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Preliminary Geologic Map of the Al Jawf Quadrangle, sheet 29D, Kingdom of Saudi Arabia

by

C. R. Meissner, Jr., S. M. Dini, A. M. Farasani,
G. P. Riddler, Marcel Van Eck, and N. C. Aspinall 1/

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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PRELIMINARY GEOLOGIC MAP OF THE AL JAWF QUADRANGLE, SHEET 29 D, KINGDOM OF SAUDI ARABIA

BY

C. R. MEISSNER, Jr., S. M. DINI, A. M. FARASANI, G. P. RIDDLER, MARCEL VAN ECK, and N. C. ASPINALL

ABSTRACT

The Al Jawf quadrangle (Sheet 29 D) lies in the northwestern part of the Kingdom of Saudi Arabia about 900 km north of Jeddah. The quadrangle is located between lat 29° 00'-30° 00' N. and long 39° 00'-40° 30' E. It includes the southeastern rim of the Sirhan-Turayf basin, and is underlain by sedimentary rocks of Paleozoic to Cenozoic age. More than half of the quadrangle is covered by surficial deposits.

The Phanerozoic sedimentary rocks of the map area were deposited under both marine and continental conditions. Marine deposits, produced by transgressions and regressions of the sea, are of outershelf to near-shore and coastal-lagoon origin, and the continental deposits are largely of fluvial and deltaic origin. Part of the Miocene-Pliocene rocks are believed to have been deposited in a lacustrine environment.

Tensional structures, such as linear macro joints, grabens, block-faulting, and some folding are characteristic of the geology of the map area, and reflect a combination of Red Sea rifting and movement of the Hail Arch.

This report introduces a new structural concept that extends the Wadi as Sirhan graben complex southeastward in the Al Jawf quadrangle into the An Nafud (Great Desert). This concept greatly increases the area of interest in the potentially oil-and-gas-bearing rocks of the Wadi as Sirhan region to include those of the An Nafud basin.

Discovery of the largest specimen of *Prototaxites* sp. in the world, in the Al Jubah area of the northeastern part of the quadrangle, has helped solve a long-standing stratigraphic problem involving Devonian and Cretaceous rocks of the southeastern part of the Sirhan-Turayf basin.

Phosphorite, a commodity of major economic interest in the Sirhan-Turayf basin, is exposed in the map area along escarpments that form the southeastern rim of the basin. The grade of the phosphorite is a much as 21 percent P_2O_5, but the beds are thin and lenticular.

INTRODUCTION

LOCATION

The Al Jawf quadrangle (Sheet 29 D) is located in northwestern Saudi Arabia, about 900 km north of Jeddah. The quadrangle lies between lat 29° 00' and 30° 00' N., and long 39° 00' and 40° 30' E. (fig. 1).

The quadrangle contains the southeastern rim of the Sirhan-Turayf basin and includes the Al Jayb, Quraymiz, and Rummamin escarpments along which phosphatic rocks are exposed. Rocks of the southeastern rim occupy the northwestern part of the quadrangle. Exposures located southeast of the rim are of folded and faulted Devonian rocks that contain the type localities of the Tawil and Jauf Formations. The type locality of the Tawil Formation is at At Tawil, a mountainous area located in the south-central part of the quadrangle. The type locality of the Jauf Formation is in the vicinity of the town of Al Jawf (also called Dawmat Al Jandal), a highly faulted area in the north-central part of the quadrangle. Between At Tawil and Al Jawf is a broad, flat area (Al Ajaiz) that is mostly covered by Miocene-Pliocene rocks and Quaternary deposits that occupy the central part of the map area. The Al Ajaiz area also contains a few outcrops of Devonian rocks north of At Tawil.

The northeastern corner of the quadrangle is occupied by the southern part of the Al Jubah topographic embayment and contains the town of Sakakah. Al Jubah is the type locality of the Al Jubah formation, a newly proposed formation composed mostly of sandstone that is introduced in this report. The Al Jubah formation contains the fossil *Prototaxites* sp., a unique tree-like fungus known to have grown only during the Devonian Period. The largest known specimen of *Prototaxites* sp. in the world was discovered by Meissner a few kilometers south of Sakakah.

The remainder of the map area, the eastern and southern parts, is covered by a segment of An Nafud (Great Desert), the second largest (after the Rub Al Khali) sand-dune desert in Saudi Arabia.

The Al Jawf quadrangle is populated only in the northern part along a paved highway that runs eastward across the area to Al Jawf and continues northeastward to Sakakah. This highway connects the quadrangle with Tabuk approximately 300 km to the southwest, and Ar Ar, about 130 km to the northeast (fig. 1). Farm communities have been established in recent years, especially in the vicinity of the towns of Al Jawf and Sakakah, and the Al Jubah area, where drill holes have tapped

deep water used for irrigation. The nomadic bedouin population varies with the season, increasing during the rainy seasons in March and April, and October and November.

Another paved highway forks off the east-west highway near the northwestern corner of the map area and runs northwestward along Wadi as Sirhan about 230 km to An Nabk (Qurayyat), and continues northwestward 30 km to the Jordan border (fig. 1).

Previous Investigations

Bramkamp and others (1963, 1982) mapped the geology of the area at a 1:500,000 scale. The sedimentary geology of the region was described by Powers and others (1966) in a report that encompasses the sedimentary geology of Saudi Arabia. Mytton (1966) described phosphate deposits along the southern rim of the Turayf basin (Jawf-Sakakah basin), including the Quraymiz area in the northwestern part of the quadrangle. Helal (1965, 1968) described the stratigraphic subdivision of the Devonian rocks of the Jawf area. A brief description of the Paleozoic and Mesozoic rocks in the northwestern part of the quadrangle and their relationship to the Tertiary phosphate-bearing rocks was written by Meissner and Ankary (1972). Bahafzallah and others (1981a, 1981b) described the stratigraphy and facies of the Devonian Jauf Formation, and identified silicified trunks of *Prototaxites*, sp. of Devonian age near the town of Sakakah.

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 parts of the Al Jawf quadrangle. The following Riofinex reports described the Cretaceous and Tertiary phosphate-bearing rocks: Futyan and Nicholson (1979), Bayliss (1981, 1982, 1983), Kluyver and others (1981), Riddler and others (1983), Riddler and van Eck (1984), and Riddler and others (1984). Riofinex reports on geologic and stratigraphic studies of Tertiary and pre-Tertiary rocks of parts of the quadrangle include Smith (1983), Lozej (1983, 1984), Aspinall and others (1985), van Eck (1985), and Riddler and others (1986).

Present Work

The geologic map of the Al Jawf quadrangle (pl. 1) was compiled from unpublished data that included nine 1:50,000-scale maps produced by the Riofinex Limited as part of its phosphate resource assessment; these maps are stored in Riofinex Data File RF-DF-00-05. Additional mapping to complete the quadrangle was provided by the U.S. Geological Survey in the present study ducted during October, November, and December 1987.

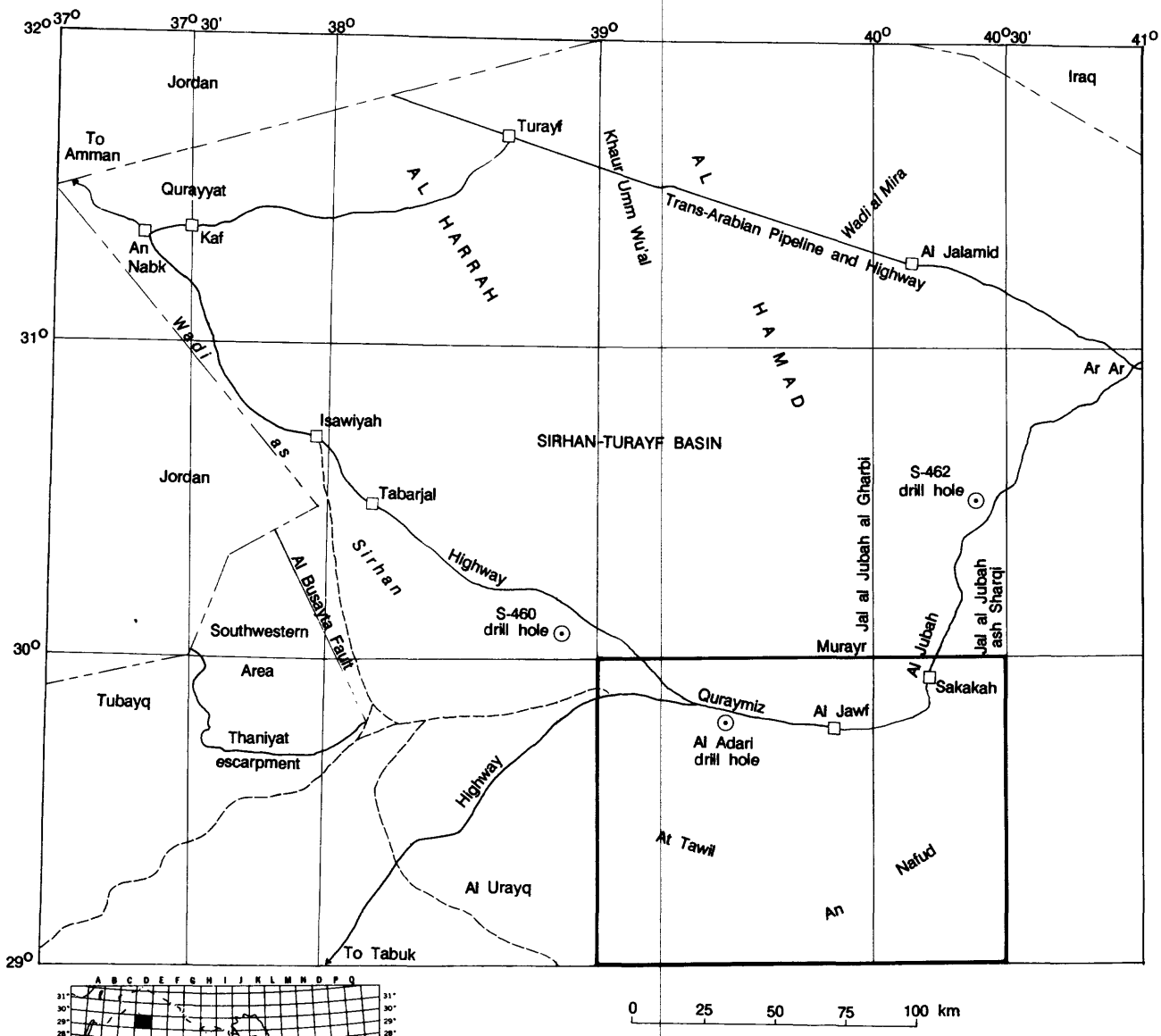

Figure 1.--Location map of the Al Jawf quadrangle (dark outline) and surrounding area

The lithostratigraphic framework of the Upper Cretaceous-Tertiary rocks (the Turayf group) and the Upper Cretaceous Aruma Formation were established by Riofinex (Riddler and others, 1984, and van Eck, 1985). The description of the pre-Tertiary rocks and post-Turayf group rocks was done by the U.S. Geological Survey. The lithostratigraphic nomenclature of this report is in accordance with the Directorate General of Mineral Resources Stratigraphic Code, but many names are new and not yet formalized.

ACKNOWLEDGMENTS

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GEOLOGIC SETTING

The Al Jawf quadrangle includes part of the Sirhan-Turayf basin of northwestern Saudi Arabia (fig. 1, and Regional Geologic Setting pl. 1). The Sirhan-Turayf basin is a complex sedimentary basin that extends north and west into Iraq and Jordan. Sedimentary rocks in this basin range in age from Cambrian to Recent; they have a maximum thickness of at least 2,300 m (Powers and others, 1966). The northwestern part of the Al Jawf quadrangle includes the southeast edge of the basin where Upper Cretaceous and Lower Tertiary rocks dip regionally northwestward toward the basin axis occupied by the Wadi as Sirhan graben complex (Regional Geologic Setting, pl. 1). According to the new concept of the continuation of the Wadi as Sirhan graben complex into An Nafud (Meissner and others, 1988, 1989), most of the map area is part of the graben complex. The Wadi as Sirhan fault, the northeast bounding fault of the Wadi as Sirhan graben, trends east-southeastward from the northwest corner of the quadrangle and passes south of the town of Al Jawf. The southwest bounding fault of the graben, the Al Huj fault, trends southeastward to the south of the map area.

