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RADIOACTIVE ANOMALY AND MINERALOGY OF THE LOWER PART OF THE TABUK FORMATION, AL QASSIM AREA

KINGDOM OF SAUDI ARABIA

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J.J. Matzko*, V.J. Flanigan*, Mustafa Mawad**,
Ziad Al Kollak*, M.I. Naqvi**, and Abdul Malik Helaby**

* U.S. Geol. Survey

** U.S. Geol. Survey Saudi Arabian Mission

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ABSTRACT

A radioactive anomaly about 10 km long was detected by an airborne survey of the Tabuk Formation, about 75 km west-northwest of Buraydah in northeastern Saudi Arabia. The gamma-spectrometer anomaly is 6 to 10 times higher than background over the adjacent Precambrian shield area and indicates anomalous concentrations of thorium-bearing minerals. Radioactive detrital minerals identified are zircon, monazite, xenotime, huttonite, and sphene. These minerals account for the anomaly; uranium and potassium-bearing minerals contribute only slightly to the overall spectrometer response. Several varieties of zircon have different morphologies, inclusions, and degree of freshness. Colorless, possibly relatively young grains showing a bright orange fluorescence, and radiation-damaged probably relatively older zircons without any fluorescence, suggest recycling during more than one erosion cycle and at least two different sources for the sediments of the Tabuk Formation. The antipathetic association of allanite and monazite further supports the thesis of more than one source for the sediments of the Tabuk Formation.

INTRODUCTION

An airborne gamma spectrometer survey was test flown in north-central Saudi Arabia in 1968 for the Saudi Arabian Ministry of Petroleum and Mineral Resources by the U.S.Geol. Survey under the supervision of V.J. Flanigan. Several hundred kilometers of traverse was flown over the Saq Sandstone and Tabuk Formation in an area north and northwest from Al Qassim airport and near the town of Buraydah (fig. 1). A 100 sq km area centered about lat 26°51'N. and long 43°12'E., is known as the Gassim Test Area Radioactive Anomaly because the flights were based at the Al Qassim airport.

Several areas of anomalous gamma radiation were detected in the basal section of the Tabuk Formation and near the contact with the underlying Saq Formation. One of the highly radioactive areas selected as a calibration test site from this 100 km^2 area was chosen for interpretation and is described in this report. It is centered about at lat 26°51'N. and long 43°12'E. The general area was mapped geologically by Bramkamp and others (1963). Radioactive anomalies in the Saq Formation were also reported by Lambolez and Vincent (1967).

Some of the petrographic study reported herein was done by Abdul Malik Helaby.

Investigations described in this report were undertaken as part of a work agreement between the

