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AIRBORNE GAMMA-RADIATION SURVEY OF THE JABAL ISHMAS QUADRANGLE KINGDOM OF SAUDI ARABIA

by

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U. S. Geological Survey
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ABSTRACT

An airborne gamma-radiation survey system, which includes digital recording and automatic data processing procedures developed by the U. S. Geological Survey Saudi Arabian Project, is used to collect spectral gamma-radiation data as an aid to regional geologic mapping of pediment areas on the Arabian Shield. The areal extent of rock units can generally be distinguished by the intensity of their radiation pattern. Rocks of ultramafic composition have low radiation response, whereas more felsic rocks reflect higher radiation response.

Interpretations based on radiometric data enable the geologist to gain some understanding about the geologic setting of an area before he begins field mapping.

INTRODUCTION

The airborne gamma-radiation survey technique was selected to provide basic geophysical data to assist geologists mapping pediment areas of the Arabian Shield. This report presents data and a qualitative interpretation of an airborne gamma-radiation survey of the Jabal Ishmas quadrangle, located between lats 20°30' and 21°00'N. and longs 43°00' and 43°30'E., Kingdom of Saudi Arabia (fig. 1).

Airborne gamma-radiation has been used as a mapping tool by a number of investigators (Moxham, 1963; Pitkin, 1968), and its use is particularly appropriate in the desert environment of Saudi Arabia.

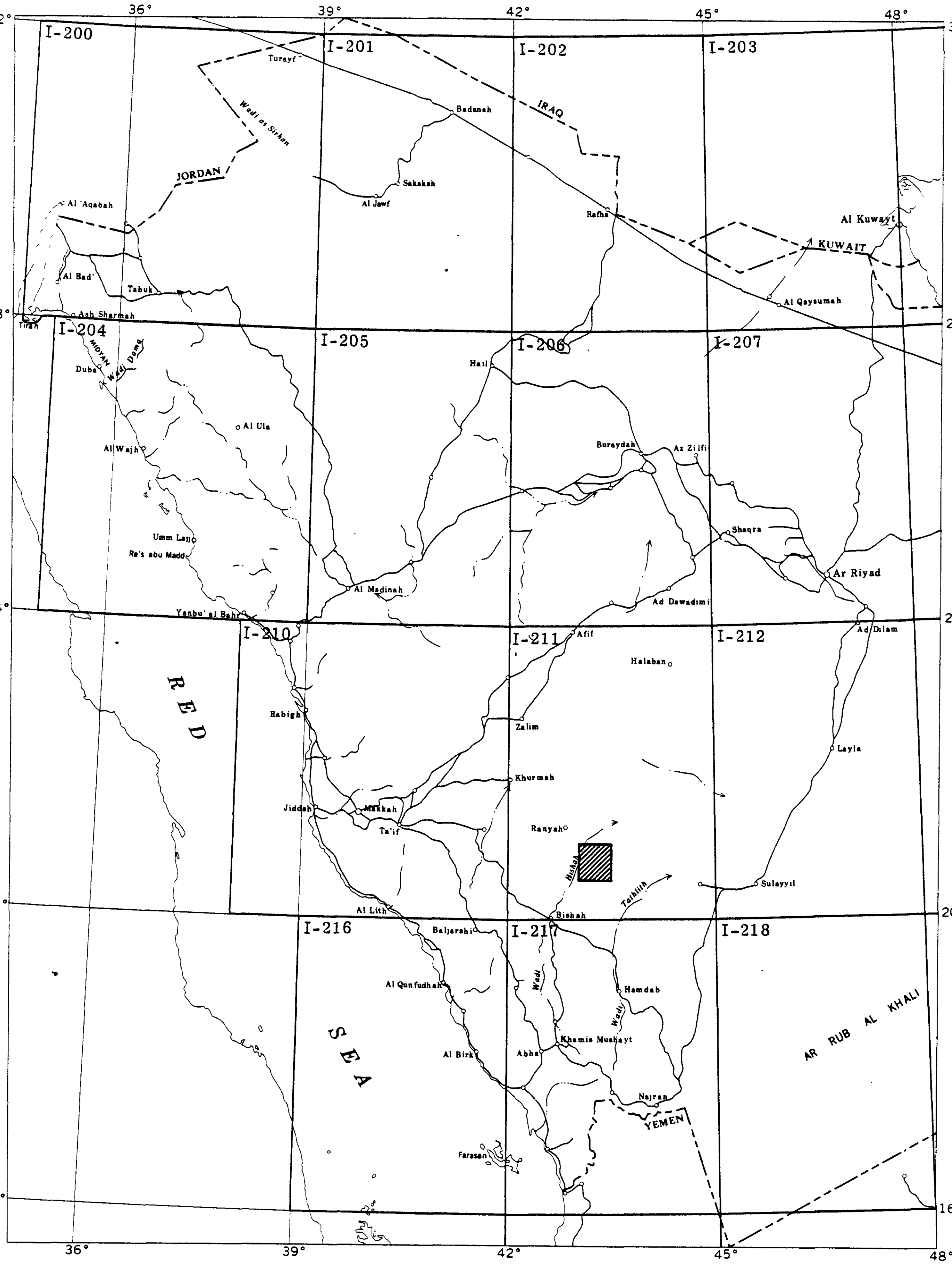

Figure 1.- Index map showing the location of the Jabal Ishmas quadrangle.

