of Iran and the Iranian coastal islands is controlled by the intense folding of the Zagros Orogeny, on a NW–SE to E–W trend' (Fig. 2). This unstable Iranian area to the east and northeast of Kuwait constitutes a major Tertiary fold belt (Lees & Falcon 1952). On the other side, to the west of Kuwait, is the relatively stable Arabian Foreland flanking the Pre-Cambrian Arabian Shield (Lees 1948). The interaction of the Arabian and the Zagros folds is

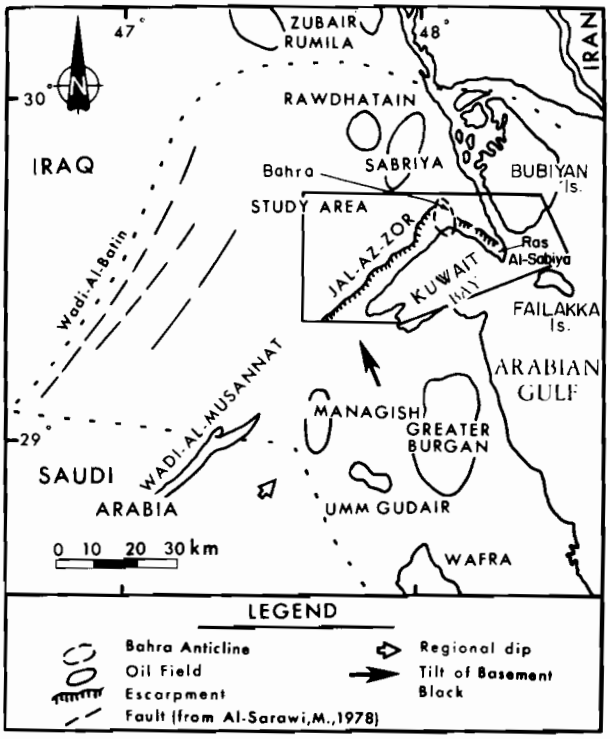

Fig. 1. Simplified structural map of Kuwait, showing the regional dip, major oil fields and Bahra anticline (after Salman (1979) and Al-Sarawi (1978)).

apparent in the submarine topography of the Arabian Gulf (Kassler 1973), as well as in the subsurface of Kuwait, i.e. Wadi Al-Batin (Al-Sarawi 1978, 1980b) (Fig. 1). Milton (1967) related the subsurface structure of Kuwait to tangential movements in post-Eocene time.

The main structural features of Kuwait are the large anticlines of the Great Burgan Oil Field and other oil fields such as Minagish, Ahmadi, Bahra, Sabriya, and Rawdhatain (Davies 1965) (Fig. 1). The anticlines have a N–S and NE–SW orientation and, according to Kassler (1973), these anticlines are thought to be the result of growth structures and salt diapiric movement (Al-Sarawi 1980a). Fox (1959) related the origin of the Great Burgan Oil Field and Magwa to an uplift during Cretaceous time.

JAL-AZ-ZOR AND BAHRA AREA

The Jal-Az-Zor escarpment lies a few kilometres inland from the northwest and north shore of Kuwait Bay. This escarpment, which exposes a sequence of sand and gravel, is Oligocene–Holocene in age (Fig. 3) and has two remarkable straight crests: (1) N 40° E direction from Al-Atraf to about the centre of the north shore of Kuwait Bay, and (2) N 35° W direction from Ras-Al-Sabiyah to Bahra anticline (Fig. 1).

The local structural feature in the area, which may be readily defined by surface observation, is the Bahra anticline (Fig. 1). It is a symmetrical plunging anticline