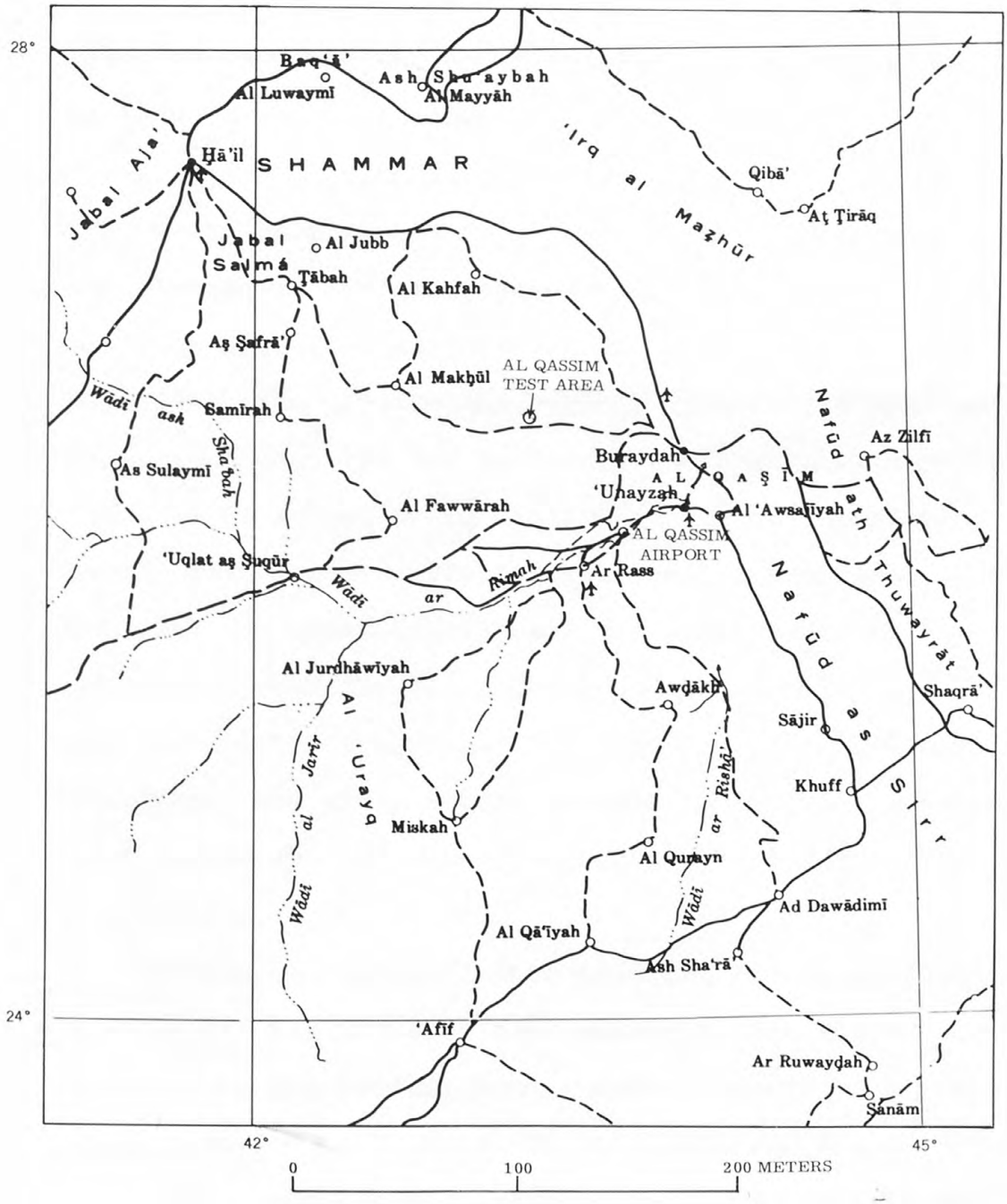

Figure 1.- Index map showing location of the Al Qassim radioactive area.

Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia, and the U.S. Geological Survey.

GEOLOGIC SETTING

Basal beds of the Tabuk Formation of Late Ordovician age exposed in the Al Qassim area dip 1°-2° in a northeasterly direction and overlie the Saq Sandstone of Early Ordovician age (Powers and others, 1966). The western contact between the Saq Sandstone and the Tabuk Formation (fig. 2) is marked by an escarpment 50- to 100-m high. Hadley and Schmidt (1974) assign the Saq Sandstone to the Cambrian and Lower Ordovician, the lower Tabuk to the Ordovician, and the upper Tabuk at the western edge of the area to the Devonian. The Tabuk is a varicolored, micaceous, and silty sandstone-siltstone; it is locally gypsiferous and contains interbedded green and purple shale units.

Powers and others (1966) describe the Tabuk Formation in detail. The Tabuk is approximately 35 m thick. At the base is the Hanadir Member approximately 12 m thick; it is a varicolored shale, in part calcareous and containing ferruginous limestone layers and abundant Didymograptus Protobifidus Ellas. At the top of the Tabuk is the Tawil Sandstone Member. It is a crossbedded, well-cemented sandstone that contains some brown to red and black, locally hematitic and pisolitic siltstone.

