UNITED STATES
DEPARTMENT OF THE INTERIOR
US GEOLOGICAL SURVEY

PHOSPHATE DEPOSITS IN THE HAWF-SAKAKAH BASIN, KINGDOM OF SAUDI ARABIA
PART II. THANIYAT TURAYF AND QURAYMIZ

By James W. Mytton

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James W. Kytton*

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INTRODUCTION

The geologic envestigation leading to this report was undertaken in support of a minerals exploration program under a cooperative agreement reached in September 1963 between officials of the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the U. S. Geological Survey.

Rocks unconformably overlying the Paleozoic sandstone at the southern end of the Jawf-Sakakah basin were examined October 19 to 25, 1965, for possible occurrence of phosphate. Two localities were visited: Thaniyat Turayf (29°40'N. x 38°00'E.) on the southwestern rim of the basin and Quraymiz, located on the southeastern rim approximately 15 kilometers southwest of 30°00'N. latitude and 39°30'E. longitude (fig.1).

Previous to this investigation, phosphatic material was identified in rocks of Eocene age by R. P. Sheldon near the Trans-Arabian Pipeline about 60 kilometers east of the village of Turayf (Sheldon, 1965). The hills in the vicinity of Thaniyat Turayf are made up of rocks which in general are lithologically similar to those occurring in the area crossed by the Trans-Arabian Pipeline. These hills have two to three hundred feet of relief and offer the best exposures of these rocks in the Jawf-Sakakah basin. The hills referred to as Quraymiz (fig. 1) have close to 200 feet of relief and also provide fairly good exposure.

GEOLOGIC SETTING

Thaniyat Turayf and Quraymiz lie on opposite sides of the northwest-trending axis of the Jawf-Sakakah basin (fig. 1). The basin is bounded by the Hail arch on the east, the Dead Sea graben on the west, and the Arabian Shield on the south. In Late Cretaceous and Early Tertiary time, the Jawf-Sakakah basin was a submerged portion of the Afro-Asian craton. The craton separated the marginal trough or miogeosyncline of the ancient body known as the Tethys Sea from the Shield proper of the Arabian Peninsula. The area described in the report is underlain by rocks of Eocene and Late Cretaceous age, which in turn unconformably overlie rocks of Devonian age.

LITHOLOGIC UNITS

The lithologic units as shown on the 1:500,000 geologic maps of the Wadi As Sirhan and Jawf-Sakakah quadrangles (Bramkamp and others, 1963) include the Tawil sandstone member of the Tabuk formation of Devonian age, the Aruma formation of Late Cretaceous age, and rocks of Tertiary age mapped as Tlc. In addition much of the area is covered by Quaternary sand and gravel.

