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AIRBORNE GAMMA-RAY SPECTROMETRY SURVEY OF THE JABAL SAYID AREA, KINGDOM OF SAUDI ARABIA

By

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ABSTRACT

An airborne gamma-ray spectrometer survey covering 2750 km^2 in the Jabal Sayid area, Kingdom of Saudi Arabia, was flown to measure anomalous concentrations of potassium in a known mineral belt. No anomalies were detected over the Jabal Sayid copper prospect, although part of the prospect is within a radioactive, high-dispersion halo associated with the Jabal Sayid granitic pluton. Anomalous potassium concentrations were detected in several areas north of the mine at Mahd adh Dhahab and over the rhyolitic rocks of the mine itself. Count-rate ratios of the potassium (K^{40}), uranium (Bi^{214}), and thorium (Tl^{208}), reached a high of 24:1 for K:Th, and 11.6:1 for K:U. Count-rate ratios over granitic rocks are generally much lower. Areas of anomalous potassium correlate with rhyolitic rocks in some places. Other potassium anomalies have no known explanation, but may reflect unmapped potassium-rich rocks and(or) zones of hydrothermal alteration. These anomalies are considered as potential targets for further exploration, but ground follow-up investigations will be necessary to ascertain the exact cause of the anomalies.

INTRODUCTION

An airborne gamma-ray spectrometry survey was made during April, 1973 of a 2750 km^2 area centered at Jabal Sayid, Saudi Arabia. The area surveyed comprises a 30' quadrangle within the Precambrian shield of west-central Sauid Arabia (fig. 1) extending from lat 23°30' to 24°00'N. and from long 40°45' to 41°15'E. The objective of the survey was to test the possibility of detecting by airborne methods enrichment of potassium that might be associated with the Jabal Sayid copper prospect. The Jabal Sayid copper deposit is of known economic potential (Delfour, 1970a, b) and was thought to be associated with metasomatic enrichment of potassium. Davis and Guilbert (1973) demonstrated that potassium-uranium enrichment could be detected at selected porphyry copper deposits in western United States with ground gamma-spectrometry methods, and concluded that potassium enrichment is of sufficient magnitude to render this method a valuable tool for exploration. Moxham and others (1965) showed also that hydrothermally altered rocks in the vicinity of several copper and copper-lead-zinc deposits in Arizona contained about twice as much potassium as the unaltered rocks, and concluded that the level of anomalous radioactivity was such as to be detectable by both ground and airborne spectrometry methods. The results of a geochemical survey in the immediate area of the Jabal Sayid copper prospect were not available at the time the initial gamma-spectrometry investigation was in progress, but showed that potassium was not anomalous and indeed was noticeably

Figure 1. Index map of western Saudi Arabia showing the area covered by the Jabal Sayid gamma-radiation survey.

lower than had been expected (Dehlavi, 1973). The gamma-spectrometry survey was extended to cover a large area around the Jabal Sayid district in order to detect other areas of possible potassium enrichment that might indicate potential mineralization.

This project was undertaken at the suggestion of the Directorate General of Mineral Resources, and the work was performed under a work agreement between the U.S. Geological Survey and the Ministry of Petroleum and Mineral Resources.

GAMMA-RAY SPECTROMETRY

Gamma-ray spectrometry is the measurement of the spectrum of natural radioisotopes that occur at or near the surface of the ground as the result of radioactive decay. These isotopes are from potassium and from members of the uranium and thorium radioactive decay series. The attenuating effect of the surficial rocks limits the measured radioactivity to the uppermost 20 to 30 cm of material. Radioactivity also decays in the atmosphere at an exponential rate, but effective measurements can be made with scintillation equipment installed in a low-flying aircraft.