Mappable geologic units of contrasting radioactivity have been delineated in pediment areas (Flanigan, 1974). Rocks of mafic to ultramafic composition are detected as areas of low radiation intensity and rocks of felsic composition are detected as areas of higher radiation intensity. Radiation levels representing rocks of intermediate composition are not readily distinguishable unless they lie adjacent to rocks of contrasting radiation expression.

The present investigation represents the culmination of several years of preliminary work which involved the development and calibration of equipment, field survey procedures, and the necessary computer programs required to process the data by computer methods. Progress during the developing process was reported in Mineral Resources Research 1967-68 and 1968-69 (Flanigan, 1967, 1968; Andreasen and Flanigan, 1968). The investigation is one of a series of studies by the U. S. Geological Survey made in accordance with a work agreement with the Ministry of Petroleum and Mineral Resources, Kingdom of Saudi Arabia.

GENERAL GEOLOGIC SETTING

A brief description of the geology of the Jabal Ishmas quadrangle has been extracted from a geologic report by Gonzalez (1975). The geologic map from that report is used as a base for the radiation data plotted on plate 1.

The oldest rocks in the quadrangle are those of the Hali Group, a thick sequence of paraschist and paragneiss derived from pelitic sediments, quartzite, limestone, and mafic to felsic volcanic rocks. The Hali rocks crop out in a belt of 10-12 km wide along the eastern edge of the quadrangle. Several other large and small exposures are found in the central and southwest parts.

Granodiorite gneiss, the largest rock unit in the quadrangle, represents large bodies of quartz monzonitic to quartz dioritic composition that are intrusive into the Hali rocks. Widespread, pervasive cataclastic textures in much of the granodiorite gneiss and generally conformable contacts between the gneiss and the Hali rocks indicate that the rocks of both units have been deformed together. Many northwesterly-trending andesitic and dacitic dikes intrude the granodiorite in the central and western parts of the quadrangle.

Metasedimentary and metavolcanic rocks of the Halaban Group unconformably overlie the rocks of the Hali Group and the granodiorite gneiss. The Halaban Group consists of a lower metaclastic-sedimentary unit derived from conglomerate, graywacke, shale, marble, and chert, and an upper metavolcanic unit derived from basalt, andesite, and andesitic pyroclastics and tuffs. Halaban rocks are exposed in a northerly-trending, antiformal and down-dropped structural block in the northeastern part of the quadrangle. This structural block includes and is bounded by several major, north-trending left-lateral faults that constitute the Nabitah fault zone.

Three major plutonic units, hornblende quartz diorite, quartz monzonite, and gabbro, are intrusive into the Halaban and older rocks as numerous large and small plutons. The quartz monzonite and gabbro are intrusive into the hornblende diorite and hence are younger, but the relative age of the quartz monzonite and gabbro is not known.

Hornblende quartz diorite underlies a total area of more than 200 sq km in and west of the Nabitah fault zone. With the fault zone hornblende quartz dioritic plutons are elongated along the Nabitah faults which suggests penecontemporaneous intrusion and faulting. The dioritic unit is generally mafic containing from 20-50 percent mafic minerals and ranging compositionally from relatively abundant hornblende diorite to much less abundant granodiorite. Numerous andesitic to dacitic dikes intrude some of the hornblende quartz diorite plutons.

Quartz monzonite underlies about 200 sq km of the Jabal Ishmas quadrangle. Plutons of quartz monzonite 3 to 6 km wide crop out on both sides of Wadi Bishah and are intrusive into the granodiorite gneiss. In the southwest corner of the quadrangle, quartz monzonite intrudes Hali rocks, although contacts are obscured under extensive pediments. A large pluton of quartz monzonite intrudes granodiorite gneiss, hornblende quartz diorite, and Halaban rocks in the south-central part of the quadrangle. Several small plutons intrude granodiorite gneiss further south to the south quadrangle border. A small pluton, about 1/2 by 3 km, intrudes one of the major Nabitah faults southeast of Bi'r Ishmas.

The quartz monzonite is mostly medium to coarse grained and leucocratic with a mafic mineral content of commonly less than 10 percent. The potassium feldspar to plagioclase is near 1:1 but ranges to 2.5:1. Biotite and hornblende constitute the mafic minerals. Significant dikes do not cut the quartz monzonite.

Gabbro, as seven distinct and widely spaced plutons and a large half ring dike, underlies about 60 sq km of the Jabal Ishmas quadrangle.

The plutons range from 2 to 6 km in diameter. One is intrusive into Halaban rocks, none are involved with the Nabitah faults, although some of the altered rocks of the Nabitah fault zone may possibly be derived from gabbro.

Serpentine, marble, and talc-actinolite schist are associated with the north-south Nabitah fault zone. The serpentine and marble form discrete bodies emplaced along the faults, and the talc-actinolite schist is metamorphosed rock at least in part derived from preexisting country rock.

Diabasic to rhyolitic dikes are abundant in the central and western parts of the quadrangle. Northwest-trending andesitic and dacitic dikes are especially abundant in granodiorite gneiss west of the Nabitah fault zone. The hornblende quartz diorite pluton at Jabal al Qatman also is cut by abundant northwest-trending andesitic to dacitic dikes. Elsewhere in the quadrangle dikes are not abundant enough in volume to influence the radiation data.

Surficial deposits of pediment gravel, terrace silt and gravel, wadi channel deposits, and eolian sand mantle nearly 50 percent of the quadrangle.