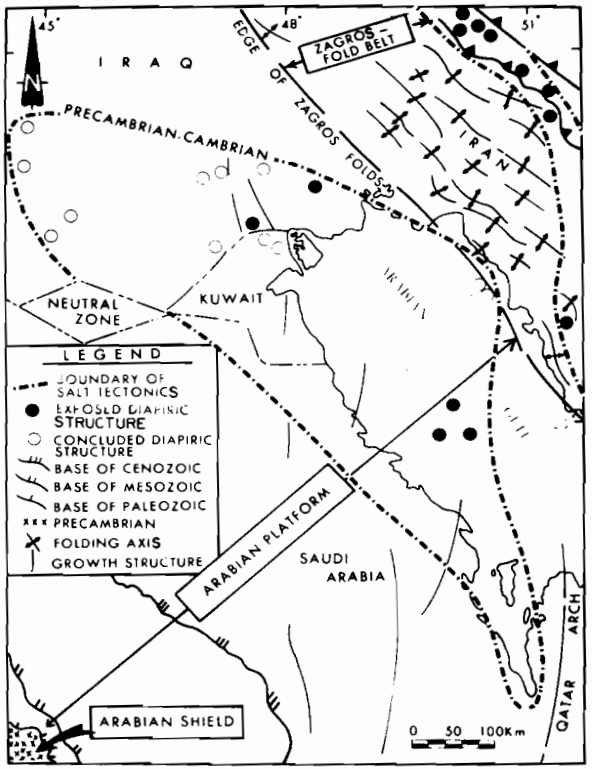

Fig. 2. Simplified regional tectonic map of the Arabian Gulf and the northeastern Arabian Peninsula (after Brown (1972), and Salman (1979)).

exposed only in its northern part. The Bahra anticline area lies on a structural trend connecting Greater Burgan–Magwa–Ahmadi to Sabriya, which is considered to be a part of the Kuwait arch (Fritz 1968). The beds cropping out over the Bahra anticline are partly covered by the outwash from the Jal-Az-Zor escarpment. The escarpment has been separated into two parts due to the intervening domal structure of Bahra anticline. The western part of the escarpment has a NE–SW orientation and extends for 50 km while the eastern part of the escarpment has a NW–SE orientation and extends for 30 km (Figs 1 and 4).

The origin of Jal-Az-Zor escarpment is still one of the unknown geological phenomena in the State of Kuwait. The following section is a synopsis of the varying theories and hypotheses regarding this origin.

Cox (1932) and Cox & Rhodes (1935) studied the superficial morphology but came to no conclusion regarding the origin of the Jal-Az-Zor escarpment. Higginbottom (1954) and Owen & Nasr (1958) considered the Jal-Az-Zor trend and its bold topographic relief to be suggestive of a faulting origin. Milton (1967) considered the escarpment to be possibly a mere erosional feature because no indications of a tectonic origin have been found in oil wells in the Bahra area. Fuchs *et al.* (1968) considered the northeastern course of the escarpment to be a continuation of the structural element of the Wadi-Musannat, the latter having a roughly parallel trend to the topographically

more impressive Wadi Al-Batin. Davies (1965) stated that 'the Jal Az-Zor escarpment and Kuwait Bay have resulted from river action and wave action against a flexure over the Central Kuwait Wrench faults'. Davies also added that 'the coastal displacement created a breach for wave erosion to take place while the western part of the escarpment was cut by stream action'. Al-Asfour (1975) related the origin of the escarpment to fluvial action and the lowermost terraces within the lower part of the section to tectonic uplift. On the basis of geophysical studies in the southwest part of the escarpment, Khalafalla (1977) interpreted the escarpment as a fault line. Salman (1979) referred the origin of the escarpment to Plio-Pliostocene faulting. His conclusion was based on the general geological setting and stratigraphical point of view and not on geophysical studies or subsurface data analysis. The present work, however, is based on the interpretation of electric logs from drilled oil wells in the area.

INTERPRETATION OF ELECTRIC LOGS

Four cross sections were studied in order to provide a clear picture of the subsurface features and the fault system along Jal-Az-Zor, the Bahra anticline and Kuwait Bay. Most correlations were based on resistivity logs obtained from geophysical surveys of the wells of the area between 1956 and 1974 by the Kuwait Oil Company (K.O.C.). The purpose of studying these logs was to determine if faults occur near and parallel to the Jal-Az-Zor escarpment. For this purpose, the most recent formations within the escarpment itself were studied.

The stratigraphic units within each log start from the Recent outcrop and extend down to Early Eocene. The Kuwait Group, which is composed of sand and gravels with occasional calcareous shale beds, represents a fluvial environment in the Pleistocene–Oligocene (Fig. 3). The Dammam Formation, which has three distinctive horizons, cherty limestone at the top underlain by a calcareous shale unit in the middle