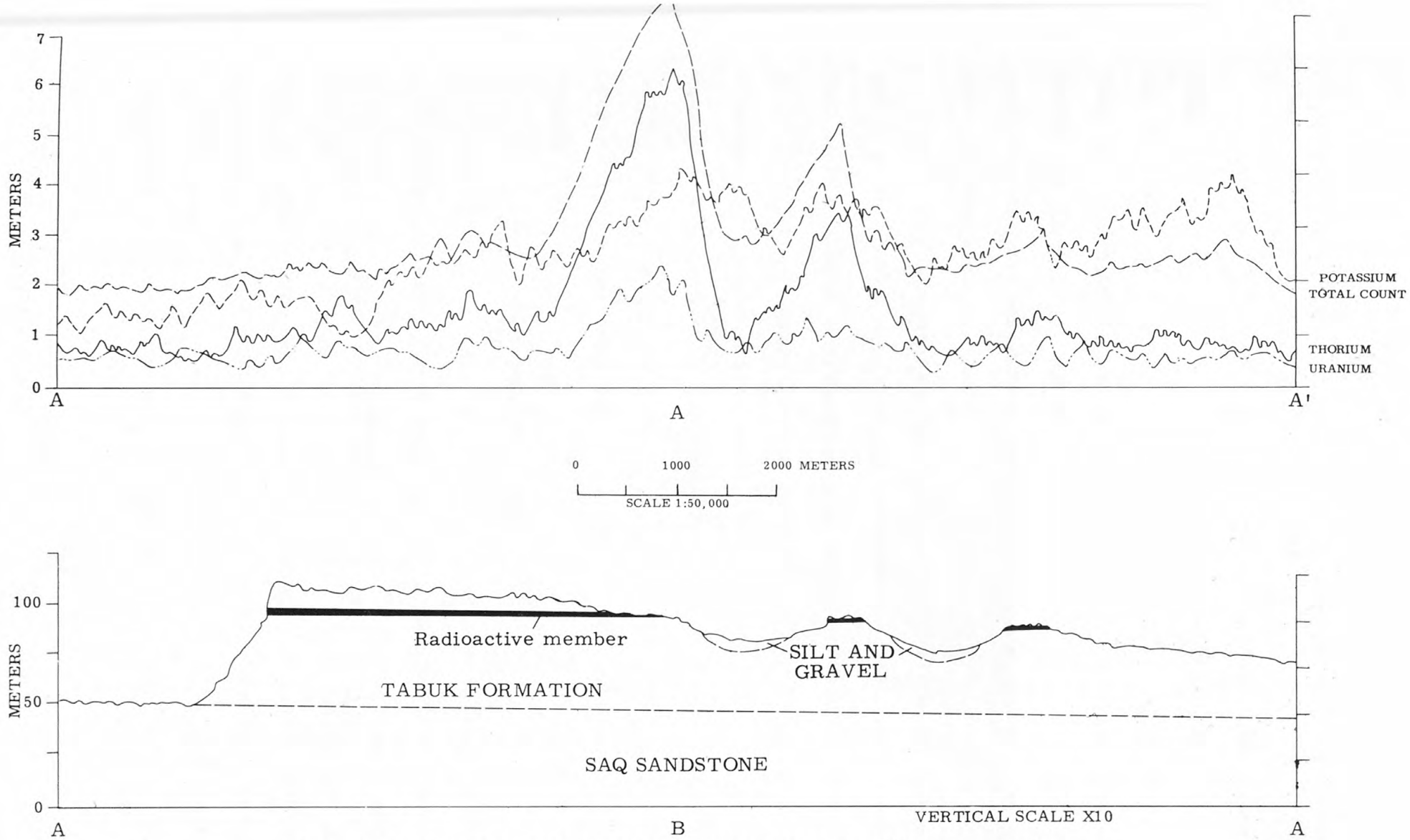

Figure 2.- Typical gamma spectrometer response (A) and geologie cross section (B) across the Al Qassim test area.

SPECTROMETER RESPONSE

In 1973, the Lockwood Corporation of Canada made a gamma spectrometer survey over the Al Qassim area for the Ministry of Petroleum and Mineral Resources. Their data are shown on figure 3, as total count gamma radiation contours. An anomalous area 10 km long in a north-south direction was detected in the southwestern part of the area.

The response of the spectrometer indicates that a major part of the total gamma activity is emanating from the higher photon energies of the thorium radioelement, thallium-208. A lesser amount can be attributed to the bismuth-214 photon energy peak in the uranium decay series. Only a slight increase across the anomalous area arises from the photon energy of potassium K-40. The gamma response across the area sampled is shown on figure 2.

