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AN INTERPRETATION OF GAMMA-RAY SPECTROMETRIC AND TOTAL-INTENSITY MAGNETIC DATA FOR THE JABAL YAFIKH QUADRANGLE, SHEET 20/43 B, KINGDOM OF SAUDI ARABIA

by

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ABSTRACT

Analysis of gamma radiation and total-intensity magnetic data in the Jabal Yafikh quadrangle provides considerable geologic information, particularly in the pediment areas where underlying rock units are masked by a veneer of surficial gravels. The spectral data include profiles and contour maps of potassium (K^{40}), uranium (Bi^{214}), thorium (Tl^{208}) radiation, as well as of the total count.

Sedimentary and igneous rocks of the Jabal Yafikh survey areas can be delineated by their unique radiation and(or) magnetic patterns. The marble unit of the Murdama group, gabbro, and amphibolites are characterized by very low gamma radiation. Granite, the conglomeratic unit of the Murdama group, and the metaclastic unit of the Halaban group display relatively high gamma radiation. The magnetic data complement the radiation data in delineating rock types. Thus, the marble unit and the conglomerate rock of the Murdama group, which have no characteristic magnetic pattern, can be delineated by the radiation data, and the diorite, granodiorite, and gabbro rocks, which have no characteristic radiation pattern, can be recognized by their unique magnetic pattern. Para-amphibolites have a low radiation response and a characteristic magnetic pattern. Fault structures and faulted contacts recognized by linear features on the magnetic map can be delineated in several places by the radiation data because of intrusion of igneous rocks of high radiation response along the fault zone.

INTRODUCTION

This report presents data from an airborne gamma-ray spectrometry survey of the Jabal Yafikh quadrangle bounded by lats 20°30'N. and 21°00'N. and longs 43°30'E. and 44°00'E (fig. 1). This quadrangle was selected as a typical pediment area on the Arabian Shield by which the gamma-radiation technique might be tested as an aid in understanding the geology of well-developed pediment areas. D. L. Schmidt of the U.S. Geological Survey provided the basic geologic map and rock

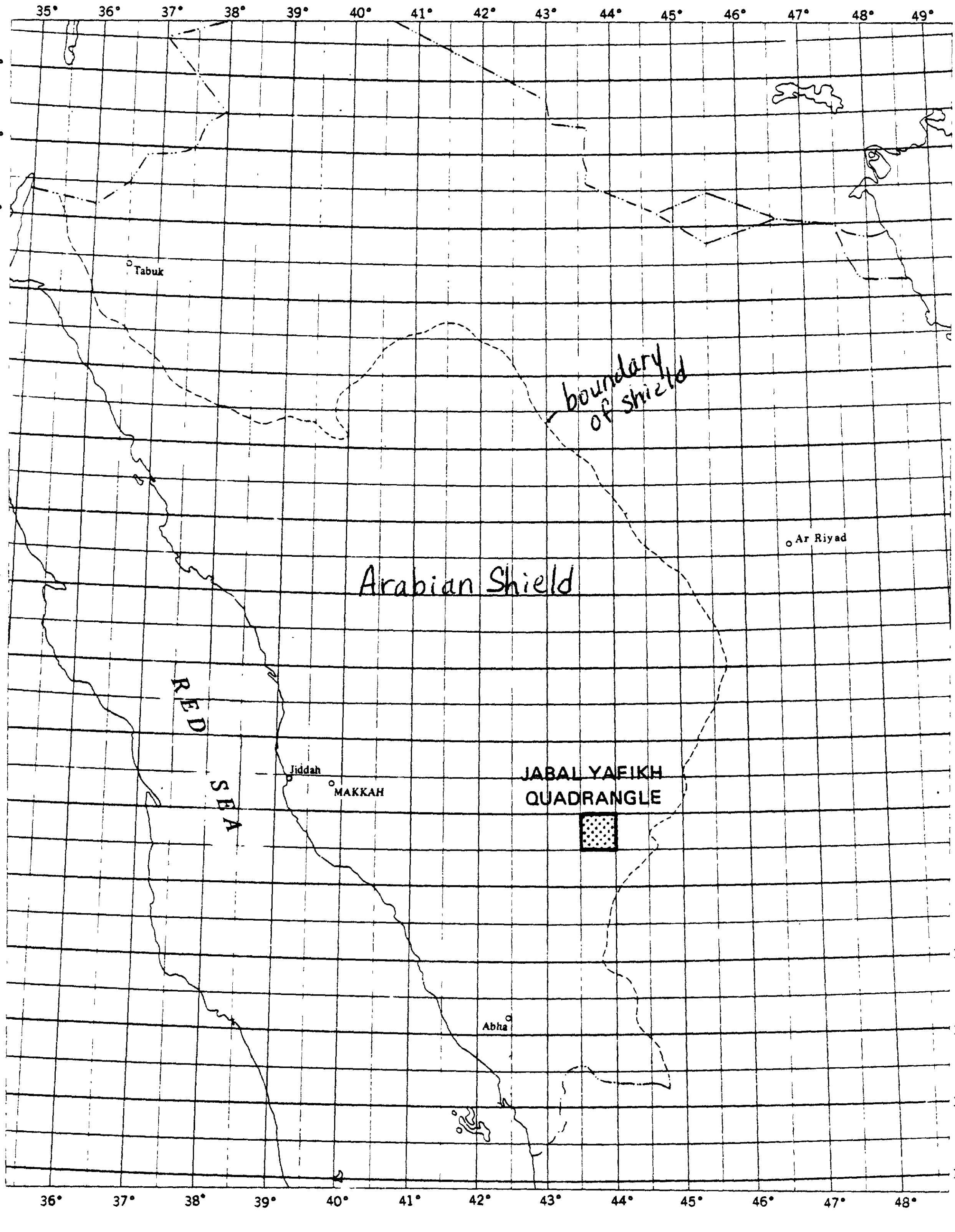


Figure 1.–Index map of western Saudi Arabia showing the location of the Jabal Yafikh quadrangle.

descriptions of the quadrangle and made helpful suggestions during the study of the radiation response of the geologic units. Gamma-radiation response is compared to mapped geologic units in an attempt to show that geologic contacts can be inferred from the airborne data. Magnetic data are also compared to the radiation data to show how the two methods correlate with and complement each other in providing a more complete picture of geologic relationships. This survey was conducted under a work agreement between the U.S. Geological Survey and the Ministry of Petroleum and Mineral Resources.