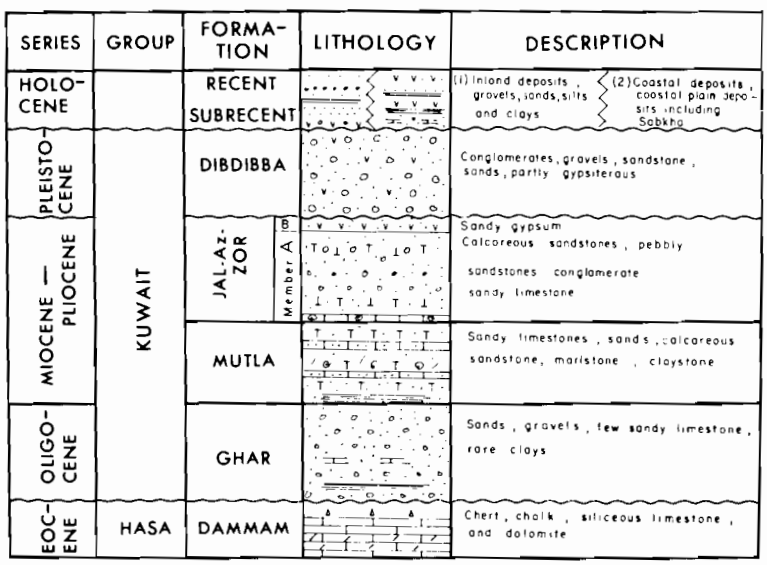

Fig. 3. Stratigraphy of the superficial deposits in Kuwait and the study area (after Salman (1979)).

and a dolomitic limestone at the base, is Middle Eocene in age. The Eocene limestone succession is an upper marine limestone series lying between the Pleistocene–Oligocene Kuwait Group and the Eocene Rus Anhydrite (Stephens 1958). The Rus Formation consists of anhydrite and calcareous shale at the base which represents shallow marine and supratidal environment. It is Early to Middle Eocene in age (Milton 1967).

The Radhumah Formation consists of limestone, mostly marly, with subsidiary recrystallised and dolomitised limestone with thin anhydrite units (Owen & Nasr 1958). The top of this formation lies at the top of the first limestone or dolomite below the anhydrite of the Rus Formation. It is Early Eocene in age (Humphreys 1965).

CROSS SECTIONS

Cross-section (1)—The data for Cross-section (1) (Fig. 4) were obtained from the Bahra Oil Field Wells Ba-2, Ba-6, Ba-4, Ba-5, and Fl-1 (Fig. 5). The major fault, as shown in Fig. 5, runs between Oil Wells Ba-5 and Fl-1 and has a NE–SW trend. The fault within Cross-section (1) shows a displacement of 50 m at the Dammam Formation level, and the displacement increases toward the base of the section. The fault line was delineated utilising the difference in thickness of the formation on both