SPECTROMETER CONSIDERATIONS

The gamma-ray spectrometer responds to electrical pulse energy generated by radiant electromagnetic energy released from the natural decay of radioactive elements. Gamma energies radiate in discrete quanta or photons. The energy of each photon is a function of its characteristic frequency (or wavelength), and each radioactive element has unique photon energy peaks. Gamma-photon energy is expressed in electron volts (eV), and the range of interest in gamma-spectrometry is from 40 keV (10^3eV) to 4 MeV (10^6eV). The sodium iodide crystal is the medium used to detect photon energy. The phenomena which occurs within the crystal when it is struck by photon energy is known as photo-electric emission. Photomultiplier tubes mounted on the face of the crystal view the minute light pulses and convert them into electrical pulses of proportional length or amplitude.

Gamma rays are emitted as excess nuclear energy from excited daughter products during the primary decay of a parent nuclide; thus bismuth 214 (Bi^{214}), a daughter product of uranium decay, is the source of gamma rays. In like manner the daughter products of potassium and thorium are potassium 40 (K^{40}) and thallium 208 (Tl^{208}). It follows that the measurements relating gamma-ray energies to the parent product assume the element is in a state of equilibrium, and reference made to concentrations of the parent nuclide is more correctly referred to as equivalent uranium (eU), equivalent potassium (eK), and equivvalent thorium (eTh). These equivalent radioactive minerals are referred to as isoelements in this report.

Gamma-ray energy released from the primary decay of potassium is monoenergetic; that is, photons of one frequency or wavelength are released. When potassium photons strike a crystal detector, the resultant output is electrical pulses of one amplitude, which reflects the single photopeak produced by the absorption of the photons within the crystal. The potassium photopeak occurs at 1.46 million electron volts (MeV). Uranium and thorium have several energy levels which produce photopeaks of correspondingly different levels. The photopeaks of uranium and thorium which are measured are selected for a minimum interference with adjacent photopeaks: for uranium this is at 1.76 MeV and for thorium it is at 2.615 MeV.

Single channel pulse height analyzers are used in the system to discriminate between pulses originating from photopeaks of the isoelements being monitored. Photopeaks of typical spectrograms of potassium, uranium, and thorium showing their relationships to the pulse height analyzer (PHA) scale are seen in figure 2. The window widths of the PHA are set so that voltage pulses from only the peak being measured are passed and counted by a ratemeter. The selection of PHA settings for the spectrometer is such that interference between channels is minimal. However, a certain amount of interchannel reaction is caused by Compton's scatter from higher energy gamma rays; that is, photons of a higher energy source that lose part of their energy through atomic collision in the air or crystal so that only part of their original energy is absorbed in the crystal, thus producing an electrical pulse of reduced amplitude. This lower amplitude pulse may be detected as one of the lower energy nuclides being measured, thus Compton's photons from thallium (Tl^{208}) contribute to the count rate recorded in the uranium and potassium channels, and photons from bismuth (Bi^{214}) contribute to the count rate recorded in the potassium channel. In order to produce reliable spectral data the amount of these contributions must be determined and removed from the uranium and potassium data. This correction is termed "the stripping ratio" and is similar to the method described by Darnley (1969). Adams and Gasparini (1970) discuss in detail the methods of absolute calibration of gamma-spectrometers.

GEOLOGIC CONSIDERATIONS

Discrimination between geologic units on the basis of their radiation response is dependent upon a number of factors. First, the