GENERAL GEOLOGIC SETTING

The following description of the general geology of the Jabal Yafikh quadrangle is based on a simplified geologic map and more detailed descriptions of rock units prepared by D. L. Schmidt (pl. 1).

The major geologic units include the Murdama group, the Halaban group, metasedimentary and metavolcanic rocks, and the granodiorite of Jabal Najeeb. Minor rock units include granite, quartz diorite, metadiorite, gabbro, serpentinite, and intrusive granitic rocks comparable to the alkalic to peralkalic granites recognized elsewhere on the Arabian Shield.

The Murdama group crops out in nearly half of the quadrangle, an area of about 1300 km^2. It consists of a thick, massive basal conglomerate composed of cobble- to boulder-size detritus derived mostly from red granite and andesitic volcanic rocks. Overlying the basal conglomerate are interbedded sedimentary rocks consisting of siltstone, sandstone, minor conglomerate, and several thin marble beds. A thick unit of intensely foliated white and blue marble forms the prominent Jabal Yafikh. The Murdama group of rocks lies unconformably on the Halaban group.

The Halaban group is exposed in a 360 km^2 area in the northeastern corner of the quadrangle and in narrow north-trending belts through the central and western part of the quadrangle. The upper part of the Halaban consists of a thick section of metaclastic rocks, including andesite and basalt flows. The lower part of the Halaban includes para-amphibolite, biotite schist, and paragneiss.

Halaban paragneiss, the oldest of the sedimentary units in the quadrangle, is exposed in a north-trending belt along the western edge of the quadrangle. Other Halaban rocks in the west consist of dark-blue to black, fine-grained, chloritized para-amphibolites and biotite schist that has undergone retrograde metamorphism to greenstone.

In the northeastern part of the quadrangle, rocks of the Murdama group are intensely folded and foliated in the Najd fault system and form a prominent anticlinal mountain range. The core of the anticline has been subjected to higher-grade metamorphism and injection of alkalic granite, serpentinite, and gabbro along faults and fractures.

Most rocks in the western part of the quadrangle are gray, coarse-grained granodiorite of Jabal Najeeb (Gonzalez, 1975). Metadiorite, quartz diorite, diorite, dioritic gneiss, gabbro, and granodiorite gneiss, apparently older than the Najeeb granodiorite, complete the series of intrusive igneous rocks mapped in the western half of the quadrangle.

Alluvial deposits are confined for the most part to the wadis and are not considered to have a major adverse effect on the radiation response of the bedrock except in some areas of very low relief in which lag gravel deposits of considerable extent and unknown thickness have developed. Even in these areas, much of the detrital material appears to have traveled only short distances from outcrops.

In the southern part of the quadrangle, long narrow belts of sand dunes trend southwesterly, normal to the prevailing wind. These dunes do not affect the overall radiation response of the bed rock except in one area where an extensive dune field causes a pronounced radiation low.

AIRBORNE RADIATION AND AEROMAGNETIC SURVEYS

Gamma radiation data presented in this report were recorded early in 1971 during an airborne survey of the Jabal Yafikh quadrangle by means of spectrometry instrumentation developed by the USGS (Andreasen and Flanigan, 1970). Fifty-four lines spaced at approximately 1 km were flown over the area. Average ground speed of the surveying aircraft was 44 m/sec. Radiation count-rate response was sampled every half second, or about every 22 m, along the flight paths. Flight height was about 91 m above terrain, and was measured and recorded by means of a radar-type altimeter. All data were recorded on analog and digital recorders.

Radiation data were reduced and compiled automatically using the IBM 360/50 computer at the College of Petroleum and Mineral Resources computer center in Dhahran. The RADPAC data reduction system (Selner and Flanigan, 1973), developed by the U.S. Geological Survey Saudi Arabian Project produced the nested profiles (figs. 2-5) and contour maps (pls. 1-4). The nested profiles are referenced to the 43°45' E. meridian.