MINERALOGIC DATA

Seven samples were collected along cross section A-A' (figs. 2 and 3) and studied for this report. The localities with gamma contours are shown on figure 3 and a sketch of the geologic relationship is shown on figure 2. Each sample represents a composite of the exposed rock in an area of approximately 2500 m^2. Area samples such as this approximate average ground concentrations as viewed by a scintillation detector 90 m above the surface.

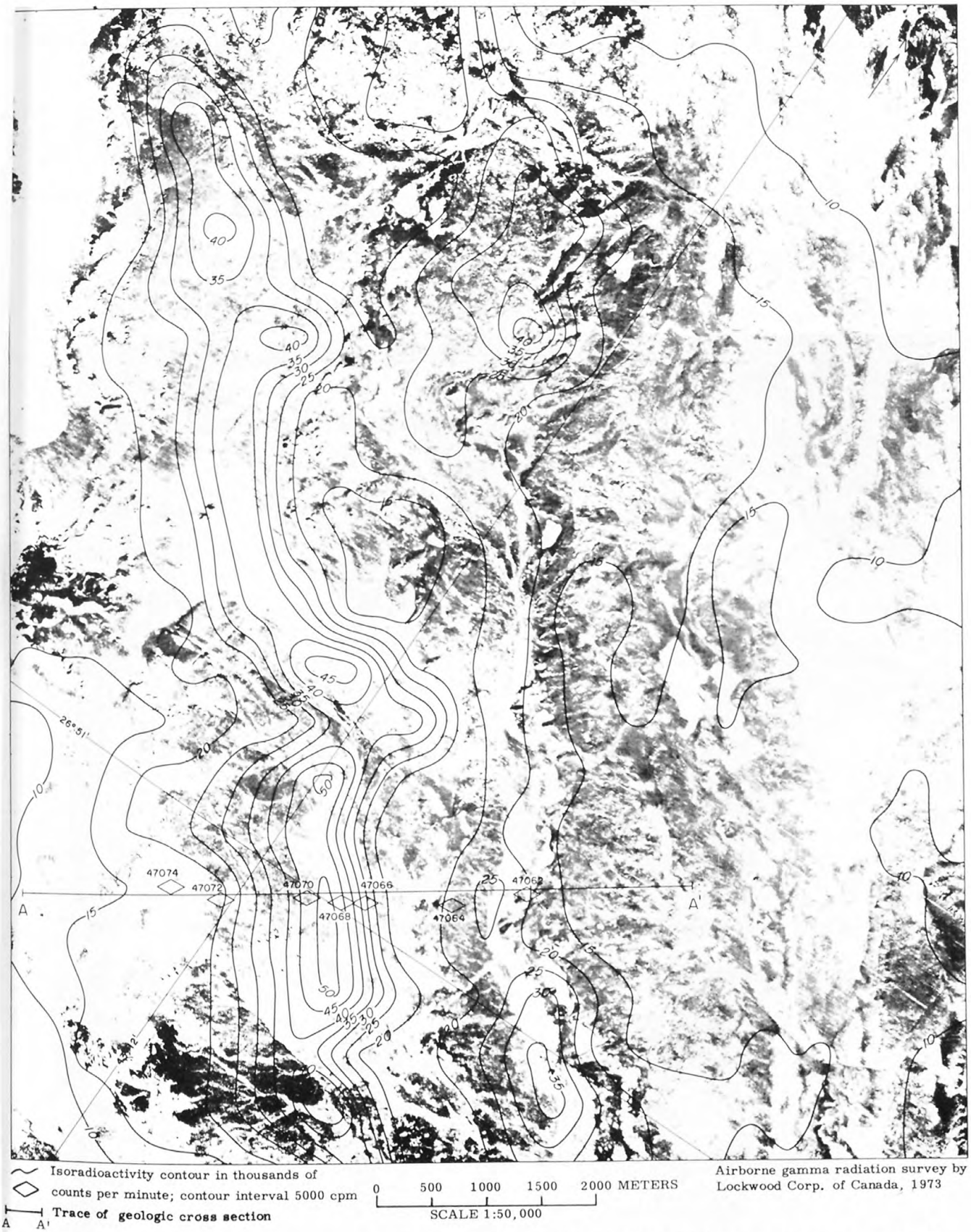

Figure 3.- Total-count gamma radiation map of the Al Qassim test area anomaly.