The terms uranium, thorium, and potassium are used throughout this report solely for ease of terminology. Gamma spectrometers measure a daughter product of radium (Ra^{226}) in the uranium (U^{238}) decay series and disequilibrium can be determined only by ground or laboratory measurements. Spectrometers also measure a daughter product of thorium (Th^{232}), but disequilibrium seldom exists in the thorium decay series because of the short half-lives involved. Potassium K^{40} exists in a constant proportion to total potassium. The physics of gamma-ray spectrometry has been described in detail by Adams and Gasparini (1970).

Spectrometry measurements can be used to aid geologic studies because the distribution of radioisotopes at ground surface is controlled by geologic processes. This distribution is originally due to bedrock composition, but is often modified by weathering, solution, and transportation, which can concentrate or deplete radioisotopes. These measurements have been used to aid geologic mapping and in exploration for radioactive and nonradioactive mineral deposits (Darnley, 1972; Flanigan, 1974).

AIRBORNE SURVEY AND GEOPHYSICAL INSTRUMENTATION

A single-engine deHavilland Otter aircraft was used to fly north-south flight lines spaced 1/2 km apart at an average ground speed of 160 km/hr and an average elevation of 91 m above ground. The survey included 101 flight lines, which averaged 55 km in length.

Photomosaics were used for position control during the flying, and a radioaltimeter measured ground clearance. A 35 mm continuous strip-film camera photographed the flight path of the aircraft, and an observer periodically activated a fiducial mark system, which correlated this film with the geophysical data.

The gamma-ray spectrometer data acquisition and recording system has been described by Andreasen and Flanigan (1970).

Briefly, the spectrometer detects incident gamma energy by means of two thallium-activated sodium iodide crystals. Each crystal was 7.6 cm thick and 22.8 cm in diameter and was coupled to four photomultiplier tubes 7.6 cm in diameter. The photomultiplier signals were summed and amplified in a mixer amplifier, which then fed identical signals to four single-channel analyzer-/rate-meter units. Rate-meter output signals were recorded in analog form on a pen-and-ink, continuously-recording, strip-chart recorder. These signals were also fed to an analog-to-digital converter whose output was to a magnetic tape recorder. The rate meters were operated with a 2 second time constant and sampling of the spectrometer and altimeter signals controlled by a digital clock at 0.5 second increments. Ground clearance data from the radioaltimeter were also recorded simultaneously on the analog and digital recorders.

The single-channel analyzer-/rate-meter units are called "windows" because they can be calibrated to monitor all or part of the spectrum of natural gamma energies. The window settings are 1) from 0.70 to 2.80 mev (million electron volts) for total count, 2) centered at the 1.46 mev photopeak of K^{40}, 3) centered at the 1.76 mev photopeak of Bi^{214} in the U^{238} decay series, and 4) centered at the 2.62 mev photopeak of Tl^{208} in the Th^{232} decay series. Window widths for the radioisotope data are each about 0.30 mev.

U^{238} and Th^{232} sources were used to calibrate the spectrometer twice per flight, and the atmospheric background radioactivity was measured twice per flight at an elevation of more than 600 m above ground.

DATA REDUCTION AND INTERPRETATION

Digital data recorded during the survey were integrated with fiducial location points using the RADPAC system of computer programs described by Selner and Flanigan (1973). This work was done on the IBM model 370/135 computer of the University of Petroleum and Minerals at Dhahran. Output from the RADPAC system is automatically plotted on an Electronic Associates Inc. model 430 data-plotter. Output usually consists of contour maps at selected scales, radiation and flight elevation profiles, and flight path maps.

Basic methods generally used in the interpretation of geophysical data are qualitative and quantitative. In both methods, profile data and contour maps constructed from these data may be used. The selection of interpretation technique is dependent on a number of factors, which include the nature of the geophysical data, the purpose of the interpretation, the scale, the type, nature, and size of the targets of prime interest, and preference and background experience of the individual geophysicist.

A good deal of useful information can be gained fairly rapidly using the qualitative method. The profiles and contours are examined as to their shape, relative amplitude, and areal extent, and anomaly shapes are compared with theoretical curves that have been computed for known geologic bodies.