Faulting and folding of the Lower Devonian rocks is a primary characteristic of the map area. At Tawil is a major up-faulted block with a series of mostly north-northeast-trending faults that extend along its west side. The northeast face of At Tawil is faulted up against folded and faulted younger Devonian rocks. North of the town of Al Jawf is an extensively block-faulted area containing many horsts and grabens; to the west of Al Jawf is a large syncline. Most of the faulting and folding in

the Devonian rocks apparently predates the overlying Late Cretaceous-Tertiary rocks that show very little structural disturbance.

The Al Jubah area, located in the northeast corner of the map area, contains a monotonous sequence of gently east-dipping clastic rocks, the western half of which is Devonian in age and the eastern half is Middle Cretaceous(?) in age. The eastern dip of these older rocks is the reverse of that of the Upper Cretaceous-lower Tertiary rocks and reflects older structural influences. More than half of the quadrangle is covered by flat-lying Upper Tertiary and Quaternary deposits and the sands of An Nafud.

PHANEROZOIC SEDIMENTARY ROCKS

Surface exposures of Phanerozoic rocks in the map area include those from the Lower Devonian, Cretaceous, Tertiary, and Quaternary; these are described from surface mapping and outcrop sections (fig. 2). Subsurface rocks ranging in age from Early Silurian to Cretaceous are described from deep drill holes (either water wells or stratigraphic test holes) that were studied by the Arabian American Oil Company (Aramco) (unpub. data).

TAYYARAT FORMATION

The oldest rocks studied in the map area are tentatively classified as part of the Lower Silurian Tayyarat formation (St) (fig.2; and cross section A-A', pl.1). The Tayyarat formation is a new subdivision of the former Tabuk Formation (Powers and others, 1966; Powers, 1968) that was named by Vaslet (1987) after its type locality Khashm Tayyarat in central Saudi Arabia. At Khashm Tayyarat, the Tayyarat is 187 m thick and consists of two members, the lower Qusaiba member and upper Sharawra member. The Qusaiba member is predominantly claystone containing interbeds of siltstone and micaceous, fine-grained sandstone in its upper part. The Sharawra member is mainly well-bedded sandstone containing signs of bioturbation (bore marks) on the upper surfaces of the beds. According to Vaslet (1987), both members are of marine origin varying from strand to outer-shelf environments. The formation is dated as Early Silurian (Middle to Late Llandoverian) in central Saudi Arabia.

In the map area, the Tayyarat was penetrated in the Al Adari drill hole (approximately lat 29° 50' N., long 39° 30' E.), located in Wadi as Sirhan about 35 km west of the town of Al Jawf. Drill samples collected between the depths of 1,498 m and 2,510 m (total depth) consisting of mostly dark-gray shale and siltstone, tained typical Lower Silurian (Llandoverian) chitinozoans and acritarchs (H. A. McClure, Aramco, written commun.). Chitinozoans include *Clathrochitina carminae,*

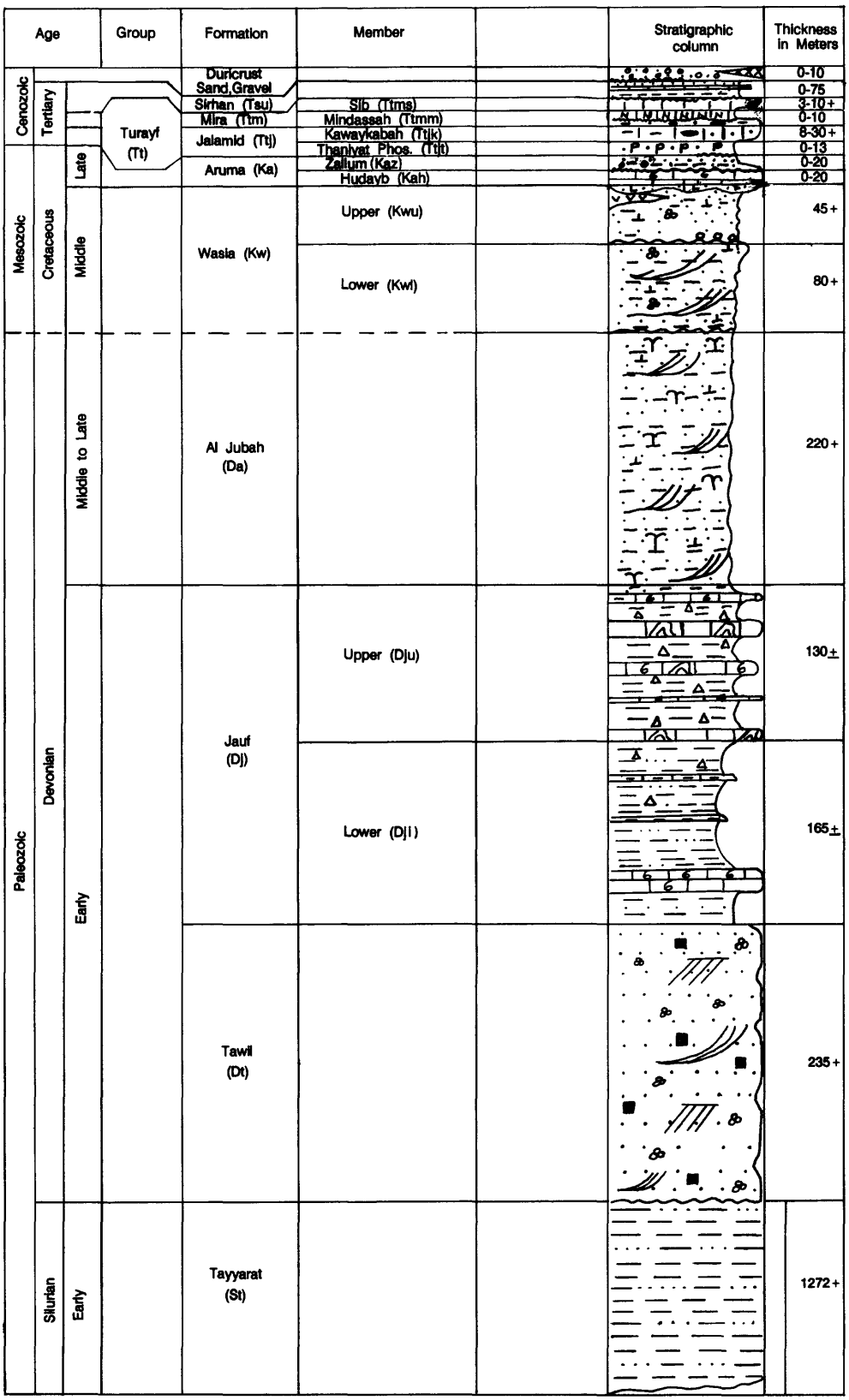


Figure 2.--General stratigraphic column of rocks in the Al Jawf quadrangle (See fig. 4 for explanation of lithologic symbols and labels)

Ancyrochitina ancyrea, Conochitina gordonensis, Clathrochitina sylvanica, and *Sphaerochitina longicollis.* Acritarchs include *Geron gracilis, Diexallophasis (Baltisphaeridium) denticulatum, Neoveryhachium carminae, Baltisphaeridium cymula, Onondagella* sp., and eight other species not listed here. They are all marine palynomorphs in the Qusaiba shale member or its equivalent, according to McClure. The interval between 1,238 m and 1,498 m in the Al Adari drill hole consists of dark-gray claystone that also may be part of the Qusaiba, but samples from this interval were not examined for palynomorphs. Therefore, Silurian rocks are at least 1,012 m thick (1,498-2,510 m) and may be as much as 1,272 m thick (1,238-2,510 m) (or more, because the hole bottomed in Silurian rocks). These thicknesses far exceed the 187 m thickness given for the Tayyarat at its type section in central Saudi Arabia, and 98 m given for the Qusaiba member of the Tayyarat. Excessive thicknesses of Silurian and other pre-Tertiary rocks have been noted in the rocks in other deep drill holes in Wadi as Sirhan to the northwest of the quadrangle (Meissner and others, 1987, 1988a, and 1988b). Apparently the Wadi as Sirhan graben was deep and probably growing deeper during the Silurian Period, which would account for such exaggerated sedimentary thicknesses (cross section A-A', pl. 1).

Samples collected above the 1,238-m level in the Al Adari drill hole are poorly sorted (rock samples from shallower intervals are mixed with deeper intervals) and all major contacts of shallower rocks are estimated. Abnormal thicknesses of the Devonian Tawil (Dt), Jauf (Dj), and Al Jubah (Da) formations in the drill hole appear to be related to apparent increased sedimentary thicknesses of formations in the axial part of the Wadi as Sirhan graben complex.

TAWIL FORMATION

The type section of the Lower Devonian Tawil Formation (former Tawil Member of Powers and others, 1966, and Powers, 1968, and changed to formation status by Vaslet, 1987) is in the north-facing escarpment of At Tawil (lat 29°29' N., long 39°30' E.) in the Al Jawf quadrangle. However, neither the upper nor lower parts of the formation are exposed at At Tawil; a more complete section at Ash Shaib, located about 250 km to the west-southwest, has been designated as a reference section (Powers, 1968). At the reference section, the Tawil is 177 m thick and composed of gray to brown sandstone in black-weathering, dominantly cross-bedded, platy and concretionary ironstone in a number of beds, and occasional shaly and silty intervals, particularly in the lower and middle parts.

The Tawil in the map area is mainly exposed in the mountainous At Tawil area, where its maximum thickness is 235 m. It is also exposed along the base of the Quraymiz and Rummamin escarpments, and in a moderate-sized area to the northeast of the Al Abd syncline. The formation consists of light-brown to brown and dark reddish-brown sandstone that weathers dark gray to black. The sandstone is composed of mostly medium to coarse, subangular to subrounded quartz grains, layers of grit, and scattered pebbles. It is medium to thick bedded with interbeds of

white to pale gray fine-grained sandstone, and silty and sandy shale that contains *Scolithos*-like vertical burrows. The bioturbated intervals are less resistant, forming narrow benches in the slopes of the mountains. High- and low-angle cross-beds, as well as ironstone layers and concretions, are common features of the sandstone. The sandstone contains ripple marks and is partly calcareous.

At the crest of the mountains in the At Tawil area, the Tawil Formation consists of silicified quartzitic sandstone and ferruginous chert breccia containing goethite and hematite nodules. Silicification and formation of iron oxides was probably caused by secondary-solution processes and severe oxidation due to a long period of exposure and weathering.

The Tawil rocks in the Al Adari drill hole (cross section A-A', pl. 1) are estimated to be about 400 m thick, whereas reported thicknesses do not exceed 235 m. Part of this additional thickness could be accounted for by including that part of the formation that was eroded away at At Tawil, as well as the part at the base that is not exposed. However, it is believed that most of the estimated additional thickness seen in the Al Adari drill hole is caused by deposition contemporaneous with down-faulting in the Wadi as Sirhan graben. The estimated total interval of rocks between the base of the Zallum member to the top of the Tayyarat in the drill hole is about 1,140 m, but the total thickness in outcrop may be only 875 m (fig. 2). Therefore, the abnormal thickness in the Al Adari drill hole is partly made up for by the increased thickness of the Tawil.

Diagnostic fossils are scarce in the Tawil Formation. A specimen of the gastropod *Plectonotus (Plectonotus)* sp. collected outside the map area is believed to be from the Early Devonian, and the presence of casts and molds of various pelecypods and brachiopods suggest an Early Devonian age (Powers and others, 1966; Powers, 1968). The depositional environment of the Tawil appears to be littoral, shallow-water marine (Powers, 1968), but Lozej (1983 and 1984) believes that parts of the Tawil contain fluvial deltaic sediments. Apparently, the Tawil underwent a period of shoreline fluctuation during cyclic episodes of marine transgression and regression.

The Tawil is conformable with the overlying Jauf Formation, but in places along the Quraymiz-Rummamin escarpments the Jauf is absent and the Tawil is unconformably overlain by the Upper Cretaceous Aruma Formation (Zallum member), or rocks of the Tertiary Turayf group.