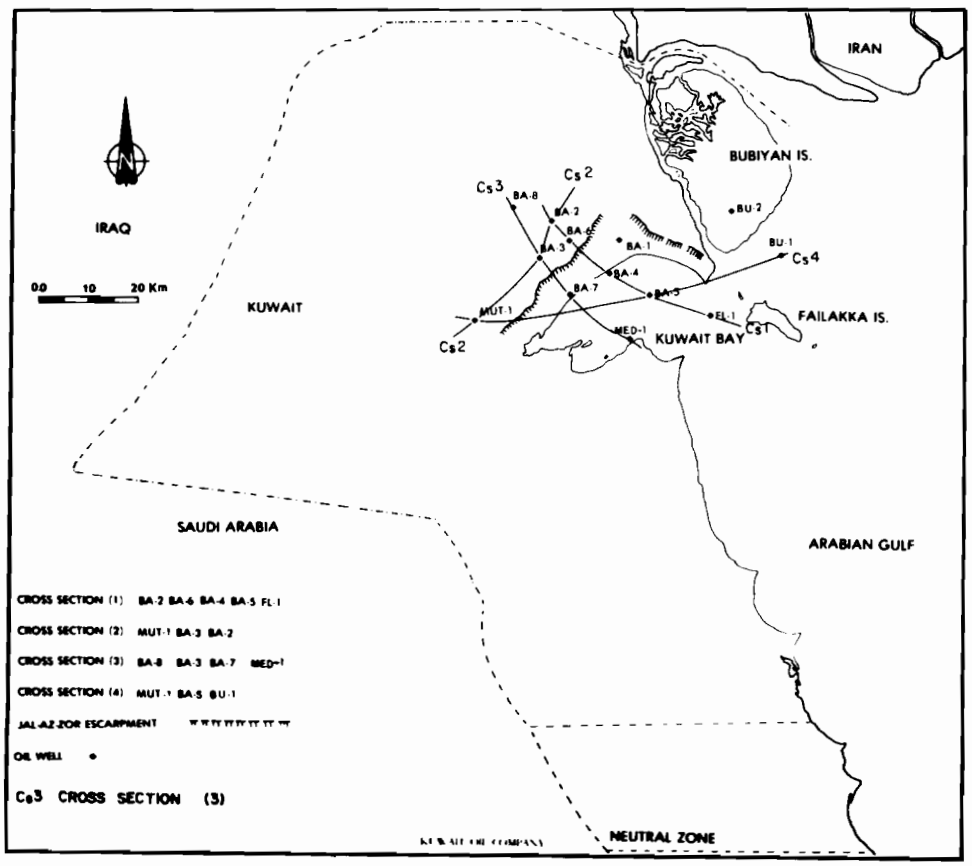

Fig. 4. Location map of the oil wells and interpretation of cross sections (after Kuwait Oil Company).

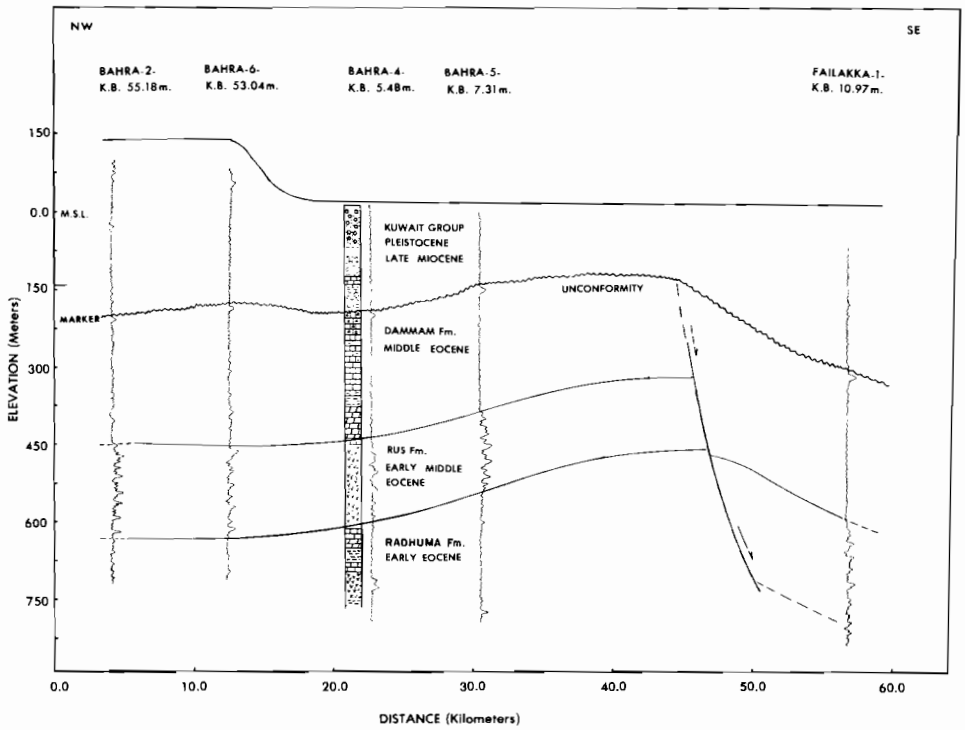

Fig. 5. Cross-section (1), showing no evidence of a fault line at the foot of the Jal-Az-Zor escarpment, i.e. the fault line is found in Kuwait Bay between Oil Wells Ba-5 and Fl-1.

sides of the fault. The fault is believed to be a growth fault. The regional dip of the beds is toward the northeast and east but, due to the influence of the fault which runs between Oil Wells Ba-5 and Fl-1, the dip in that particular area shows a reversal in direction. The fault system in this cross-section is located in Kuwait Bay. Nothing denoting faulting occurs within the foot of the escarpment, i.e. the formations correlate well in that area.

The fault, which is believed by Davies (1965) to have originated during Late Jurassic–Early Lower Cretaceous time and its subsequent history, compares with that of the Ghawer Structure in Saudi Arabia. But whether this fault has affected the Miocene beds and the younger sediments is still obscure, as there were insufficient geophysical data to base conclusions on. On the other hand, the electric log correlations do not show any evidence of movement within the Miocene and younger rock.