Other geologic and geophysical data are then correlated with the basic data set.

The quantitative methods require the mathematical treatment of geophysical data, in which certain parameters such as depth of burial, size, approximate shape and physical properties of the source of the anomaly are computed. These methods are generally applied to geophysical data that involve potential field theory, such as gravity and magnetics. Radiation data cannot be treated in the same manner as potential field data because radiation is essentially a surface phenomenon. Two corrections are routinely made to radiation data; these are the cosmic background correction, and the altitude attenuation correction. Cosmic radiation is normally measured before and after each survey flight at an altitude high enough to exclude any natural ground radiation. This level of radiation is mathematically subtracted from the observed data during data processing so that only natural radiation from ground sources remains. Altitude attenuation of natural gamma-radiation is empirically determined by flying over a radiation source at various altitudes and computing the attenuation coefficients. Compensation for changes in flight elevation are applied to the data programmatically. The correction for the Compton-scattering effect was not applied to these data. For a discussion of this effect the reader is referred to Darnley (1972). Also, no attempt has been made to convert the count-rate measurements of the Jabal Sayid survey to ground concentrations of the radioelements.

The interpretation of the profile data is accomplished by determining the relative amplitudes of the individual anomalies as is commonly done in the interpretation of magnetic data that have no absolute base value. Such interpretation requires, however, consideration of possible contributions from the higher gamma-ray energies into the lower-energy windows because of Compton-scattering. Therefore, in this report, only those potassium and uranium anomalies are considered and discussed that are clearly not associated with thorium anomalies.

The specific approach used in this study is similar to that used by the Lockwood Corporation in its analysis of a gamma-ray spectrometer survey of selected areas of Paleozoic rocks adjoining the Arabian Precambrian shield (Lockwood, 1973, unpublished report). The radioelement profiles are examined and three arbitrary levels are determined by which the data are divided into high, normal, or low levels of count rate for each radioelement window. The profile levels are then compiled into radioelement zone maps in which the three levels are studied in relationship to each other and to the known geology.

For the Jabal Sayid survey, an anomaly map (fig. 2) was constructed that shows the areas that are thought to be anomalous in uranium and potassium. Areas of high radioactivity that reflect the normal radioactivity of a particular rock type are not shown on the map inasmuch as these areas are not considered anomalous. These areas are typified on