JAUF FORMATION

The description of the Jauf Formation is based on a composite of 10 isolated sections occurring within a 30-km radius north and northwest of the town of Al Jawf (Steineke and others, 1958; Powers, 1968). The Jauf Formation of the type locality is described as probably Early and Middle Devonian in age. More recent work,

however, places the Jauf entirely in the Early Devonian (Emsian) age (H. A. McClure and A. J. Boucot, written commun., 1988). At the type locality, the formation is about 300 m thick and the general range of thicknesses reported elsewhere is from 215 m to 308 m. The Jauf is estimated to be more than 308 m thick in the Al Adari drill hole in Wadi as Sirhan (cross section A-A', pl.1); this is believed to be caused by deposition contemporaneous with down-faulting of the Wadi as Sirhan graben. The Jauf consists of varicolored silty shale with numerous thin beds of limestone and dolomite in the upper part and near the base, and thin beds of sandstone at several levels. At the type locality, the formation has been divided into five informal units that are briefly described below (base to top):

Sha'iba shale member -- 33.6 m thick, consisting of green and red silty shale and subordinate impure limestone and sandstone.

Qasr limestone member -- 18.8 m thick, consisting of limestone and dolomite; grayish tan, thin bedded, and locally contains reef mounds 1 to 5 m high.

Subbat shale member -- 113.4 m thick, consisting of banded red and greenish-gray silty shale with minor beds of micaceous sandstone and siltstone, and plates of secondary gypsum.

Hammamiyat limestone member -- 106.3 m thick, consisting of tan, thin-bedded limestone and dolomite, locally coral bearing and stromatolitic, that alternates with grayish-green silty shale.

Transition zone -- 27.1 m thick, consisting of complexly interbedded sandstone, shale, and siltstone with several thin beds of platy impure limestone and dolomite.

In this report, the Jauf Formation is divided into two members, Lower and Upper, for purposes of lithologic description, but the members are combined on the map (Djlu) due to poor boundary exposures.

Lower Member

The Lower member of the Jauf (Djl) is correlated with the Sha'iba shale, Qasr limestone, and Subbat shale members at the type locality (table 1). It is about 165 m thick and consists of red-and-green-banded shale, claystone, mudstone, and siltstone with interbeds of sandstone and some argillaceous limestone. A thin-bedded, partly argillaceous limestone unit occurs near the base and is overlain by red-and-green-banded micaceous shale that is partly calcareous and contains minor sandstone and siltstone interbeds, and very thin layers of gypsum. The upper part of the Lower member is green shale with a few red bands, several very thin impure limestone beds, and abundant thin layers of gypsum. The rocks are nonresistant and form slopes and basins.

The Lower member is believed to have been deposited in a marine to brackish marine and coastal lagoon hypersaline environment. The member is in conformable contact with the overlying Upper member.

Upper Member

The Upper member of the Jauf (Dju) is correlated with the Hammamiyat limestone member and Transition zone of the type locality (table 1). It is about 130 m thick and consists mostly of fossiliferous, partly dolomitic limestone and shale. There are at least four separate limestone beds in the Upper member, each 7-10 m thick. The bedded limestone is light gray to light brown, microcrystalline, thin bedded, and contains fossil coral reefs, bioherms, and stromatolites. Locally the stromatolites form concentric circles of limestone more than 3 m in diameter. The limestone beds form the cap rock of buttes, mesas, and "hog-back" ridges on the flanks of structural anticlines and synclines; weathering causes it to decompose into smooth, tabular fragments. The limestone beds are separated by grayish-green, silty calcareous shale that contains primary gypsum in thin layers and secondary gypsum in fractures and joints. The top of the Upper member consists of sandstone, siltstone, and shale. The sandstone is very thin bedded to laminated with cross-beds, and is calcareous. The shale and siltstone are light green to light tan with abundant secondary gypsum and one chert bed. Near the top of this unit is a gastropod coquina bed (first described by Lozej, 1983) that is only 2-3 cm thick but very resistant; it is an excellent marker bed for the top of the Jauf Formation.

A limestone bed of the Upper member contains fossils of the pelecypods *Modiolopsis obliqueducta* and *Leptodesma lamellosa* that are, according to Bahfzallah and others (1981a), typical Lower Devonian (Siegenian) species. The spore *Emphanisporites* sp. was collected from the Jauf Formation and is also referred to by Bahfzallah and others (1981a) as being typical of the Lower Devonian.

The depositional environment of the Upper member of the Jauf Formation is described as shallow marine with carbonate-platform facies (Lozej, 1984). The top of the Upper member (top of Jauf) is stratigraphically conformable with the overlying Al Jubah formation, but in areas northeast of the town of Al Jawf the contact is faulted. In the southern part of the Al Jayb escarpment, the Al Jubah sandstone is absent and the Upper member of the Jauf is in unconformable contact with the overlying Zallum member of the Cretaceous Aruma Formation. At Al Jayb, the contact is erosional and marked by a distinctive conglomerate bed.

Al Jubah Formation

The Al Jubah formation (Da) is a new formation name proposed in this report for the Devonian sandstone, silty shale, and siltstone that conformably overlies the Jauf Formation in the Al Jubah area of the northeastern part of the quadrangle. The Al Jubah area extends northward into the Ash Shuwayhitiyah quadrangle and is

bounded by the Jal al Jubah al Gharbi escarpment on the west and Jal al Jubah ash Sharqi escarpment on the east. The town of Sakakah is located in the south-central part of the area (fig. 1).

The Al Jubah formation includes rocks that have had a controversial stratigraphic history, being variously dated from Paleozoic to Cretaceous, and variously named Sakaka, Wasia, and Wasia-Biyadh (table 1). The controversy continued even after the identification of the Devonian index fossil *Prototaxites* sp. associated with these rocks by Bahafzallah and others (1981b). *Prototaxites* sp. is a unique tree-like fungus (or algae) that grew only during the Devonian Period (Francis M. Hueber, Smithsonian Institution, Washington, D. C., personal commun., 1988), and fossilized specimens of this fungus were first identified by Bahafzallah and others (1981b) at a single site 2-3 km west of Sakakah. However, none of the specimens at the Sakakah site are in place; they are worn and weathered, and appear to have been transported, and therefore were not considered positive evidence of the presence of Devonian rocks at that locality. Later, while mapping in the Ash Shuwayhitiyah quadrangle to the north of the Sakakah locality, *Prototaxites* sp. fossils were found by Meissner and others (1986). These specimens were much less worn and weathered, and some were partially imbedded in the rocks, offering more convincing evidence of a Devonian age for the enclosing rocks. Meissner and others (1986) then introduced an Upper member of the Jauf Formation that placed the Devonian *Prototaxites*-bearing sandstone above the originally described Jauf, thus giving the Jauf a three-part subdivison: Lower, Middle, and Upper members (table 1). This subdivision was perpetuated in the Thaniyat Turayf quadrangle to the west of the Al Jawf quadrangle.

Mapping in the Al Jawf quadrangle and more exploration in the Ash Shuwayhitiyah quadrangle led to the discovery of a number of additional excellent *Prototaxites* sp. sites that considerably expanded the Upper member of the Jauf to the point that it seemed more stratigraphically plausible to abandon the Upper member subdivision and introduce the Al Jubah formation, thus leaving the Jauf Formation as originally described at its type locality (table 1).

The thickness of the Al Jubah formation cannot be measured accurately because it is nowhere in total vertical outcrop section, and its complete thickness has not been positively identified in drill holes. However, by calculation of regional dip and measurement of a partial section at Jabal Qiyal al Kabir in the Ash Shuwayhitiayh quadrangle, thickness is estimated to be at least 220 m. (An estimated thickness of about 340 m is interpreted for the Al Jubah formation in the Al Adari drill hole to conform with the excess thicknesses apparent in the Wadi as Sirhan graben). The formation consists of sandstone that is white, pale brown or pale gray, to greenish gray in fresh appearance, but most everywhere is weathered reddish-brown to brown and brownish-gray. It is fine to medium grained, generally well sorted with subangular to subrounded quartz grains. The sandstone is mostly thin to medium bedded, but locally it is thick bedded and contains low-angle cross-bedding and a few ripple marks. Dark mineral grains are scattered throughout

Table 1.--Schematic nomenclature correlation chart, for Paleozoic and Mesozoic rocks in the Al Jubah area, Sirhan-Turayf Basin.

Bramkamp & others 1963		Powers & others 1966		Powers, 1968		Bahafzallah & others 1981a		Bahafzallah & others 1981b		Lozej, 1983		Lozej, 1984		Van Eck, 1985* Meissner & others 1986		Van Eck, 1985* This report Meissner & others 1988		
Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	Series	Formation, member	
Upper Cretaceous	Aruma Formation	Upper Cretaceous	Aruma Formation	Upper Cretaceous	Aruma Formation		Aruma Formation		Aruma Formation	Upper Cretaceous	Aruma Formation	Upper Cretaceous	Aruma Formation	Upper* Cretaceous	Aruma Fm. Badanah Mbr.	Upper* Cretaceous	Aruma Fm. Badanah Mbr.	
															Zallum Mbr.		Zallum Mbr.	
															Hudayb Mbr.		Hudayb Mbr.	
Paleozoic or Mesozoic	"Sakakah Sandstone"	Middle Cretaceous	Wasia Formation	Middle Cretaceous	Wasia Formation	Middle + Upper Cretaceous	"Sakakah Sandstone"	Devonian	"Sakakah Sandstone"	Mid. Cret. / Lower Cretaceous	Wasia Formation / Biyadh Formation	Lower to Upper Cretaceous	Wasia-Biyad undivided	Middle Cretaceous	Wasia Formation: Upper member	Middle Cretaceous	Wasia Formation: Upper	
															Middle member		Lower	
										Paleozoic	"Sakakah Sandstone"				Lower member	Middle + Upper Devonian	Al Jubah	
														Lower to Upper Devonian	Upper member			
Devonian	Jauf Formation	Lower? Devonian	Jauf Formation	Lower? + Middle Devonian	Jauf Formation: Transition zone / Hammamiyat Ls.Mbr. / Subbat St. Mbr. / Qasr Ls. Mbr. / Shaiba Sh. Mbr.	Lower Devonian	Jauf Formation: Transition silts / Hammamiyat Ls.Mbr. / Subbat St. Mbr. / Qasr Ls. Mbr. / Shaiba Sh. Mbr.	Lower Devonian	Jauf Formation	Lower + Middle Devonian	Jauf Formation: Upper member / Lower member		Upper Mbr. / Middle member / Lower member		Jauf Formation: Middle member / Lower member	Lower Devonian	Jauf Formation: Upper member / Lower member	
	Tawil Sandstone member	Lower Devonian	Tawil Sandstone member	Lower Devonian	Tawil member	Lower Devonian	Tawil Sandstone	Lower Devonian	Tawil Sandstone	Lower Devonian	Tawil Formation	Lower Devonian	Tawil member	Lower Devonian	Tawil Formation	Lower Devonian	Tawil Formation	

the fabric of the sandstone, and mica flakes are seen along laminated bedding planes. The sandstone is calcareous, locally shaley, and contains white clay (kaolinite?) in places. The Al Jubah sandstone is interbedded with silty and sandy shale that is light green to varicolored buff, green, yellow, reddish brown, and also light green and light purple banded, or mottled white and pink. A few clay beds (suggestive of an underclay to a coal bed) occur in the upper part of the Al Jubah, and casts and molds of plant debris are associated with thin-bedded, shaly sandstone layers. There are minor interbeds of mottled yellow, red, and brown siltstone.

The areal extent of the Al Jubah formation and its contact with the overlying Wasia Formation was determined mainly on the basis of the distribution of *Prototaxites* sp. found in the rocks. Additional fossil evidence of a Devonian age for the Al Jubah occur in the form of fossilized fish remains, including dermal scutes and spines of acanthodians and arthrodires, believed to be fresh water fish possibly of Middle Devonian age (H. A. McClure, Aramco, written commun., 1988). In the Al Jubah area, the Al Jubah formation is believed to be in fault contact with the Wasia just west of Sakakah, but continues roughly northward along a hypothetical line projected into the Ash Shuwayhitiyah quadrangle to a point immediately east of a Devonian fossil-fish site (at lat 30° 14.3' N., long 40° 10.7' E.). (This area includes the former Lower member of the Wasia Formation of Meissner and others, 1986; table 1). There is no apparent stratigraphic break at this contact and the sandstone to the east appears to be identical to the sandstone west of the line; however, no fossil evidence of Devonian rocks has been found, as yet, east of the interpreted contact. The Al Jubah formation also occurs along the north flank of the Al Abd syncline, and in several isolated areas south of the Al Ajaiz and Tais al Fahham (near Al Murut) areas 60 to 70 km southwest of the Al Jubah area.