Cross-section (2)—This cross-section runs parallel to and westwards from the escarpment (Fig. 4). The oil wells studied within Cross-section (2) were Mut-1, Ba-3 and Ba-2 (Fig. 6). They do not show any sign of faulting, and the formation correlation runs laterally and very homogeneously from one well to the other.

Cross-section (3)—This cross-section is perpendicular in direction to the trend of the western escarpment, and runs in a NW–SE direction starting from the top of the

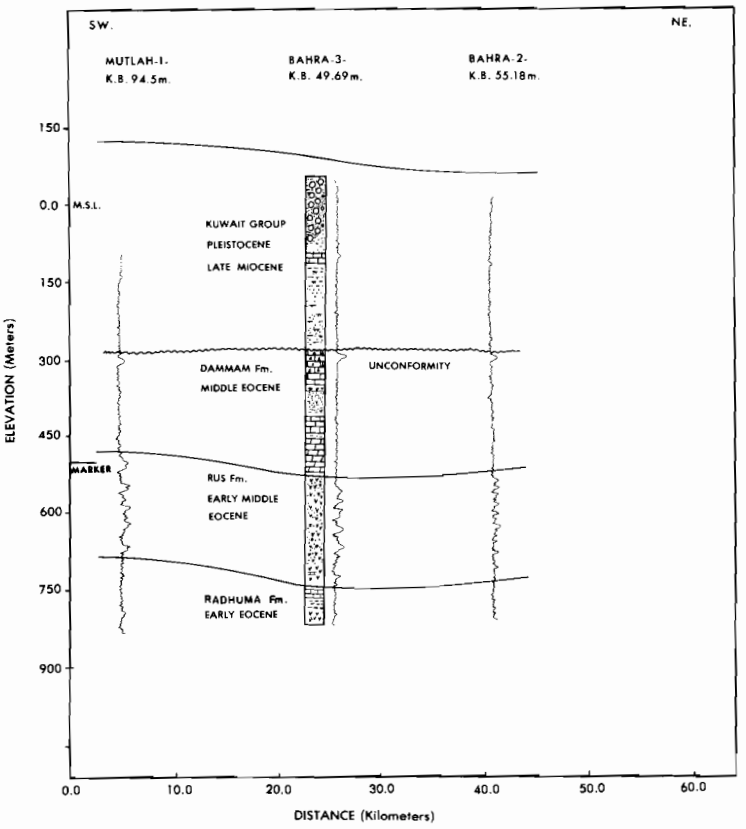

Fig. 6. Cross-section (2), showing no evidence of movement, i.e. the beds show homogeneity and good correlation.

escarpment and extending offshore into Kuwait Bay (Fig. 4). The data for this cross-section were obtained from Oil Wells Ba-8, Ba-3, Ba-7, and Med-1 (Fig. 7). This cross-section has strengthened the evidence for a morphological origin of the escarpment, in that it shows no sign of any movement at the foot of the escarpment. On the other hand, the interpretation shows the presence of a fault running in a NW–SW direction offshore in Kuwait Bay between Oil Wells Ba-7 and Med-1. The fault runs almost parallel to the orientation of the scarpment. This fault too is believed to be a growth fault, i.e. it shows an increase in thickness on the downthrown side of the fault line. The displacement within the fault is 50–70 m.

Cross-section (4)—This cross-section runs oblique to the two portions of the escarpment (Fig. 4) from Oil Well Mut-1, into Kuwait Bay through Ba-5 and Bu-1 (Fig. 8). The interpreted fault line is located offshore in Kuwait Bay between Oil Wells Ba-5 and Bu-1 and has a NE–SW orientation and the displacement is 50 m. It appears to be the same fault as that recorded in Cross-section (1). No movement was recorded from the foot of the escarpment. This cross-section might prove that Failakka Island was a part of the Jal-Az-Zor escarpment trend and, later in Eocene time, became