The Tawil member of the Tabuk formation is made up of white, fine- to medium-

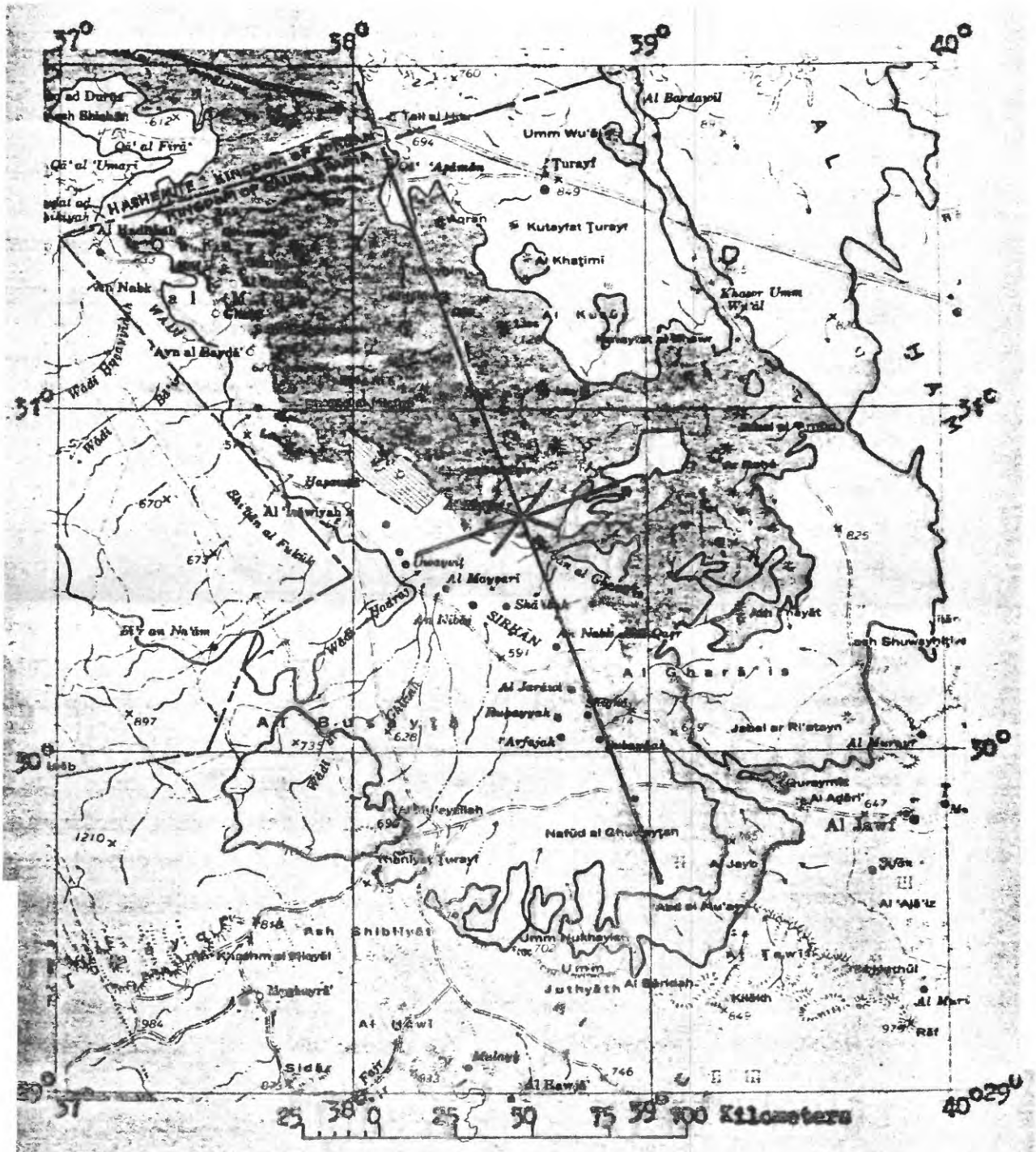

Figure 1. - Map showing outcrop pattern of Kibr formation and axis of Jauf-Sakakah basin. Adapted from geologic map of Arabian Peninsula, 1963.

grained, cross-stratified, friable quartz sandstone which weathers dark reddish-brown. The unit exhibits medium scale cross-stratification. The Tawil member is represented by subdued hills and knobs as well as benches.

The Aruma formation consists of yellowish- to ochre-colored marly claystone and siltstone. At Thaniyat Turayf the Aruma formation contains sparse lenticular coquinal beds and scattered siliceous geodes. At Quraymiz it includes a bed of black oolitic to pisolitic phosphatic chert one-half foot thick. The Aruma forms rather steep slopes at both localities and contrasts markedly in color and topographic expression with the underlying and overlying formations.

The rocks mapped as Tlc are referred to as the Hibr formation by geologists of the Arabian American Oil Company (Aramco). The term Hibr is used in this report for the massive cliff-forming limestone and marl units which overlie the Aruma formation. These units make up the hills at Thaniyat Turayf and vicinity and the uppermost part of Quraymiz.

The lithologic boundary, interpreted to be the contact between the Aruma and Hibr formations by the writer, closely approximates the formational contacts shown on the 1:500,000 maps of the Wadi As Sirhan and Jawf-Sakakah quadrangles. The position of the boundary between Cretaceous and Eocene rocks is problematical. Nummulites occur in limestone beds in the Thaniyat Turayf area 190 feet or more stratigraphically above the contact between the Hibr and Aruma. These foraminifera are commonly found in the Eocene rocks of the Middle East. No other index fossils were observed in the rocks examined at either Thaniyat Turayf or Quraymiz.

STRUCTURE

The strata in the general region appear to be nearly flat-lying. At Thaniyat Turayf the regional dip is about one and one-half degrees to the northeast. At Quraymiz the regional dip is about the same but is toward the northwest. Numerous faults occur in the area but the strata are only slightly offset. Beds in the vicinity of faults have dips up to 5 degrees. The most prominent faults are northwest-trending, and they are several kilometers long. The faults strike about

N.20°W., which closely approximates the trend of the Red Sea graben. The axis of the Jawf-Sakakah basin is interpreted to have the same trend. The graben of the Khawr Umm Wu'al which crosses the Trans-Arabian Pipeline in the northeastern corner of figure 1 also has the same trend.

THANIYAT TURAYF AND VICINITY

Hibr formation

At Thaniyat Turayf the Hibr formation includes over 300 feet of massive limestone and marl alternating with thin-bedded chert. As a whole, the limestone is aphanitic to very fine-grained crystalline, hard, thick-bedded, and forms ledges. Some units are coarse-grained, bioclastic to coquinal; others are fine-grained and dolomitic. All are to a degree marly. The term marl as used in this report means impure limestone containing an intimate mixture of clay and calcite. The marl is very fine-grained, soft to medium hard, thick-bedded, massive, and form cliffs and ledges. It comprises units up to 100 feet thick. The marl grades laterally as well as vertically into marly limestone. Megafossils are sparse and consist of pelecypods and gastropods. A stratigraphic section of the Hibr formation was measured on the west side of Thaniyat Turayf at Locality 1 (fig. 2). A written description of the section is given in table 1.

Three major zones of chert occur in the Hibr formation at Thaniyat Turayf. The lower one is 20 feet above the base of the Hibr. The middle and upper zones are approximately 180 feet, and 300 feet respectively above the base. In addition to the three major zones of chert, a fourth one 350 feet above the base of the Hibr and of limited extent caps the highest hills in the area.