Subsurface evidence of the Al Jubah formation is interpreted from data of two deep drill holes, one at the town of Sakakah, and the other in the Ash Shuwayhitiayh quadrangle to the north. A deep water well is located at Sakakah between the south side of town and the old airport. Middle and Upper Devonian spores and pollen where found in shale interbeds of a sandstone unit between 110 m and 255.5 m total depth (Aramco, unpub. data). The shale interbeds occur at 144-152 m, 186-196 m, and 252-255 m, and consist of gray to greenish-gray, micaceous, partly silty shale. Brown to dark brown material originally identified as fossil wood was found in the sandstone at a depth of 220-238 m; this is most probably *Prototaxites* sp. The age and clastic nature of this unit strongly suggests that it is part of the Al Jubah formation. Sandstone also occurs from the surface to 110 m that is reported to be Cretaceous (Aramco, unpub. data). (Also see discussion on the Wasia Formation in this report). If this is true then the Al Jubah formation must be faulted down at least 110 m at the drill site because *Prototaxites*-bearing sandstone occurs on the surface in the hills at the west edge of Sakakah (pl. 1, and cross section A-A'). The other deep drill hole, S-462 (lat 30° 30'19" N., long 40° 25'39" E.; fig. 1), near the east-central border of the Ash Shuwayhitiyah quadrangle, contains rock fragments described as "continental clastics" between 445 m and 855 m total depth, that yielded Middle to Upper Devonian (Givetian to Frasnian) spore and pollen assemblages (H. A.

McClure, Aramco, unpub. data). The age and clastic nature of this unit also suggests that it belongs to the Al Jubah formation or its equivalent. If this is the equivalent Al Jubah formation, then it is at least 190 m (total depth of hole still in clastics) thicker than the 220 m estimated at the surface, suggesting that the Al Jubah thickens northeastward.

The Al Jubah formation appears to be of continental origin, probably deposited in a fluvial-deltaic environment. Its contact with the overlying Wasia Formation is unconformable with slight angular discordance.

It is important to note the scientific interest generated by the discovery of outstanding specimens of *Prototaxites* sp. in the Al Jubah area. Francis M. Hueber, Curator of Paleobotany, Department of Paleobiology, National Museum of Natural History (Smithsonian Institution), Washington, D. C., is an international *Prototaxites* sp. expert and has visited practically every known locality of the fossil fungus in the world. Hueber has visited the Al Jubah area twice on research grants from the Smithsonian Institution: once in November, 1985, and again in March, 1988. The results of Hueber's first trip are mentioned in the report on the Ash Shuwahitiyah quadrangle (Meissner and others, 1986). On his second trip, he examined newly discovered specimens in the Al Jawf quadrangle, including a 4.2 m x 1.2 m "log" of the fungus discovered by C. R. Meissner, Jr. about 4 km south of Sakakah (fig. 3a). According to Hueber, this specimen has the largest diameter of any other specimen in the world. Another large log, 3.1 m long and nearly 1 m wide at the base, was found by Saleh Dini to the northwest of the world-record holder (fig. 3b). *Prototaxites* sp. is an important Devonian index fossil and its recognition in the Al Jubah area has been extremely useful in helping resolve the lithostratigraphic and chronostratigraphic history of the southeastern part of the Sirhan-Turayf basin.

WASIA FORMATION

The type section of the Wasia Formation (Kw) is "in the lower slope of Al Aramah escarpment extending from the pre-Wasia unconformity (lat 24° 23'04" N., long 47° 45'12" E.) southeast to low hills near Wasi (lat 24° 22'38" N., long 47° 45'49" E.)" (Powers, 1968). The Wasia at the type section is 42 m thick and consists of brown-to-black-weathering sandstone with interbedded red and green shale in the lower part. It is Middle Cretaceous in age.

Drill-hole data has revealed lateral extension of the Wasia from the type section to the Al Jawf quadrangle (Al Jubah area). The original description of Powers (1968) and Bramkamp and others (1963, 1982) included all of the sandstone units in the Al Jubah area, but we now know that the western half of that area contains the Devonian Al Jubah formation. Therefore, the remaining eastern half of the Al Jubah area presumably contains the Middle Cretaceous Wasia Formation.

Figure 3A.--Record-size *Prototaxites* specimen found near Sakakah. "Log" measures 4.2 m long and 1.2 m wide.

Figure 3B.--Large *Prototaxites* log, Al Jubah area. Log is 3.1 m long and nearly 1 m wide at base.

The Wasia has been subdivided into two informal units within the quadrangle, Lower and Upper, with a minimum estimated exposed thickness of 125 m. [The Lower member of the three-member subdivision described by Meissner and others (1986) is now part of the Al Jubah formation; therefore, the Middle member is now the Lower member of the two-part subdivision described in this report (table 1).

Lower Member

The Lower member (Kwl) has an estimated exposed thickness of at least 80 m and consists of sandstone, silty shale, and mudstone. The sandstone is pale brown to light gray with a "salt-and-pepper" texture (dark and light mineral grains); it weathers reddish brown to brown with a black coating locally. It appears to have more reddish color than the underlying Al Jubah sandstone. It is fine to coarse grained and the grains are subangular to subrounded. Locally, it is conglomeratic, containing quartz pebbles, and is ferruginous, manganiferous, and micaceous. The sandstone is thin to thick bedded, abundantly cross bedded, and locally contains linguloid ripple marks. A few beds are bioturbated with vertical worm burrows. The interbedded silty shale and mudstone is mottled green, red, purple, and gray. Sandstone at the top of the member forms a bench at the foot of a high scarp that contains the Upper member of the Wasia Formation.

The Lower member of the Wasia appears to be of continental origin, and like the underlying Al Jubah formation, was probably formed in a fluvial-deltaic environment. Its contact with the Upper member is disconformable.

Upper Member

The Upper member of the Wasia Formation (Kwu) is well exposed in a 30-60-m-high scarp, Jal al Jubah ash Sharqi, capped by the Hudayb member of the Aruma Formation in the northeast corner of the map area (pl.1). The member is estimated to be at least 45 m thick and consists of sandstone and claystone with a lenticular veneer of lateritic sandstone, siltstone, and mudstone at the top. The sandstone is white to light brown, locally weathers to a reddish color, is composed mostly of fine to coarse, clear to frosted subangular quartz grains, and contains gritty layers and minor quartz-pebble conglomerate. The sandstone matrix contains abundant white clay with clay flakes and pebbles (kaolinite?). The sandstone is thin to thick bedded, friable, locally very calcareous and argillaceous, and contains numerous cross-beds. The Upper member contains lenses of quartzite near its top and limestone cobbles at the base. It has white clay beds in places that are slightly sandy, loose, and friable. Fossil-wood molds of sandstone occur locally.

The top of the Upper member (top of the Wasia Formation) consists of varicolored friable sandstone, siltstone, shale, and mudstone that are each mottled green and red. This unit is lenticular, pinching out in many places along the outcrop. It appears to represent a partially lateritized surface consisting of fine-grained to conglomeratic quartz sand beds. Petrified wood that weathers out of the topmost

layer of the unit is found in abundance at one site north of the map area. This material was examined by Hueber to confirm that it is, in fact, fossil wood and not *Prototaxites* sp.

The Wasia Formation in the Subsurface

Subsurface evidence of the Wasia Formation has been obtained from water well drill holes located in the Al Jubah area, and from a deep stratigraphic test hole (S-462) north of the map area. The Sakakah drill hole (mentioned earlier in the discussion of the Al Jubah formation) contains Wasia sandstone from the surface to a depth of 110 m (Aramco, unpub. data). Middle Cretaceous ostracods were identified between 0-2 m and 16-18 m; it is believed that if not in place, these fossils are at least penecontemporaneous with the deposition of the sandstone (H. A. McClure, Aramco, personal commun. 1987). The remainder of the Wasia is barren of fossils, consisting of red, pink, buff, and tan micaceous sandstone that also contains a few siltstone beds. The S-462 drill hole, located near the east-central border of the Ash Shuwayhitiyah quadrangle (fig. 1), contains 267 m of Wasia rocks at depths of 178-445 m (Aramco, unpub. data). No fossils were reported from the Wasia in this hole, and its lithology is presumed to be mostly sandstone. Its thickness is more than twice the 125 m estimated at the surface in the Al Jawf quadrangle, and like the underlying Al Jubah formation, the section evidently thickens northeastward.

Water-well drilling in the Al Jubah area north of the quadrangle has supplied data that allows for a reasonable interpretation of the relationship between the Wasia and Al Jubah formations (Ministry of Agriculture and Water, unpub. data). The Wasia overlaps part of the Al Jubah in slight angular discordance so that there is a sandstone-to-sandstone contact of very similar rocks (fig. 4). Both the Wasia and Al Jubah dip gently eastward and the contact between the two formations is irregularly eroded, making it very difficult to trace on the surface. There is no recognizable topographic break at the Al Jubah-Wasia contact and the formations can not be distinguised in the Ash Shuwayhitiyah quadrangle. The situation is different in the Al Jawf quadrangle where the Wasia and Al Jubah are in fault contact (pl. 1).

The lithology of the Upper member of the Wasia Formation suggests shallow water to shoreline deposition. The contact of the Upper member with the overlying Hudayb member of the Aruma Formation is unconformable.

ARUMA FORMATION

The type section of the Aruma Formation (Ka) is on the Al'Aramah plateau, where a composite sequence was constructed from several sections located along a traverse from Khashm Khanasir (lat 25° 38'12" N., long 46° 22'29" E.) northeast to a point on the back slope of Al'Aramah escarpment (lat 25° 39'18" N., long 46° 30'41" E.) in which the top of the Aruma Formation is exposed (Powers and others, 1966,

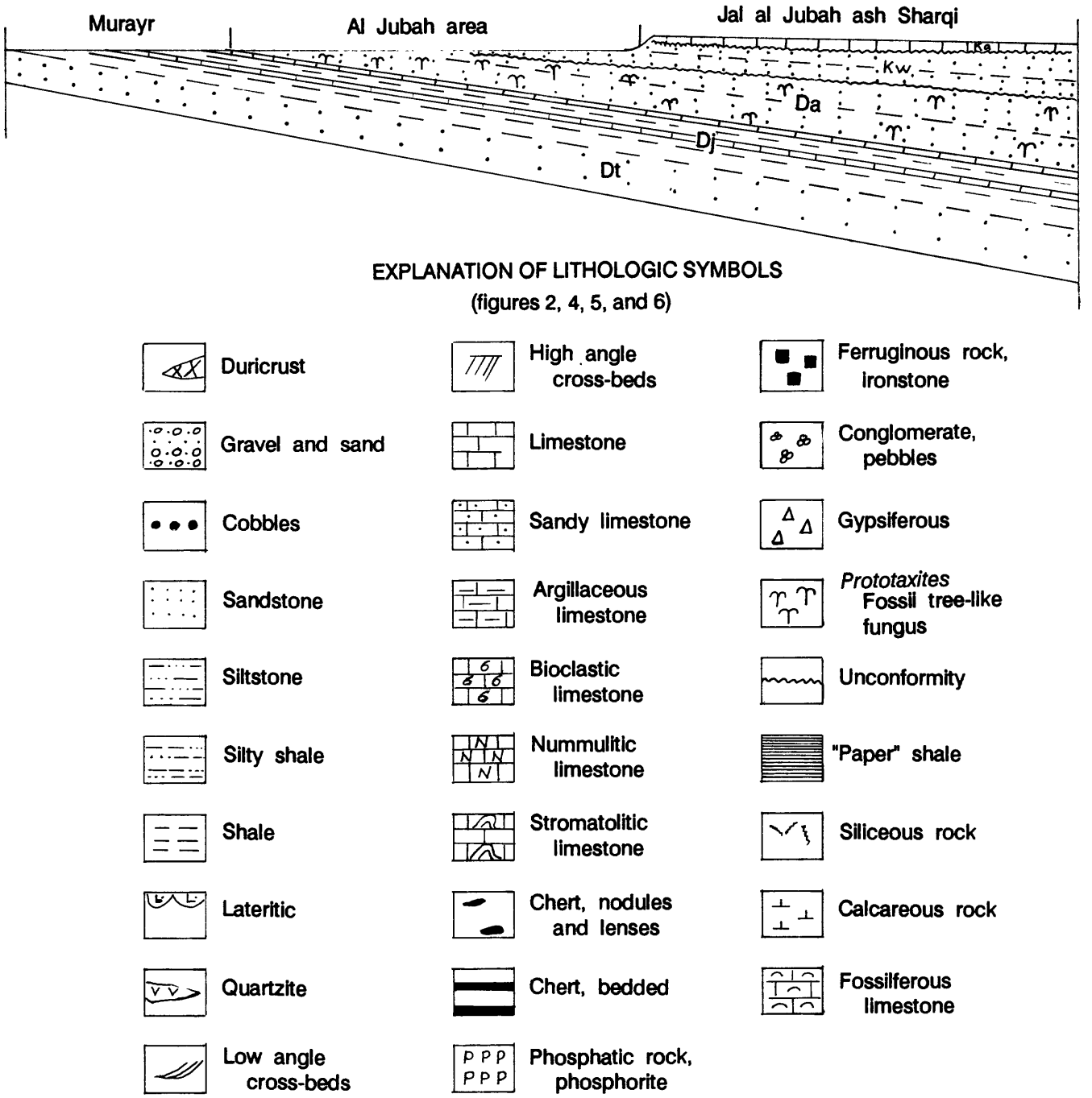


Figure 4.--Schematic stratigraphic cross section of Cretaceous to Devonian units in the Al Jubah and adjacent areas.