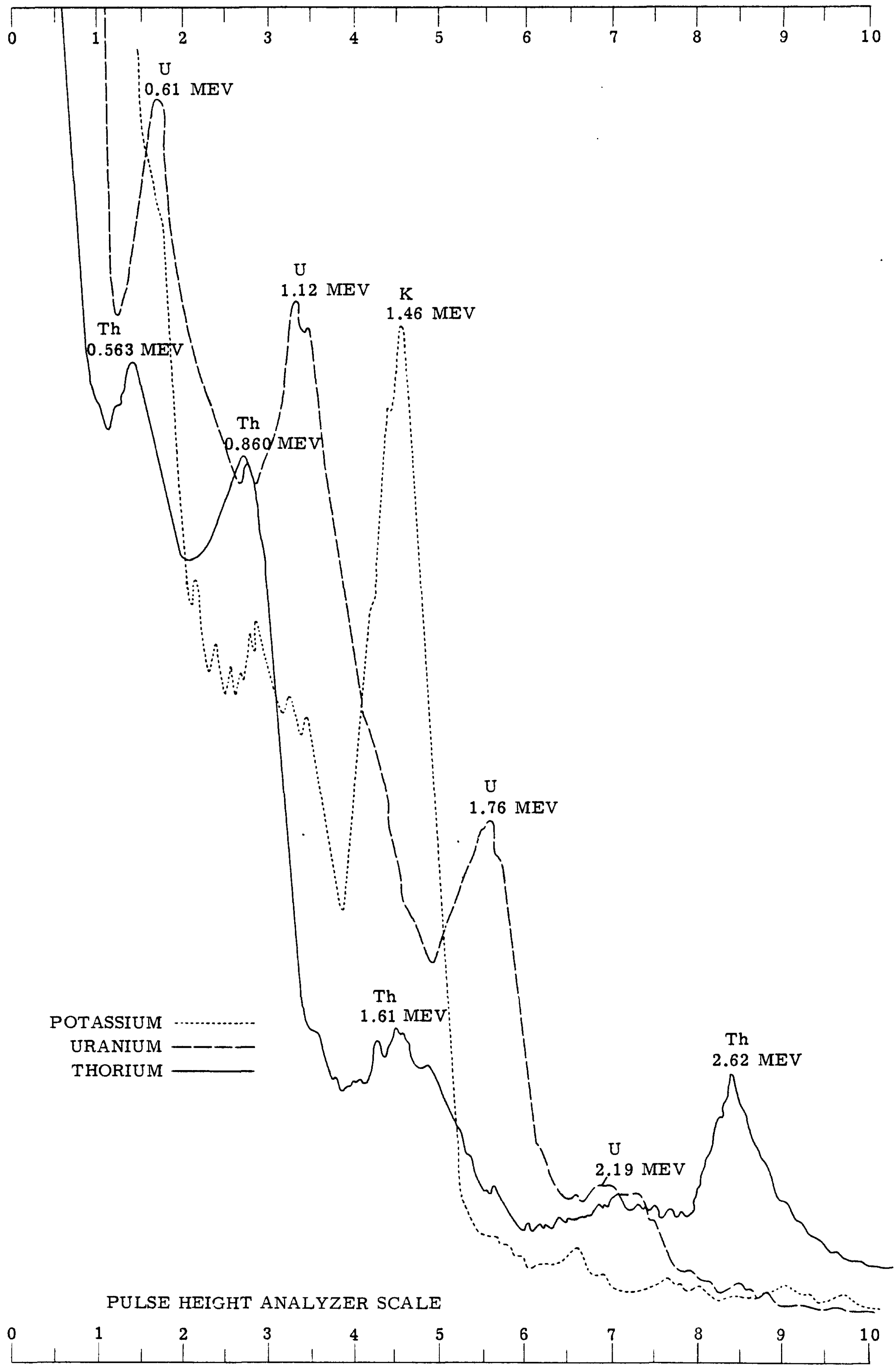

Figure 2. - Photopeaks of typical spectrograms of potassium, uranium, and thorium, showing relationships to the pulse height analyzer (PHA) scale.

radiation response of a geologic unit is directly dependent upon the amount of radioactive elements present in the rock. In general, uranium and thorium are more abundant in felsic rocks than in those of ultramafic composition (Larsen and Phair, 1954).

Potassium is an abundant element in nature; however, only 0.0119 percent of potassium is the radioactive isotope K^{40}, and it contributes less gamma photons to the total radiation spectrum than does uranium and thorium (Nier, 1950). The potassium content of a particular rock type can vary greatly so a firm relationship cannot be easily established. However, from the spectral radiation data it appears that in the igneous rocks the same general potassium relationship exists as for uranium and thorium; that is, felsic rocks contain more potassium than do more mafic types (Ahrens, 1954). Foote (1969) presents spectrometer data taken over a Tertiary region of west Texas which graphically illustrates this relationship.

Homogeneous rock units are not attained in nature, so the gamma-radiation response over a particular rock type is variable. Local variations of radioactive element concentration tend to be smoothed out by the airborne survey method, because the detector crystals at any given place are responding to the radiation from a large volume of material. The ability to discriminate between rock units of different composition is dependent on their radiation contrast. It is obvious that two rock types of similar radiometric composition cannot be distinguished from each other.

A second consideration that affects the ability of the spectrometer to measure the radiometric response of a rock unit is the survey procedure. The physical size of the rock unit, flight height, the ground speed of the aircraft, the line spacing, and total crystal detector volume are factors which contribute to the radiometric resolution. At a flight height of 91 m, 75 percent of the measured count-rate comes from a circular area of approximately 120 m diameter directly beneath the crystal detectors (Duval and Cook 1971). The aircraft ground speed averages about 45 m/sec and gamma scintillations from the detectors are integrated over a 2-second time period. A minimum of 5 seconds or 225 m in the flight direction are necessary to detect a significant change between two geologic units. It has been shown by Schwarzer and others (1971) that resolution can be increased by decreasing the flight height and aircraft speed. In the present investigation, parameters were selected so that spectrometer resolution of mappable units could be detected at 1:100,000 scale.

Traverses were flown normal to the strike of the majority of rock units in the Jabal Ishmas quadrangle, so that linear features of more than 1 km in length could be detected on adjacent flight lines.

Photons of gamma energy that emerge from the ground are affected by the depth of soil, the density of the material, and the coefficient of attenuation for the given gamma-ray energy (Duval, 1971). It has shown by Darnley (1969), however, that on the Canadian Shield shallow overburden has a radiometric composition similar to that of the associated outcrop. Neuschel (1971) shows a close correlation between airborne radiation response and isoelement concentrations of bedrock samples, where the bedrock is covered by a deep residual soil. In the desert environment of the Arabian Shield, well developed pediments are covered by alluvial materials ranging in size from silt to pebbles.

The thickness of the alluvial material varies from a few centimeters to probably a few meters. It is obvious on the smaller pediments that the coarser debris is from nearby outcrops and the radioactive response reflects the local bedrock. Much of the finer fraction on the pediments is fluvial-worked eolian sand and silt that must act as a nondiagnostic dilutant to the radiation response. Extensive areas adjacent to Wadi Bishah are covered by thick alluvium and the nafud areas are covered by blown sand. Because of their homogeneous nature, the radiation response of these materials can be distinguished from other pediment areas.