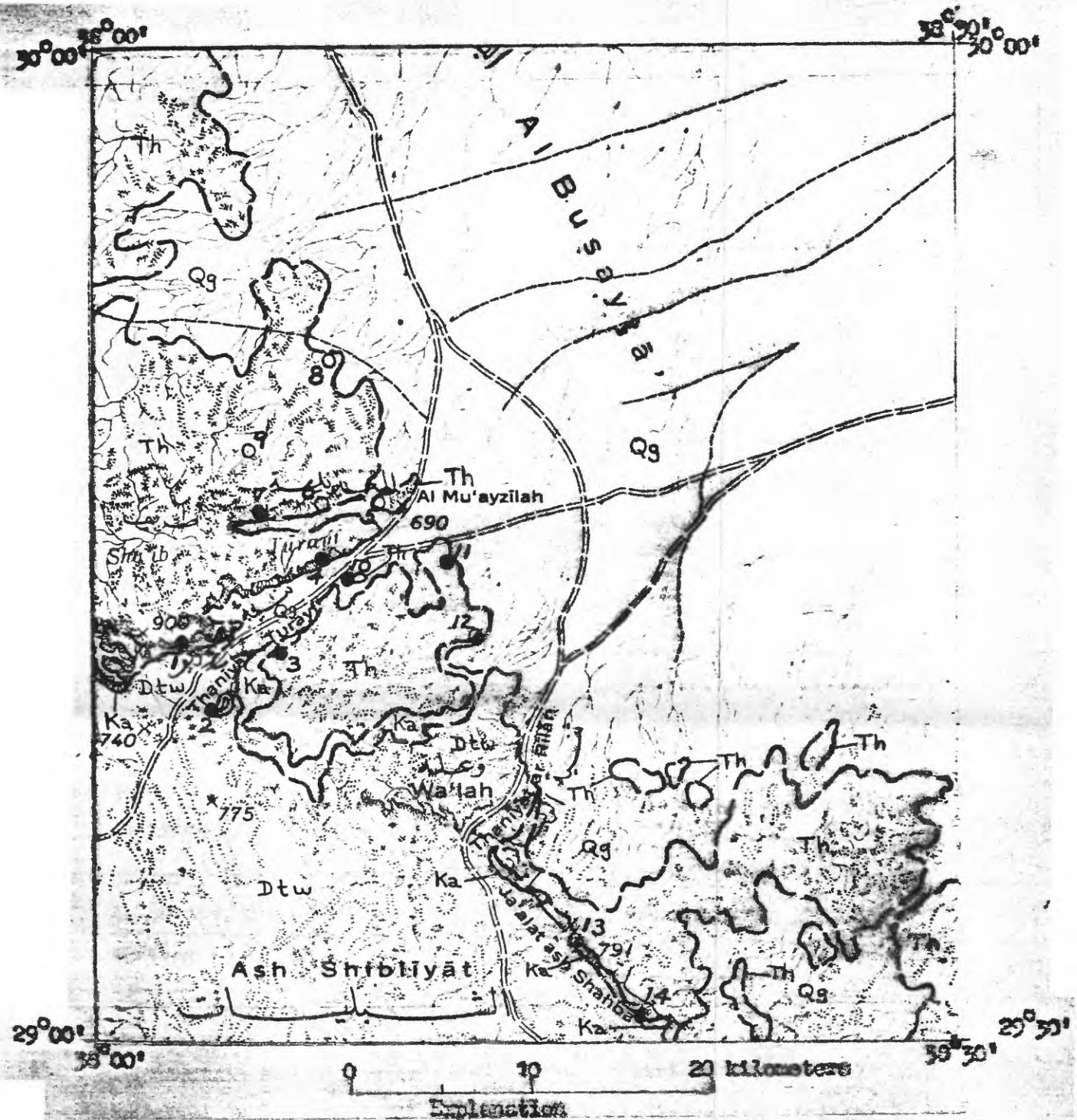

Figure 2. – Generalized geologic map of Thaniyat Turayf and vicinity showing localities sampled for phosphate. Adapted from Brenkamp and others, 1963.

Table 1 - Stratigraphic section of the Hibr and Aruma formations, Thaniyat Turayf, Locality 1, approximately 29°43'N. x 38°04'E., Kingdom of Saudi Arabia.

Description	Feet
Hibr formation	
Chert, brownish gray, aphanitic; caps top of hill and represents highest unit of Hibr formation at this locality.....	
Limestone, light-gray, medium-grained thick bedded, massive, bioclastic to coquinal; may contain some pelletal material; has good pinpoint porosity; weathered surface is reddish-brown and rough.....	48.5
Chert, tan aphanitic, banded.....	1.0
Limestone, light gray, medium-grained, thick-bedded, massive exhibits pinpoint porosity.....	5.5
Limestone, light brownish-gray, aphanitic, thick-bedded, massive, dolomitic, marly; may be more of a dolomitic marl; chert nodules at base.....	8.0
Marl to marly limestone, very light gray, very fine-grained, thick-bedded, massive, soft to medium-hard; forms ledges and cliffs; may contain Nummulites in middle to upper part and phosphatic material in lowermost part.....	99.0
Chert, olive-gray, aphanitic, banded, thin-bedded.....	6.0
Dolomite to dolomitic limestone, light olive-gray, aphanitic; has pin-point porosity; contains pelecypods (?) and gastropods	11.0
Marl to marly limestone, very light gray, very fine-grained, thick-bedded, massive soft to medium-hard; forms ledges and cliffs.....	97.0

Table 1 (cont.)

