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Preliminary Geologic Map of the Turayf Quadrangle, Sheet 31C, and part of the An Nabk Quadrangle, Sheet 31B Kingdom of Saudi Arabia

by

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PRELIMINARY GEOLOGIC MAP OF THE TURAYF QUADRANGLE, SHEET 31 C, AND PART OF THE AN NABK QUADRANGLE, SHEET 31 B, KINGDOM OF SAUDI ARABIA

BY

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ABSTRACT

The An Nabk and Turayf quadrangles lie at the northern border of the Kingdom of Saudi Arabia. Middle and upper Cenozoic sedimentary and volcanic rocks form the surface of the quadrangles, and sedimentary rocks of the Paleozoic, Mesozoic, and lower Cenozoic are found in the subsurface. The Paleozoic and Mesozoic rocks, described from drill hole records, include the Tabuk, Upper Sudair, Lower Jilh and Aruma formations which are mostly of marine origin.

The map area is part of the Sirhan-Turayf Basin and contains the Thaniyat, Ghina, and Arqah Phosphorite members of the Upper Cretaceous-Tertiary Turayf group. Only the Arqah Phosphorite, the uppermost of the three members, crops out at the surface. From its outcrop along the east border of the area, the Arqah dips westward into the subsurface and passes into an argillaceous deeper water facies. The Thaniyat and Ghina also dip westward in the subsurface and pinch out into a deeper water facies.

Upper Eocene calcareous claystone and chalk mapped in the Wadi As Sirhan depression on the west side of the map area are named the Rashrashiyah formation, and may be partly equivalent to Eocene bioclastic, chert-bearing carbonate rocks of the Turayf group mapped to the east.

The Sirhan formation is a new name for rocks of Miocene(?) age occurring in the Wadi As Sirhan area. These rocks are mostly sandstone of probable continental origin, and contain thin beds of fresh water limestone. However, marine limestone beds also occur, indicating periodic incursions by the sea.

Al Harrah, a large Quaternary-Tertiary basalt field in the Sirhan-Turayf Basin, occupies the central part of the map area. The flows consist of silicic alkali olivine basalt, typical of the Cenozoic lava flows of Saudi Arabia. Volcanism appears to be of the continental rift-type and is related to Red Sea rifting.

Quaternary calcareous and gypsiferous duricrust is found discontinuously throughout the western part of the map area. At one time it apparently formed a carapace-like cover over all surface rocks, and indicates a much wetter in northern Saudi Arabia than the present climate.

The Arqah Phosphorite member is exposed in the northeast corner of the map area and contains thin beds of phosphorite grading from 18 to 30 percent P_2O_5.

Oil shows have been reported in Cretaceous rocks of the Wadi As Sirhan depression, and oil has been discovered recently nearby in Jordan. Geologic and geophysical conditions are favorable for the entrapment of oil in the Wadi As Sirhan area and additional exploration is recommended.

INTRODUCTION

LOCATION

The Turayf 1:250,000-scale quadrangle, sheet 31 C, and part of the An Nabk 1:250,000-scale quadrangle, sheet, 31 B, are in northwestern Saudi Arabia, about 1100 km north of Jeddah. The quadrangles lie between lat 31°00' and 32°00' N. and long 37°00' and 39°00' E., and include the north and west border of Saudi Arabia with Jordan (fig. 1).

The dominant topographic features in the area are the ancient lava flows and volcanic cones (Al Harrah) that occupy all of the central part of the area. The highest volcanic cone, Jabal Liss, has an elevation of 1128 m. Most of northeastern part of the area consists of desert plains (Al Hamad) with intermittently wet flats (sabkhahs) and stream beds (wadis). Wadi As Sirhan is a broad, elongate trough along the western side of the map area adjacent to Jordan.

Large towns include Turayf on the Trans-Arabian Pipeline and highway in the northeastern part of the area and An Nabk (Qurayyat) in Wadi As Sirhan in the northwestern part. The village of Al Hadithah is in the extreme northwestern corner of Saudi Arabia, is about 8 km from the Jordanian border. Wadi As Sirhan also contains a few small agricultural settlements near oases.

PREVIOUS INVESTIGATIONS

Bramkamp and others (1963) mapped the geology of the area at 1:500,000 scale. The sedimentary geology of the region is described by Powers and others (1966) in a report that encompasses the sedimentary geology of Saudi Arabia. Several reports on the geology of Jordan pertain to adjacent areas in Saudi Arabia, especially in the vicinity of Wadi As Sirhan. These reports include Quennell (1951, 1958), Gardner (1955), McKelvey (1959), Burdon and Quennell (1959), and Bender (1974, 1975).

Sheldon (1967) discovered phosphate rock in the Al Hamad plains just east of the Turayf quadrangle, and initial geologic reconnaissance for phosphate deposits was undertaken by Mytton (1966), and Meissner and Ankary (1972). In 1976, Riofinex Limited was requested by the Deputy Ministry for Mineral Resources to undertake a phosphate resource assessment of the Sirhan-Turayf region including the northeastern part of the Turayf quadrangle. Several Riofinex reports were published describing the phosphate-bearing rocks of Cretaceous and Tertiary age; These include: Futyan and Nicholson (1979), Bayliss (1981, 1983), Kluyver and others (1981), Riddler and others (1983), and Riddler and van Eck (1984). Reports by Riofinex on geologic and stratigraphic studies of the Tertiary in part of the Turayf quadrangle include Riddler and others (1984), and Aspinall and others (1985).

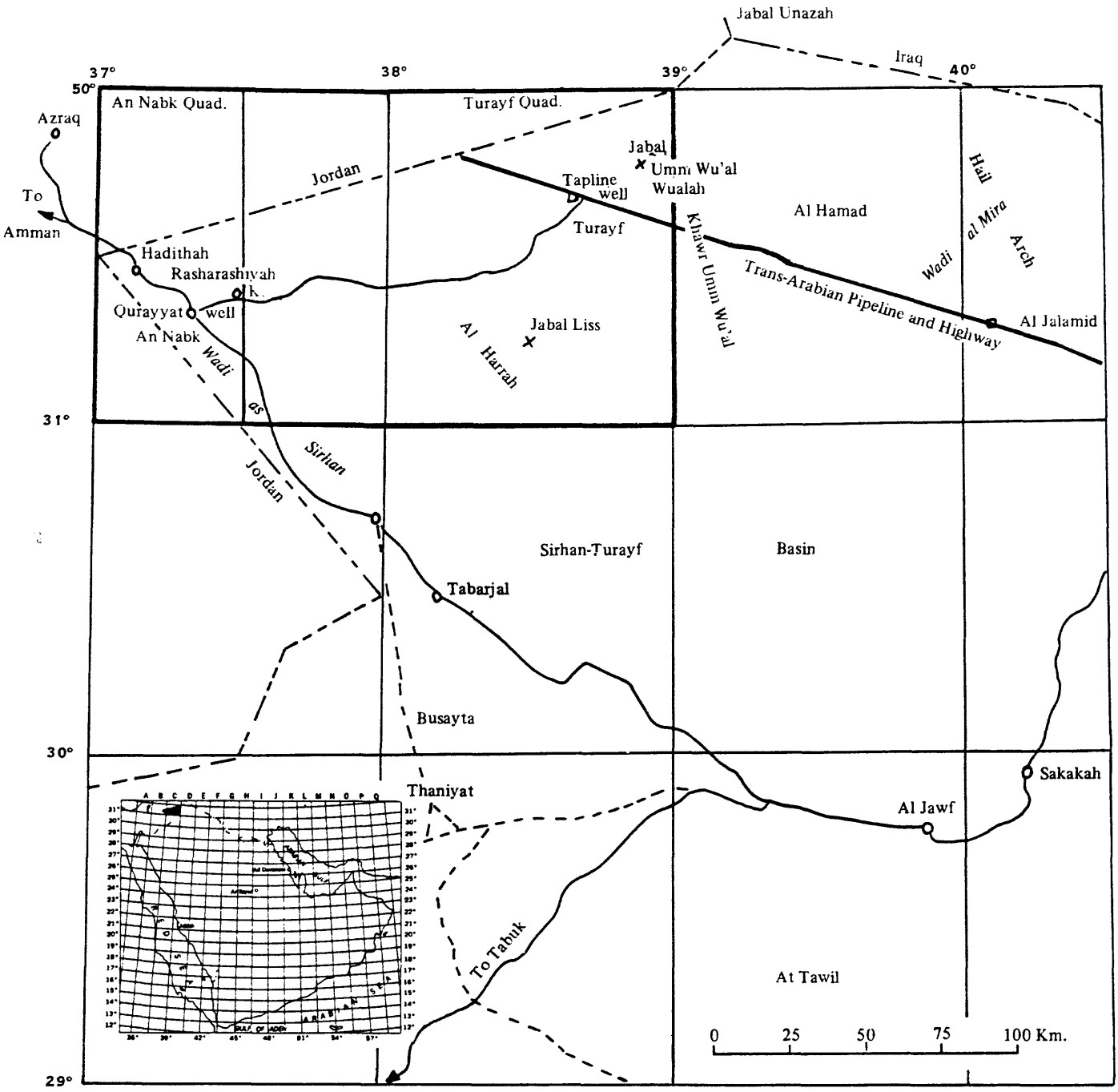

Figure 1.--Location map of the An Nabk and Turayf quadrangles and surrounding area.