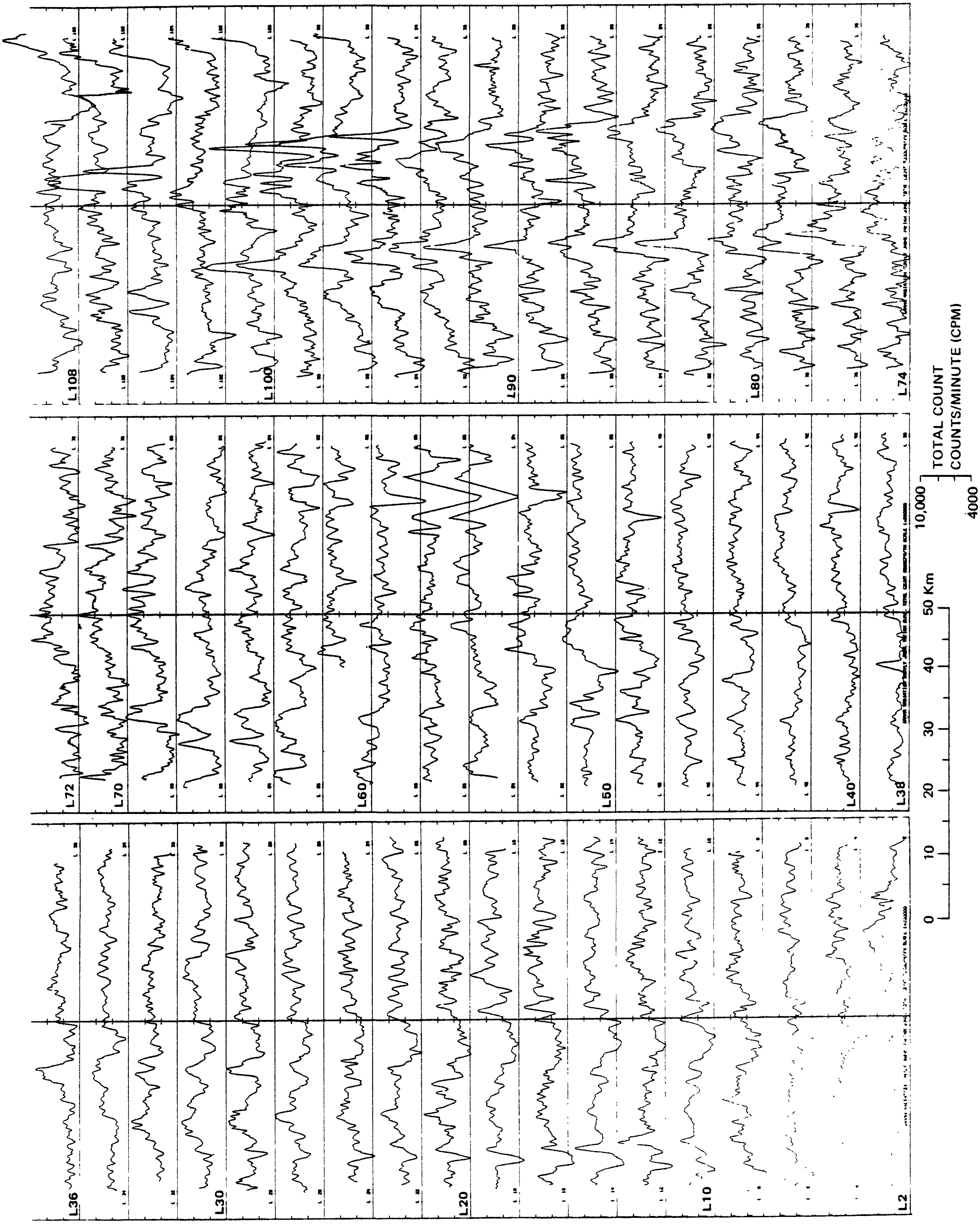


Figure 2.--Nested profiles of total count gamma radiation, Jabal Yafikh quadrangle.

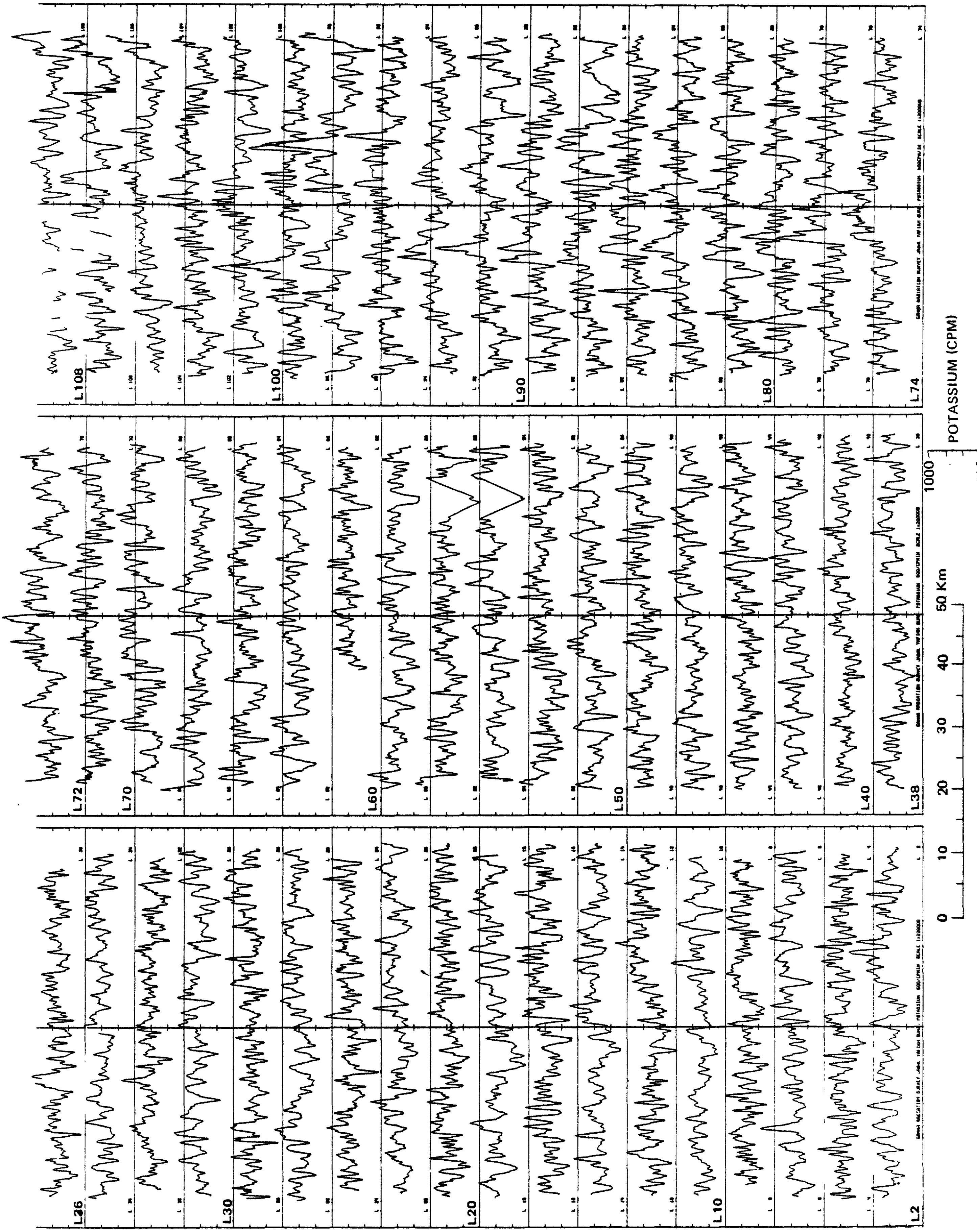


Figure 3.--Nested profiles of gamma radiation from potassium (K^{40}), Jabal Yafikh quadrangle.