Limestone, light brown gray, fine-to medium-grained, thick-bedded, massive, medium-hard; weathers reddish-brown with rough surface; forms ledges and cliffs.....	48.5
Chert, dark olive-gray, aphanitic, thin-bedded with undulating bedding planes; marks base of massive limestone and marl units.....	6.0
Shale or mudstone, olive-colored, crinkly with lenticular layers of phosphate rock made up of pellets, oolites, silt-size quartz grains and lithic fragments of marl; (sample 21220AA).....	0.5
Phosphate rock, buff, very fine-grained, thick-bedded, massive soft, friable; made up of pellets, oolites, silt-sized quartz grains, fossil fragments and lithic fragments of marl; (sample 21220BB)..	3.5
Mudstone, buff, hard, siliceous, possibly marly, thin-bedded (?); contains some oolites; forms prominent ledge; (sample 21220CC)...	3.5
Shale or mudstone, olive-colored, crinkly with geodes of silica about 4 inches in diameter.....	0.5
Phosphate rock, buff, medium-grained, oolitic, soft, very friable, marly; contains fossil fragments and some quartz grains; (sample 21220DD).....	2.5
Phosphate rock, buff, medium-grained, oolitic, hard, siliceous, marly; contaihs fossil fragments and scattered quartz grains; forms thin ledge; (sample 21220EE).....	0.3
Phosphate rock, buff, medium-grained, oolitic, soft, friable, marly; (sample 21220FF).....	2.5
Alternating crinkly shale, some hard and resistant, and friable oolitic marl.....	2.0
Phosphate rock, buff, very fine-grained, oolitic, soft marly, silty, fossiliferous; increase in number of quartz grains; (sample 21220GG).....	2.5

Table 1 (cont.)

Siltstone, buff, hard to slightly friable; contains large pebbles, lithic fragments, and oolites; marks base of cyclic sequence that commences at base of chert; (sample 21220HH).....	1.0
Total thickness	349.3

Aruma formation

Siltstone to claystone, ochre-colored, marly; contrasts markedly in color with overlying units; contains scattered geodes; forms slope.....	10.0
Coquina, silified, lenticular; made up of large shell fragments and siltstone, may be only locally represented.....	0.5
Siltstone, ochre-colored, marly; forms slope.....	30.0
Total thickness	40.5

Tabuk formation

Tawil sandstone member

Sandstone, white, fine- to medium-grained, cross-bedded, friable; weathers dark reddish

The two lower zones are both 6 feet thick and consist of dark olive-gray, banded, aphanitic chert which occurs in thin beds with slightly undulating surfaces. The third zone is only a foot or two thick at the most, and the fourth forms a thin layer no more than a few inches thick at the top of the measured stratigraphic section. These zones make excellent marker units that can be traced for some distance both on the surface and on the 1:60,000 aerial photographs of the area. These major zones of chert therefore make possible the correlation of intervening units.

Phosphate-bearing zones

Phosphatic material was identified in the lowermost units of the Hibr formation just below the lowest chert zone and in units above and below the middle chert zone, approximately 180 feet above the base of the Hibr.

Lower phosphate zone

In the measured stratigraphic section the lower phosphate zone (fig. 3) includes 19 feet of alternating crinkly shale, mudstone, and silty marl to marly siltstone containing sparse to abundant phosphatized pellets, oolites, fossil remains, and lithic fragments. The soft, friable, silty marl to marly siltstone is poorly consolidated and contains more phosphatic material than the more highly indurated mudstone and shale which is hard and siliceous. The total footage of phosphatic rock running 14 percent or better in P_2O_5 is 11 feet and of this total 5 feet contain 24 percent or more P_2O_5. Some of the crinkly shale contains lenses of phosphatic pellets and oolites with a P_2O_5 content as high as 19 percent. The phosphate-bearing sequence in the vicinity of the measured section is thin-bedded in contrast to the overlying massive limestone and marl of the Hibr and underlying siltstone to claystone of the Aruma formation. The thin-bedded chert separates the sequence from the massive cliff-forming units above and can be used to locate the lower phosphate zone where the phosphatic units are not as well exposed.

The lower phosphate zone is also exposed at the base of the hills that border the east side of Thaniyat Turayf. In the vicinity of Locality 3 (fig. 2) the lower phosphate zone is nearly 24 feet thick and is much more arenaceous than