PRESENT WORK

The geologic map of the Turayf and An Nabk quadrangles (pl.1) was compiled in June and July 1985, from unpublished data that included thirteen 1:50,000-scale maps produced by the Riofinex Geological Mission as part of its phosphate resource assessment; these unpublished maps are stored in Riofinex Data File RF-OF-00-05. The western part of the map area, which includes Wadi As Sirhan, was compiled from mapping by the U.S. Geological Survey conducted during October, November, and December, 1985.

The lithostratigraphic framework of the Late Cretaceous-Tertiary rocks (the Turayf group) was established by Riofinex (Riddler and others, 1984); the description of other pre-Tertiary rocks, and post-Turayf Tertiary rocks is by the U.S. Geological Survey.

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GEOLOGIC SETTING

The Turayf and An Nabk quadrangles are in the north-central part of the Sirhan-Turayf Basin of northwestern Saudi Arabia. (fig.1). The Sirhan-Turayf Basin is a complex, shallow sedimentary basin that extends north and west into Iraq and Jordan. Sedimentary rocks and surficial deposits range in age from Cambrian to Recent with a maximum thickness of at least 2300 m (Powers and others, 1966). The east side of the basin is flanked by the Hail Arch, a broad anticlinal feature that is thought to separate sedimentary rock facies of the Arabian Gulf from those of the Mediteranean Sea Basin (Powers and others, 1966, D103-104). The western part of the map area is in the Wadi As Sirhan graben complex (Regional Geologic Setting, pl. 1). Prominent lineaments are visible on Landsat imagery and aerial photographs. Those on the east side of the map area may be related to uplift and other structural movement along the Hail Arch, whereas those on the west side are probably related to movement of the Wadi As Sirhan graben. Tertiary-Quaternary volcanism produced an extensive lava field in the middle of the Sirhan-Turayf Basin and a large part of this field lies within the map area.

PHANEROZOIC SEDIMENTARY ROCKS

Surface exposures of Phanerozoic rocks in the map area include only those from the upper part of the Paleogene through Quaternary age and are described from surface mapping, outcrop sections, and some shallow drill hole data (fig. 2). Descriptions of older rocks, from Silurian to the upper part of the Paleogene, are based mostly on data from two widely spaced deep drill holes, on descriptions of similar rocks in the Turayf group mapped at the surface in the Al Hamad quadrangle (adjacent to the map area), and on geologic interpretation (fig. 2, and lithostratigraphic column and cross section A-A', pl. 1).

TAYYARAT FORMATION

The oldest rocks described in the map area are Silurian shale and sandstone penetrated in the Tapline water well (Turayf pump station) from 689 m to the total depth of the hole at 1068 m (Aramco, unpub. data). These rocks, tentatively correlated with the Tayyarat formation (St) (Vaslet, 1987), were formerly designated the middle part of the Tabuk Formation. The type locality of the Tabuk Formation (Powers, 1968) was in the vicinity of the town of Tabuk, about 300 km southwest of the map area, where the type sequence was composited from several sections totalling 1071.5 m. The age of the Tabuk at its type locality is Ordovician, Silurian, and Early Devonian.

According to the graphic log in the Tapline water well, the Silurian rocks are entirely mottled shale with a few sandy zones near the top. Possibly the shale is equivalent to the Qusaiba member of the Tayyarat formation, and the sandy zones to the Sharawrah member (Vaslet, 1987). There are no data to determine the continuity of the Silurian rocks down dip to the west. Fossils prove that much, if not all, of the rocks are marine, most likely deposited in the shallow-water nearshore and littoral-beach zone (Powers, 1968).

The contact with the Tayyarat formation with the overlying Sudair Shale is unconformable in the Turayf Tapline water well.

SUDAIR SHALE

The type section of the Sudair Shale has been pieced together from three sequences along the Al Arid escarpment between lats 19°17 '- 19°36' N. and longs 45°06' - 45°08 E. (Powers, 1968). The Sudair Shale at its type locality consists of 116 m of brick- to dark-red shale that is silty in places. It is described as Permian-Triassic in age.

The Upper Sudair (TRPs) was penetrated in the Turayf Tapline water well between 671 m - 689 m (Aramco, unpub. data). It consists of shale containing a few thin beds of limestone and dolomite and is interpreted to have been deposited in tidal flats and shallow, intermittently restricted seas (Powers, 1968). There are no data to determine its continuity west of the Tapline well, but extrapolation from structure sections constructed by Aramco (unpub. data), in the Al Hamad quadrangle to the east of the Turayf quadrangle, suggests that the Sudair pinches out toward the east edge of the map area.

The contact of the Upper Sudair with the overlying Jilh Formation is believed to be conformable.

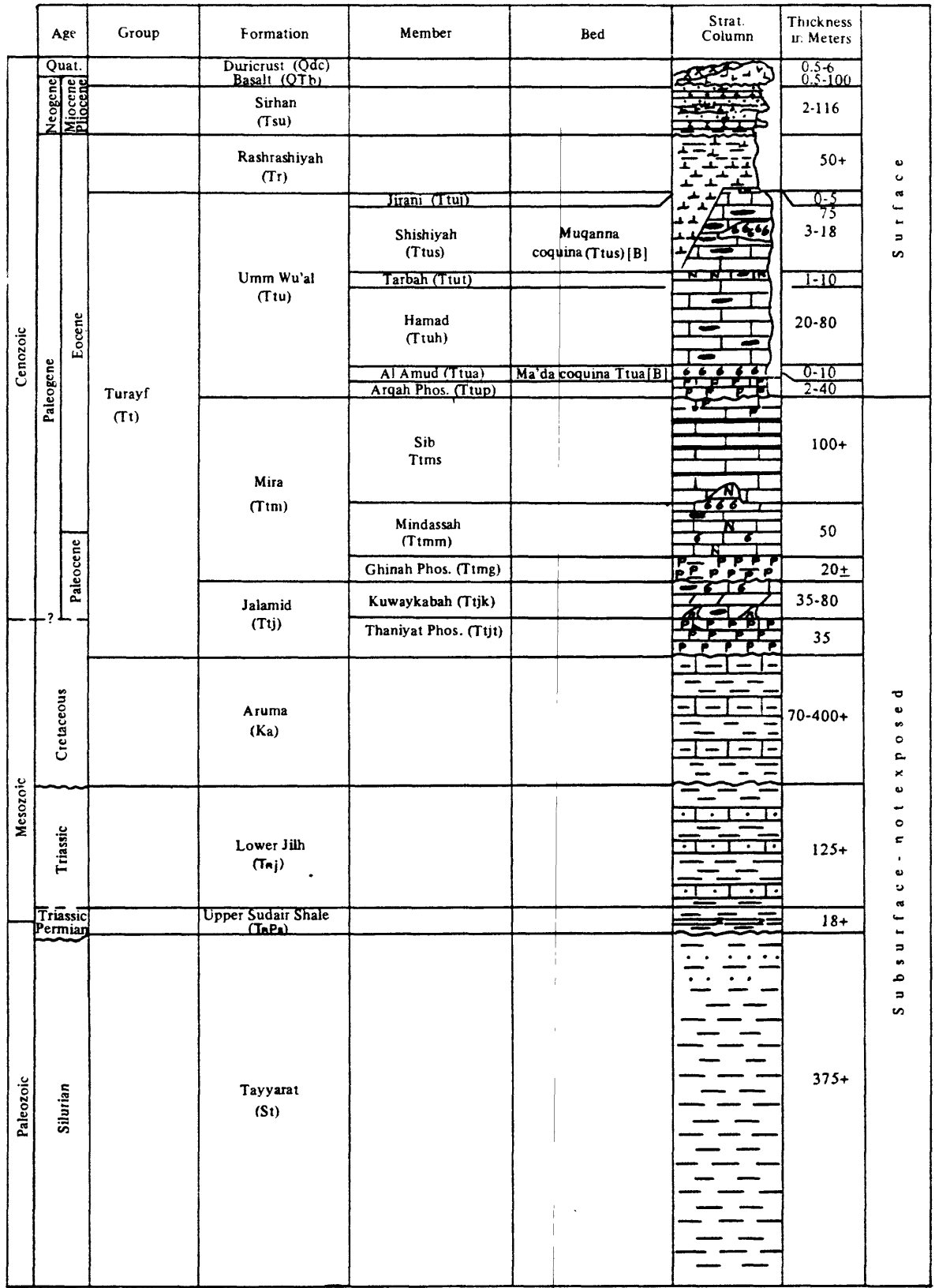

Figure 2.--Generalized stratigraphic column of rocks in the An Nabk and Turayf quadrangles.