Table 1 lists the radioelement concentrations of the samples analyzed by the delayed neutron counting method.

Table 1. Radioelement analyses (in ppm) of total bulk composite samples, Al Qassim area. Neutron activation analyses by U.S. Geological Survey, Denver, Colorado, 1973.

Sample No.	Uranium	Thorium
47062	5.4	29.1
47064	10.1	39.1
47066	2.8	13.4
47068	22.0	167.3
47070	16.0	98.7
47072	8.6	48.7
47074	3.8	21.7

Sample 47068, which has the maximum concentration of thorium (167 ppm) and uranium (22 ppm), is from the area where the highest airborne count rate was recorded (fig. 2). Ground examination of the anomalous area by scintillometer traverses shows that the radioactivity is concentrated in a bed of siltstone and sandstone 50 cm to 1 m thick. This bed shown on the geologic cross section (fig. 2), is exposed on the northeast-facing slope of the escapement.

The radioactive bed is tightly cemented by calcite. It is medium to thin bedded, and buff to pink in color.

Part of sample 47072 was disaggregated with 10 percent hydrochloric acid, and grain size analyses of the insoluble residue show a single peak at 3.5 Phi, with a sharp dropoff on either side (fig. 4). Fifty-four weight percent of the sample was removed in leaching. Grain size analyses were also made on samples 47072 and 47064, which were disaggregated by mechanical means only. Both analyses show more or less similar curves with two peaks and one major peak at 1.5 Phi. These analyses of mechanically disaggregated samples are not considered to present as valid a picture of the actual grain size distribution of the detritals as does the analysis of acid-leached material.

Petrographic examination shows that the anomalous unit is a fine-grained calcareous, ferruginous, feldspathic sandstone. Thin sections from Al Qassim samples contain the following mineral percentages: quartz, 44.0; matrix of limonitic stained calcite, 33.7; labradorite An^{60}, 3.7; potassic feldspar, 4.3; zircon 8.0, rutile, 2.6; and others, 3.7. The quartz is semirounded to angular, clear to milky; some grains are frosted; the average size is 0.1 mm. Complete extinction with only very minor overgrowths is common indicating that the quartz was not under strain and siliceous ground water circulation was