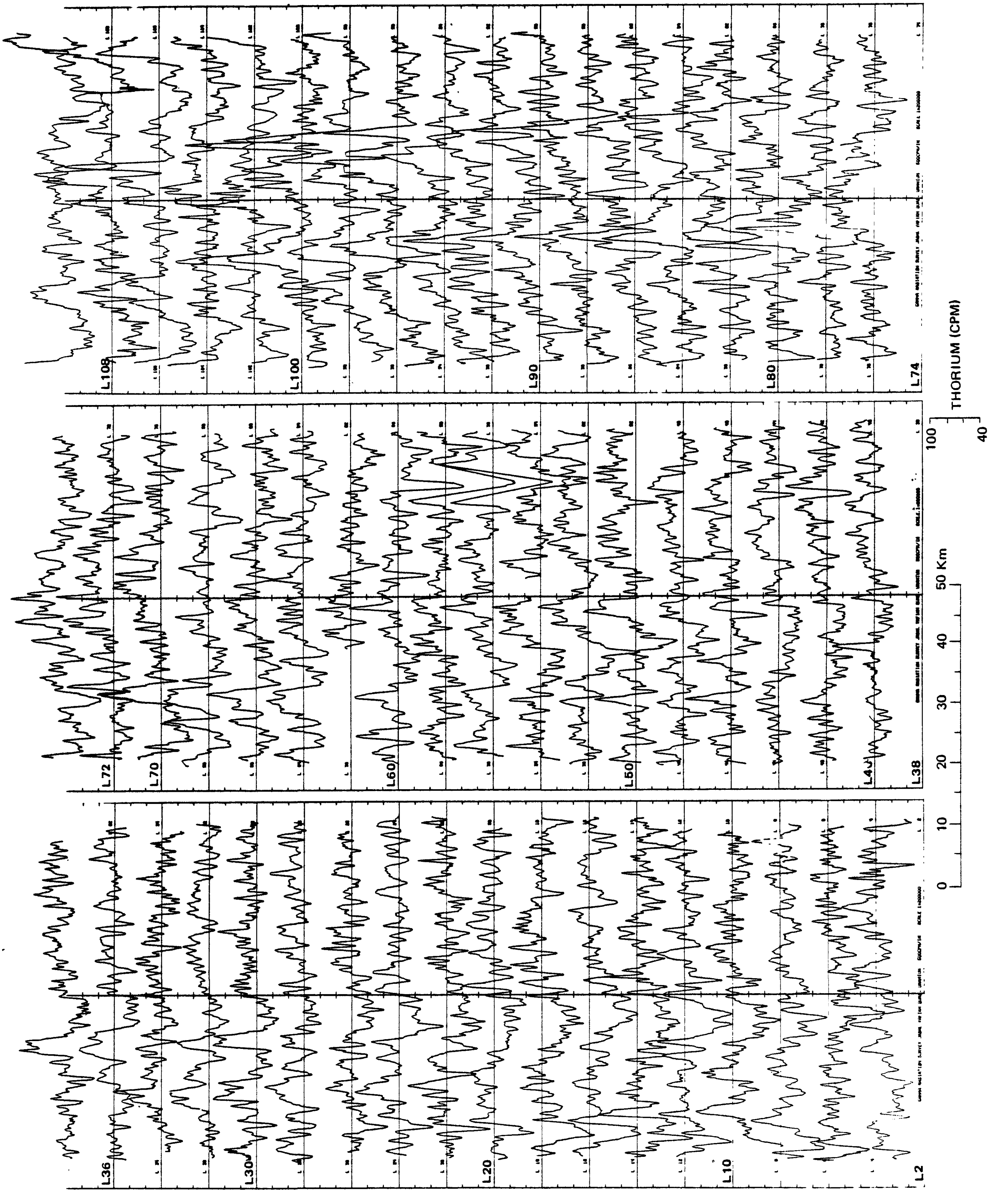


Figure 4.–Nested profiles of gamma radiation from thorium (Tl^{208}), Jabal Yafikh quadrangle.

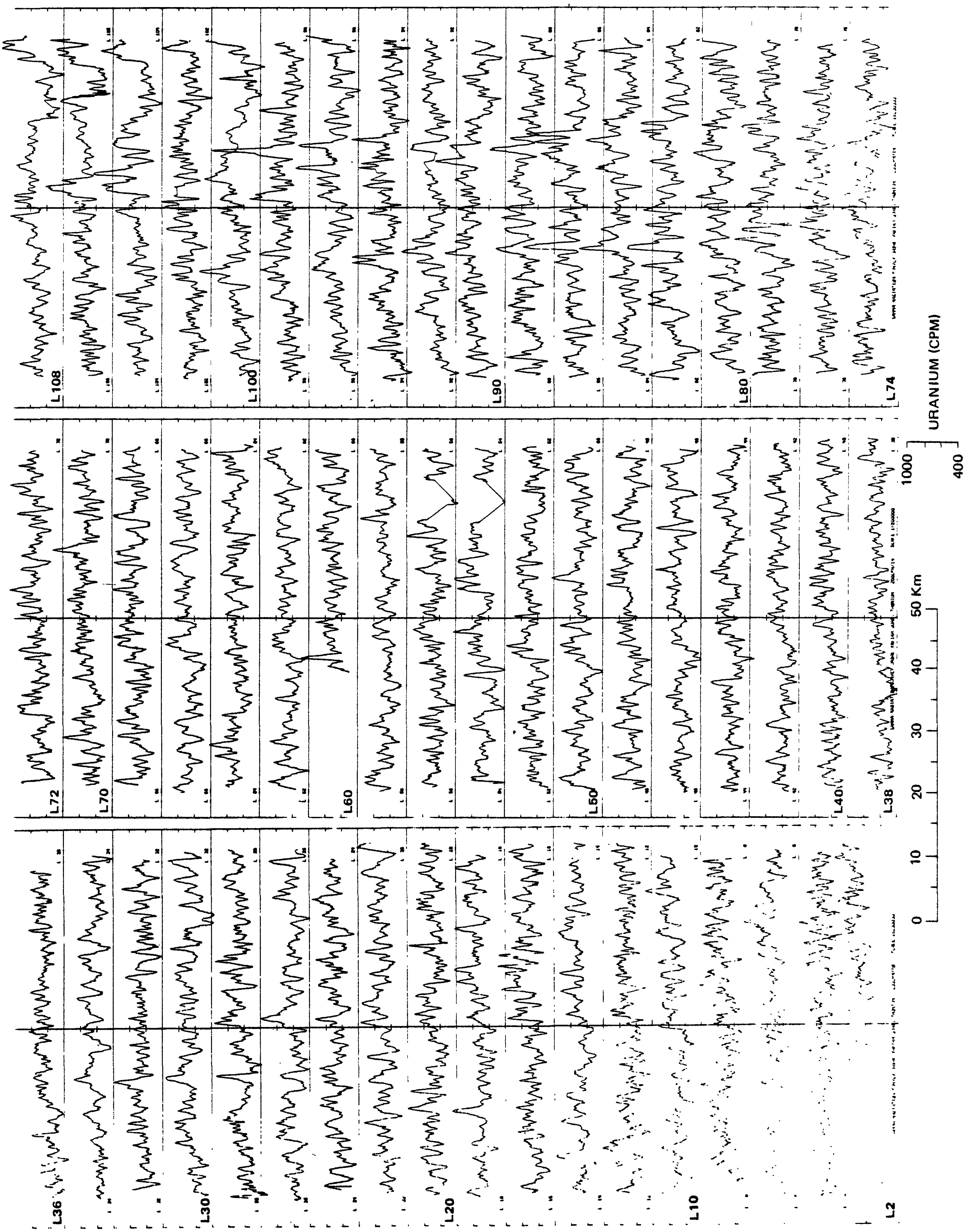


Figure 5.--Nested profiles of gamma radiation from uranium (Bi^{214}), Jabal Yafikh quadrangle.