EXPLANATION
[Figs. 2, 3, and 4]


Duricrust


Basalt


Calcareous sandstone


Shale


Calcareous claystone


Limestone


Sandy limestone


Argillaceous limestone


Stromatolitic limestone


Dolomitic limestone


Chalk


Bioclastic rock, Coquina


Nummulitic rock


Phosphatic rock, Phosphorite


Chert, nodules and lenses


Chert bedded


Chert fragments


Pebbles


Cross bedded


Bioturbated

JILH FORMATION

The type section of the Jilh Formation (TRj) is at Jilh al'Ishar from lat 24°03'48" N., long 45°46'00" E. to lat 24°11'06" N., long 45°51'30" E. (Powers, 1968). The Jilh at the type section is 326.1 m thick and consists of sandstone with interbeds of siltstone and shale and several beds of limestone. It is Early and Middle Triassic in age.

The Lower Jilh (TRj) was penetrated in the Turayf Tapline water well between 549 m - 671 m (Aramco, unpub. data) and consists of shale and sandy limestone, probably marine in origin. Continuity of the Jilh westward is unknown but, as with the underlying Upper Sudair, it is believed to pinch out eastward toward the edge of the Turayf quadrangle.

Contact with the overlying Aruma Formation is unconformable.

ARUMA FORMATION AND RELATED CRETACEOUS ROCKS

The type section of the Aruma Formation is the Al' Aramah plateau where a composite sequence was made from several sections located along a traverse from lat 25°38 12" N., long 46°22 29" E. to lat 25°39'18" N., long 46°30'41" E. (Powers, 1968). The Aruma at the type section is 141.5 m thick and consists of light colored dolomite, limestone, and calcareous shale with a few sandy layers near the base. Its is Late Cretaceous in age.

The Aruma Formation (Ka) was penetrated in the Turayf Tapline well between 478 m - 549 m (Aramco, unpub. data) and consists of limestone and shale. The Aruma, or at least rocks of Cretaceous age, apparently are continuous from east to west across the map area and thicken westward (cross section A-A', pl. 1). Cretaceous rocks (Ku) (cross section A-A', pl. 1) were penetrated in the Qurayyat water well, near the town of An Nabk, on the western side of the map area, between 908 m - 1300 m (Aramco, unpub. data). This well was later deepened to 1800 m but the rocks penetrated below 1300 m have not been identified. The Cretaceous rocks in the Qurayyat well are at least 392 m thick, or 321 m thicker than at the Turayf well. Thickening of the Cretaceous in the Qurayyat well is probably partly related to down faulting in Wadi As Sirhan.

The Cretaceous rocks in the Qurayyat well are mostly dark-brown, earthy, argillaceous limestone that, in part, grade almost to shale. Foraminifera, including "Globotruncana", identify these rocks as Late Cretaceous.

The contact with the overlying Turayf group is disconformable.

TURAYF GROUP

The Turayf group (Tt) was previously described as "limestone, chalk-marl, or crystalline cherty limestone" by Bramkamp and others (1963), as Aruma Formation and Hibr formation by Powers and others (1966) and Meissner and Ankary (1972) and, in terms of sedimentary cycles and units, by Kluyver and others (1981), and Ryder and Kluyver (1983).

The Turayf group is an informal designation used in mapping the sedimentary phosphatic carbonate succession of the Sirhan-Turayf Basin. The group ranges in age from Late Cretaceous (Maastrichtian) to Middle Eocene (Lutetian) (Riddler and others, 1984), and is subdivided into three formations; the Jalamid, the Mira, and the Umm Wu'al, in ascending order (fig. 2).

The Turayf Tapline well penetrated rocks of Paleocene-Eocene age from the surface to 478 m (El-Khayal, 1974; Aramco, unpub. data). This interval contains the Turayf group, although this term was not in use at the time the well was drilled. Subdivisions of the Turayf group, as shown in cross section A-A' (pl. 1), are based partly on surface mapping of rocks exposed in the Turayf quadrangle (Aspinall and others, 1985), and partly on extrapolation of mapping and subsurface work by Riddler and others (1984, 1985), mainly in the adjacent Al Hamad quadrangle.

Jalamid Formation

The Jalamid formation (Ttj) takes its name from outcrops around the Al Jalamid pump station in the Al Hamad quadrangle, about 100 km east of the map area. The formation is not exposed in the map area, but is estimated to be from 70 to 115 m thick in the subsurface along the eastern side of the Turayf quadrangle. It is subdivided into two members, the Thaniyat Phosphorite and Kuwaykabah.

Thaniyat phosphorite member: The Thaniyat Phosphorite member (Ttjt) is estimated to be about 35 m thick in the area. It dips gently westward until passing into a deeper water facies towards Wadi As Sirhan. Depth of the member, or its equivalent, at the Turayf Tapline well is estimated to be about 440 m. Here it consists of interbedded shale, limestone, and chert; no phosphorite was identified. Paleocene foraminifera have been identified in the Thaniyat interval of the Tapline well (Aramco, unpub. data) and the basal part has an inferred Maestrichtian age for the Thaniyat in the Al Hamad quadrangle to the east and at Thaniyat escarpment (Bayliss, 1983; Capetta and Riddler, 1985).

Kuwaykabah member: The Kuwaykabah member (Ttjk) ranges in thickness from 35 to more than 80 m. It dips gently basinward to the west and may thicken at the expense of the Thaniyat Phosphorite member and the thin overlying beds of the Mira formation. Depth of the member at the Turayf Tapline well is estimated to be about 370 m. The Kuwaykabah in the Al Hamad quadrangle to the east of the map area is described as a buff to off-white, cherty, dolomitic limestone (Riddler and others, 1985) that is similar to the upper third of the member in the Tapline well; however, the remainder of the section is shale that suggests a deeper water facies. Paleocene foraminifera have been identified in the lower part of the Kuwaykabah interval of the Tapline well.

The Kuwaykabah is disconformable with the overlying Ghinah Phosphorite member of the Mira formation.

Mira formation

The Mira formation (Ttm), not exposed in the map area, takes its name from Wadi al Mira that traverses the formation in the Al Hamad quadrangle about 70 km east of the Turayf quadrangle. It is divided into four members, in ascending order, the Ghinah phosphorite, and the Hawsa, Mindassah, and Sib members, of which the Hawsa is absent in the map area. The formation is estimated to be 175 m thick in the subsurface along the eastern side of the Turayf quadrangle, and dips gently to the west.

Age determinations on diagnostic dynophyte cysts from shales in the Ghinah Phosphorite member to the south of the map area indicate a Late Paleocene to Early Eocene age for the formation.

Ghina Phosphorite member: The Ghina phosphorite member (Ttmg) is estimated to be "topped" at a depth of 350 m in the Turayf Tapline well, where the well log shows dolomitic limestone and chert. No phosphorite was recognized in the drill hole. The Ghinah probably pinches out westward into a deeper-water facies, and may become a part of an expanded Kuwaykabah member of the Jalamid Formation.

Mindassah member: The Mindassah member (Ttmm) is estimated to be at a depth of 300 m in the Turayf Tapline well, where the log shows limestone and chert. Outcrop of the Mindassah, in the Al Hamad quadrangle about 65 km to the east, is a nummulitic, bioclastic limestone and coquina, and is described as traceable downdip to the west for about 50 km from drillhole data. The Mindassah in the Turayf quadrangle is much less bioclastic than that in the Al Hamad quadrangle, because it was deposited in deeper water. The member probably grades laterally into the expanded Kuwaykabah member of the Jalamid formation west of the Tapline well.

Sib member: The Sib member (Ttms) was intersected in three drill holes within the Turayf quadrangle along the western end of Riofinex line 260N (Riddler and others, 1984, figs. 5 and 12). This line runs east-west a few kilometers south of the town of Turayf. Depth to the top of the Sib in the three drill holes ranges from near the surface along the east border of the Turayf quadrangle to more than a 100 m at a distance of 30 km down dip to the west.

The Sib consists of white to pale-gray, friable, medium bedded carbonate rocks with thin bands of silicified limestone and chert that becomes more argillaceous west of the town of Turayf indicating deeper-water facies. Its thickness where intersected in drill holes is 100 m and more.

The contact of the Sib with the overlying Umm Wu'al formation is disconformable.