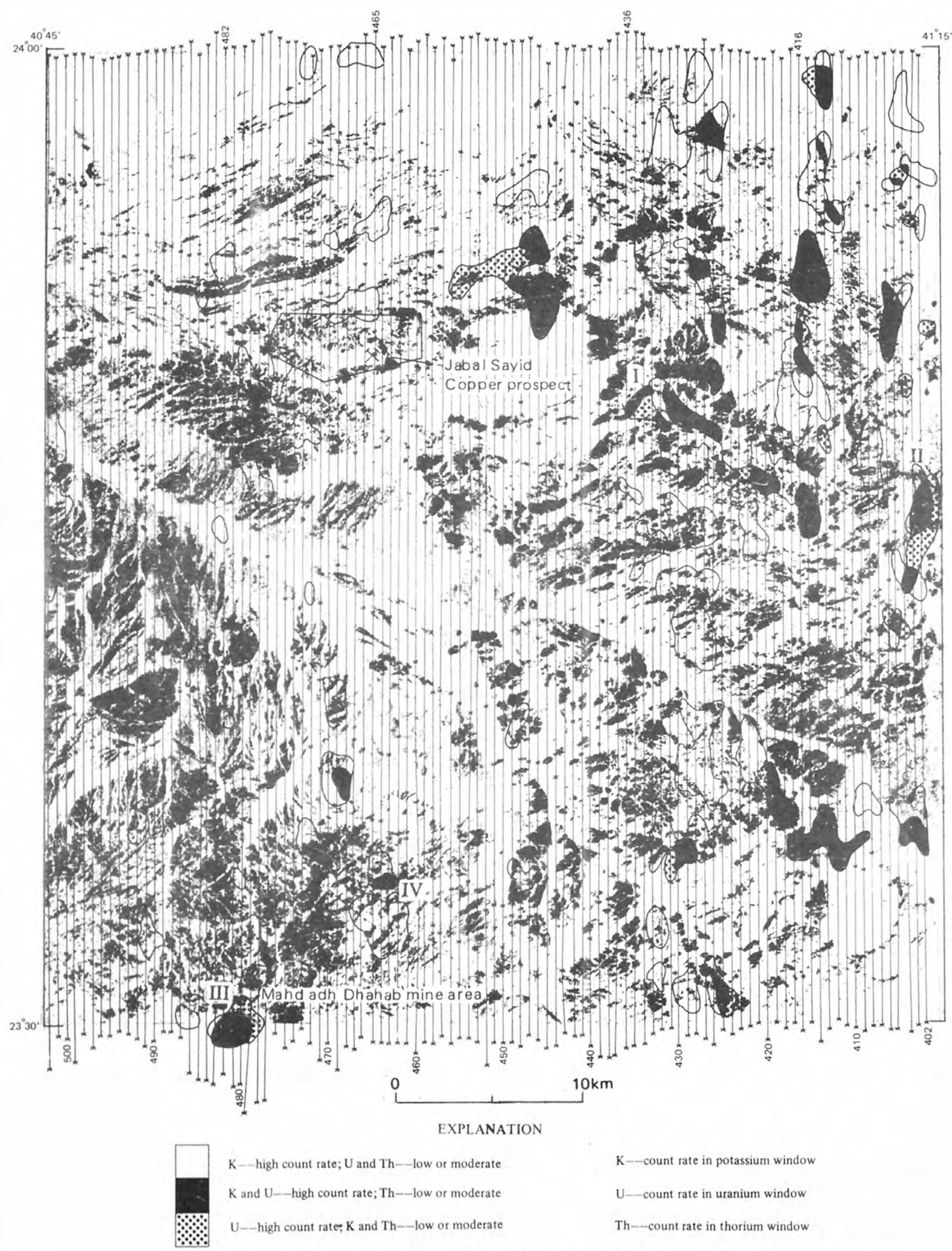

Figure 2. Map of the Jabal Sayid area showing gamma-radiation anomalies.

the profile data (figs. 3-14) by sharp increases of count rate in all three radioelement windows. An intermittent malfunction was discovered in the thorium channel, which made some of the data suspect. These segments of thorium data were eliminated from the profiles shown in figures 3-14.

GENERAL GEOLOGY

Bedrock in the study area consists of metamorphic and igneous rocks of Precambrian age. These rocks are discontinuously mantled by Tertiary and Quaternary detritus along pediment surfaces, wadi courses, and pediment-wadi interfaces. Desert varnish composed of iron and manganese oxide occurs pervasively on rock surfaces, especially on the silica-rich, finer-grained rocks.

Results of geologic mapping in the study area have been reported by Aguttes and Duhamel (1971), Campi (1969), Conraux (1966), and Delfour (1970a). Part of the survey area was mapped by Goldsmith (Goldsmith and Kouther, 1971) during a geologic-geochemical mineral reconnaissance survey. The published geologic maps differ in many details and therefore correlation of the spectrometry data with geologic units is discussed only for those areas in which there is reasonably good agreement among the maps.