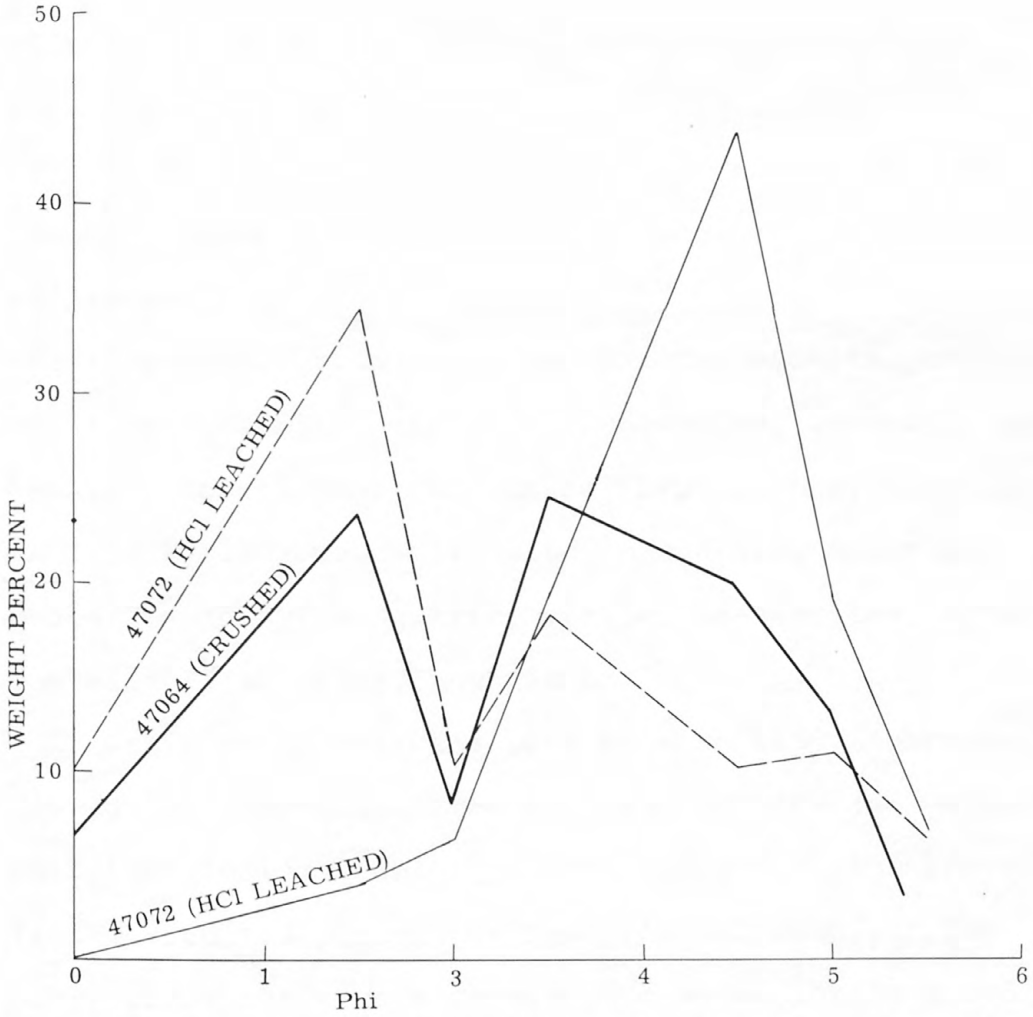

Figure 4.- Grain size analyses of samples from the radioactive bed, lower Tabuk Formation, Al Qassim area.

at a minimum. Some minor postdepositional movements produced microfractures that are filled with a mineral of very low birefringence and anomalous extinction, probably chlorite.

Minerals were identified by optical methods and many identifications were verified by X-ray diffraction. In alphabetical order, the minerals identified are allanite, andesine-labradorite, apatite, barite, biotite, calcite, chlorite, chromite, diopside, forsterite, goethite, gypsum, hematite, hornblende, huttonite, hypersthene, ilmenite, kaolinite, leucoxene, limonite, magnetite, monazite, muscovite, olivine, quartz, rutile, spessartine, sphene, tourmaline, xenotime, and zircon.

Grain-count analyses were made on heavy concentrates (sp. g. 3.3) prepared from 100-gram samples and using methylene iodide (table 2). The heavy fraction ranged from 0.2 to 1.3 percent of the original sample. The heavy fractions were screened into more closely-sized fractions and weighed, generally 300 grains were counted in each fraction, and the proportions of each mineral were recalculated to weight percentages of heavy minerals. Several minerals that contain varying amounts of thorium and uranium were identified; the principal thorium-bearing minerals are allanite, huttonite, monazite, sphene, and xenotime.

Table 2. Mineralogy of heavy fraction (sp.g. >3.3) from lower Tabuk Formation, Al Qassim area.

Sample number	47062	47064	47066	47068	47070	47042	47074
Percent of heavy minerals in 100 grams	2.1	4.4	9.1	5.1	4.2	8.3	1.1
Magnetite (weight %)	2.0	4.2	8.9	4.5	2.9	8.1	0.4
	Percent in heavy fraction						
Opaque*minerals	97.2	93.9	83.0	64.0	95.0	80.4	94.5
Zircon	1.0	.6	.7	16.2	1.9	.7	1.1
Monazite	.2	.1	.3	2.5	.2	tr	tr
Rutile	.1	.1	.2	7.6	.6	.5	.3
Other**minerals	1.5	5.3	15.8	9.7	2.3	18.4	4.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Opaque minerals include abundant magnetite and limonite-goethite, and lesser amounts of ilmenite and leucoxene. Magnetite weighed separately indicates the percentage of this mineral in the opaques.