Umm Wu'al formation

The Umm Wu'al formation takes its name from Khawr Umm Wu'al located along the western side of the Al Hamad quadrangle to the east of the Turayf quadrangle. It is the only part of the Turayf group that is exposed in the map area. The formation is divided into six informal members that are, in ascending order, the Arqah Phosphorite member, and the Al Amud, the Hamad, the Tarbah, the Shihiyah, and the Jirani members. The formation dips gently to the west, and its thickness ranges from 38 to 220 m.

Benthic and planktonic foraminifera have been identified locally indicating a Middle Eocene age for the formation (Riddler and others, 1985). The Umm Wu'al was deposited in an inner shelf subtidal to restricted shelf environment that became a more open shelf to the west.

Arqah Phosphorite member: The Arqah Phosphorite member (Ttup) crops out in the extreme northeast corner of the map area, along the west side of the Khawr umm Wu'al graben. This member consists of off-white to gray, interbedded, finely crystalline limestone, bioclastic limestone, phosphatic chert, and pelletal carbonate-cemented, semi-friable to friable phosphorites. It ranges in thickness from 2 to 40 m, and thickens steadily down dip to the west where argillaceous carbonates indicate deeper-water facies. There, its sparse and disseminated phosphorite content makes it virtually indistinguishable from the enclosing Sib member of the Mira formation and the Hamad member of the Umm Wu'al formation (Riddler and others, 1984).

The Arqah Phosphorite member is conformable with the overlying Ma'da coquina bed of the Al Amud member.

Al Amud member: Only one of the subdivisions of the Al Amud member, known as the Ma'da coquina bed (Ttua [B]), is present in the map area. It crops out in the extreme northeastern corner of the area where it is about 10 m thick, and, according to drill-hole data, pinches out in the subsurface at an estimated distance of about 15 km down dip to the west (Riddler and others, 1984, fig. 12).

The Ma'da coquina bed consists mainly of fine bivalve debris set in a calcitic matrix. The bed contains a nummulitic layer near its top in most places, with nummulites 1- to 1.5-cm in diameter.

The bed is conformable with the overlying Hamad member.

Hamad member: The Hamad member (Ttuh) crops out in the northeastern part of the map area. It consists of well-bedded, white to cream-colored, finely crystalline, slightly siliceous limestone, interbedded with chert lenses and bands. Down dip to the west of its outcrop area, the Hamad undergoes a change to deeper-water facies, becoming more argillaceous; it is dominated by limestone, and is indistinguishable from the Arqah Phosphorite member and the Sib member of the Mira formation. The Hamad member ranges in thickness from 20 to 80 m.

The Hamad member is conformable with the overlying Tarbah member.

Tarbah member: The Tarbah member (Ttut) forms a narrow, northwest-trending outcrop in the northeastern corner of the map area that was cut off by faulting and subsequent erosion. This member consists of thin sheet-like beds of

bioclastic, recrytallized, sparry limestone and coquina with nummulites and bivalve debris. Pelecypod and gastropod casts and molds occur at the base of the member but decrease upward and are replaced by nummulites that range in diameter from 0.5 to 2.5 cm. The member ranges in thickness from 1 to 10 m.

The Tarbah member effectively separates the Hamad member from the overlying and lithologically similar Shihiyah member, thus providing one of the few marker horizons within the Umm Wu'al formation.

Shihiyah member: The Shihiyah member (Ttus) forms most of the slightly undulating plains (Al Hamad) east of the Al Harrah basalt field to the eastern border of the map area. It also has been mapped in windows along the eastern side of the Al Harrah. Type locality of the member is in the southeast corner of the quadrangle, at 31°03' N., 38°59' E.

A series of separate, stacked and offset shell banks and coquinas, as thick as 18 m, have been named the Muqanna coquina bed (Ttus[B]). This bed crops out in inliers within the Shihiyah member, and its white color makes it easily distinguishable on aerial photographs. Fossils consist of pelecypod fragments, including oyster fragments, gastropod and bryozoa fragments, and foraminifera.

Jirani member: The Jirani member(Ttuj), the uppermost member of the Umm Wu'al formation and of the Turayf group, forms limited exposures and its type locality (about 31°43' N., and 38°16' W.) in the north-central part of the map. It consists of chalky-white limestone and light-gray marl (calcareous claystone), with a minor amount of bioclastic fragments, and a few chert nodules. Diagnostic fossils (Nummulites?) found within the Jirani member are Middle Eocene in age (Bayliss, 1984 in Aspinall, 1985).

PALEOGENE ROCKS OF WADI AS SIRHAN AREA

Rocks of Paleogene age in the Wadi As Sirhan area are the Turayf group and the overlying Rashrashiyah formation. The Turayf group (Tt) is not divided in the Wadi As Sirhan depression where a complete section of Paleogene rocks has been penetrated in the Qurayyat water well at the town of An Nabk. Upper Eocene rocks of the Rashrashiyah formation (Tr), the only surface exposure of the Paleogene in the Wadi As Sirhan area, crop out in the Rashrashiyah area north of An Nabk.

Eocene rocks were topped at a depth of 116 m in the Qurayyat well, and the top of Cretaceous rocks at a depth of 908 m (Aramco, unpub.data). Depth to the top of the Paleocene rocks in this interval is unknown.

The thickness of the Paleogene rocks in the Qurayyat well is 792 m compared to 478 m in the Turayf Tapline well. This thickening of Paleogene rocks into the Wadi As Sirhan graben complex suggests subsidence contemporaneous with sedimentary deposition.

The upper two thirds of the Paleogene rocks in the Qurayyat well consists mainly of marl (calcareous claystone) and soft shale (chalk?) with a minor amount of chert. Near the middle of this section there is about 40 m of marly, slightly dolomitic limestone. The lower third of the Paleogene contains marl and marly limestone with brown and dark-brown chert.

The Paleogene rocks of Wadi As Sirhan appear to have been deposited in a shallow marine environment, on the basis of marine fossils that include echinoids and foraminifera (Aramco, unpub. data).

Rashrashiyah formation

The Rashrashiyah formation (Tr) is informally named herein for white calcareous claystone and chalk that crops out in the Rashrashiyah scarp about 16 km north of An Nabk. Fifty two meters of the marl and chalk were measured in a section at pt. 82 (pl. 1), at the scarp where it is unconformably overlain by the Sirhan formation (fig. 3).

Echinoids and foraminifera collected from the Rashrashiyah formation tentatively have been classified "Upper" Eocene in age (Aramco, unpub. data).

The relationship of the Rashrashiyah formation to the Turayf group is uncertain, although the lithology of its upper beds is similar to that of the Jirani member at the top of the Turayf group. It is possible that much of the upper part of the Turayf group changes laterally into the marls and chalks of the Paleogene in Wadi As Sirhan. However, lacking more definitive data, the Rashrashiyah is placed stratigraphically above the Jirani.

SIRHAN FORMATION

The youngest Tertiary sedimentary rocks in Wadi As Sirhan are believed to be mostly Miocene in age, but may be in part Pliocene. Fossils are sparse, and diagnostic fossil identification too limited to make positive age designations at this time. These rocks are herein informally named the Sirhan formation for exposures in the western part of the map area. Similar rocks in the eastern part of the quadrangle near Khawr umm Wu'al, informally named the Sirhan group by Riddler and others (1984), are included in the Sirhan formation.

Wadi Sirhan area

The Sirhan formation (Tsu) forms discontinuous flat-topped outcrops, generally only a few meters high, scattered about the alluvial plains of the Wadi As Sirhan area. The formation consists of sandstone with thin interbeds of limestone and minor chert. The sandstone is white to light brown, poorly sorted, with fine sand to pebble-sized sub-angular to sub-rounded quartz grains. The quartz grains are clear to frosted and are mixed with a few opaque grains. The sandstone is calcareous and friable, and locally contains layers and fragments of dark-colored chert. In places it is vugular and bioturbated, and contains abundant worm tube casts. Rarely the sandstone grades into argillaceous and calcareous sandstone and mudstone which weathers brownish red.

The poorly sorted character of the Sirhan sandstone, which contains grit and pebble conglomerate, suggests high energy deposition with rapid deceleration so that the grains could not be deposited selectively. A continental alluvial fan deposition along the flanks of the Wadi As Sirhan trough may explain this type of sedimentation. Absence of marine fossils further suggests a continental origin for the sandstones.