COMPARISON OF RADIATION DATA AND MAPPED GEOLOGY

Total count map

Radiation intensities, as represented by the total-count data, and the mapped geology are compared on plate 1. Total count, as used in this report, is a measure of the total gamma-radiation activity above an energy level of 0.8 MeV. To insure measurements at this level, the base discriminator on the pulse height analyzer was set so that no photon energy below 0.8 MeV passed through to the counting and recording circuits.

Radiation intensities range from approximately 1,000 counts per minute (cpm) to 12,000 cpm. The highest intensities are observed over the quartz monzonite and the granodiorite gneiss and the lowest intensities over the gabbro, the mafic rocks along the Nabitah fault zone, and the hornblende quartz diorite units (plate 1). The average radiation response of the major rock units is presented in table 1 below. These average radiation intensities are a guide for interpretation, but because of the heterogeneous nature of the rock units, the range of radiation intensity of a particular unit may differ from place to place within the quadrangle. Thus, while it is useful to be able to relate average radiation pattern intensities to particular rock units, hard and fast relationships cannot be made.

Table 1. Average radiation response in counts per minute of rock units in the Jabal Ishmas quadrangle.

Rock type	Total count	Potassium	Thorium	Uranium
Quartz monzonite	11,250	950	150	1000
Granodiorite gneiss east of Nabitah fault	8,500	760	125	1100
Granodiorite gneiss west of Nabitah fault	6,750	600	100	860
Hali Group	7,000	400	75	600
Halaban Group	6,000	450	75	700
Hornblende quartz diorite	2,200	575	50	350
Gabbro	4,800	300	50	420
Surficial sand and gravel	6,500	650	50	800

Quartz monzonite, intrusive into granodiorite gneiss, is reasonably well outlined by its radiation intensity in the southwest quadrant of the map (plate 1). However, the radiation pattern suggests that the area of the quartz monzonite is larger than that mapped. Much of the area is underlain by pediment, but it is apparent from the radiation data that the thin pediment cover does not significantly affect the radiation intensity of the underlying quartz monzonite. In the north-west quadrant, the mapped quartz monzonite plutons in general show higher radiation anomalies in comparison to the radiation of the intruded granodiorite gneiss, but the coincidence is not exact. No doubt compositional complexities between these two units and the abundant pediment and eolian cover tends to obscure the lithologic contrast both in mapping and in radiation survey. The quartz monzonite cropping out in the south central part of the map conforms well to the high radiation pattern, and demonstrates clearly the value of radiation survey as an aid to geologic mapping.

The granodiorite gneiss east of the Nabitah fault zone has a different radiation response than the gneiss west of the fault zone. On the east side the radiation response ranges from 8,000 to 10,000 cpm, whereas on the west side the radiation response ranges from 5,000 to 7,000 cpm. This difference suggests that the granodiorite gneiss east and west of the Nabitah fault zone may be different rock units. Alternatively Gonzalez (oral commun., 1972) has suggested that a difference in level of erosion between the east and west masses of granodiorite may account for the different radiation levels. The present erosion level of the eastern mass is relatively high. In general radioactive minerals tend to concentrate in the periphery and upper part of intrusive bodies. Thus, it is reasonable to expect a higher radioactivity from granodiorite gneiss cropping out east of the fault zone. The contact between the granodiorite gneiss and the meta-sedimentary rock of the Hali Group is characterized by a steep contour gradient, reflecting a good radiation contrast between the two units.

Several wadis cross the granodiorite gneiss in a west to east direction in the eastern part of the quadrangle and the covering alluvium reduces the radiation level because most of the alluvium is derived from low radiation rock units to the west. The contact of granodiorite gneiss west of the Nabitah fault zone can be distinguished by radiation intensity, where it separates rock of contrasting radiometric expression such as quartz monzonite, gabbro, and hornblende quartz diorite.

The radiation intensity detected over the Hali Group of rocks ranges from 6,000 to 7,000 cpm. The Hali contact can be distinguished by radiation data, where it is next to the eastern granodiorite gneiss, the quartz monzonite, and the belt of serpentine along the Nabitah fault zone. The Hali, the Halaban, the western exposure of the granodiorite gneiss, and surficial materials mapped as eolian sand, and sand, silt or gravel have about the same total-count radiation expression. The radiation pattern of these units of intermediate expression cannot be used to separate them on the map.

Rocks mapped as gabbro stands out as areas of radiation lows. Radiation response ranges from 3,000 to 5,000 cpm over the gabbro plutons. The ability to delineate the contact of the gabbro is dependent upon the radiation contrast to the enclosing rocks. In the southwest quadrant of the map (plate 1) a gabbro pluton intrudes the granodiorite gneiss. The gabbro is well outlined by moderate to steep radiation gradients as seen between the 6,000-8,000 cpm contours. In the center of the quadrangle, another gabbro pluton intrudes hornblende quartz diorite. The radiation contrast is less between these two units, 4,000-5,000 cpm contrasting to 5,000-6,000 cpm, thus the radiation expression over the gabbro appears as closed contours of slightly lower level. Other gabbro bodies mapped in the field show similar closed contour expression, but of even less contrast to the enclosing rocks.

In the north-central part of the quadrangle the areal extent of the hornblende quartz diorite is expressed by the 4,000 cpm contour. A steep contour gradient marks the eastern contact with the Halaban. Within the 4,000 cpm contour are several areas of radiation of less than 2,000 cpm and indicate rocks of more mafic composition than quartz diorite and probably reflect a complex of mafic intrusive rocks within the hornblende quartz diorite pluton. Hornblende quartz diorite mapped in the center of the quadrangle is only slightly lower in radiation expression than the surrounding rocks, and its areal extent cannot be easily delineated by the radiation pattern.