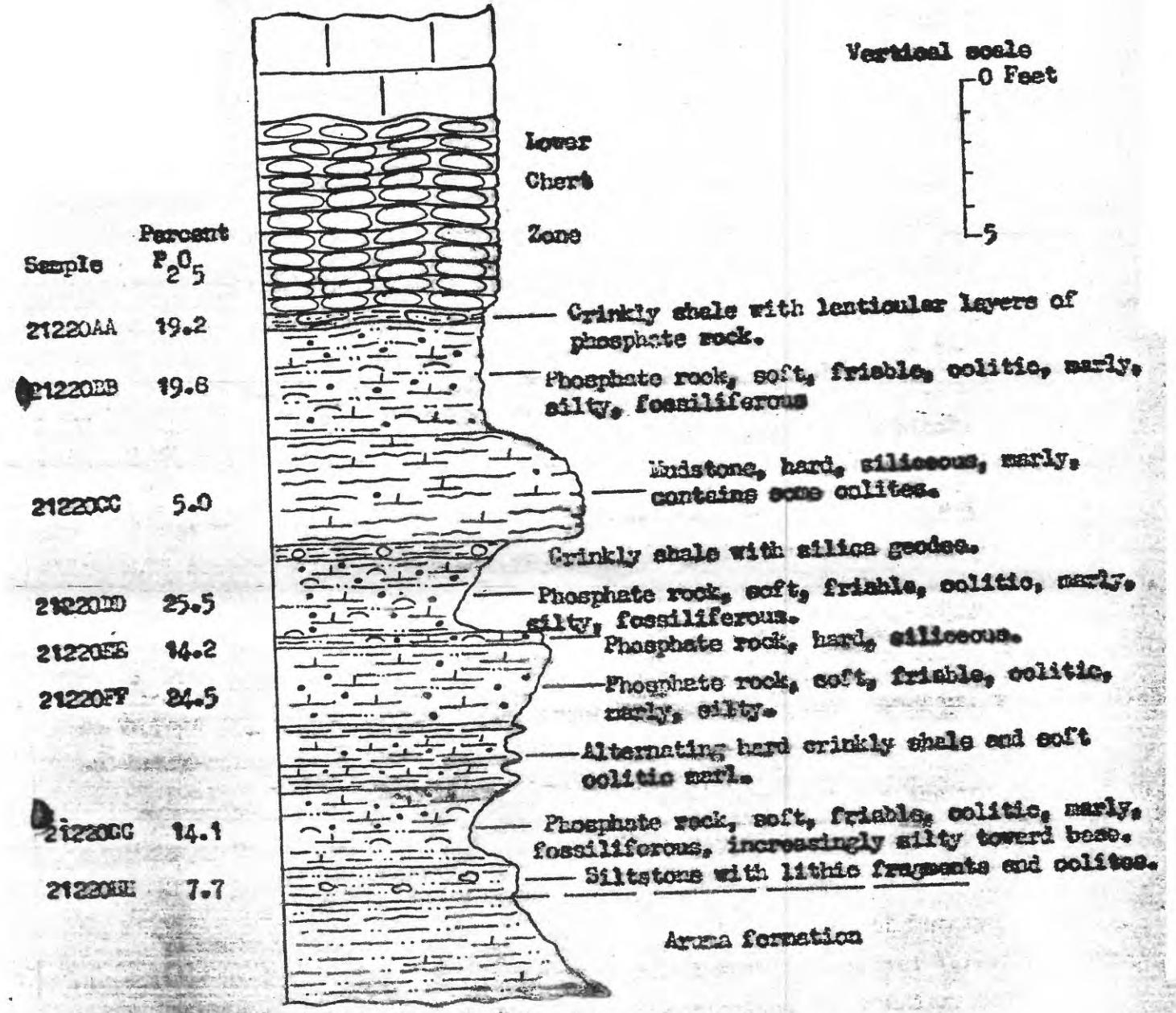

Figure 3. - Lower phosphate zone of Hibr formation at Locality 1, Thaniyet Turayf

in the measured section. To the northeast, the lower phosphate zone disappears under the surface because of the gravel cover as well as the regional dip. At Locality 2 the lower zone is at least partially exposed but it is increasingly sandy. Only 5 feet of good phosphate rock was observed in the outcrop. The Aruma formation is about 60 feet thick at this locality compared to 40 feet in the measured section. The contact of the Hibr and Aruma appears to be gradational and the marly siltstone of the Aruma may be thickening at the expense of the lower phosphatic units of the Hibr.

The lower phosphate zone cannot be traced southeast of Thaniyat Turayf because of cover from rubble and windblown sand. Where the lower units of the Hibr are again exposed, over 20 kilometers southeast of Thaniyat Turayf, only rocks that are sparsely phosphatic are present. At Locality 13, scattered blocks of light gray, hard limestone with a mixture of oolites, fossil debris, and quartz grains were found on the slope below cliffs of massive-bedded fossiliferous limestone. The P_2O_5 content of material sampled was less than 5 percent. At Locality 14, a sample collected from a bed one foot thick was composed of oolites, fossil debris, marl fragments, and quartz grains and had a P_2O_5 content of 21 percent. The bed occurs in a cliff of massive-bedded fossiliferous limestone containing abundant gastropods and pelecypods. The bed itself is nearly 50 feet above units of purplish and ochre-colored marly claystone.

Virtually no phosphatic material of any kind is present in the rocks in the vicinity of Umm Nukhaylah (fig. 1). The area beyond this point was not examined because of limited time and relative inaccessibility.

The lower phosphate zone is apparently absent southeast of Thaniyat Turayf because of a change in facies and was not traced west of Thaniyat Turayf for any distance because at the time of the field investigation the boundary between the Kingdom of Saudi Arabia and the Hashemite Kingdom of Jordan was located at 38°00'E. longitude.

Upper phosphate zone

Phosphate-bearing units which occur just above and below the middle chert zone

are included in the upper phosphate zone. These units were not observed in the measured stratigraphic section at Locality 1 (fig. 2) because they either were not present or were covered by rubble. However, they were observed elsewhere in the area and tied into the measured section by reference to the chert zone. In the measured section itself, no phosphatic material was observed in rocks exposed below the 6 feet of thin-bedded chert. The beds underlying the chert are made up of light olive-gray aphanitic dolomitic limestone with pelecypods and gastropods. The beds overlying the chert are poorly exposed because of rubble.