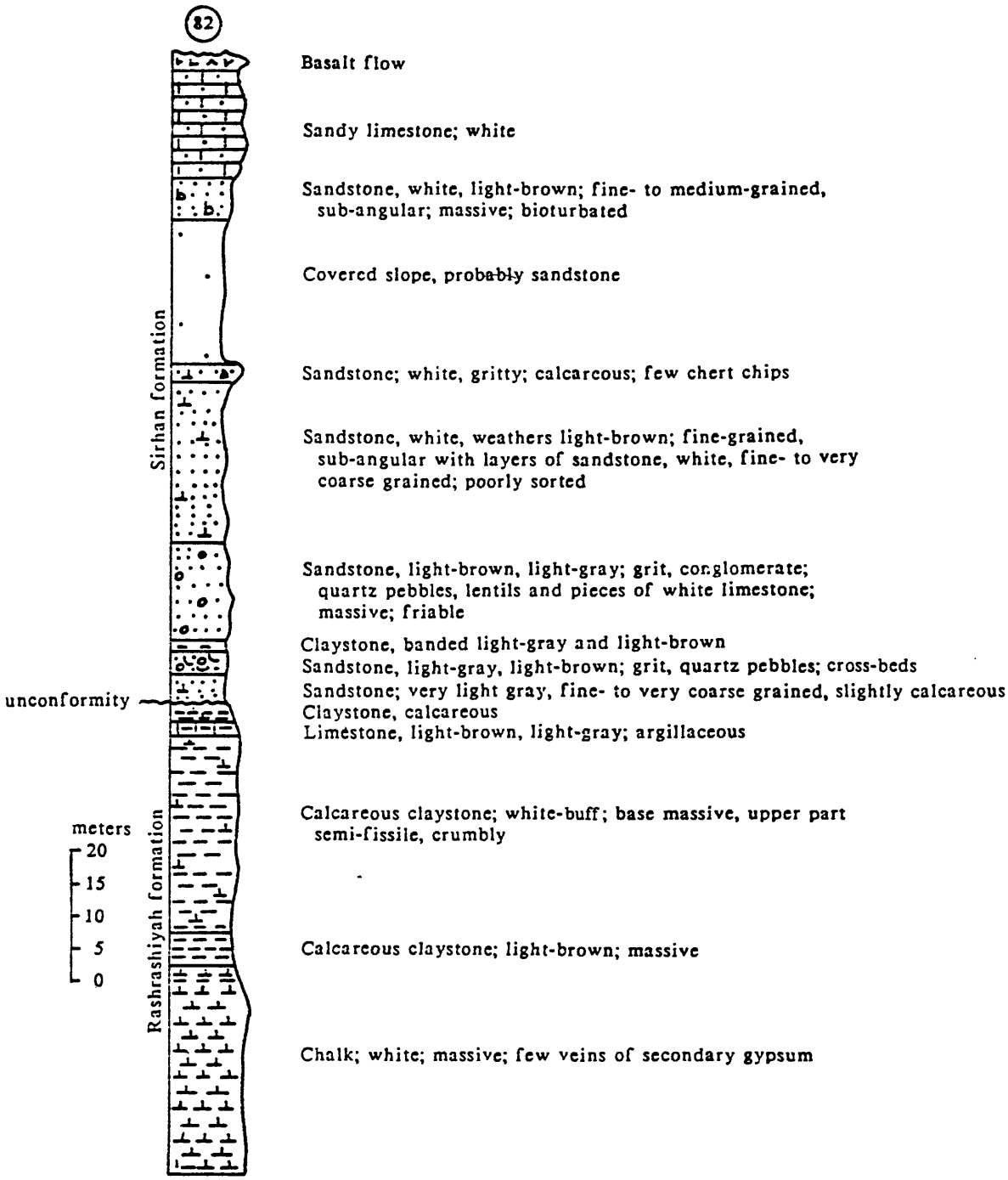

Figure 3.--Measured section of the Rashrashiyah and Sirhan formations (pt. 82), An Nabk quadrangle.
(See fig. 2 for explanations of lithologic symbols.)

The source of the quartz sand in the Sirhan formation is unknown. The terrain at the time of deposition of the sandstone appears to have been mostly carbonates, and possibly some early basalt lava flows, neither of which would contain sufficient clear or light-colored quartz to account for the Sirhan formation sandstone. Dark grains could be chert from older carbonate rocks or basalt fragments, but clear to frosted quartz grains must have come from some other rocks. No positively identified Oligocene rocks have been recorded in the region, but if they were formerly present and subsequently eroded away, they could have contributed the light colored quartz to the Sirhan formation. Less speculative is the possiblity that some of the finer, frosted grains are of eolian origin, blown in from quartz-bearing rocks remote from Wadi As Sirhan.

Limestone beds in the Sirhan formation commonly form the cap rock to the friable, nonresistant sandstone. The formation contains two main types of limestone: one is siliceous and chert-like, and the other is sandy with a high calcareous clay (marl) content.

The siliceous limestone occurs as beds usually no more than a meter or so thick. It is white to light gray, dense, very hard, and weathers with a pocked appearance. The limestone has become so siliceous as to resemble chert, and in places is associated with white chert beds. The limestone also contains light gray to light-brown, and uncommonly, black chert nodules. It is everywhere in close association with sandstone either as a cap rock to slope-forming sandstone, or as an interbed in a sandstone slope.

The sandy, marly limestone is in beds from a few meters to as much as 12 m thick. It is white and semi-hard, containing embedded fine- to medium-sized quartz grains that are clear to translucent and subangular to subrounded. The limestone is partly resistant and forms irregular ledges.

The only fossils reported from the limestones are marine echinoids collected from a "sandy marl...northwest of Qurayyat" (probably near the town of An Nabk) (Aramco, unpub. data). These fossils are Agassizia near scrobiculata Valenc., Brissoides? sp.near B. melitensis Greg., Scuttella sp., Schizaster prob. parkinsoni Defrance, and Ciradoid indel. that are classified as Miocene in age. On the other hand, a later report by Kier (1972) doubts this age classification and says "no definite age determination can be made of these echinoids".

One thin bed of limestone, located in the very northern part of the map area, contains vertical burrows seen frequently in limestone beds of the Sirhan formation in the Wadi As Sirhan quadrangle, to the south of the An Nabk and Turayf quadrangles. These vertical burrows, many interconnected, are very similar to the trace fossils of "Scolithos", a bottom-dwelling, suspension-feeding animal that lived in a marine intertidal environment. However, "Planorbis", a fresh water snail, and "Chara", a fresh water algae, were also found, suggesting a fresh water lake deposit (Aramco, unpub. data).

Apparently, the Sirhan formation had a varied depositional history including continental sandstone, and both lacustrine and marine limestone. The area may have been emergent for long periods with occasional marine incursions.

In surface exposures the Sirhan formation ranges in thickness from several meters to 52 meters measured at pt. 82 (pl. 1, and fig. 3) on the Rashrashiyah scarp. The Sirhan at pt. 82 is capped by a Quaternary-Tertiary basalt flow.

In the Qurayyat water well, a 116-m succession of the Sirhan formation was penetrated and described as white and tan, sandy, marly limestone, in part argillaceous, with some calcareous sandstone (Aramco, unpub. data). The ratio of limestone to sandstone appears reversed to that seen at the surface, the reason for which can be resolved only by more subsurface data.

In a large area in the northeastern part of Wadi As Sirhan basalt lava flows cap, underlie, and are interbedded with the Sirhan formation (QTb/Tsu). This area required separate map designation because basalt talus covers the underlying Sirhan formation to such an extent that in many places the outcrops appear to be all basalt, although they are composed mostly of the Sirhan formation (fig. 4).

Gullies eroded in the sides of jabals in the area expose mostly nonresistant slope-forming sandstone, and beds of chert and limestone. At least two lava flows are present in this area: an upper capping flow, and a lower flow that is either interbedded with, or at the base of, a Sirhan formation outcrop.

Khawr umm Wu'al area

Miocene(?) rocks called the " Sirhan group" have been mapped along the west side of the Khawr umm Wu'al graben-trough, mainly in the Al Hamad quadrangle to the east of the Turayf quadrangle (Riddler and others, 1985). However, the north end of the Miocene outcrop belt extends along the east border of the Turayf quadrangle, just south of Wu'aylah. The Sirhan group of Al Hamad is considered to be the same as the Sirhan formation of the type area. As no subdivisions were mappable in the Wadi As Sirhan area, it is premature to give a group designation to these rocks.

The Sirhan formation in the Khawr umm Wu'al area occurs as float fragments that form a distinctive white surface. Outcrops include sparry, bioclastic limestone that contain 1-cm-long gastropod molds, and vertical interconnecting tubular structures from 0.5 cm to 1.25 cm in diameter, and 3 to 7 cm in length. The interconnecting tubes are characteristic of limestone beds in the Wadi As Sirhan region that contained fresh water snails and algae. A drill hole in the Khawr umm Wu'al graben intersected the Sirhan, which is composed of red and brown, marly, calcareous sandstone, sandy marl and shale (Meissner and Ankary, 1972).