Powers, 1968). The Aruma at the type section is 141.5 m thick and consists of dolomite, limestone, and calcareous shale with a few sandy layers near the bottom. The age of the Aruma is Late Cretaceous.

Powers (1968) described the marked lithologic changes of the Aruma in the northern part of its outcrop where at Khashm Zallum (lat 30° 18' N., long 40° 21' E., in the Ash Shuwayhitiyah quadrangle) 61 m of sandstone overlies an 11-m-thick basal-limestone bed. The sandstone has been informally designated the Zallum sandstone by Powers (1968), and the basal limestone bed in the quadrangle has been informally referred to as the Hudayb limestone after the village of Hudayb, located about 25 km northeast of Sakakah (Lozej, 1984). A redefinition of the Aruma Formation in the Sirhan-Turayf basin was made by van Eck (1985), in which he subdivides the formation into three members, from bottom to top: the Hudayb, Zallum, and Badanah (table 1). The Badanah member is absent in the map area.

Hudayb Member

The Hudayb member (Kah) has been described as an 11-meter-thick basal unit of the Aruma limestone by Powers and others (1966), and Lozej (1984) refers to it as the Lower Aruma carbonate (Unit 2) Hudayb limestone. The member is well exposed east of Hudayb village, forming a prominent ledge capping the nearby Jal al Jubah ash Sharqi escarpment (fig. 1); it trends southeastward along the scarp into the northeast corner of the Al Jawf quadrangle.

In the map area, the Hudayb consists of limestone, which is dolomitic and algal, light yellowish brown to pale gray, microcrystalline, slightly sandy, and thin bedded. The member is eroded and only 1-3 m thick at the edge of the Jal al Jubah ash Sharqi escarpment; east of the escarpment, it is locally as much as 20 m thick. The weathered surface of the limestone is porous and vuggy with a rough texture. It contains marine fossils, including a large gastropod seen elsewhere in the Aruma carbonates, and abundant casts and molds of pelecypods. The presence of the foraminifera *Lepidorbitoides* sp. and *Omphalocylus* sp., and fragments of *Loftusia* sp. from a locality southeast of the quadrangle, indicate a Late Cretaceous tian) age for the Hudayb member (Lozej, 1984).

The lithology of the Hudayb suggests a shallow marine environment of deposition. The overlying Zallum member has been eroded away at the Jal al Jubah ash Sharqi escarpment, and where the Zallum is exposed in the western part of the map area, the Hudyab pinches out, and thus is absent.

Zallum Member

The Zallum member (Kaz) has been described as the Zallum sandstone by Powers and others (1966), and as the "Zallum facies" by Lozej (1984). The Zallum member is regionally continuous and has been divided into three predominant facies (van Eck, 1985), of which the sandstone facies occurs within the Al Jawf quadrangle.

The Zallum is a good marker bed for Cretaceous rocks in the quadrangle. Its numerous bright colors make it readily visible in parts of the Al Jayb and Rummamin escarpments; it is apparently absent or covered by scree at Quraymiz and along parts of the Az Zilliyah-Ajrabah escarpments, near the north-central border of the quadrangle. The Zallum ranges in thickness from a few meters to about 20 m, and consists of sandstone, conglomeratic sandstone, argillaceous sandstone, shale, and mudstone. Its colors include white, light green, yellow, red, purple, tan, brown, and black. The mottled colors are mostly due to weathering of its minerals with high iron content. It is fine grained, friable, loose and soft, except where case-hardened by hematite; the quartz grains are subrounded to subangular. A sandstone cobble bed approximately 0.5 m thick lies at the base of the Zallum near its contact with underlying rocks.

The foraminifera *Loftusia* sp., found in the upper part of the bioclastic carbonate-shale facies of the Zallum member near Ar'Ar, to the northeast of the map area, indicates a Late Cretaceous (Maastrichian) age. The Zallum was deposited under near-shore marine conditions (van Eck, 1985), and it is in unconformable to transitional contact with overlying formations of the Cretaceous-Tertiary Turayf group.

TURAYF GROUP

The Turayf group (Tt) 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 (Maastrichian) 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 stratigraphic order. These formations represent three periods of cyclic carbonate sedimentation comprising repetitive, short, onlapping transgressive-regressive events on shallow marine shelves, with phosphorite members occurring at the base of each sedimentary cycle. An inner-shelf subtidal to restricted-shelf depositional environment is generally indicated (Riddler and others, 1986).

The Al Jawf quadrangle contains parts of the Jalamid and Mira formations (fig. 2) that form the cap rocks of the Al Jayb, Quraymiz, Rummamin, Az Zilliyah, and Ajrabah escarpments, extending from the southwestern part of the map area to the north-central border. The thickness of the combined Jalamid and Mira formations ranges from about 11 to 60 m, and it is believed that the Turayf group increases in thickness westward from the rim of the basin.

Descriptions of formations of the Turayf group given in this report are summaries of observations from current mapping, and from detailed descriptions by Smith (1983) and Aspinall and others (1985).

Jalamid Formation

The Jalamid formation (Ttj) takes its name from outcrops around the Al Jalamid Trans-Arabian Pipeline pump station located about 150 km north of the map area. The Jalamid is subdivided into two members: the Thaniyat phosphorite, and the Kuwaykabah member, in ascending stratigraphic order.

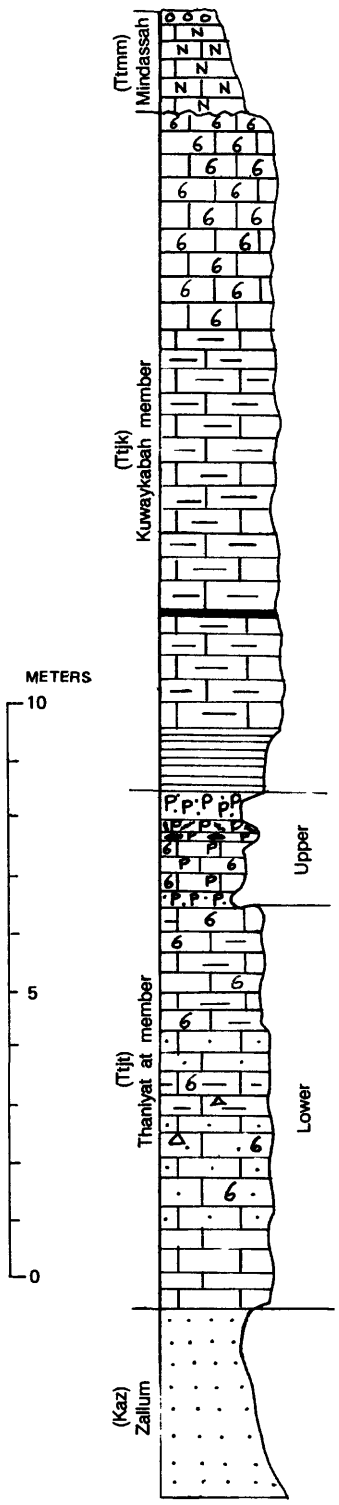
Thaniyat phosphorite member -- The Thaniyat phosphorite member takes its name from exposures in the Thaniyat escarpment, located about 100 km west of the map area (fig.1), where it consists of interbedded phosphorite, chert, shale, micrite, and dolomicrite. The Thaniyat in the map area ranges in thickness from 0 to 13 m and consists of sandy, argillaceous, partly bioclastic and phosphatic limestone; it contains at least one phosphatic chert bed and several thin beds of phosphorite, especially near the top.

In the Al Jawf quadrangle, the Thaniyat phosphorite is best exposed along the Rummamin escarpment between lats 29° 56' N. to 30° 00' N., and longs 39° 30' E. to 39° 40' E., where it is described in two parts, lower and upper, as shown in the measured section DF 18 (fig. 5). The lower part is lenticular, ranging in thickness from 0 to 7 m, and consists of a light-brown, sandy limestone that contains fossilized fish-bone fragments and shell debris; it becomes argillaceous toward the top. The upper part is about 2 m thick and consists of sandy conglomeratic phosphorite interbedded with phosphatic limestone and chert. The phosphorite beds are from 0.10 to 0.50 m thick. The Thaniyat member grades eastward from the Rummamin escarpment into a coarse chert coquina that contains lenses of phosphorite, and then pinches out at about long 39° 40' E., in the Az Zilliyah area.

The Thaniyat phosphorite member is poorly exposed in the Quraymiz area, southwest of Rummamin, because of abundant scree from the overlying Kuwaykabah member. However, where found, it appears to be similar in composition to the Thaniyat phosphorite at Rummamin.

South of Quraymiz, in the Al Jayb escarpment, the Thaniyat phosphorite, or its equivalent, is lenticular and difficult to distinguish from the overlying Kuwaykabah member. The Thaniyat consists of partly phosphatic argillaceous limestone and shale, and contains lenses of calcareous phosphate near the base; the Kuwaykabah also consists of similar-looking argillaceous limestone and shale, but in most places is nonphosphatic (section DF 2, fig. 6). The member is discontinuous along the Al Jayf escarpment and is shown in two isolated areas on the geologic map (pl.1) where it is best exposed.

The age of the Thaniyat phosphorite member is Late Cretaceous (Maastrichtian) to Early Paleocene, based on microfossils and fish teeth found in the Thaniyat area (Bayliss, 1983; Capetta and Riddler, 1985). Contact with the overlying Kuwaykabah member is conformable.



Residual chert and siliceous limestone gravel of Sib member

Nummulitic limestone, white, dolomitic; abundant nummulite molds (2mm-4mm); leached, partly silicified

Bioclastic limestone, yellowish brown; contains large pelecypod shells

Argillaceous limestone, yellowish brown

Chert, chocolate-colored

"Paper" shale, very finely fissile, yellowish brown

Phosphorite, friable (0.50m); shark's teeth, coprolites; sandy (18% P_2O_5)
Siliceous phosphate rock.
Phosphatic chert.
Phosphatic bioclastic limestone; clay pebbles.
Phosphorite, friable (0.30m); sharks teeth, clay pebbles; sandy (11% P_2O_5)

Limestone, white with yellowish stain; argillaceous; shell debris, slightly porous; hard and soft layers

Sandy limestone, light brown; contains fine quartz grains; fish bone fragments; gypsum and clay towards top

Sandstone, purple, maroon, tan with black spots; poorly consolidated

Figure 5.--Measured section (DF 18) of rocks of the Turayf group at the Rummamin escarpment. (See pl. 1 and fig. 4 for explanation of lithologic symbols and labels).