DISCUSSION OF SPECTROMETRY DATA

Of prime interest to this study is the area northwest of Jabal Sayid, which includes the Jabal Sayid copper deposit. This deposit (outlined on fig. 2) occurs in an arcuate-shaped

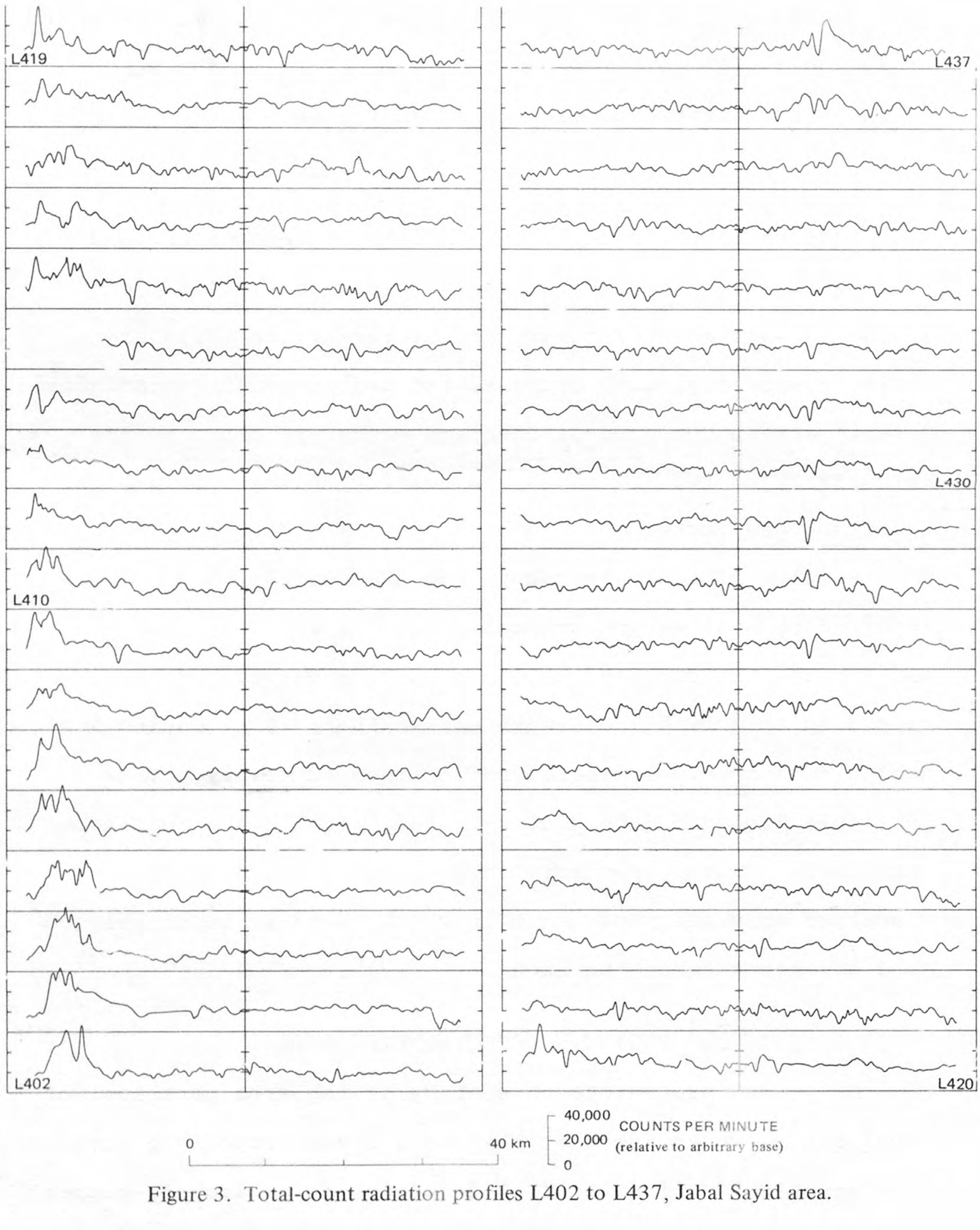

Figure 3. Total-count radiation profiles L402 to L437, Jabal Sayid area.