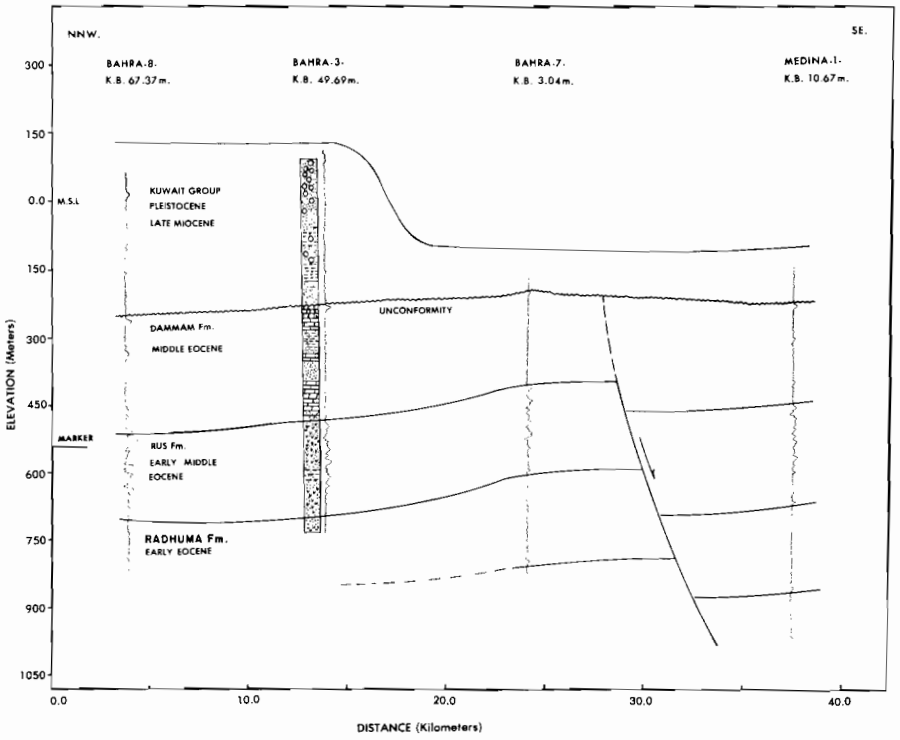

Fig. 7. Cross-section (3). The fault line is located between Oil Wells Ba-7 and Med-1, with a 50–70 m displacement which increases downward.

separated by a fault line. This fault is also believed to be a growth fault, and shows an increase in bed thickness on the downthrown side.

STRUCTURAL MAP OF THE AREA

The structure map of the Jal-Az-Zor area is based on the correlation of the electric logs which were recorded in the oil wells of the area. The two faults (Fig. 9) which were recorded by these logs are *en echelon* and are located beneath Kuwait Bay. They show a downward movement of 50–70 m and are interpreted as growth faults, with an increase in thickness on the downthrown side. The movement along the faults occurred during the Eocene.

GROWTH FAULTS

Deposition of the Dammam Limestone Formation was closely linked to movements along the growth faults which controlled the pattern of drastic northeasterly thickening of three formations from Early Eocene up to Middle Eocene. The Rus Anhydrite Formation shows an increase in thickness from 150 m to 250 m over a distance of less than 17 km. Cossey & Ehrlich (1977) showed six well-exposed growth faults in the Jurassic of northern Tunisia spaced as close as 300 m over a distance of 1·5