Kuwaykabah member -- This member (Ttjk) takes its name from Wadi al Kuwaykabah, located about 130 km to the west of the Al Jawf quadrangle (to the north of the Thaniyat area). At its type locality, it is 45-80 m thick and is subdivided into two beds: the lower Qutayfah bed and the upper Ghuzay bed. The Qutayfah bed consists of cherty micritic limestone, and the Ghuzay bed consists of bioclastic limestone.

The Kuwaykabah is undivided in the map area and is the main ledge-former or cap rock from Al Jayb to Ajrabah. The member ranges in thickness from less than 8 m to more than 30 m. It consists of white to yellowish-brown, partly sandy and argillaceous, microcrystalline, marly dolomitic limestone that contains shale beds, chert lenses and nodules, and fossil casts and molds. Locally, the Kuwaykabah contains silicified coquina beds. The basal part of the member is commonly sandy and (or) argillaceous, phosphatic, and locally contains brown, very fissile "paper shale" (especially in the Rummamin area). At places in the Al Jayb escarpment there is a thin, sandy carbonate conglomerate at the base of the Kuwaykabah.

The Kuwaykabah member is presumed to be Paleocene in age and its contact with the overlying Mindassah member of the Mira formation is unconformable.

Mira Formation

The Mira formation (Ttm) takes its name from Wadi al Mira, located about 160 km north of the map area in the northeastern part of the Sirhan-Turayf basin. The Mira is subdivided into four members: the Ghinah phosphorite, the Hawsa, Mindassah, and Sib, in ascending stratigraphic order. The Ghinah phosphorite and Hawsa members are absent in the Al Jawf quadrangle, and only the Mindassah and Sib crop out within it.

Mindassah member -- The type localities of the Mindassah member (Ttmm) are located in the Wadi umm Arta and Busayta al Mindassah areas about 90 km west of the quadrangle, north of the Thaniyat escarpment. This member is an important stratigraphic marker within the Turayf group. It consists of banks of bioclastic limestone or coquina that are highly leached; weathered surfaces are commonly silicified, jagged, and very rough. The thickest exposures (the Mindassah is combined with the overlying Sib member in most places [pl. 1] because of steep terrain) in the quadrangle are in the Quraymiz area, where it is nearly 10 m thick and consists of white, massive dolomitic limestone that contains abundant, small (2-4 mm) almond-shaped *Nummulites* sp. molds. Some of the small nummulites have been preserved by silicification and their ages are classified as Early Eocene (Bayliss, 1982). The member is also exposed in the Rummamin escarpment and the western part of the Az Zilliyah escarpment, to the northeast of Quraymiz, where it is 3 to 5 m thick. The Mindassah is absent in the Al Jayb area. The contact of the Mindassah with the overlying Sib member is conformable.

Sib Member -- The Sib member (Ttms) takes its name from Khabra as Sib, in the Ash Shuwayhitiyah quadrangle, about 25 km north of the map area. The member forms the cap rock of the Al Jayb-Quraymiz-Rummamin escarpments and the western part of the Az Zilliyah escarpment. It is chiefly represented by siliceous, partly phosphatic float at the tops of the escarpments, but in outcrops along the cliff rim it consists of alternating chert and limestone. The chert is dark brown to black, fine grained, banded, locally phosphatic, and thin bedded. The limestone is light gray, hard, micritic, siliceous in many places, and locally phosphatic. The thickness of individual beds ranges from a few centimeters to generally less than a meter; the overall thickness of the member in the map area ranges from a few meters to more than 10 m.

Mytton (1966) was the first to describe phosphate in the Sib member in the Quraymiz area. He measured a 19.8-m-thick section of rocks of the "Aruma" and "Hibr" formations (old names for the Kuwaykabah, Mindassah, and Sib members) located on the eastern scarp of Quraymiz (lat 29° 53' N., long 39° 25' E.) that contains a 1.6-m-thick bed of interlaminated chert and oolitic, phosphatic limestone. According to Mytton (1966) the phosphate bed is in the (lower) Hibr formation that consists of alternating thin-bedded chert and limestone units. These characteristics identify the Sib member. A sample of the phosphatic limestone from Mytton's measured section contained only 9.93 percent P_2O_5, but a sample from the same unit collected about 10 km to the west of the measured section contained 19.8 percent P_2O_5. This is the first reported instance of phosphate in what we now know as the Sib member of the Mira formation.

Smith (1983) reported thin phosphatic layers "in the east-facing scarp cliff of the Al Jayb block"; he noted that they do not correlate with either "Zone 5" (original designation for the Thaniyat phosphorite), or "Zone 4" (original designation for the Ghinah phosphorite), but are higher in the section. Samples collected from these phosphatic layers contained a maximum P_2O_5 concentration of 21 percent. If one considers Smith's statement that the height of the phosphatic layers in the section is greater than the Ghinah phosphorite member (absent in the map area), it is reasonable to assume that the phosphate is in the Sib.

Aspinall and others (1985) reported the presence of phosphatic chert and thin calcareous phosphorite lenses in the Sib of the Quraymiz and Rummamin areas.

A 1-m-thick bed of calcareous and siliceous phosphorite discovered during the current mapping project near the base of the Sib member in the Al Jayb area (lat 29°39'32" N., long 39°24'00" E.) includes a 0.20-m-thick phosphorite bed that contains about 17 percent P_2O_5. Measured outcrop section DF 2 (fig. 6) is located about 1 km south of the above-mentioned outcrop locality and contains about 8 m of Sib (interbedded limestone, chert, phosphatic chert, and calcareous phosphorite).

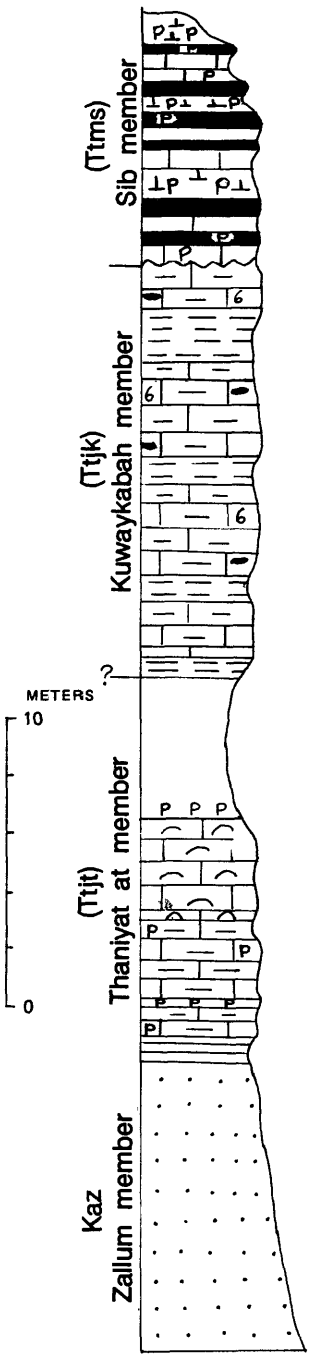


Figure 6.--Measured section (DF2) of rocks of the Turayf group at the Al Jayb escarpment. (See pl. 1 and fig. 4 for explanation of lithologic symbols and labels).

The dominance of silicification within the Sib member suggests that these rocks represent a major erosional episode during a marine regression. Minor transgressional events within it are represented by thin phosphatic layers (Griffin and others, 1984). Lower Eocene *Nummulites planulatus* have been identified in the Sib by Bayliss (1983). The member is the uppermost stratigraphic unit of the Turayf group exposed in the map area. It is in unconformable contact with the overlying Miocene-Pliocene Sirhan formation; where the Sirhan is absent, it is in unconformable contact with Quaternary deposits.

SIRHAN FORMATION

The youngest Tertiary sedimentary rocks in the map area are believed to be mostly Miocene in age, but may be in part Pliocene. Diagnostic fossil identification in the Sirhan formation is too limited to make positive age designations at this time. These rocks are informally named the Sirhan formation after the Wadi as Sirhan depression that extends northwestward from the northwestern part of the map area to the Jordan border (fig. 1 and Regional Geologic Setting on pl.1). In many places the Sirhan is poorly exposed, and outcrops are extensively weathered and partly covered by Quaternary deposits, making it difficult to determine the areal extent of the formation. There are a number of small scattered outcrops that are in sufficient quantity to map as a continuous unit rather than as numerous individual outcrops.

The formation is composed of multicolored sandstone and shale with interbeds of limestone. The sandstone is white, brown to mottled green, red, and gray, and consists of fine to grit-sized, subrounded quartz grains. It is friable, calcareous, and locally argillaceous. The shale is light yellow, grayish red, and mottled and banded red and green, looking very much like shale of the Jauf Formation. There also are beds of multicolored sandy claystone. The interbedded limestone of the Sirhan is white, gray to pale gray, pale yellow, pale purple, and mottled light gray and red. It is sandy, thin bedded, and commonly contains vertical *Scolithos*-like worm tubes.

The many colors of the Sirhan limestone and sandstone in the Al Jawf quadrangle contrast with the dominantly white color of the formation in the Wadi as Sirhan depression to the northwest of the map area. Furthermore, shale and stone, relatively common in the map area, are practically absent in the Wadi as Sirhan region to the northwest. The coloration of the Sirhan and an increase in shale content from the northwest to southeast, may reflect the exposure of the lower part of the formation rather than a lateral facies change. Meissner and others (1988a) suggested that, on the basis of deep drill-hole data, there is a three-part subdivision of the Sirhan, and the basal part is more shaly. The upper part of the formation is exposed in the northwestern part of Wadi as Sirhan, the middle part farther to the southeast (Meissner and others, 1988b), and now it is suggested that the lower part is exposed in the Al Jawf quadrangle (at the southeastern end of Wadi as Sirhan). This would mean that the Sirhan gradually thins from top to bottom along Wadi as Sirhan, and successively lower parts of the formation are exposed from the northwest to the southeast.

The Sirhan formation is exposed mainly in the central part and northwestern corner of the quadrangle. Banded red and green shale of the formation are exposed in breaks in the flat lowlands of the central area; these are also the only vertical exposures in the quadrangle. Maximum exposed thickness in the breaks is about 20 m; otherwise, outcrops of the Sirhan are 3-4 m or less. The Al Adari test well (water) located south of Quraymiz (lat 29° 00' N., long 39° 30' E.) in Wadi as Sirhan, contains an estimated 76 m of Sirhan, based on very poor percussion-drill samples. Directly southwest of the town of Al Jawf, undisturbed, flat-lying Sirhan stone caps steeply dipping Devonian Al Jubah sandstone that displays a remarkable angular unconformity. Sirhan limestone is also exposed in a low north-facing bluff immediately south of Al Jawf (not shown on pl.1) that supports a broad south-extending tableland (the Al Jouf airport is located on this tableland), where the limestone has been altered to duricrust.

No fossils have been found in those rocks of the Sirhan formation that are within the map area; it is assumed that the Sirhan has a continental origin, probably partly lacustrine. *Planorbis* sp., a fresh water snail, and *Chara* sp., a fresh water algae was found in Sirhan limestone to the northwest of the map area (Meissner and others, 1988b), indicating that at least some limestone beds were formed in a lake.

SEDIMENTARY HISTORY

A review of the descriptions of the Phanerozoic sedimentary rocks of the Al Jawf quadrangle shows that the rocks were deposited in marine and continental conditions produced by cyclic transgressions and regressions of the sea. These cycles were probably influenced by tectonic processes at work in the Sirhan-Turayf basin and its surroundings.

The Lower Silurian Tayyarat formation, which consists of thick dark-colored shale and contains abundant fossil chitinozoans and acritarchs, indicates deposition in a marine environment (probably outershelf). The Tayyarat was followed by a long hiatus in the geologic record prior to deposition of the Lower Devonian Tawil Formation. The Tawil contains *Scolithos* sp. trace fossils as well as casts and molds of pelecypods, indicating intertidal, near-shore conditions. Marine conditions alternated with fluvial-deltaic environments (caused by periodic regressions of the sea) characterized by braided streams, channel filling, and delta-plain features. Marine conditions prevailed during the deposition of the Lower Devonian Jauf Formation. The Lower member of the Jauf formed in a coastal lagoon brackish-water environment; it also contains one unit of reefal limestone and abundant gypsiferous shale with thin clastic limestone beds. The Upper member contains coral-bearing and stromatolitic limestone beds, indicative of shallow marine conditions and carbonate-platform facies.