The Halaban ranges from 3,000-6,000 cpm in total count radioactivity. The clastic facies is slightly higher in radioactivity than the volcanic facies, but no clear radiation distinction can be made between them.

Some exposures of marble associated with the Halaban and Hali have been mapped in the field. Radiation data from other surveys on the Shield have shown that marble units are extremely low in radioactivity. Marble units mapped in the Jabal Ishmas quadrangle are not of sufficient size to be identified at the line spacing and sampling rate used in this survey.

Serpentine and talc associated with the major north-south Nabitah fault zone in the eastern part of the quadrangle are well expressed as linear anomalies. North-south anomalies in the 3,000-4,000 cpm contours reflect the low radiation response of these units.

Spectral data

Gamma spectral data recorded on this survey are shown as contour maps of potassium, thorium, and uranium count rates (figs. 3, 4, 5). The maps and the total count map have several things in common. Rocks of higher total-count radioactivity, such as the quartz monzonite and the granodiorite gneiss, generally have a higher spectral radioactivity. Likewise, rocks of low total-count radioactivity, such as the quartz diorite, gabbro, and serpentine, generally have lower radioactivity in all the isoelement spectral windows. Hence, in general highs and lows in the three spectral windows tend to correlate with each other, and the total-count data. Where this relationship is not true, the spectral data becomes more valuable. One such area is on the potassium map (fig. 3) at about lat 20°40'N.; long 43°20'E., where the potassium anomaly increases about two times the average count rate over the Halaban. The Halaban in this area is mapped as the volcanic facies and the increased potassium count may be reflecting an increased potassium content of a rhyolitic extrusive.

Count rates recorded for thorium (fig. 4) are very low and as a result the thorium map is rather flat and expressionless with only the quartz monzonite showing a significant increase in thorium content. It is estimated that the variation in the thorium map represents ground concentrations from a few parts per million (ppm) to approximately 20 ppm thorium (eTh).

The uranium map (fig. 5) shows more variation in recorded count rates than the thorium, with the higher counts recorded over the quartz monzonite and the granodiorite gneiss east of the Nabitah fault zone.