** Other minerals include allanite, olivine, and pyroxene as major constituents, and lesser amounts of hornblende, spessartine, sphene, xenotime, and "Unidentified" in trace amounts.

Monazite can be conveniently identified by its bright-green absorption with unfiltered shortwave light; however, a mineral (n_z = 1.735) that has been identified by optics and X-ray gives the same bright-green absorption. This characteristic of the epidote mineral prevented the binocular scanning of samples for monazite by this convenient and rapid method. Deer and others (1967, p. 212) classify epidote rich in cerium and other rare earths as allanite, and that procedure will be used here.

Zircon is most commonly doubly terminated, generally well rounded to subrounded, ranges from 0.1 mm to 0.07 mm in length, and occurs primarily in the -200 +325-mesh fraction. Some zircons show color zoning, inclusions, radiation damage, and no fluorescence or absorption under shortwave light (2535Å), whereas others are colorless and exhibit a bright-yellowish orange fluorescence. The radiation-damaged and nonfluorescent zircon are believed to be older than the fluorescent zircons, and the two types of zircon are believed to indicate two different source areas.

Rutile, like zircon, occurs mainly in the -200 fraction. The rutile is deep red and has prismatic habit, and X-ray analyses indicate that it is niobium-rich. Rutile is reported to contain variable amounts of niobium as well as tantalum and some tin (Deer and others, 1962,

v. 5, p. 36). Rutile may thus contain some of the niobium and tin reported in the spectrographic analyses (table 3) for the Saudi Arabian samples. Cassiterite was looked for but not identified.

Labradorite, identified by X-ray diffraction and in immersion oils (N_z = 1.565), is common in the light fractions. It is gray to bluish black, generally fresh looking, coarse-grained, and angular. Authigenic formation is unlikely because the labradorite shows twinning and exsolution textures that are more typical of high-temperature formation.

Spectrographic analyses (table 3) show many similarities in the chemistry of the sandstone samples, although there are some variations in percentages. Samples 47068 and 47070 contain high cerium and also have consistently higher contents of rare earths and thorium than the other three samples, as would be expected. The high neodymium content of these two samples is a reflection of their high monazite content. These two samples also contain high contents of titanium and niobium which are believed to reflect the rutile content, as mentioned previously. Silver and tin are also somewhat higher in samples 47068 and 47070, but the source minerals were not found. Tests for cassiterite in the concentrates by the metallic tin-plating method were

Table 3. Semiquantitative spectrographic analyses of unconcentrated total (total bulk composite) sandstone from the Tabuk Formation, Al Qassim area (Analyses by Joseph L. Harris, U.S. Geological Survey, Washington D.C.)

	47062	47064	47066	47068	47070
			In percent		
Si	19.9	22.7	25.8	26.6	22.6
Al	2.9	3.5	4.2	4.3	3.2
Fl	3.4	4.2	3.1	2.9	3.0
Mg	3.2	1.8	2.5	1.3	1.0
Ca	4.4	3.4	3.6	5.0	7.3
Na	>0.3	>0.3	0.2	0.2	0.1
K	>1.0	>1.0	4.4	>1.0	>1.0
Ti	0.1	0.2	0.2	0.6	0.4
P	< 0.1	0.8	<0.1	0.1	0.1
Mn	0.3	0.2	0.3	0.1	0.2
			In parts per million		
Ag	<0.1	<0.1	<0.1	0.5	0.2
B	32.7	48.9	34.2	66.1	38.6
Ba	360	400	651	624	518
Ce	128	212	55.9	615	403
Co	5.1	7.1	4.6	6.8	5.8
Cr	30.3	33.1	34.7	79.9	71.7
Cu	38.5	35.4	29.2	30.6	43.5
Dy	<3.2	11.4	6.7	23.4	11.1
Er	<2.1	9.4	<2.1	15.6	8.2
Eu	1.2	3.9	<1.0	5.2	3.0
Gd	<3.2	14.2	<3.2	22.5	13.8
Ho	<1.0	5.2	<1.0	<2.1	2.7
La	64.3	113	38.4	344	210
Mo	2.9	2.5	1.2	2.6	3.3
Nb	4.0	5.0	3.4	20.0	11.8
Nd	69.4	97.9	53.9	420	268
Ni	11.6	15.2	14.2	16.5	20.9
Pb	15.3	<0.7	<0.2	<0.2	<0.2
Pd	<0.2	<0.7	<0.2	<0.2	<0.2
Pr	13.5	19.5	8.7	56.3	36.4
Pt	<2.1	<6.8	<6.8	<6.8	<6.8
Sc	4.0	6.6	5.8	12.3	7.6
Sm	9.0	12.5	5.6	41.2	27.2
Sn	<3.2	<3.2	<3.2	3.9	4.7
Sr	142	217	137	309	245