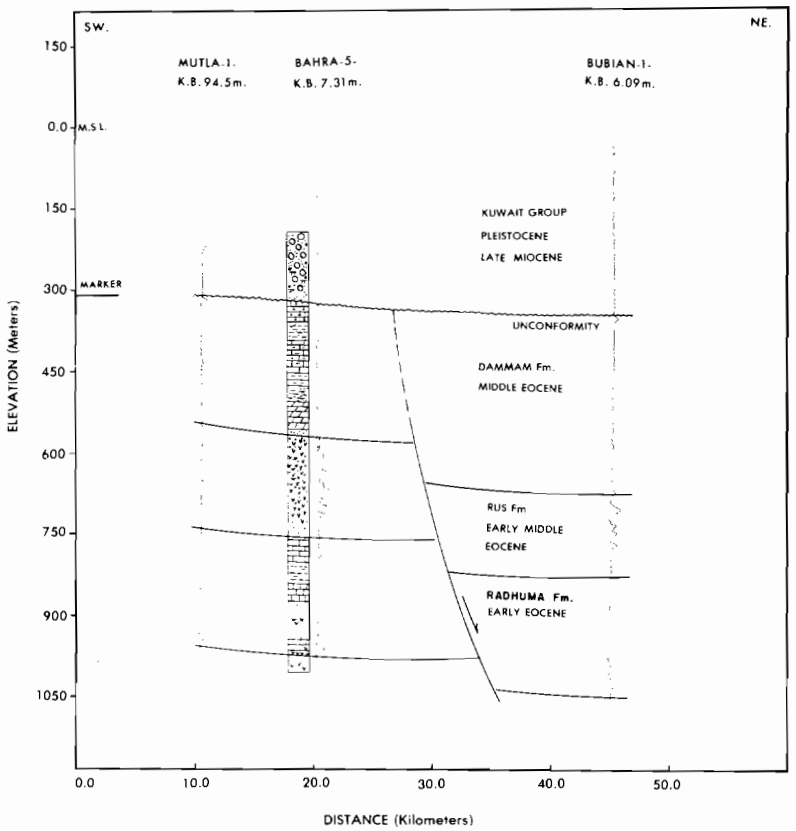

Fig. 8. Cross-section (4). The fault line is located between Ba-5 and Bu-1, with a 50–70 m displacement which increases downward.

km. An ancient example of another well-exposed growth fault is the Triassic of Svalbard (Edwards 1976) which shows nine growth faults in a distance of 4 km.

CONCLUSIONS

Based on electrical logs and seismic sections, two *en echelon* fault lines from 10 to 20 km to the east and southeast of the main western Jal-Az-Zor escarpment were mapped within Kuwait Bay. The fault lines are Middle Eocene in age and run parallel to the present western escarpment with a NE–SW orientation. The existence of vertical fractures within the present Jal-Az-Zor escarpment provides avenues for water infiltration, bedrock dissection and gradual retreat of the front of the escarpment. From the subsurface studies it appears that the present status of the escarpment is an erosional feature, while its origin may have been initiated by growth faults in Kuwait Bay.

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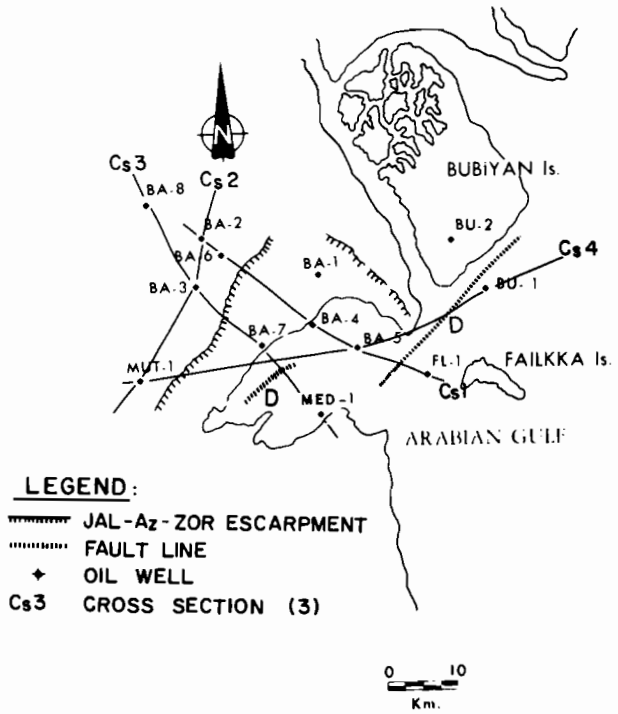

Fig. 9. Map of Jal-Az-Zor and the adjacent area, showing the position of the two faults based on interpretation of the electric logs.

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REFERENCES

Al-Asfour, T.A. 1975. Changing sea-level along the north coast of Kuwait Bay. Unpubl. Ph.D. thesis, University of Durham, England, 310 pp.

Al-Sarawi, M. 1978. Geomorphology and general geology of Wadi Al-Batin, Kuwait. Unpubl. M.Sc. thesis, Ohio University, U.S.A., 88 pp.

Al-Sarawi, M. 1980a. Morphology of Jal-Az-Zor escarpment and Holocene–Pleistocene sedimentation along the Northern Kuwait Bay. Unpubl. Ph.D. thesis, University of South Carolina, U.S.A., 170 pp.

Al-Sarawi, M. 1980b. Tertiary faulting beneath Wadi Al-Batin. Kuwait. Geol. Soc. Am. Bull. **91:** 610–18.

Brown, G. 1972. Tectonic map of the Arabian Peninsula. Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, Map AP2.

Cossey, S.P.J. & Ehrlich, R. 1977. Growth fault-controlled submarine carbonate debris flow and turbidiate deposits from the Jurassic of Northern Tunisia—possible canyon fill sequences. In **Stanley, D.J. & Kelling, G. (Eds).** Submarine canyon, fan and trench sedimentation. Soc. Econ. Paleont. Mineral. Symp. Stroudsburg, Pennsylvania, U.S.A.