Flight line locations are shown on plates 1-4.

Total-intensity aeromagnetic data for the quadrangle (fig. 6) were obtained as part of a major magnetic survey of the Precambrian Shield of Saudi Arabia during 1966-67. The survey was made by a consortium of companies that included Lockwood Survey Corp. Ltd., Aero Services Corp., Hunting Geology and Geophysics, Ltd., and the Arabian Geophysical and Surveying Co. The aeromagnetic data were obtained along northeast-southwest flight lines spaced about 800 m apart at an altitude of 150 m above the land surface.

RADIATION RESPONSE

Typical radiation responses of the mapped geologic units (pl. 1) are listed in table 1. Granite, the conglomerate of the Murdama group, and igneous rock intruded in the Najd fault zone display the highest radiometric responses. Gabbro, metadiorite, para-amphibolite and marble of the Murdama group display the lowest radiation response. Several rock units display nearly identical radiation patterns (table 1). Quartz diorite, Murdama undivided, and granodiorite of Jabal Najeeb have radiation responses in the range of 8,000 to 11,000 total counts per minute (cpm). A second group of rocks, the Halaban (volcanic facies), diorite and granodiorite gneiss, yields total-count rates in the range of 6,000 to 9,000 cpm. A third group of rocks, Halaban biotite schists and para-amphibolites, displays a low count-rate in the range of 5,000 to 8,000 total cpm.

The ratio between the isoelement count-rates is nearly constant irrespective of rock type (table 1). This relationship can also be seen in the radiation contour maps (pls. 1-4). In those areas in which the count-rate of one of the isoelements is high, count-rates of the other isoelements measured are also high. Exceptions to this relationship do occur, however, and it is in these areas where the radiation spectral data may be of additional use. It seems likely that coincidences of isoelement highs and lows are related to unique rock units, whereas departures from this relationship may be related to geothermal alteration, weathering, or other geologic processes that cause either enrichment or depletion of the isoelements being measured. For example, a relative potassium low in the Murdama group occurs in the southeastern corner of the map (pl. 2) and forms a distinct lineation that coincides with mapped bedrock lineations for nearly 15 km. In the western part of the map area, a number of potassium highs along a major north-trending fault system coincide with high uranium count-rates in several places

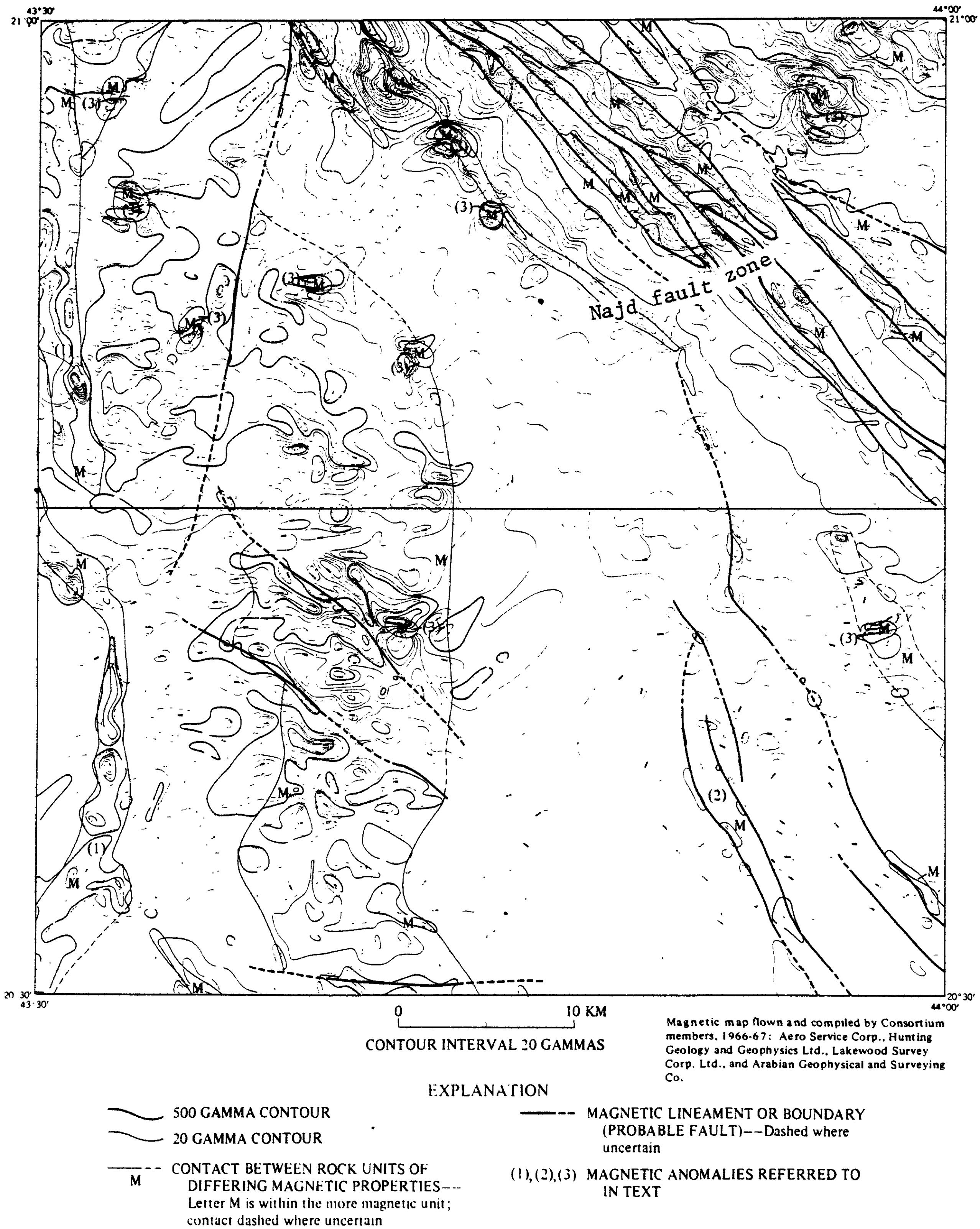


Figure 6.–Total-intensity aeromagnetic map of the Jabal Yafikh quadrangle showing aeromagnetic patterns.