During the formation of the Devonian (Middle to Upper) Al Jubah formation, the sedimentary process reverted to continental deposition upon regression of the sea. Al Jubah has the characteristic of a fluvial-deltaic environment and contains *Prototaxites* sp. fossils, a tree-like fungus that is believed to have grown on land with abundant organic material, possibly near water sources such as rivers and deltas. There was another long hiatus between the deposition of the Devonian Al Jubah formation and the Middle Cretaceous Wasia Formation, during which time wanaland broke up and what is now the Arabian peninsula was rafted northward. The Lower Wasia was also deposited in a fluvial deltaic environment and its rocks are very similar to those of the Al Jubah. Shallow marine, near-shore conditions returned with the formation of the white, relatively clean sandstone of the Upper Wasia.

Shallow marine, near-shore sedimentation continued during deposition of the Upper Cretaceous Aruma Formation. The lower member of the Aruma, the Hudayb member, is a foraminiferal limestone indicative of a shallow marine environment. The middle member of the Aruma, the Zallum member, consists of sandstone probably of marine-strand origin. The upper member of the Aruma, the Badanah member, is absent in the map area. At the time of the deposition of the Upper Cretaceous-Tertiary (Paleocene to Middle Eocene) phosphate-bearing carbonate sequence of the Turayf group, the Tethys sea (ancestor of the Mediterranean sea) occupied the Sirhan-Turayf basin in the form of a wide, shallow marine shelf. In the map area, the Turayf group includes parts of the Jalamid and Mira formations, in ascending stratigraphic order. An inner shelf subtidal to restricted shelf depositional environment is generally indicated for the Jalamid and Mira.

After the Middle Eocene, there was another hiatus in the sedimentary record prior to the deposition of the Miocene (and possibly Pliocene) Sirhan formation. The Sirhan is composed of mostly nonfossiliferous continental sandstone and shale. Interbedded with the sandstone and shale are thin beds of limestone, and in one of the limestone beds northwest of the map area *Planorbis* sp. and *Chara* sp. were identified, indicating a lacustrine environment.

QUATERNARY DEPOSITS

Quaternary deposits, including duricrust, gravel, eolian sand, and undifferentiated deposits of alluvium, silt, sand, and gravel cover more than half of the map area. It is difficult to map these deposits separately because they overlap each other and their boundaries are broad and vague. Duricrust, although it is a consolidated deposit, locally breaks down by weathering and forms its own gravel that partly covers the surface. Therefore, it is possible to map the area as duricrust, to map it separately as gravel, or to map it as both, using the fractional symbol "Qg/Qdc" on the map (pl. 1). Unconsolidated deposits are even more approximately delineated because wind-blown sand merges with gravel, and both sand and gravel merge with, or become a part of, the alluvium.

Therefore, Quaternary deposits as mapped (pl. 1) are, by definition, approximate and interpretive.

DURICRUST

Duricrust (Qdc) occurs in scattered patches in the map area and ranges in thickness from less than a meter to several meters. A large elongated patch extends from immediately south of the town of Al Jawf eastward to the eastern border of the quadrangle. Here the duricrust formed on the surface of the limestone of the Sirhan formation and can be seen in various stages of alteration (of the limestone) up to the point where it is considered a true residual crust. In places, the duricrust still contains the *Scolithos*-like vertical tubes, but they are more jagged and irregular than in the undisturbed limestone. The characteristic encrusting habit of the duricrust can be seen elsewhere in the map area, particularly in a large irregular patch that extends from south of Quraymiz to southeast of Al Adari, where calcareous crust also contains altered vertical *Scolithos* sp. tubes. The calcareous duricrust is sandy and contains a few quartz pebbles.

Duricrust is a product of the underlying bedrock as seen with the calcareous crust of the Sirhan limestone, and is also evident in the areas bordering on the east and south of Nafud Ghuwaytah in the northwestern part of the map area. Near Ghuwaytah, the crust is formed over Turayf group chert-bearing carbonates and contains random, disorientated, angular chert clasts and pieces of siliceous limestone in a sandy, calcareous matrix. In these areas, and east of the Al Jayb escarpment, much of the duricrust is partly covered by gravel, largely formed from disentegration of the crust, leaving loose chert and sand (Qg/Qdc, pl. 1). These areas of mixed gravel and duricrust are difficult to map and have been incorporated in the Sirhan formation or the Turayf group by earlier workers.

Other smaller patches of duricrust and duricrust-gravel mixtures are present elsewhere in the map area, especially between the Al Jawf highway and the At Tawil area. Two inverted wadi courses in the northeastern part of the quadrangle have been preserved by calcareous duricrust; they are now topographic ridges. The duricrust that formed in the wadis protected the underlying rocks, while the less resistant surrounding rocks were weathered faster, leaving the wadis elevated above the desert surface. These ancient wadis appear to have flowed southwestward, running against the general easterward slope of the present terrain. The wadi in the northeast corner of the map area originates in the southeast corner of the Ash Shuwayhitiyah quadrangle, adjacent to the northern map area; it was described by Meissner and others, 1986. The crust formed on Post-Pliocene rocks and is believed to be of Quaternary age.

UNCONSOLIDATED SURFICIAL DEPOSITS

Unconsolidated surficial deposits, including gravel, eolian sand, and undifferentiated deposits of alluvium, silt, sand, and gravel, make up most of the Quaternary deposits in the quadrangle. The northwestern fringe of the An Nafud desert occupies most of the eastern and southern parts of the map area; Nafud Ghuwaytah occupies a large part of the west-central border area.

Gravel Deposits

In Wadi as Sirhan gravel fans and outwash plains are deposits of material eroded from the Quraymiz escarpment; similar deposits of gravel are found between Quraymiz and the Rummamin escarpment. The gravel consists of fine to coarse chert clasts and siliceous limestone fragments derived from rocks of the Turayf group that cap the escarpments; quartz sand and pebbles in these gravel deposits are derived from the Tawil formation that forms the lower parts of the escarpments. Gravel found in wadi channels south of Nafud Ghuwaytah consists of large chert fragments, siliceous limestone, and small dark chert boulders and slabs derived from underlying chert and limestone residium and lag of the Turayf group (probably Sib member). Narrow sheets of gravel occur locally at the foot of the north-facing slope of the At Tawil hills and in other small patches within the map area. A small area of regolith gravel (Qg_2) in the northwest corner of the quadrangle consists of a semiconsolidated mixture of chert clasts and siliceous carbonate derived from residual disintegration of the underlying Sib member.

Eolian Sand Deposits

In the northeastern part of the map area, eolian sand (Qes) of An Nafud mostly forms barchanoid ridge-type dunes (McKee, 1979) transverse to the prevailing westerly wind. These dunes are mostly stabilized and contain vegetation, such as grasses, bushes, and small trees. Westward into the Ajaiz area, the dunes become thin and spread out with bare patches between them. In the southern and southeastern parts of the quadrangle, the dunes are a combination of barchniod ridge type and linear (sief) dunes (McKee, 1979) trending in an east to southeast direction, and are the result of two dominant wind directions, probably northwesterly and southwesterly. These dunes are mostly stabilized and support grasses, bushes, and trees. In fact, An Nafud contains more perennial vegetation than the surrounding rocky desert.

In the northwest border area of the quadrangle, Nafud Ghuwaytah is a gently undulating sand body pocked with bowl-shaped "blow outs" (McKee, 1979) that are features of deflation. There is only minor evidence of eolian activity, and the nafud appears to be largely stabilized, and contains many small bushes. Just east of Sakakah there is a relatively small dune field that appears to be growing; in places, fences have been installed in order to control sand movement and prevent it covering the highway south of town. The prevailing westerly wind is broken up here by hills to the west, so the sand moves about in various directions.

In the Tais al Fahham area, the east-central part of the quadrangle, localized white sand dunes and loose pieces of white limestone may have been derived from leached and disintegrated rocks of the Sirhan formation that may have originally underlain this area (see "Alluvium", below). Small patches of sand and sand "shadows" are found in many places in that part of the quadrangle that is predominantly rocky desert.

Alluvium

Alluvium consisting of unconsolidated silt, sand, and gravel (Qu) occurs along wadi courses and in depressions and basins in many places in the map area. Finer grained deposits consisting of silt and clay (Qs) are found in undrained depressions (kabras), and form flat surfaces commonly devoid of vegetation. A few salt-encrusted silt and clay sabkah deposits (Qsb) occur near Al Jawf.

Southeast of Al Ajaiz, in the Tais Al Fahham area (east-central part of the quadrangle), there is a large point of land that protrudes into the An Nafud and eventually merges with the sand desert. This area is partly covered with sand dunes and was formerly mapped as sandstone, marl, and limestone of Miocene-Pliocene age (Bramkamp and others, 1963, 1982), which would be equivalent to the Sirhan formation. However, if Sirhan is the bedrock of the area it has been completely eroded and disintegrated into silt and sand, forming a flat, featureless plain except for the partial dune cover. In areas mapped as the Sirhan formation in the current mapping program, there are always outcrops, even though locally small and low, but in this area there are none. Therefore, the area is shown as alluvium (Qu, undifferentiated silt, sand, and gravel, pl. 1).

Isolated alluvium (erosional remnants) of poorly sorted sand and gravel mixed with a few cobbles is located on the upper surfaces of the Devonian sandstone mountains of At Tawil. These alluvial deposits contain chert and limestone derived from rocks of the Tertiary Turayf group whose nearest outcrops are well to the west at practically the same elevation and do not appear to be the source of the alluvium. However, the deposits could be erosional remnants that resulted from the stripping of <u>in situ</u> Tertiary rocks that once covered at least part of the At Tawil area. The coarseness of the alluvium indicates rapid, high-energy erosion, presumably during periods of heavy rainfall.

STRUCTURE

The Al Jawf quadrangle contains some very significant faults and folds. The main northeast bounding fault of the Wadi as Sirhan graben complex trends southeast (and possibly curves eastward) through the northern part of the map area. The interpreted trend of the Devonian axis of the Hail arch is south-southeast through

the north-central part of the map area (Regional Geologic Setting, part of pl. 1) until it is intersected by the Wadi as Sirhan fault. The Al Jayb fault trends in a general north-south direction, bisecting the western part of the At Tawil area. A major fault trends sinuously southeastward along the north edge of At Tawil. A striking array of block faults occurs in the Al Jawf (town) area. Anticlinal and synclinal folds, mostly interrupted by faults, occur in the central and north-central part of the map area. The best developed syncline, the Al Abd syncline, is located in the north-central part of the quadrangle south of Rummamin escarpment. Subordinate faults, flexures, fractures, and macrojoints occur in many places within the map area.

The Wadi as Sirhan fault trends southwestward from the northwest corner of the quadrangle (nearly parallel to the southwest-facing Quraymiz escarpment) to a point south of the town of Al Jawf. From south of Al Jawf it is believed to continue eastward to the eastern border of the map area (Regional Geologic Setting, a part of pl. 1). The throw of the fault at the surface is at least 100 m up to the north as estimated from the difference of the elevation of the Turayf group rocks exposed on top of Quraymiz, north of the fault, and similar rocks in the plains below, south of the fault. Subsurface data from the Al Adari drill hole in Wadi as Sirhan (pl. 1, and cross section A-A') and other drill holes in Wadi as Sirhan northwest of the map area show a marked thickening of the rocks (especially pre-Upper Cretaceous), and increased fault throw with depth, indicating down-faulting contemporaneous with deposition (Meissner and others, 1988). The stratigraphic section in the Al Adari drill hole is estimated to be about 1,140 m thick from the Cretaceous Zallum member to the top of the Silurian Tayyarat formation (includes the Jubah, Jauf, and Tawil formations), which is considerably thicker than the 875 m estimated for a composite of the same rocks exposed at the surface (fig. 2). The Tayyarat alone is estimated to be nearly 1,300 m thick in the Al Adari drill hole , which is 5 to 10 times thicker than at any surface exposure; it is down-faulted about 1,100 m, the combination of which certainly indicates a deep and growing trough, especially during Silurian times.