At Locality 4, a little over 9 kilometers northwest of the measured section, one foot of friable phosphate rock with a P_2O_5 content of 18 percent occurs just below the chert. Another bed only a few inches thick occurs about 10 feet above the chert. The chert is also 6 feet thick at Locality 4 and can be traced on 1:60,000 aerial photographs between this locality and Locality 1. A few kilometers to the northwest, the chert and phosphate rock disappear under the surface. At Locality 5 the chert and phosphate units are absent. Light gray, hard, aphanitic to medium-grained fossiliferous limestone grading into softer marl underlies the area. Similar rocks crop out at Localities 8 and 9 and contain abundant Nummulites. The outcrops of massive limestone and marl at these localities are stratigraphically above the phosphate and chert units of Locality 4 and are equivalent to the massive cliff-forming units that overlie the same chert zone in the measured section.

The phosphatic units observed at Localities 10 and 11, are considered to be equivalent to those of the upper phosphate zone at Localities 4 and 6. The same chert zone is easily identified on aerial photographs of the region east of Thaniyat Turayf and its position as traced on the 1:60,000 aerial photographs coincides with the location of the sample localities. At Locality 11 a bed of light colored friable phosphate rock less than a foot thick occurs above the chert zone in a marly claystone. The claystone is about 14 feet stratigraphically below marly fossiliferous limestone which makes up most of the hill. The P_2O_5 content of material collected from this bed ran as high as 32.4 percent. No phosphatic

material was seen in the rocks underlying the chert zone.

Just north of Locality 3, two to three feet of exposed phosphate rock occurring above the chert zone was recently sampled by Ismail Husseini of the Ministry of Petroleum and Mineral Resources and John C. Dunlap (oral communication, June, 1966) and found to contain 27.5 percent P_2O_5. Nummulites were also found in massive limestone above the phosphate-bearing units.

The phosphate-bearing rocks of the upper phosphate zone apparently are of small extent. Locality 4 has beds containing phosphatic material above and below the chert zone; however, Localities 3 and 11 only have phosphate rock above the chert; and Locality 7 only has phosphate-bearing rock below the chert. The outcrop at Locality 10 was so poor that its exact position with reference to the chert zone could not be determined. The outcrop at Locality 12 is also poorly exposed and may even represent the lower phosphate zone. It was only sparsely phosphatic.

The units of both the upper and lower phosphate zones are discontinuous and are represented by lenticular beds that are at the most only a few kilometers in areal extent. The overall thickness of the upper zone, including the intervening chert, is estimated to be 15 feet; however, the maximum thickness of phosphate-bearing rock observed at any one locality was 4 to 5 feet (Locality 7, fig. 2). The upper zone is not present above the escarpment of Ja'alat ash Shaba, southeast of Thamiyat Turayf because the upper part of the Hibr has been removed by erosion.

Phosphatic material

The phosphate-bearing rocks of both the upper and lower phosphate zones contain a mixture of pellets, oolites, broken shells, and lithic fragments that are loosely bound together by marl. The rocks are extremely friable and can be easily disaggregated. The phosphatic material in the lower zone contains sparse to abundant silt-sized grains of quartz, with the quartz content increasing toward the base of the Hibr formation. The phosphatic material of the upper zone is relatively free of detrital quartz.

The P_2O_5 content of samples collected from the lower phosphate zone in the measured stratigraphic section at Locality 1, ranges from 5 to 25.8 percent (fig. 3 and table 2). The weighted average, based on 16 feet of the sequence of phosphate-bearing rocks that were sampled, is 16.4 percent P_2O_5. Mudstone and siltstone units which contain only a small quantity of pellets, oolites, and fossil and lithic fragments have 5 and 7.7 percent P_2O_5; whereas units made up almost wholly of these components have between 19.8 and 25.5 percent P_2O_5. There is no question that the pelletal and oolitic material is the chief contributor, as the more highly phosphatic rocks contain a greater quantity of these particular components. Random samples collected at Localities 2 and 3 (table 2) had P_2O_5 contents of 18.8 and 12.0 percent respectively. Two samples collected near Locality 3 by Husseini and Dunlap (J. C. Dunlap, oral communication, June 1966) both had 20.6 percent P_2O_5.

The P_2O_5 content of samples collected from the upper phosphate zone ranges from 0.6 to 32.4 percent. The phosphate-bearing rock below the chert zone is comprised of medium-sized oolites, broken shells, and lithic fragments in a marly matrix. The P_2O_5 content of material from Localities 4 and 7 (table 2) is 18.1 percent and 10.6 percent respectively. The phosphate rock above the chert zone is made up primarily of medium-sized oolites bound together by marl. Samples of this material from Locality 11 and a site near Locality 3 contained respectively 32.4 percent and 27.5 percent P_2O_5. The phosphate-bearing rock sampled at Locality 10 was a highly siliceous limestone containing sparse oolites. It probably occurs adjacent to the chert which would explain the high silica. Its P_2O_5 content was only 0.6 percent.