Table 1.--*Gamma radiation response for rock types in the Jabal Yafikh quadrangle*

Rock Type, Group or Member	Map Symbol	Range of Radiation Response in Counts per Minute			
		Total Count	Potassium	Thorium	Uranium
Serpentinite	s	6,000-7,000	400-500	100-150	800-1,000
Murdama group					
Arkosic and volcaniclastic	mu	8,000-10,000	400-600	150-200	1,000-1,400
conglomerate with granite					
cobbles	mc	12,000-17,000	900-1,200	250-350	1,800-2,200
Marble	mm	5,000-7,000	300-400	50-100	400-800
Granite, red	rgr	12,000-18,000	900-1,200	250-400	1,800-2,400
Granodiorite of Najeeb	ngd	8,000-10,000	400-500	100-150	1,200-1,400
Quartz diorite	qd	9,000-11,000	500-600	150-200	1,200-1,400
Diorite	di	6,000-9,000	500-600	100-200	1,000-1,200
Gabbro	gb	6,000-7,000	200-400	100-150	800-1,000
Halaban group					
Metaclastic	hc	10,000-12,000	600-900	150-300	1,200-1,400
Metasedimentary and metavolcanic	hu	6,000-9,000	400-600	150-200	1,000-1,400
Paragneiss	pgn	8,000-10,000	600-800	150-200	1,400-1,600
Para-amphibolite	am	5,000-7,000	300-400	100-150	600-800
Biotite schist	bs	7,000-8,000	400-600	150-200	1,000-1,200
Metadiorite	mdi	6,000-8,000	400-600	150-200	800-1,000
Granodiorite and	mgg				
diorite gneiss	mdg	7,000-9,000	300-500	100-150	1,000-1,200

Spectral data from the isoelements thus appear to add little to the geologic picture as revealed by the total-count response. The isoelement maps are more important as an indirect guide for mineral exploration; that is, excess potassium producing high potassium count-rates is commonly present in areas of hydrothermal mineralization. On the other hand, the potassium content may be abnormally low in other types of alteration associated with mineralization (Flanigan and Pitkin, 1979). Thorium is a good indicator of rare-earth minerals, and high thorium count-rates may indicate significant concentrations of valuable heavy minerals. The uranium response is a good indicator of terrestrial concentrations of uranium minerals, but it needs to be evaluated in terms of possible variations in radon concentration. Radon, a radioactive gaseous byproduct of the nuclear decay of uranium, may concentrate under certain atmospheric conditions, and adds significant error to the uranium count-rate.

COMPARISON OF RADIATION DATA AND MAPPED GEOLOGY

This discussion of correlation of radiation data with mapped geology is based on visual comparison of the composite map of total-count radiation with the simplified geologic map (pl. 1).

Several prominent radiation highs outlined in the quadrangle correspond reasonably well with geologic units mapped in these areas. An anomaly of 17,000 cpm maximum intensity and characterized by steep gradients is located at lat 20°55'N., long 43°40'E. This anomaly covers about 40 km^2 and clearly outlines the basal conglomerate of the Murdama group mapped in this area. The radiation response most likely reflects the increased content of radioactive elements in the granitic detritus of the conglomerate. This conglomerate is especially interesting because conglomerates of the Canadian Shield are being mined for uranium and constitute 92 percent of Canada's uranium reserves (Little and Smith, 1969). A more detailed ground examination should be made to ascertain more accurately the source of the anomaly. That the same conglomerate extends south nearly to the southern edge of the quadrangle but does not show any other pronounced radiation highs indicates either that it contains a smaller concentration of radioactive minerals or that it is being masked by surficial cover.

A second radiation high, maximum intensity 16,000 cpm, is over a 40 km^2-area of granodiorite gneiss within the Najd fault system at about lat 21°55'N., long 43°50'E. Here the radiation response reflects the increase of radioactive minerals associated with granitic rocks intruded into the core of an anticline. Granitic dikes in this area may be related to younger alkalic granitic rocks of high radiation response that crop out several kilometers to the east; granitic intrusives are clearly outlined by their high radiation response and closely spaced contour lines.

A third area of high radioactivity is in the northeastern corner of the quadrangle and coincides quite closely with the volcaniclastic facies of the Halaban group mapped in this area. The volcaniclastic facies here contains silicic volcanic rocks. In the west-central part of the quadrangle the Halaban is again outlined reasonably well by its higher radiation. In the south-central part of the quadrangle the relatively high radioactive expression suggests that the rocks are the metaclastic facies of the Halaban. Two anomalies detected in the Halaban northeast of the Najd fault system near the northeastern corner of the quadrangle appear as a prominent radiometric high and low respectively. The low, 5000 cpm minimum intensity, coincides with a prominent mountain, and the radiometric expression suggests that this rock is somewhat more mafic in composition than the surrounding rocks. In the same area a radiometric high, 10,000 cpm maximum intensity, approximately 4 km northwest of the low may reflect an intrusive of felsic composition.

The granodiorite of Jabal Najeeb generally displays high radioactivity. Steep radiation gradients mark the contact of the granodiorite where it adjoins para-amphibolites in the southwestern corner of the quadrangle. Through the west-central part of the quadrangle, the radiation contours show a marked north-northeasterly trend along the contact of the Najeeb granodiorite to the west and an older granodiorite gneiss mapped to the east; this trend seems to reflect an increase in the radioactive-element content associated with a granitic rock (map unit rgr) that apparently intrudes the north-trending fault transecting this area.