Cox, P.T. 1932. A report on the oil prospects of Kuwait Territory. In: The First Kuwait Oil Concession—A record of the negotiations 1911–1934. Ministry of Information, Kuwait, 1975, pp. 143–55.

Cox, P.T. & Rhodes, R.D. 1935. A report on the geology and oil prospects of Kuwait Territory. Kuwait Oil Company (unpubl.), 34 pp.

Davies, C.C.S. 1965. The Post Jurassic tectonic history of Kuwait and vicinity. Kuwait Oil Company, KR-11 (unpubl.), 34 pp.

Edwards, B. 1976. Growth faults in Upper Jurassic deltaic sediments, Svalbard. Am. Assoc. Pet. Geol. Bull. **6:** 341–55.

Fox, R.L. 1959. Some problems of petroleum geology in Kuwait. J. Inst. Petroleum **45:** 95–110.

Fritz, D.C. 1968. A review of the Bahra area. Kuwait Oil Company, KR-16 (unpubl.), 6 pp.

Fuchs, W., Gattinger, T.E. & Holzer, H.F. 1968. Explanatory text to the synoptic geologic map of Kuwait. Geol. Surv. Austria, Vienna, 87 pp.

Higginbottom, I.E. 1954. Report on the surface geology of Kuwait with reference to the natural resources of building material. Ministry of Public Works, Kuwait (unpubl.).

Humphreys, A. 1965. Kuwait stratigraphy from the known to the unknown, with comments on undeveloped oil potential. Kuwait Oil Company (unpubl.), 41 pp.

Kassler, P. 1973. The structural and geomorphic evolution of the Persian Gulf. In **Purser, B.H. (Ed.).** The Persian Gulf, pp. 11–32. Springer-Verlag.

Khalafalla, M.N. 1977. Applicability of the electrical resistivity method for ground water research and prospection in Kuwait. Unpubl. M.Sc. thesis, Kuwait University, 195 pp.

Less, G.M. 1948. The physical geography of Southeast Arabia. Geogr. J. **121:** 141–5.

Lees, G.M. & Falcon, N.L. 1952. The geographical history of the Mesopotamian plains. Geogr. J. **116:** 125–30.

Milton, D.I. 1967. Geology of the Arabian Peninsula, Kuwait. U.S. Geol. Survey, Prof. Paper 560-F, 7 pp.

Owen, R.M. & Nasr, S.W. 1958. Stratigraphy of Kuwait-Basra area. In: Habitat of Oil Symposium, Am. Assoc. Pet. Geol., pp. 1252–78.

Salman, A.M.S. 1979. Geology of Jal-Az-Zor–Al-Liyah area, Kuwait. Unpubl. M.Sc. thesis, Kuwait University, 128 pp.

Stephens, R.J.L. 1958. Notes on formation boundaries and marks. Geological Division, Kuwait Oil Company (unpubl.).

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أصل مرتفعات جال الزور ، الكويت

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خلاصة

الغرض من هذا البحث هو دراسة أصل منطقة جال الزور في الكويت وكيفية تكوينها . تقع مرتفعات جال الزور في الشمال الغربي لخليج (جون) الكويت حيث تمتد لمسافة ٦٠ كم باتجاه شمال شرقي ، ويبلغ أقصى ارتفاع لها ١٣٥ مترا فوق سطح البحر .

ويمكن تمييز الرسوبيات إلى طفل رملي ، وطفل جيري ، وصخر رملي حصوي جيري ، وتغطى مرتفعات جال الزور برسوبيات من الحصى والجلاميد ذات الأصل الناري والتي جرفتها السيول من الدرع العربي في شبه الجزيرة العربية في العصور المطيرة .

وقد دلت المضاهاة لنتائج الدراسات الزلزالية والكهربائية العميقة لمنطقة جال الزور على وجود فالق في خليج (جون) الكويت من عصر الميوسين ولم تظهر الدراسات الجيولوجية أي دلائل على تحركات تكتونية تحت منطقة جال الزور في الوضع الحالي .

ولهذا فإن الباحث يرجع التكوين الحالي لجال الزور إلى عوامل طبيعية نحتية أساسها فالق في خليج (جون) الكويت .