VOLCANIC ROCKS

The Al Harrah basalt lava flows and flood basalts (QTb) overlie sedimentary rocks over half of the map area. The volcanic field is about 80 km wide and trends northwest across the map area, continuing into Jordan. In places the basalt is scoriaceous and vesicular, and includes bedded pyroclastics, sills, dikes, plugs and cones. Coleman and others (1983) state that the predominant mode of eruption is fissure eruptions followed by pyroclastic cone building. Both pahoehoe and aa flows are present but mechanical weathering has destroyed the primary features of most flows. Explosive eruptions associated with broad, low relief craters known as maars have brought up fragments of underlying sedimentary rocks (Aspinall and others, 1985).

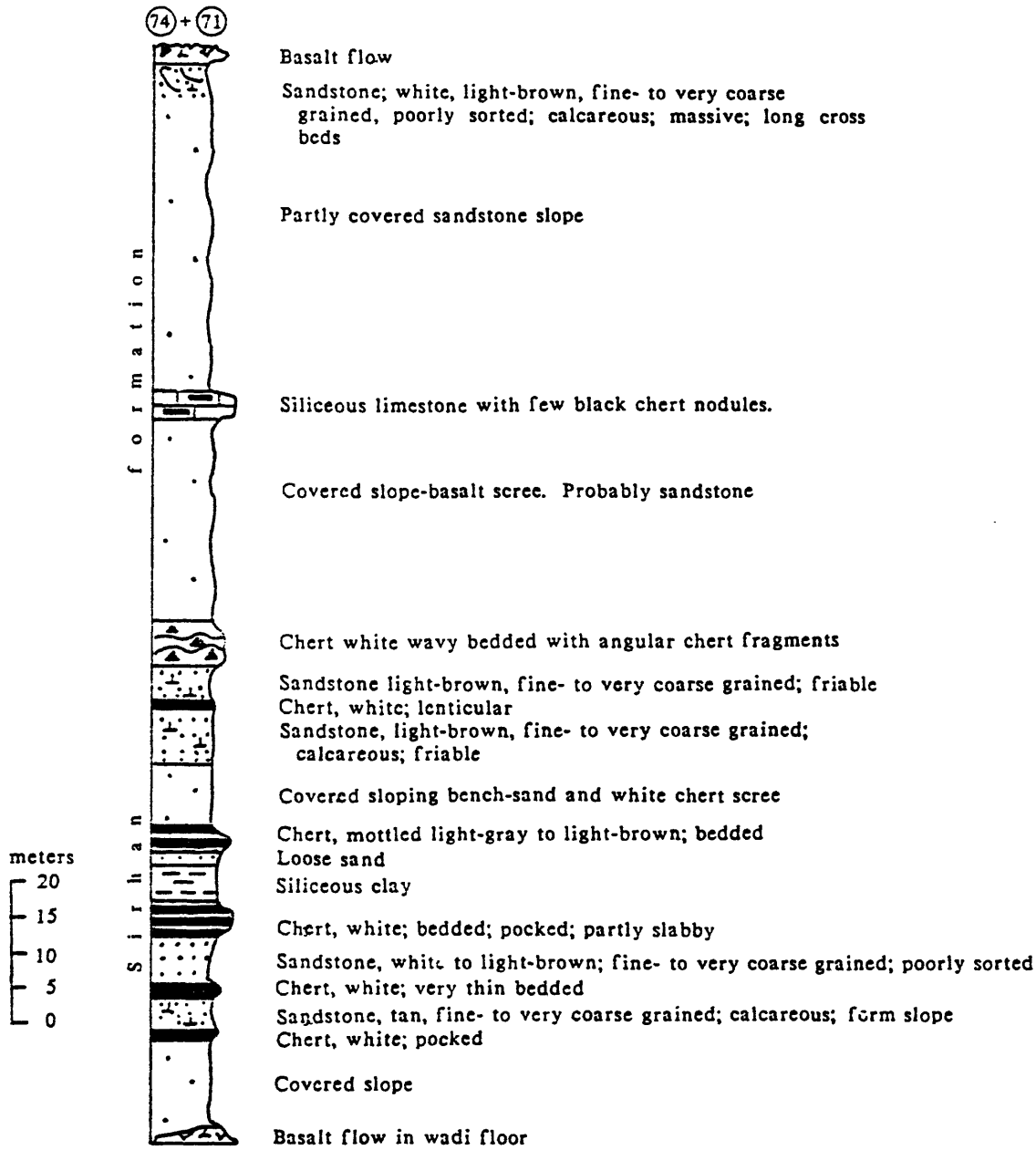

Figure 4.--Composite section, pts. 74 and 71, Sirhan formation, Turayf quadrangle. (See fig. 2 for explanations of lithologic symbols.)

The highest volcanic cones in Al Harrah are along the east side of the field, including Jabal al Matahah in the southeast, followed northwestward by Jabals Liss, Al 'Aqir, Al Hinw, Aqran, and Nu'ayj. The cones range in elevation from 945 to 1128 m above sea level; Jabal Liss, at 1128 m is the highest in the map area. One cone, Jabal umm Wu'al, is isolated to the east of the main basalt field, at the east border of the Turayf quadrangle, and is related to rifting along the Khawr umm Wu'al graben.

Craters about 50 m deep have rims and walls of very hard vesicular basalt which show flow layering and jointing. The jointing in some places is characteristically columnar (fig. 5). A canyon along Shaib al Usayd in the south-central part of the field, has exposed as much as 60 m of basalt apparently in two separate flows, one directly on top of the other. The underlying flow appears much older containing numerous vugs filled with calcite and geodal material, is gray and weathered looking, coarse grained, and crumbly; whereas, the upper flow is black, very dense, compact and fine grained, with only a few minute calcite-filled vugs, and is partly columnar jointed. These flows are similar to the two flows separated by sedimentary rocks of the Sirhan formation in the Wadi As Sirhan area (QTb/Tsu).

Unique geodal, thunder egg-like, pieces of tuff whose interiors contain clusters of olivine crystals are found eroded out of the lava flow about 11 km southwest of Jabal Liss.

Thickness of the Al Harrah basalt ranges from about 1 m, in many places, to as much as 60 m, as seen in the canyon of Shaib al Usayd. Powers and others (1966) reported a thickness of 100 m at Jabal umm Wu'al.

Figure 5.--Columnar jointing in Al Harrah basalt.

Four widely spaced samples of the upper, fresh-looking basalt were collected along the west edge of the Al Harrah field (pl. 1). Thin sections of each sample examined by Carl Thornber (written commun. 1986) indicated that the rocks are alkali-olivine basalt of similar mineralogical character. Petrologically the basalt is sparsely vesicular (some calcified vesicles), and porphyro-aphanitic; it contains sub-round, anhedral olivine phenocrysts (less than 0.2 mm to 0.5 mm) with iddingsitized rims (about 7 volume percent); minor zonation of phenocrystic olivine is reflected by strained extinction, slight Fe enrichment during growth. It also contains a few partially melted, reacted Al-rich clinopyroxene xenocrysts (as much as 0.5 mm). The aphanitic matrix is comprised of elongate plagioclase (0.1 by 0.5 mm) that is ophitically intergrown with Al/Ti rich(?) clinopyroxene. Later stage opaque minerals are interstitial to matrix silicates.

A sample reported by Powers and others (1966) from Qitab ash Shamah (lat 31°36' N., long 37°57' E.) showed phaneritic basalt containing zoned plagioclase (andesine-labradorite), augite, commonly altered olivine, calcite, and black opaque minerals (probably ilmenite and magnetite).

Portions of the same four samples of basalt from which thin sections were cut for petrographic examination were fused into glass for analysis of major oxides, and powdered for analysis of trace elements.

The glass samples were analyzed by M. Amjad Hussain using the Scanning Electron Microscope. Eight to ten quantitative analyses were made for each sample and the average percent of 11 oxides is listed in table 1. It is evident from the table that the oxide content varies very little in the four widely-spaced samples.

The powdered samples were analyzed by Abdul Malik Helaby using the X-ray fluoresence method. The blend of semiquantitative analyses with the cadmium and americium sources is shown for 13 elements in table 2.

The only noteworthy anomaly in the trace element content of the four samples was barium in sample 217012. A value of 2819 ppm, an amount is 5 to 13 times that of the other three samples, was reported confirmed by analyses of duplicate samples. Excessive weathering of the original basalt sample is a possible cause but is not likely, considering that no other elements are anomalous. Resampling of the area will be necessary to explain the high barium.

A Zr-Nb variation diagram (fig. 6) was computer-generated for six samples of basalt, including analyses from the four samples of table 2, and two samples taken in the Al Harrah field to the south of the map area. The diagram format is the same as that shown for continental rift volcanism in the volume "Basaltic Volcanism on the Terrestial Planets" (Basaltic Volcanism Study Project, 1976-1979, p. 118). The Zr-Nb ratio points fall in that part of the diagram typical of silicic alkalic (olivine) basalt.