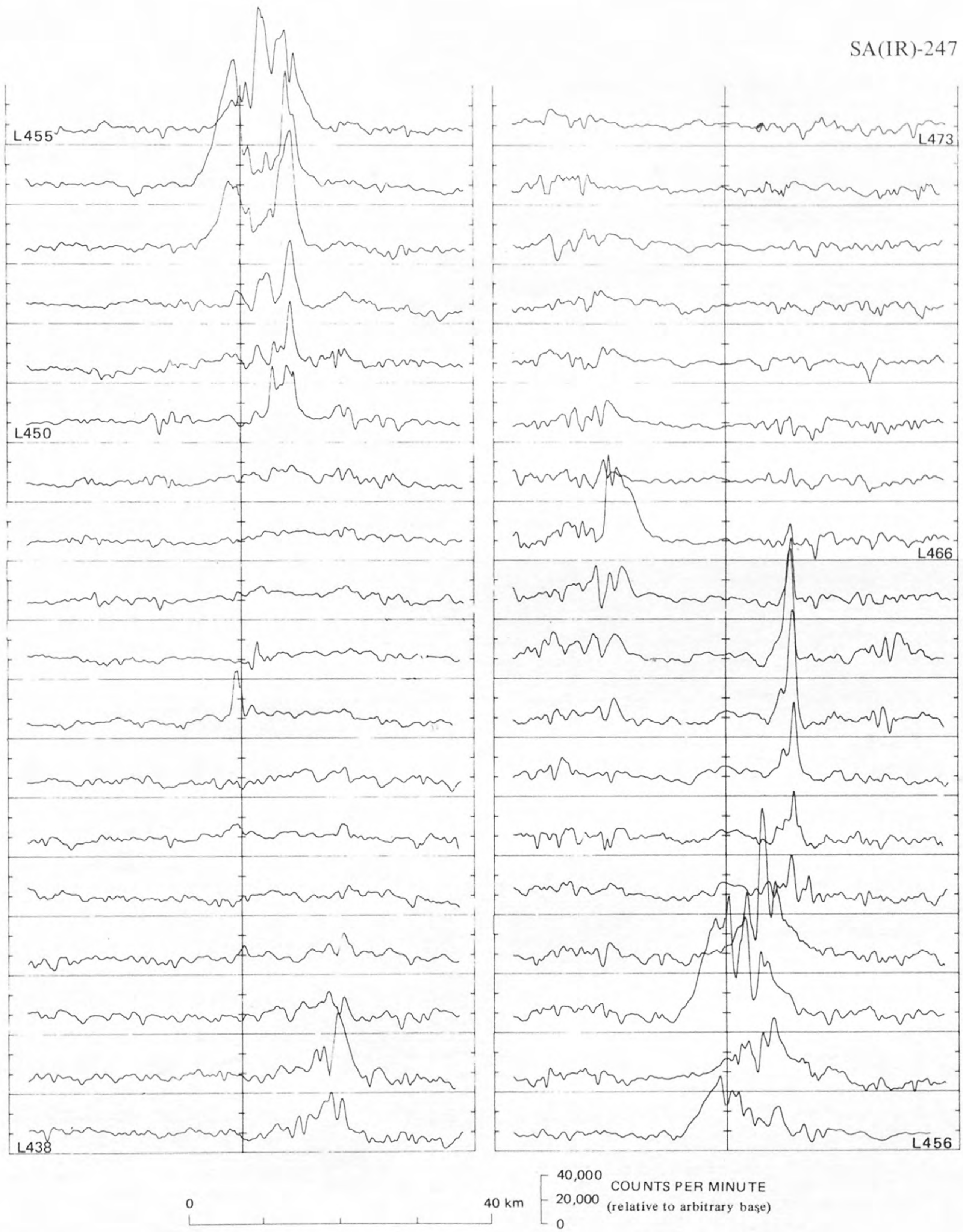

Figure 4. Total-count radiation profiles L438 to L473, Jabal Sayid area.