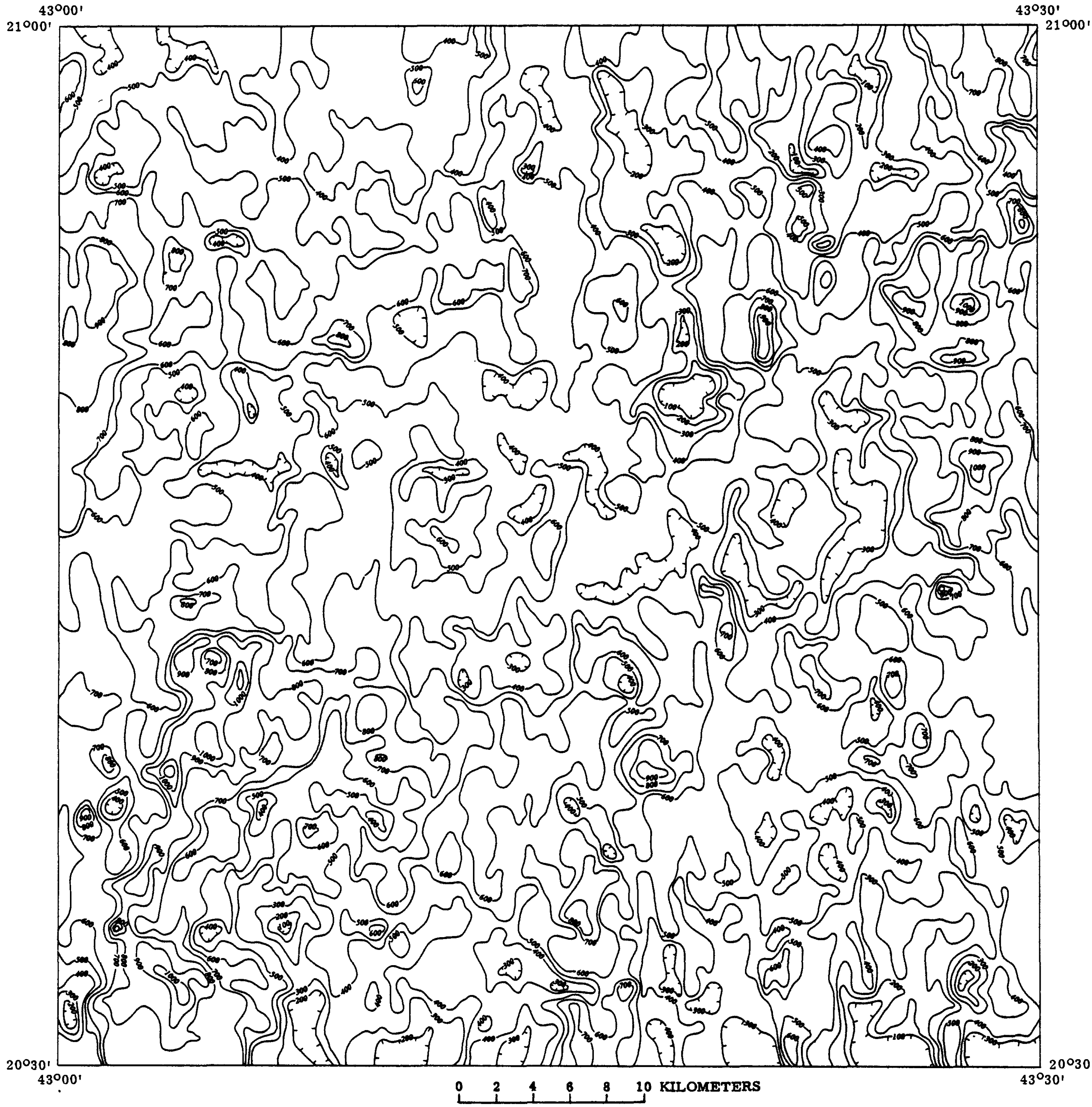

Figure 3.- Gamma radiation survey of the Jabal Ishmas quadrangle showing isoelement potassium. Isorads are in counts per minute (CPM); the contour interval is 100 CPM.

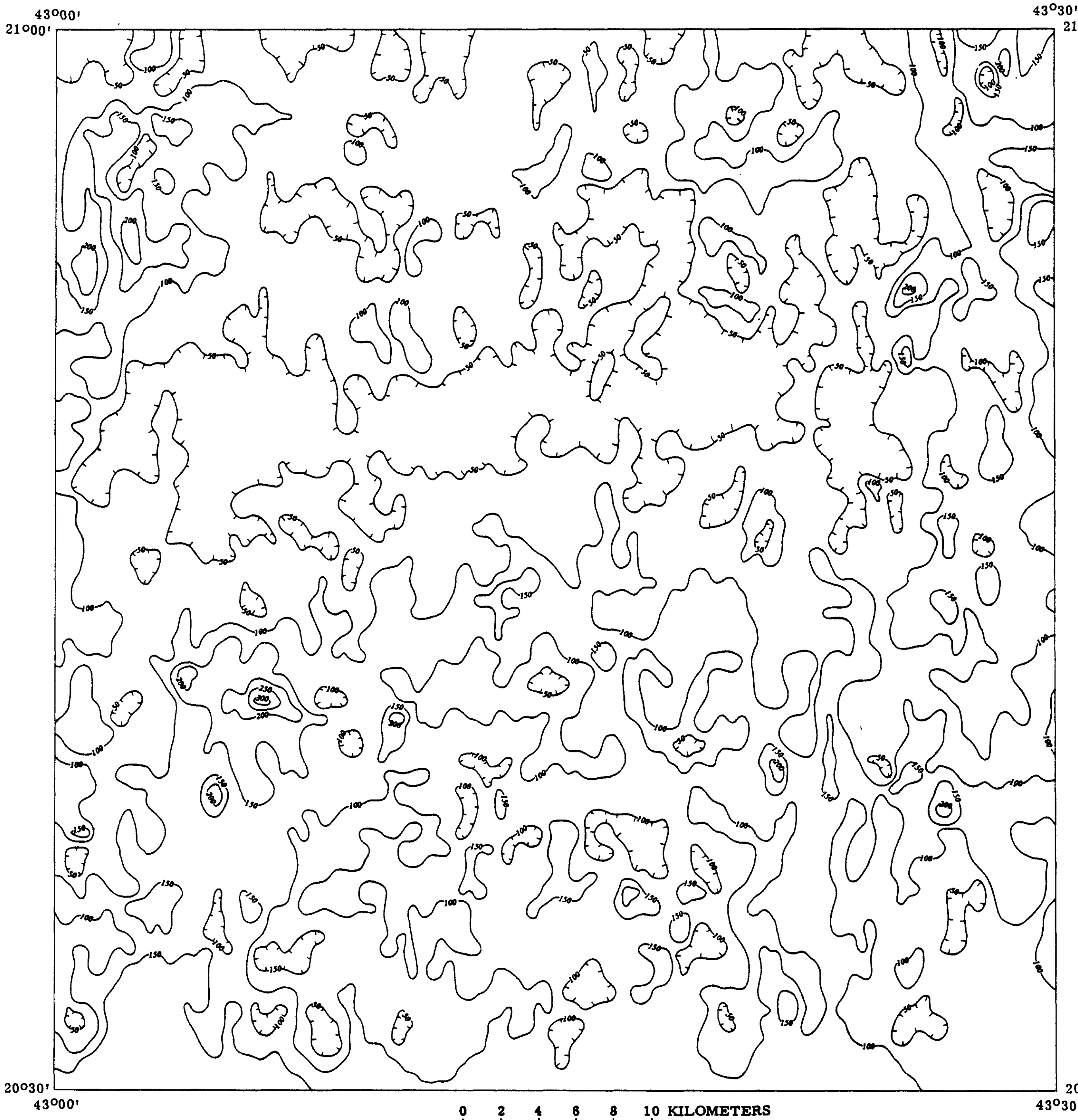

Figure 4. - Gamma radiation survey of the Jabal Ishmas quadrangle showing isoelement thorium. Isorads are in counts per minute (CPM); the contour interval is 100 CPM.