The percentage of calcium, magnesium, sodium, silicon, aluminum, and iron in samples from the lower and upper phosphate zones at Thaniyat Turayf and vicinity is given in Table 2. Samples from the lower phosphate zone contain 1 to >10 percent phosphorous and samples from the upper zone contain 3 to >10 percent phosphorous. All other elements detected in samples from both zones were below 0.1 percent with the exception of titanium and strontium which reached 0.1 percent in

Table 2 - Percentage P_2O_5 and percentage calcium, magnesium, sodium, silicon, aluminum, and iron in samples from Thaniyat Turayf and vicinity, Kingdom of Saudi Arabia.

Locality No.	Sample Number	Chemical P_2O_5 1/	Chemical P_2O_5 2/	Spectrographic Determinations 3/ Ca	Mg	Na	Si	Al	Fe
			Lower Phosphate Zone						
1	21220AA	18	19.2	>10	.7	3.	>10	.7	2.
"	" BB	16	19.8	"	.3	1.5	"	.3	.7
"	" CC	2	5.0	"	>10	5.	3.	.7	2.
"	" DD	18	25.8	"	.7	5.	7.	1.5	.5
"	" EE	16	14.2	"	.3	1.5	>10	.3	1.5
"	" FF	23	24.5	"	1.	2.	"	1.5	1.5
"	" GG	14	14.1	"	.5	2.	"	1.5	3.
"	" HH	5	7.7	"	.7	.3	"	1.5	2.
2	21221	12	18.8	"	.5	.5	>10	2.	1.5
3	21222	9	12.0	"	.3	5.	"	.7	.7
14	21232	21	20.9	"	.2	.7	3.	.15	.3
			Upper Phosphate Zone						
4	21223	14	18.1	"	2.	>10	.7	1.5	.3
7	21225	12	10.6	"	3.	.7	.15	.07	.1
10	21228	0.5	0.6	"	3.	.1	>10	.03	.015
11	21229	28	32.4	"	1.	.7	1.5	1.5	.5

1/ P_2O_5 determined by E. Brady, Ministry of Petroleum and Mineral Resources, Jiddah.

2/ P_2O_5 determined by W. D. Goss, U. S. Geological Survey, Denver.

3/ Spectrographic determinations by B. Tobin, U. S. Geological Survey, Denver.

one sample each.

In general, samples from the upper phosphate zone have more magnesium than samples from the lower phosphate zone. Sodium tends to be one order of magnitude higher in material from the lower zone. Silicon, as would be expected, is greater than 10 percent in samples containing appreciable silty or siliceous material. Aluminum and iron are in greater abundance in material from the lower phosphate zone.

Quraymiz

One day was spent at Quraymiz (fig. 1), where the stratigraphic sequence above the Tawil sandstone member of the Tabuk formation was examined for occurrences of phosphate-bearing rock. A stratigraphic section 111.5 feet thick was measured at a point where the units are best exposed. A written description of this section is given in table 3.

At Quraymiz the Hibr formation is made up chiefly of interbedded limestone and chert. The total thickness of the Hibr is only 46.5 feet. The Aruma formation consists of 65 feet of yellowish- to whitish-colored marl and claystone. The contact between the Hibr and Aruma is placed at the base of a yellowish-gray, fossiliferous, marly limestone that is thick-bedded, massive and forms a prominent cliff that can be seen from some distance.

A 5.5 foot unit of phosphate-bearing limestone occurs just above the massive limestone. The cliff can therefore be used as a guide in locating the phosphatic unit. The unit is made up of brown to black, aphanitic, banded, thin-bedded chert which is interlaminated with light gray, medium-hard, oolitic limestone composed almost wholly of medium-sized oolites cemented by calcite. Both the chert and limestone laminae are somewhat lenticular.

The P_2O_5 content of the oolitic limestone in the measured section is only 9.93 percent (P_2O_5 determined by W. D. Goss, U. S. Geological Survey, Denver). However, a sample collected from the same unit at a locality 10 kilometers west of the measured section contains oolitic material which has as much as 19.8 percent

Table 3. Stratigraphic section of the Hibr and Aruma formations Quraymiz, approximately 29°50'N. x 39°25'E., Kingdom of Saudi Arabia

Description	Feet
Hibr formation	
Alternating chert and limestone: chert, dark-brown to black, aphanitic, banded, thin-bedded; limestone, light gray, hard, aphanitic, thin-bedded; each unit is 4 to 6 inches thick; in places chert and limestone are interlaminated; forms weak ledges.....	21.5
Chert, brown to black, aphanitic, banded, thin-bedded; interlaminated with light gray medium hard oolitic limestone containing medium- to coarse-sized oolites.....	5.5
Limestone, yellowish-gray, fossiliferous, marly, hard, thick-bedded, massive; contains pelecypods; weathers rough; forms cliffs.....	19.5
Total thickness	46.5
Aruma Formation	
Marl, yellowish- to whitish-colored, soft to hard, thin-bedded; forms slopes.....	24.0
Marl to claystone, yellowish- to whitish-colored,.....	8.0
Chert, black, oolitic to pisolitic, phosphatic, forms prominent ledge in marl unit; may occur only locally.....	0.5
Claystone, yellowish- to whitish-colored, marly; forms slope to top of Tawil member of Tabuk formation.....	32.5
Total thickness	65.0
Tabuk formation	
Tawil sandstone member	
sandstone, dark brownish to reddish, cross-stratified...	