Age of the Al Harrah basalt flows are generally reported as Tertiary to Quaternary. Powers and others (1966, p. D98) tentatively assigned the younger flows to the Quaternary; older flows, informally known as Garaiyat (probably Qurayyat) lavas, are considered to be Miocene and Pliocene. Bender (1975, p. 122-123) believes the same basalt field in Jordan contains flows that are Miocene to mid-Pleistocene. Brown (1971) in the Tectonic map of the Arabian Peninsula

shows the lava field of northwestern Saudi Arabia (Al Harrah) to be Middle Miocene (10-14 m.y.) based on K-Ar determinations and field relations.

Potassium-argon ages of 5 samples from the southwest edge of the Al Harrah volcanic field, about 10 km south of the Turayf quadrangle (20 km northeast of Isawiyah), range from 11.4 to 13.4 m.y. (Coleman and others, 1983, table 2).

Stratigraphic relationships in the map area demonstrate that the volcanic flows are at least younger than the Paleogene rocks of the Turayf group and the Rashrashiyah formation: nowhere are the flows interbedded with these rocks, but rather lie on them. On the other hand, lava flows are interbedded with rocks of the Sirhan formation along Wadi As Sirhan, indicating a Neogene, probably Miocene age, for the flows. Younger flows of Pliocene and Quaternary age are not positively known except that the uppermost basalt along the west edge of Al Harrah (described on page 17), is very fresh looking and is probably of Quaternary age.

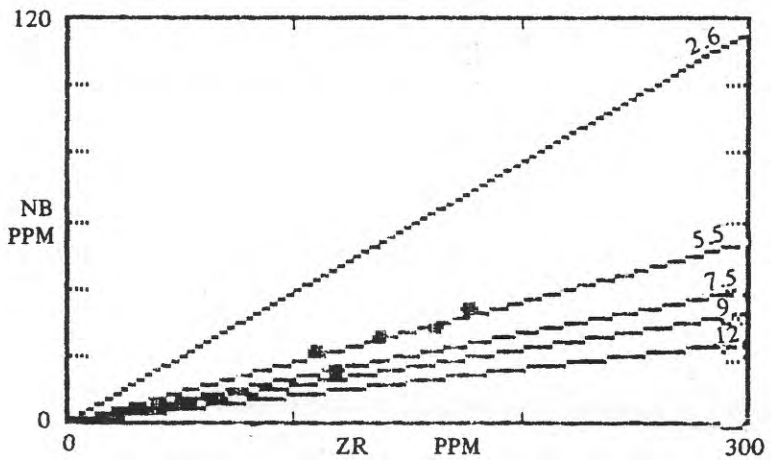

Figure 6.--Zr/Nb diagram for 6 samples of basaltic lavas of the Al Harrah field. [Reference lines are constant Zn/Nb ratio.]

Table 1.-- Major oxides in basalt from Al Harrah, Sirhan-Turayf Basin.

[The second column of figures under each sample is the standard deviation for each element in percent.]

Sample No.	217012	G.AVE*	217014	G.AVE*	217020	G.AVE*	217021	G.AVE*
Na_2O	3.52	8	3.58	6	3.26	6	3.55	6
MgO	7.61	2	9.00	3	6.86	2	7.42	2
Al_2O_3	14.89	<1	14.50	1	16.16	<1	15.52	2
SiO_2	46.88	<1	47.30	<1	48.19	<1	48.07	<1
K_2O	0.95	7	0.98	7	0.83	7	0.84	7
CaO	11.64	1	10.90	<1	11.65	<1	10.11	2
TiO_2	1.92	4	1.73	7	1.81	6	1.89	11
Cr_2O_3	0.04	>99	0.08	>99	0.07	>99	0.01	>99
MnO	0.10	72	0.14	46	0.17	64	0.14	65
FeO	11.43	2	11.18	2	10.34	2	11.92	1
P_2O_5	0.38	20	0.31	27	0.20	75	0.35	32
TOTAL	99.38		99.69		99.54		99.83	

*Geometric average

Table 2.-- Trace elements in basalt from Al Harrah, Sirhan-Turayf Basin.

[Concentrations in parts per million. The second column of figures under each sample is the standard deviation for each element in percent]

Sample No.	217012		217014		217020		217021	
CU	102	38	49	76	121	31	43	90
ZN	97	28	130	19	130	19	107	25
RB	19	30	23	22	16	39	20	28
SR	718	2	544	2	493	2	474	2
Y	22	15	23	14	25	13	25	13
ZR	138	6	138	6	110	7	119	7
NB	26	17	25	17	21	20	16	29
W	33	>99	0	>99	66	>99	104	64
SN	22	32	24	28	32	19	15	44
LA	42	34	13	88	4	>99	13	76
ND	36	20	0	>99	23	31	56	13
BA	2819	9	521	48	209	>99	226	>99
CE	25	42	11	91	5	>99	20	50

QUATERNARY DEPOSITS

DURICRUST

Calcareous and gypsiferous duricrust discontinuously mantles bedrock rock in the Wadi As Sirhan region, and is associated with basalt lava flows, especially along the west edge of the Al Harrah field (Qdc/QTb).

The calcareous duricrust is massive, consolidated, hard, and has a rough surface. It is usually sandy and resembles ragged, massive limestone. The gypsiferous duricrust is also massive, sandy, and partly calcareous, but in many places it is very porous and tough rather than hard.

Powers and others (1966, pp. D98-D99) surmise that duricrust is the product of a moister climate than exists in present-day Arabia. During the dry season ground water moved upward to the surface where soluble substances were deposited by evaporation. Over the years, this formed a caliche-like carbonate- and(or) gypsum-enriched crust.

Thin limestone beds that cap outcrops of the Sirhan formation in Wadi As Sirhan have a partly eroded mantle of duricrust, and duricrust is seen between joint and bedding planes of the limestone (fig. 7).

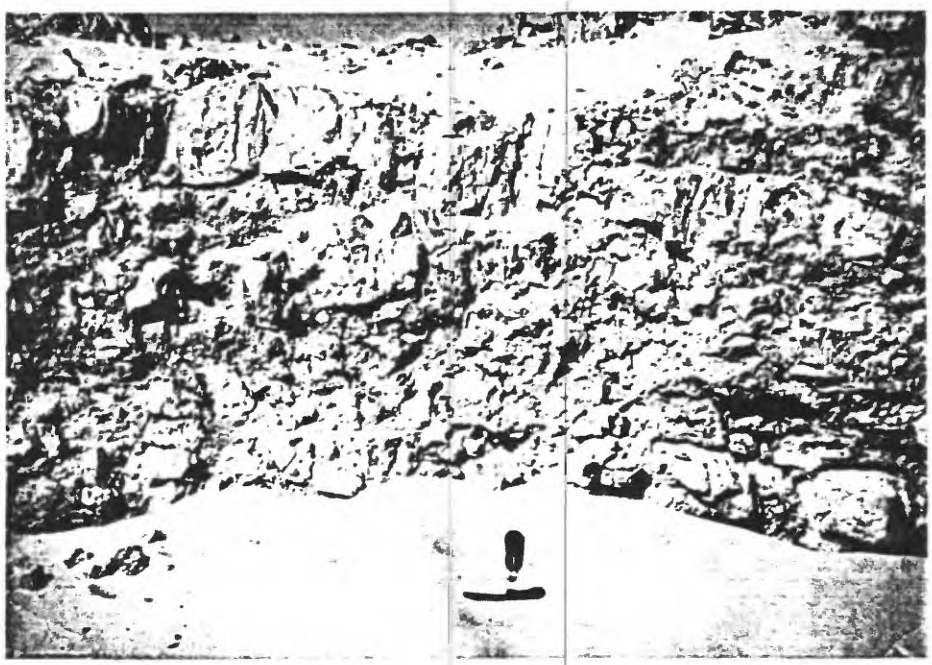

Figure 7.--Duricrust in bedding planes and joints of limestone in the Sirhan formation.

Basalt flows that cap jabals along the west edge of the Al Harrah lava field appear to have been encased in duricrust which has partly eroded away, leaving blocks of basalt scattered about the surface. The sides of the jabals are largely covered by duricrust as much as 6 m thick conforming to the slope of the sides not to the flatlying bedrock that it covers. Bedrock exposed within erosion gulleys is mostly sandstone and thin limestone interbeds of the Sirhan formation. Irregular blocks of basalt are seen in many places at the base of the duricrust. The eastern extent of duricrust in Al Harrah is not defined, but has been seen mixed with basalt fragments in large areas of the volcanic plains in the central part of the map area.

The duricrust is assigned a Quaternary age because it mantles the youngest lava flow, believed to be of Quaternary age, and it seems to have formed a carapace over all rocks exposed at the surface at the time it was deposited.