Granodiorite gneiss and dioritic gneiss mapped in an area of about 170 km^2 centered near lat 20°35'N., long 43°40'E. shows a varied radioactive pattern. One area of 5,000-7,000 cpm contrasts with another area of 8,000-10,000 cpm. The higher radioactivity seems to be related to the granodiorite of Jabal Najeeb cropping out to the west, but it may reflect alteration that occurred during a period of tectonism and injection of dike swarms.

Several areas of low radiation intensity occur over rocks mapped as para-amphibolite, gabbro, serpentinite, and the marble member of the Murdama group. The areal extent of the para-amphibolites is clearly outlined in the southwestern corner of the quadrangle, where a linear radiation low, characterized by steep gradients along the contact, extends for 15 km in a northerly direction. This anomaly is terminated at its northern end by an east-northeast-trending low associated with an area of sand dunes. Another distinctive low associated with granodiorite gneiss is seen at lat 20°50'N., long 43°55'E. In this area, the 6,000-8,000 cpm contour level clearly defines a narrow belt of rocks caught in the Najd fault system. The marble member of the Murdama causes particularly prominent radiometric lows. Jabal Yafikh, at lat 20°45'N. and long 43°55'E. is clearly defined by its low radiation pattern. This same marble member occurs as thin units within the Najd fault system but their lack of a distinctive radiation pattern indicates that the resolution of the spectrometer system may be too low to detect them. Several small bodies of serpentinite along the western edge of the Najd fault zone produce distinctive radiation lows of 7,000-8,000 cpm intensity, in marked radiation contrast to the surrounding Murdama group. One gabbro body located at lat 20°53'N., long 43°33'N. is also delineated by a radiation low of less than 6,000 cpm.

COMPARISON OF RADIATION DATA AND MAGNETIC DATA

A comparative study of magnetic and radiation data assists in understanding geologic relationships because it provides a more complete picture of the geophysical properties of rock units. In the Jabal Yafikh quadrangle the radiation data not only correlate with the magnetic data, but in areas of rocks of more felsic composition the radiation data complement the magnetic data by indicating variation in rock types that do not have a unique magnetic pattern associated with them.

The magnetic map of the Jabal Yafikh quadrangle is shown in figure 6. Superimposed on the magnetic map is a qualitative interpretation modified after A. Griscom (1971, unpublished data. Magnetic features have been outlined, and discrete magnetic units interpreted as rock units of significantly different magnetic properties are indicated. The letter "M" along contacts is in the rock unit of more magnetic character. Prominent magnetic features include the northwest-trending magnetic lineations associated with the rocks caught up in the Najd Fault system crossing the northeastern corner of the quadrangle. In the northwest quadrant of the quadrangle, a north-trending lineation in the magnetic contours expresses dikes or rocks of more magnetic character associated with a fault mapped in this area.

A belt of magnetic anomalies indicated as "(1)", about 2 to 3 m wide, trends northerly along the west side of the quadrangle. In the southern half of this belt of anomalies, the rocks are reversely magnetized. This reversal indicates either that the magnetic minerals were aligned at a time when the earth's field was in a direction different from the present magnetic field or that the geometry of the rock unit, that is, the dip and strike of the body, is such as to present a negative anomaly to the magnetic detector when polarized in the present earth's field. This anomaly is associated with the para-amphibolite.

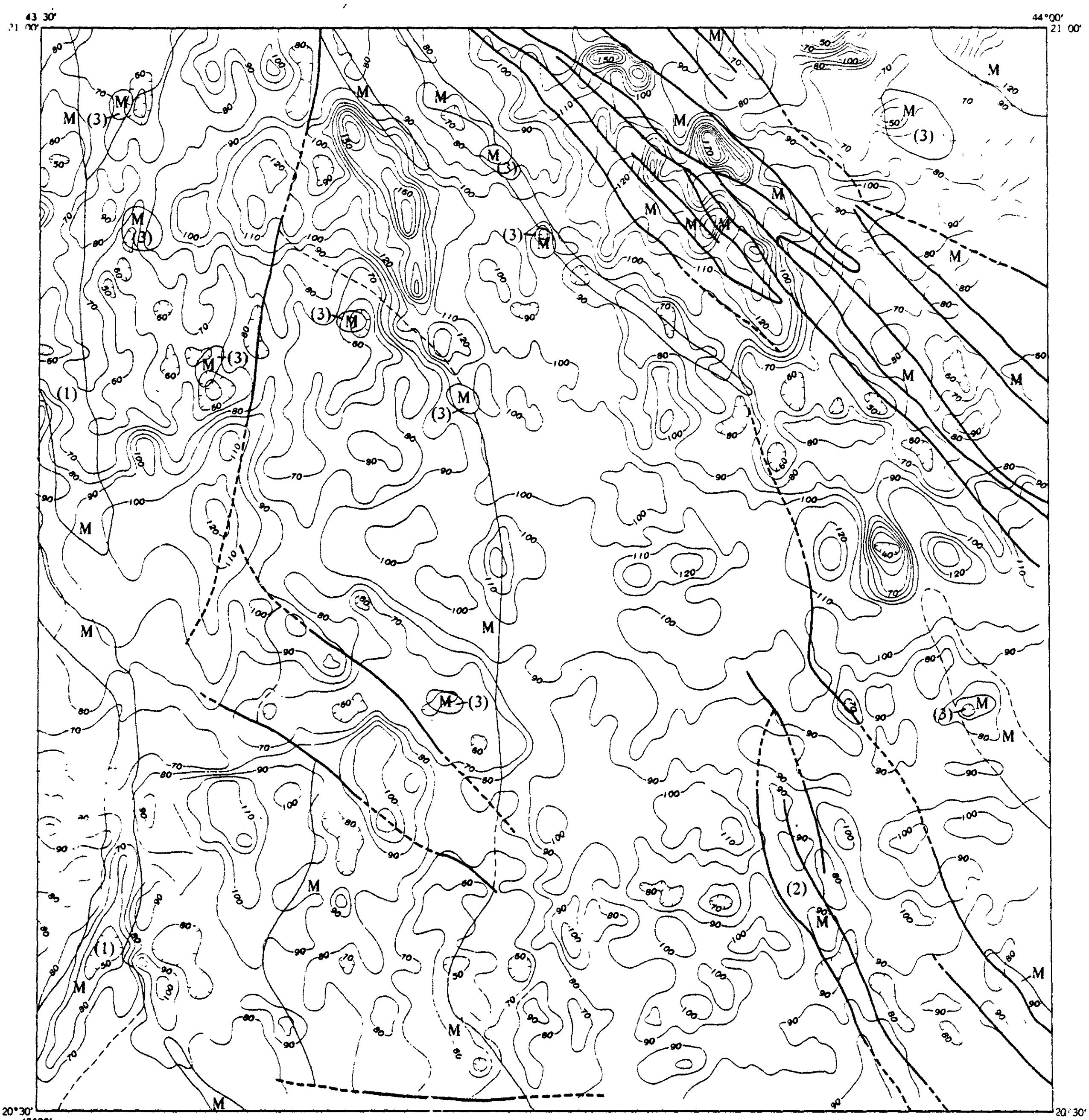
Rocks of more magnetic character appear to underlie an area of about 300 km^2 in the southwestern corner of the quadrangle. The magnetic pattern in this area consists of numerous closely packed, elliptical anomalies of 100-200 gamma intensity. Several northwest-trending lineaments through the area suggest that the granodiorite and diorite gneiss mapped in this area has been subjected to tectonic movement during its geologic history.