P_2O_5. Spectrographic analyses by B. Tobin, U. S. Geological Survey, Denver, show the oolitic limestone collected from both sample sites to contain 1.5 to 7.0 percent phosphorous, greater than 10 percent calcium, 1.5 to 5.0 percent magnesium, 0.3 to 0.5 percent sodium, 0.3 percent silicon, 0.07 percent aluminum, and 0.02 to 0.07 percent iron. The phosphate-bearing unit at the locality sampled west of the measured section is also 5 feet thick.

A bed of black oolitic to pisolitic chert one-half foot thick forms a prominent ledge in the middle of the Aruma formation (table 3); however, it may be only locally present as it was not observed at any other locality sampled. The oolitic material sampled contained 10.1 percent P_2O_5 and 7.0 percent spectrographic phosphorous. In addition, it contains greater than 10 percent calcium and silicon, 0.07 percent magnesium, 0.7 percent sodium, 0.3 percent aluminum, and 0.05 percent iron.

CONCLUSIONS

Phosphate-bearing rock is present in the southern part of the Jawf-Sakakah basin. It has been identified in the sequence of strata that unconformably overlies the cross-stratified sandstones of Devonian age rimming the basin at its southern end. This sequence is Late Cretaceous to Eocene in age and is made up of limestone, chert, marl, claystone, and siltstone. Those rocks which are largely calcareous, cherty, marly, and form cliffs and ledges have been included in the Hibr formation; those which are dominantly silty, marly, argillaceous, and form steep slopes have been included in the underlying Aruma formation. The lithologic contact is, to a certain degree, gradational. The Hibr and Aruma formations are respectively Eocene and Late Cretaceous in age according to the 1,500,000 geologic maps of the Wadi As Sirhan and Jawf-Sakakah quadrangles; however, the position of the boundary between Late Cretaceous and Eocene rocks is problematical.

Except for a minor unit of phosphatic chert in the Aruma formation at Quraymiz, all the phosphate-bearing rocks occur in the Hibr formation. Only one phosphatic unit 5 feet thick is present in the Hibr formation at Quraymiz; however, two major

zones of phosphate occur in the Hibr formation at Thaniyat Turayf, one about 20 feet thick near its base and the other, estimated to be about 15 feet thick, approximately 180 feet above the base. Both phosphate zones are associated with prominent chert units that have considerable areal extent and which can be used as key beds for purposes of correlation.

The lower phosphate zone in a measured stratigraphic section at Thaniyat Turayf has a little over 10 feet of phosphatic rock with P_2O_5 content of 14 percent or greater. Two units totaling 5 feet contain over 24 percent P_2O_5. The phosphatic rock is poorly consolidated and consists of phosphatized pellets, oolites, shells, and lithic fragments loosely bound by marl. Silt-sized quartz grains are sparse to abundant. The phosphatic material is extremely friable and can be easily disaggregated. The pellets and oolites which are believed to have the highest phosphate content could be mechanically separated and the material considerably upgraded.

The upper phosphate zone also has beds of friable oolitic material, but they are less numerous and the total thickness of phosphate-bearing rocks at any one locality is less than 5 feet. This phosphatic material is freer of silt than the lower zone, and the phosphate rock found above the chert unit with which the upper phosphate zone is associated is the richest in P_2O_5, of any phosphatic unit sampled in the Jawf-Sakakah basin. Samples representing this unit contain between 27.5 and 32.4 percent P_2O_5, which is approaching commercial grade without beneficiation.

The lower phosphate zone in the measured section has a little over 330 feet of overburden. Though faults in the area are numerous, the rocks are not highly fractured and the massive limestone unit overlying the phosphate-bearing sequence should withstand extensive mining with proper support. The lower zone is discontinuous to the southeast and may change facies in less than 10 kilometers. However, the Hibr formation as shown in figure 1 crops out for nearly 50 kilometers west of Thaniyat Turayf, and the lower phosphate zone may continue for most of this distance.

The upper phosphate zone has considerably less overburden than the lower zone. Probably the overburden is no more than 160 feet thick. The upper phosphate zone should also crop out over a considerably greater area, especially northwest of Thaniyat Turayf. The phosphatic beds are similarly overlain by massive limestone units.

The phosphate-bearing unit at Quraymiz contains oolitic material with a P_2O_5 content of nearly 20 percent, but the oolitic material is cemented with calcite and the 5-foot unit contains 50 percent or more chert. Overburden, however, is only a little over 20 feet thick because the unit is close to the crest of Quraymiz.

Both Thaniyat Turayf and Quraymiz are accessible over major thoroughfares that pass through the areas. Thaniyat Turayf is about 200 kilometers in a straight line from the town of Tabuk and the Hejaz railroad.

Thaniyat Turayf is by far the most promising area to date in the southern part of the Jawf-Sakakah basin, because of its location, grade of phosphate, amenability of material to beneficiation, and probability of relatively large tonnage. The phosphate deposits will require extensive underground mining, a costly operation any place, and even more so in a remote area such as this one. Nevertheless, further work is highly recommended in the Thaniyat Turayf area especially to the northwest, because commercial grade phosphate is present and may be found in quantity.

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