UNCONSOLIDATED SURFICIAL DEPOSITS

The map area contains large deposits of unconsolidated alluvial silt, sand, and gravel (Qu). These deposits are found in large depressions, notably Wadi As Sirhan, and smaller depressions and basins, as well as along wadi courses. The deposits are mostly alluvium mixed with eolian sediments. Finer-grained deposits consisting of silt and clay (Qs) are found in undrained depressions and khabras and form firm, flat surfaces commonly void of vegetation. A small area composed mostly of chert clasts derived from Tertiary carbonates (Qg) is found in the northwest part of Wadi As Sirhan. An elongate sabkhah, consisting of saline-encrusted clay, silt, and sand (Qsb) is located east of Kaf in the northeastern part of Wadi As Sirhan.

The north end of a sabkhah is mapped in the lava field at a point on the south-central border of the map area. This sabkhah forms a shallow lake during the winter rainy season, as is the case for many other undrained depressions in the region.

STRUCTURE

The Phanerozoic sedimentary rocks in the Turayf and Abn Nabk quadrangles lie on the west flank of the Hail Arch and form a homocline that dips very gently westward about 7 m/km towards the Wadi As Sirhan graben complex. The succession is cut by north- to northwest-trending faults with displacement mostly down to the southwest.

WADI AS SIRHAN GRABEN

Wadi As Sirhan is a broad elongate depression believed to have been partially formed by a series of normal faults, down-thrown to the southwest (cross section A-A', pl. 1). No evidence of major faulting is seen in the flood basalt at the surface, but lineaments on aerial photographs and Landsat imagery may reflect later movement along some of these faults. Possibly in places the basalts came up along fissures coinciding with normal faults.

Powers and others (1966) described Wadi As Sirhan as a half graben faulted only on the northeast side, but recent work by the Riofinex Geological Mission to

the south of the map area revealed normal faults down-thrown to the northeast along the southwest side of Wadi As Sirhan (Al Busayta lineament, Regional Geologic Setting, pl. 1, and Griffin and others, 1984). Gravity mapping in Jordan adjacent to Wadi As Sirhan, just west of the map area, shows major faults approximately parallel to the border with Saudi Arabia that could be the continuation of the faults mapped by Riofinex (Bender, 1975). This evidence of possibly continuous faulting along the southwest side of Wadi As Sirhan strongly suggests that the Wadi As Sirhan graben is a full graben.

A gravity map of the Sirhan-Turayf Basin shows as much as 300 gravity units of relief, or an estimated 1800 m, from a high just east of the 38° parallel to a gravity low at the axis of the Wadi As Sirhan graben (Aramco, unpub. data). Most of the normal faults are speculated to lie between this gravity high and low. Although there is no major evidence for these faults in the Al Harrah lava field, the Al Khalad and Al Misma lineaments are positioned over the gravity high and later movement along that high may have caused these lineaments. Furthermore, it is possible that the Al Khalad-Al Misma lineaments are the surface reflection of the northeast border of the Wadi As Sirhan graben.

The axes of the Wadi As Sirhan graben as shown on plate 1 have been located according to interpretation of the gravity survey of the region (Aramco, unpub. data) and surface mapping. The gravity axis curves to the southwest and apparently a southeasterly bifurcation begins at the south border of the map area. The southwesterly branch of the axis continues toward the Jordanian border and the southeasterly branch continues along Wadi As Sirhan south of the map area. The surface axis is west of the gravity axis and is on trend with a sabkhah and a series of lineaments Its continuation to the south is unknown.

A surface high is evident at the northwest end of Wadi As Sirhan in the vicinity of Samra ar Rashrashiyah. The exposure of the Upper Eocene Rashrashiyah formation in an area otherwise composed of the Miocene? Sirhan formation indicates uplift, probably arching. A gravity high occurs just south of the surface high, and although offset, could be the subsurface expression of the same structural feature.

KHAWR UMM WU'AL GRABEN

The north end of the Khawr Umm Wu'al graben occurs in the northeast corner of the Turayf quadrangle. The main extent of the graben has been mapped in the Al Hamad quadrangle adjacent to the east (Riddler and others, 1985). Amount of downthrow of the graben at its north end is unknown but the graben does form a trough-like depression filled with silt, sand, and gravel. The Jabal umm Wu'al and Wu'aylah volcanics may have erupted through faults along the flank of the graben.

LINEAMENTS AND FAULTS IN THE AL HAMAD PLAINS

Many lineaments, some of which are faults, are visible on aerial photographs and Landsat imagery in the Tertiary carbonate plains on the eastern side of the Turayf quadrangle. Orientation of the lineaments varies from north-south to northwest, and a few trend northeasterly. Displacement is not apparent in most cases along these lineaments and they may be only tension joints in the rock

formed in adjustment to uplift of the Hail arch to the east, or movement associated with the Wadi As Sirhan graben to the west. Wadi courses follow a few of the lineaments which suggests they are narrow grabens that have influenced the drainage.

A fault was mapped in the northeastern part of the Al Hamad plains, where the Shihiyah member of the Umm Wu'al formation is faulted down against the Hamad member, with a displacement of approximately 30 m.

ECONOMIC GEOLOGY

PHOSPHORITE

The Arqah Phosphorite member is exposed in the northeast corner of the Turayf quadrangle on both sides of the Khawr Umm Wu'al graben. Drilling and prospecting in the Arqah Phosphorite are summarized by Riddler and others, (1986). Several areas of near-surface phosphorite with favorable stripping ratios have been indicated (MODS 03937, 02253) in what is called the Umm Wu'al North work area (Riddler and van Eck, 1984). Carbonate-cemented, semi-friable and friable phosphorite is present. The friable phosphorite ranges in thickness from a few centimeters to more than a meter, and grades in excess of 30 percent P_2O_5 are common. The carbonate-cemented phosphorite grades range between 18 and 24 percent P_2O_5.

The Arqah phosphorite member dips westward under the surface from its exposure at the edge of the Khawr umm Wu'al graben and has been penetrated by drill holes at least as far as the vicinity of the town of Turayf where it is more than 100 m deep below the surface. The member thickens steadily to more than 40 m down dip to the west and becomes argillaceous with a sparse phosphorite content. The Arqah, as well as the Ghinah and Thaniyat Phosphate members, are interpreted to extend through the Turayf Tapline water well 6-2 (cross section A-A', pl. 1) but no phosphorite was noted in the drillers log of that hole.

OIL AND GAS

Gardner (1955) wrote about the oil possibilities of eastern Jordan, which included Wadi As Sirhan along the east border of Jordan, where marine rocks of the Upper Cretaceous and Paleocene-Eocene are preserved. In 1985 the Jordanian National Oil Co. made Jordan's first oil discovery near Azraq in the Azraq depression. Three wells that were drilled each flowed 600 to 1000 barrels per day of low-sulfur crude from 10,500 feet (3200 m). Jordan has named this discovery the Hamza field. Current production of the Hamza field is unknown, but it has proved the existence of hydrocarbons in the Azraq depression and enhances the possibility of oil in the Wadi As Sirhan depression to the south in Saudi Arabia.

The Qurayyat deep water well near An Nabk in Wadi As Sirhan contains 792 m of Paleocene-Eocene marine carbonates and at least 392 m of Upper Cretaceous, mostly dark-colored, argillaceous, earthy, marine limestone and carbonaceous shale that may be good source rocks for oil. Residual hydrocarbon flecks were reported in drill cuttings of the Upper Cretaceous rocks between 1132 and 1238 m, and free, heavy asphalt was reported at a depth of about 1256 m (Aramco, unpub. data). These residual oil shows indicate that hydrocarbons may have originated in the Cretaceous rocks and migrated towards structural traps.

There are a number of possible oil traps in the Wadi As Sirhan area. Arching of the Rashrashiyah formation and the associated gravity high may indicate that sufficient structural closure exists to trap migrating oil or gas, and faults along the flanks of the Wadi As Sirhan graben could be seals for oil and gas. Fault traps and closures are especially likely to occur between the axis of the Wadi As Sirhan depression and the large gravity high that crests just east of 38° (Al Khalad-Al Misma lineaments). Although there are favorable signs for hydrocarbons in the Wadi As Sirhan region much more geological and geophysical work is necessary to prove potential drilling prospects.

DATA STORAGE

DATA FILE

All original data used in the preparation of this report are stored in the Jeddah office of the U.S. Geological Survey Mission in Data File USGS-DF-06-13, the contents of which are listed below:

(1) Field notebooks.
(2) Aerial photographs and maps used in the field for plotting geologic data.
(3) Plotted measured sections and well logs.
(4) Original notes, maps and drawings used by authors to compile map and report.
(5) Laboratory results.

MINERAL OCCURRENCE DOCUMENTATION SYSTEM

No new Mineral Occurrences Documentation System (MODS) entry has resulted from this project.

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