Table 3. (Cont'd.)

	47062	47064	47066	47068	47070
	In parts per million				
Th	54.4	60.3	<21.5	272	164
U	<215	<215	<215	<215	<215
V	48.1	60.5	37.1	74.7	62.5
Y	59.7	111	33.5	>215	88.5
Yb	7.7	11.6	4.9	14.1	12.7
Zn	<14.7	44.7	27.7	<14.7	<14.7
Zr	>681	>681	296	>681	>681

negative. Sample 47064 is third highest in cerium but differs from the two other high cerium samples in having the second highest yttrium content and highest phosphorus content. Both these elements probably reflect a higher xenotime content.

DISCUSSION

Highly radioactive, thorium-rich, uranium-poor huttonite, monazite, and xenotime have been identified in the sandstone. Less radioactive minerals are zircon, sphene, and allanite. These heavy minerals are commonly found in beach and stream placers.

The mineral associations include two types of zircon, allanite, and monazite and indicate sedimentary accumulation derived from two or more different crystalline source rocks. Overstreet (written commun., 1971) indicates that an antipathetic relationship exists between allanite and monazite, such that monazite is absent, or is only sparsely present, where allanite is common.

The major source rocks for monazite in stream or beach placers are synkinematic granite, gneiss, and granulite schist or metamorphic rocks of the upper amphibolite facies. Monazite-bearing placers such as those in India and Brazil (Overstreet, 1967) can be traced into Precambrian shield areas where high-grade metamorphic rocks containing abundant accessory monazite are exposed. At places where monazite-bearing beach sands

apparently are not related to high-grade metamorphic rock complexes, such as the coasts of Queensland and New South Wales, it can be shown that the detrital monazite has been recycled through a Paleozoic sedimentary cover derived from buried plutonic rocks (Overstreet, 1960).

Huttonite was described by Pabst and Hutton (1951) as being associated with other heavy minerals in beach sands, and, they concluded that the huttonite was probably derived from the nearby low-grade schists.

In the Al Qassim-Jal at Tiraq area, the original source of the radioactive minerals in the Tabuk Formation was probably gray biotite-hornblende gneissic granite and younger red granite. The source rocks of the early to middle Paleozoic Tabuk Formation are most likely the older rocks to the west as shown on the geologic map by Bramkamp and others (1963). These include the lowermost Saq Sandstone immediately beneath the Tabuk Formation and Precambrian crystalline rocks beneath the Saq. The Precambrian rocks include the andesitic Halaban Group (Schmidt and others, 1973), gray granite, conglomerates containing granite and metamorphic pebbles, and red granite. In the Wadi Ar Rima quadrangle, Mytton (1970) found anomalous lanthanum and yttrium contents in sediments from wadis draining granitic stocks, and in red and pink granites of late Precambrian age. No mineral identifications were made.

Because of the thinness of the radioactive zone and the low concentration of heavy minerals in it, the Tabuk does not appear to be of economic interest. Concentrations may possibly be found in wadis draining the source beds, but no exploration of the wadis was made. The Tabuk Formation contains beds of silty and micaceous shale, purple to olive-green shale, and sandstone (Powers and others, 1966), that would be generally more favorable targets for uranium exploration. Another possible source of radioactive heavy minerals is the underlying Saq Sandstone which may be correlated with the Wajid Sandstone of Cambrian and Ordovician age in southern Saudi Arabia. The Wajid Sandstone is known to be radioactive, and Matzko and Naqvi (1976) describe heavy mineral accumulations similar to those in the Tabuk Formation.

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