About 3 km south of the southwest corner of the map area, the southwest bounding fault of the Wadi as Sirhan graben complex (Al Huj fault) trends southeastward (Regional Geologic Setting, pl. 1). This follows the new concept (Meissner and others, 1988a) that the Wadi as Sirhan graben complex continues into and merges with the An Nafud basin. The axis of the graben complex trends southeastward from near the northwest corner of the map area, parallel to (and 5 to 10 km south of) the Wadi as Sirhan fault; it may continue as far as An Nafud. This axis represents the lowest part of the Wadi as Sirhan trough, both at the surface and in the subsurface. The axis extends northwestward from the map area to the Jordan border, generally along the eastern side of Wadi as Sirhan; the axial area contains large sabkahs in the Wadi as Sirhan quadrangle to the northwest of the map area (Meissner and others, 1988, 1989). Gravity and magnetic geophysical maps helped to define the axial trend by a series of subsurface lows, and drill holes in the axial area reveal abnormally thick sedimentary rock sequences. The area between the Al Huj fault and the At Tawil highlands is probably a depressed area in the southern

part of the Wadi as Sirhan graben complex; it forms the Al Urayq arm of the An Nafud that protrudes northwestward into the Thaniyat Turayf quadrangle.

The Hail arch is a much written about, but little known regional feature of northern Saudi Arabia (Powers and others, 1966; Brown, 1972; Greenwood, 1973; Riddler and others, 1985). Parts of the arch occur in the Sirhan-Turayf basin where there are two axes, not just one, as is popularly theorized. One of these axes supposedly trends southeastward under the An Nafud to the Precambrian shield in the Hail area (a distance of about 250 km). The two axes in the Sirhan-Turayf basin trend southeastward and are roughly 50 to 100 km apart. The eastern axis lies to the east of the map area and is in rocks no older than Upper Cretaceous, whereas the western axis lies within the map area in pre-Upper Cretaceous rocks. The interpreted trend of the western axis runs southeastward from the Ash Shuwayhitiyah quadrangle (Meissner and others, 1986) across the northern part of the Al Jawf quadrangle, through the town of Al Jawf, to where it intersects the Wadi as Sirhan fault (Regional Geologic Setting, on the margin of pl. 1). Whether or not it is faulted down and continues southeastward under An Nafud is unknown.

The prolific block-faulting in and around the Al Jawf area (pl. 1, and cross section A-A') may have been caused by movement along the crest of the western axis of the Hail arch. Fault trends vary from nearly due north to N. 65 W., and rarely in a northeasterly direction. Most of the faulting in the Devonian Jauf Formation consists of high-angle (70° +) normal faults; there is as much as 200 m of throw. Locally, Tawil beds are vertical at the fault plane with the Jauf, but are flat again just to the west of the fault line. In the Ajrabah escarpment to the north, flat-lying Tertiary carbonates of the Turayf group are underlain by steeply dipping and folded rocks of the Jauf Formation, showing an excellent example of angular unconformity. Evidence of minor rejuvenation of pre-Late Cretaceous faulting can be seen in the Tertiary rocks capping Ajrabah where renewed movement of a few faults in the Jauf produced about 1 m of offset in the capping rocks.

The At Tawil fault trends sinuously southeastward along the foot of the northeast face of the At Tawil area, and possibly merges with the Al Jayb fault to the northwest (pl. 1, and cross section A-A'). It appears to be a high-angle normal fault, down to the north, with a surface throw of approximately 150-300 m. The At Tawil highland is composed of the Devonian Tawil sandstone that is faulted against the Jauf Formation. The Tawil sandstone is flatlying and undisturbed right up to the fault plane, but the less competent interbedded Jauf limestone and shale to the north of the fault plane is folded and faulted. The relatively thin, light-colored limestone beds of the Jauf form readily visible hog-back ridges on the flanks of faulted synclinal features. This is especially true at Barqa ash Shairah near the middle of the At Tawil fault trend, where there is a 10-12-km-long south-southeast-trending structure in the Jauf Formation and hog back limestone beds of the Jauf dip 20-40° WSW. The east side of this structure appears to be an imbricated fault zone containing repeated sequences of Jauf and Tawil. Near the south end of the Barqa ash Shairah structure there are faulted beds dipping southeastward. At a point about

4 km west of the south end of the Barqa ash Shairah structure, green, light grayish-green, and pale-red Jauf shale is in direct fault contact with the Tawil sandstone; this is one of the few places the fault contact is well enough exposed to be examined. Toward the southeast end of the At Tawil fault there is a structure in the Jauf Formation that looks like the northwest end of a syncline with dips curving from SW to SE to NE (on a counterclockwise traverse).

The Al Jayb fault (or fault zone) is a major cross-cutting feature that trends southward across the west side of At Tawil (pl. 1). This fault may continue northwestward under Nafud Ghuwaytah and connect with a normal fault mapped in the northeast corner of the Thaniyat Turayf quadrangle, to the west of the map area (Meissner and others, 1989). The Al Jayb fault trace is visible in the plains west of the Al Jayb escarpment as a low 1-2 m high scarp with partly gravel-covered Tawil on the west, and partly gravel-covered Tertiary carbonates (Sib member?) to the east, on the lower side of the embankment. South-southeastward in the vicinity of the mouth of Wadi al Mu'ay, beds are dragged downward on the west in the Tawil and upward on the east in the Sib, creating a normal fault with the down-thrown block on the east. Faulting south of the mouth of Wadi al Mu'ayy is contained entirely within the Tawil sandstone; the occurrence of two or three closely spaced parallel fault traces indicate the presence of a fault zone rather than a single break. Continuing southward, the fault is manifested by brecciated sandstone "dikes" that are vertical, or dip steeply east or west, with evidence of vertical offset across the fault. Locally, faults possess gouge about a meter thick and slickensides, suggesting horizontal as well as vertical movement. Near the south end of the Al Jayb fault, in the Kilakh area, the beds are vertical to steeply dipping eastward in a fracture zone more than 10 m wide. The beds are slickensided and there is evidence of lateral slip, with the west side moved south in relation to the east side. There also has probably been some vertical movement in the fault zone at this point. The amount of movement, either lateral or vertical, has not been determined at any point because of the lack of good marker beds along or on either side of the faults. At all points examined along the Al Jayb fault the beds are abruptly flat on either side of the fault zone with no evidence of disturbance.

Al Abd syncline lies between Quraymiz and the Rummamin-Az Zilliyah escarpments in the north-central part of the map area (pl. 1, and cross section A-A'). Both flanks of the syncline are easily seen between Khashm Adari and Jabal az Zilliyah because light-colored parallel hog-back ridges of thin-bedded limestone dip southwest on the northeast flank of the syncline and northeast on the southwest flank. The northwest end of the syncline is mostly covered by Quaternary deposits that extend to the Rummamin escarpment; most of the center of the syncline is also covered. Limestone beds of the northeast flank trend southeastward toward the town of Al Jawf where the beds are disrupted by faulting. The Al Abd syncline is assymetric with a steeper northeast flank; the northeast flank dips 12° -34° and the southwest flank dips 5° -20° .

The Al Jawf quadrangle contains many northwest-southeast oriented "lineaments" visible on aerial photographs and Landsat imagery. Many of these linear features are several kilometers long. They are probably fractures and macrojoints related to tensional forces produced by a combination of up-lift of the Hail Arch and subsidence of the Wadi as Sirhan graben complex. In turn, the Wadi as Sirhan graben complex is probably related to the rifting of the Red Sea.

ECONOMIC GEOLOGY

PHOSPHORITE

Thaniyat Phosphorite Member

Phosphorite of the Thaniyat phosphorite member is generally thin and lenticular in the Al Jawf quadrangle, and locally it is absent. The Thaniyat phosphorite member is best exposed along the Rummamin escarpment where the member ranges in thickness from 0 to 9 m and contains lenses of conglomeratic, cherty, sandy, bioclastic, friable phosphorite as thick as 0.50 m (fig. 5). Three samples of the phosphorite at Rummamin contained 11-18 percent P_2O_5.

Several drill holes were completed about 2 km north of the Rummamin escarpment to determine if there was any northward development of the phosphorites seen in outcrop. Higher grade phosphorite was not found at these drill sites, and so the (Rummamin) area is considered to have limited potential for phosphate exploitation (Riddler and van Eck, 1984).

The member is poorly exposed in the Quraymiz area southwest of Rummamin and has been mapped along with the Kuwaykabah member (pl. 1), but appears to be similar in character to phosphorite seen at Rummamin. South of Quraymiz, along the Al Jayb escarpment, the Thaniyat phosphorite member is as much as 13 m thick and consists of mostly argillaceous and fossiliferous limestone that contains fishbone debris, coprolites, and fossil bivalve shell fragments, as well as one or two thin (0.20 m) calcareous phosphate lenses (fig. 6). These phosphate lenses contain as much as 21 percent P_2O_5.

Sib Member

The Sib member contains phosphatic lenses at Quraymiz, along the Rummamin, and parts of the Al Jayb escarpments. Mytton (1966) discovered phosphatic carbonate rock in the Sib (part of the former "Hibr" formation) in the Quramiz area that is up to 1.6 m thick and contains 10-20 percent P_2O_5. Smith (1983) mentions phosphate layers at Al Jayb, in what is believed to be the Sib, that contained a maximum value of 21 percent P_2O_5, and Aspinall and others (1985) reported phosphatic chert and thin calcareous phosphorite lenses in the Sib of both

Quraymiz and Rummamin. During the present investigations a phosphate bed located near the base of the Sib member was sampled (lat 29° 39'32" N., long 39° 24'00" E.) at the Al Jayb escarpment north of the DF 2 section (pl. 1). The bed is about 1 m thick and includes a 0.20 m bed containing 17 percent P_2O_5.

OIL AND GAS

Conditions favorable for the formation and accumulation of oil and gas in the Wadi as Sirhan graben complex (in the Turayf, Thaniyat Turayf, and Wadi as Sirhan quadrangles) (Meissner and others, 1987, 1988, and 1989) are believed to continue into the Al Jawf quadrangle. At the Al Adari drill hole south of Quraymiz on the south side of the Wadi as Sirhan fault, over 1,000 m of organic-rich Silurian shale and siltstone were penetrated revealing potential source rocks for hydrocarbons. The Al Adari drill hole is located near the axis (and probably the deepest part) of the Wadi as Sirhan trough that extends into the An Nafud basin. Ideal reservoir conditions and structural (i.e., fault traps) could exist along the Wadi as Sirhan or At Tawil faults, and in the Tawil Formation sandstone or Jauf Formation limestones. If the Hail arch extends south from the town of Al Jawf under An Nafud, as suggested by Greenwood (1973, fig. 1), then the arch may offer focal points for the accumulation of oil and gas in associated anticlinal traps.

These possibilities for hydrocarbon entrapment within rocks of the map area are naturally very speculative, but not without merit. Oil has been discovered in the Azraq depression of Jordan, which is the northwest extension of the Wadi as Sirhan depression, and gas has been discovered in Silurian rocks in the eastern desert of Jordan, not too far from the northern extension of the western axis of the Arch. Aramco has recently become interested in the Sirhan-Turayf basin and the Al Jawf quadrangle for its oil and gas potential and is presently (1988) engaged in both geological and geophysical exploration activities.

COAL

Both the Devonian Al Jubah formation and the Cretaceous Wasia Formation, located in the Al Jubah area of the northeastern part of the quadrangle, are of fluvial-deltaic origin that is favorable for the formation of coal. No coal was seen in outcrop, but weathering is so advanced that a coal bed could be thoroughly oxidized at the surface and not be recognized. Coal chips have been reported from water well drill holes in the Al Jubah area (Ministry of Agriculture and Water, personal commun., 1986), but so far there has been no systematic investigation to confirm the occurrence of coal in the subsurface and determine its thickness and quality.

LIMESTONE

There are several limestone quarries located in the Jauf Formation (near the highway between Al Adari and Al Jawf, pl. 1). No specific information is known about these quarries; they are presumably quarrying the rock to make gravel and crushed stone for construction purposes and possibly powdered limestone for agricultural applications.

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-08-04, or in the Riofinex Geological Mission Data File RF-DF-00-05, 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 (MODS)

The number of this report has been submitted for entry in the bibliography of the MODS file listed below in order to update the file number.

Occurrence	File No.
Quraymiz, General	00369

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