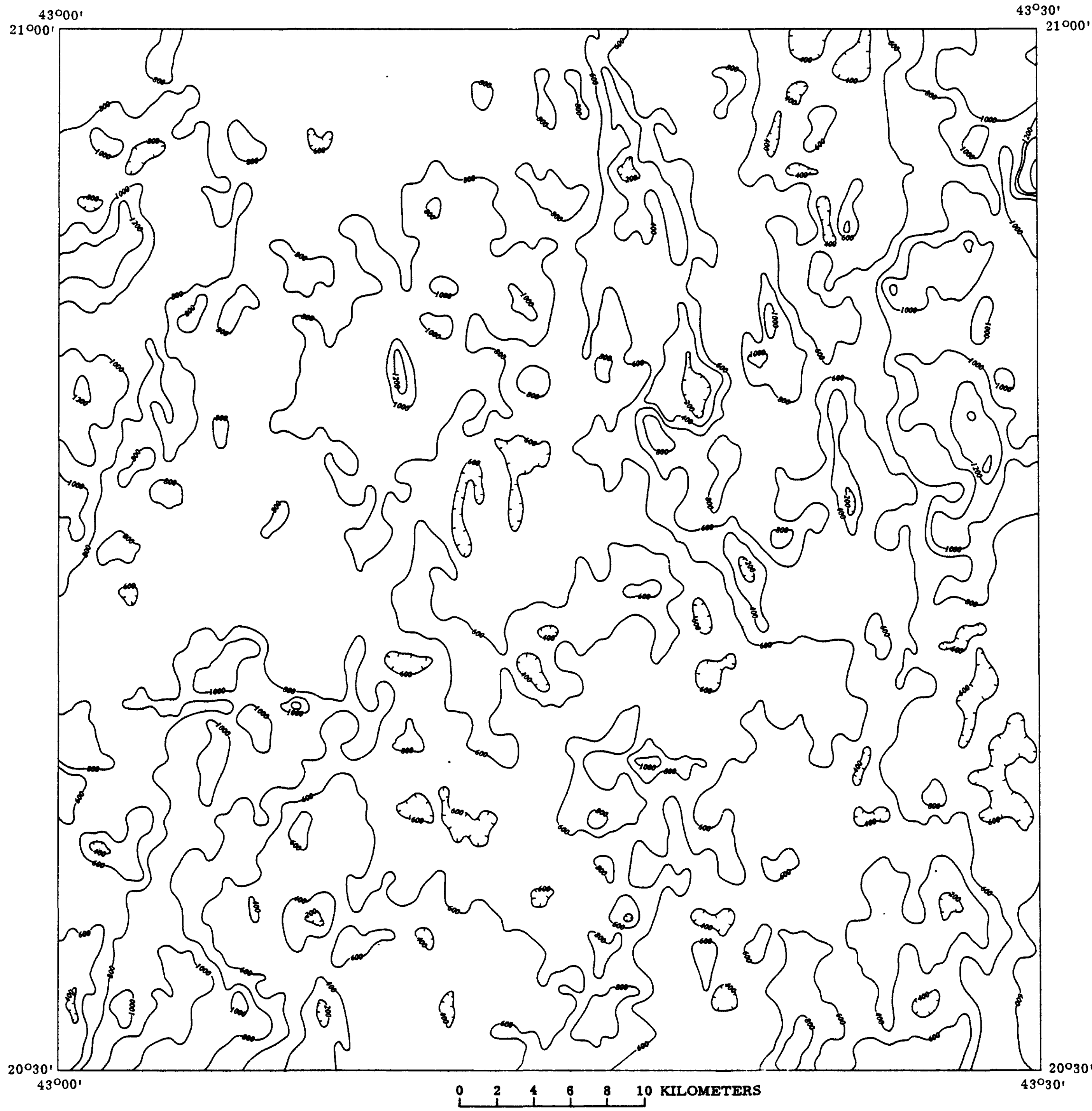

Figure 5. - Gamma radiation survey of the Jabal Ishmas quadrangle showing isoelement uranium. Isorads are in counts per minute (CPM); the contour interval is 100 CPM.

Areas of low uranium count rate correspond to the gabbros, quartz diorite and the belt of serpentine rocks associated with the fault system. No anomalous areas were detected, that is, areas where uranium content increased significantly without like increase in potassium and thorium. Variations on the potassium isoelement map are somewhat greater than the uranium and thorium maps, and therefore, of the three isoelement maps, the potassium map best delineates the geologic units.

No attempt has been made to establish possible spectral radiation patterns over various rock types. Uncertainties such as counting statistics, repeatability, homogeneity of rock units, and effect of surficial cover need to be studied in more detail. No doubt the spectral data will become more valuable as interpretative experience is gained and more detailed studies made. At this time it is most valuable as a rapid means of evaluating total count anomalies by being able to determine the approximate concentration of the isoelements contributing to the anomaly.

CONCLUSIONS

Airborne gamma-radiation surveys provide a rapid means of obtaining basic geophysical data that may be used to delineate lithologic rock units in relatively low relief desert environments, where bedrock pediments are covered by thin sheets of alluvium. Spectral data provides a means by which the source of radiation anomalies detected during the surveys may be determined. Quartz monzonite, intrusive into the granodiorite gneiss, is detected as the most radioactive rock in the quadrangle, and its areal extent can be reasonably well outlined by the contrast in radiation level between the two units. Hornblende quartz diorite, intrusive gabbro, and mafic rocks associated with the Nabitah fault system are detected by low radiation intensities, and are outlined by their radiation patterns. The contact between rocks of intermediate radiation levels such as the Hali Group, the Halaban Group, and eolian sand cannot be separated by their radiation response except in those areas where they lie next to rocks of contrasting radiation response. Sand, silt, and gravel mask radiation from underlying rocks, except where present only as a thin cover where the radiation pattern may be typical of the underlying rocks.

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