The rather flat, low-intensity magnetic pattern displayed by the Murdama group reflects the low magnetic susceptibility of these sedimentary rocks. In the southeastern part of the quadrangle, the normal magnetic pattern of the Murdama is broken by a series of northwest-trending anomalies of less than 100 gammas, marked "(2)" on figure 6. These anomalies suggest intrusions of more magnetic rocks in the form of dikes, most probably associated with the Najd faulting.

A number of discrete subcircular magnetic anomalies are noted on the magnetic map as "(3)". These anomalies have intensities of 100-300 gammas and most probably reflect small bodies of gabbro, serpentinite, or other mafic intrusive rocks.

For the purpose of comparing the magnetic-data interpretation with the radiation data, the lines of magnetic interpretation have been combined with the total-count radiation data (fig. 7). In general, areas of steep magnetic gradients and short wavelength anomalies correlate with areas of low radiation intensity. Furthermore, rocks such as the Murdama group and the granitic rocks, which show a rather flat magnetic pattern, can be distinguished by their radiation level.

The elongate radiation low in the southwestern corner of the quadrangle (fig. 7) correlates very well with the southern half of the zone of magnetic anomalies (1) over mapped para-amphibolite. Farther north, the radiation low is terminated, at least in part, by the masking effect of sand deposits. Over the northern extension of the magnetic rocks of this same belt (1) the radiation pattern is somewhat more complex; the contour lines show some northerly trends but the



0 10 KM

CONTOUR INTERVAL 1000 COUNTS PER MINUTE
(MULTIPLY BY 100 FOR TRUE VALUES)

Magnetic map flown and compiled by Consortium members, 1966-67: Aero Service Corp., Hunting Geology and Geophysics Ltd., Lakewood Survey Corp. Ltd., and Arabian Geophysical and Surveying Co.

EXPLANATION

RADIATION CONTOUR

RADIATION LOW

M CONTACT BETWEEN ROCK-UNITS OF DIFFERING MAGNETIC PROPERTIES--Letter M is within the more magnetic unit; contact dashed where uncertain

MAGNETIC LINEAMENT OR BOUNDARY (PROBABLE FAULT)--Dashed where uncertain

(1),(2),(3) MAGNETIC ANOMALIES REFERRED TO IN TEXT

Figure 7.--Total-count gamma radiation map of the Jabal Yafikh quadrangle showing total-intensity aeromagnetic patterns.

pattern does not correspond to the magnetic pattern nearly so well as it does farther south. The lack of correspondence indicates that the geology is probably more complex in the northern area.

A zone of magnetic anomalies (2) in the southeastern corner of the quadrangle correlates with a radiation low. These anomalies, as suggested earlier, may be associated with rocks of more mafic composition that may have been injected into the Murdama group during tectonic movement.

A magnetic high occurs in the northeastern corner of the quadrangle and correlates with a radiation high over metaclastic rocks of the Halaban group.

Small magnetic anomalies 1 to 2 km across at several places in the quadrangle are accompanied by radiation lows and may be covered by mafic intrusive rocks such as gabbro and serpentinite.

Within the Murdama group, which shows little magnetic variation, a number of prominent radiation anomalies have been detected that relate closely to several facies of the Murdama. The basal conglomeratic facies and the Yafikh marble facies are two of the units that can be delineated by their radiometric expression but that do not display distinctive magnetic patterns.

The radiation data and the magnetic data correlate reasonably well in those areas where the rock is mafic to ultramafic; however, radiometric anomalies associated with rocks of more felsic composition have no correlative magnetic expression. The high radiometric expression of the alkalic granite and the granodiorite of Jabal Najeeb are examples of this lack of correlation. In these areas, the radiation data add significantly to the basic knowledge of the geologic relationships.

CONCLUSIONS

Geologic units that can be outlined reasonably well by their radiation response are the marble unit and the conglomeratic facies of the Murdama group, the para-amphibolite rocks, and the igneous rocks such as the granite, gabbro, and serpentinite. These rocks display either a high or very low radiation response. Rocks of intermediate radiation response are not so well defined by their radiation pattern.

Radiation data when coupled with magnetic data provide valuable information for the regional geologist mapping in a pediment environment on the Arabian Shield. Rocks of mafic to ultramafic composition are detected as areas of low radiation intensity, whereas most of these same rocks are rich in minerals that increase their magnetic susceptibility and cause, in many instances, their characteristic magnetic patterns. In contrast, most rocks of felsic composition have a lower content of mafic minerals and thus show no strong magnetic patterns, but they contain more radioactive minerals (containing potassium, uranium, and thorium), which produce detectable radiometric highs.

Spectral radiation data, that is, for potassium, thorium, and uranium separately, add little more to the geologic picture than does the total-radiation count. The isoelement maps are valuable mainly as a rapid means of evaluating a total-count anomaly, and as indirect means for mineral exploration.

A more detailed ground examination is recommended for the area marked by a radiometric high over the basal conglomerate of the Murdama group at lat 20°55'N., long 43°40'E. The anomaly is believed to reflect an increase of radioactive minerals in the granitic detritus, but the exact cause of the anomaly should be ascertained.

The use of gamma spectrometry as an aid to geologic mapping has considerable potential value, and as experience is gained in interpreting radiation data on rocks of the Arabian Shield it should become more widely used.

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