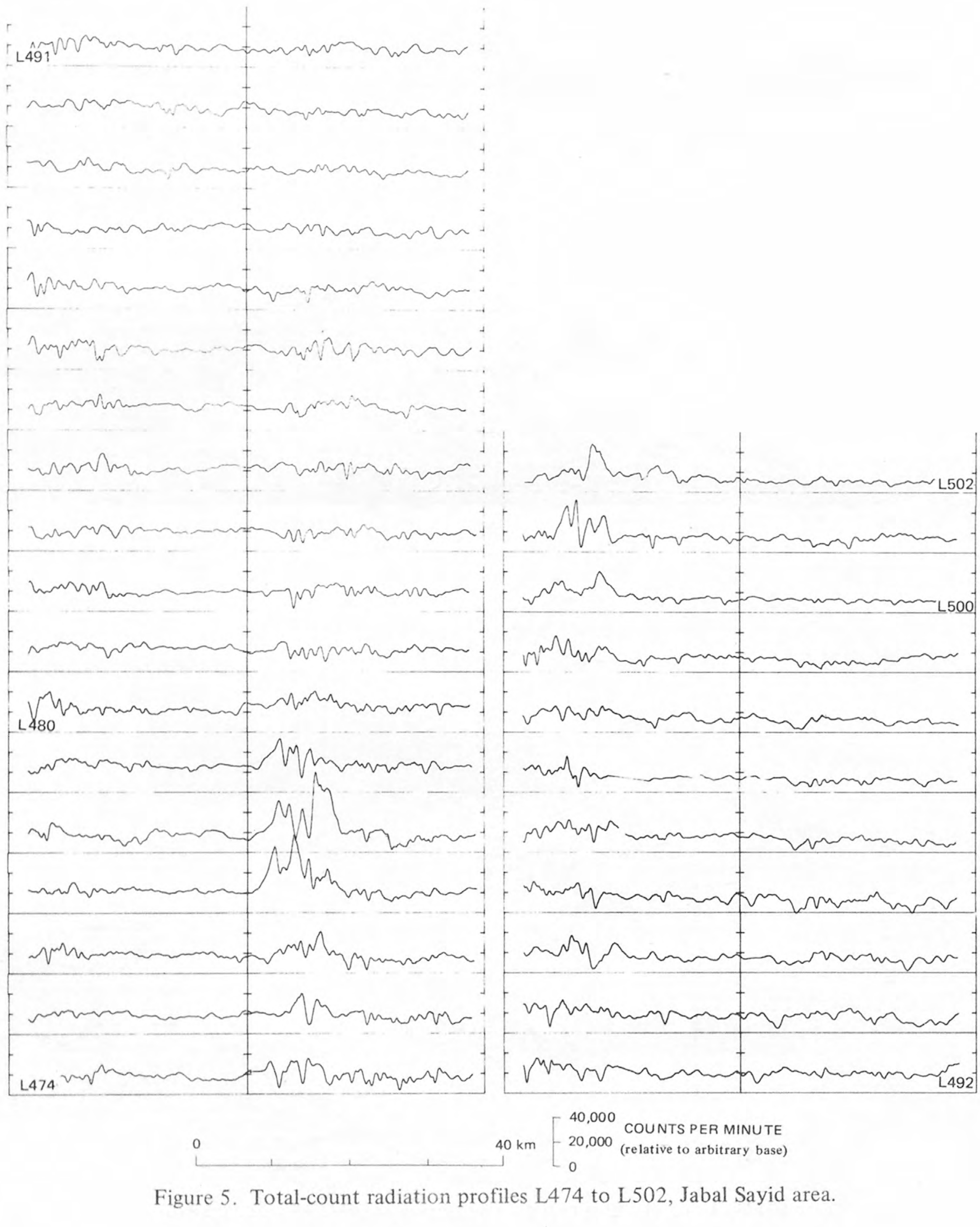

Figure 5. Total-count radiation profiles L474 to L502, Jabal Sayid area.

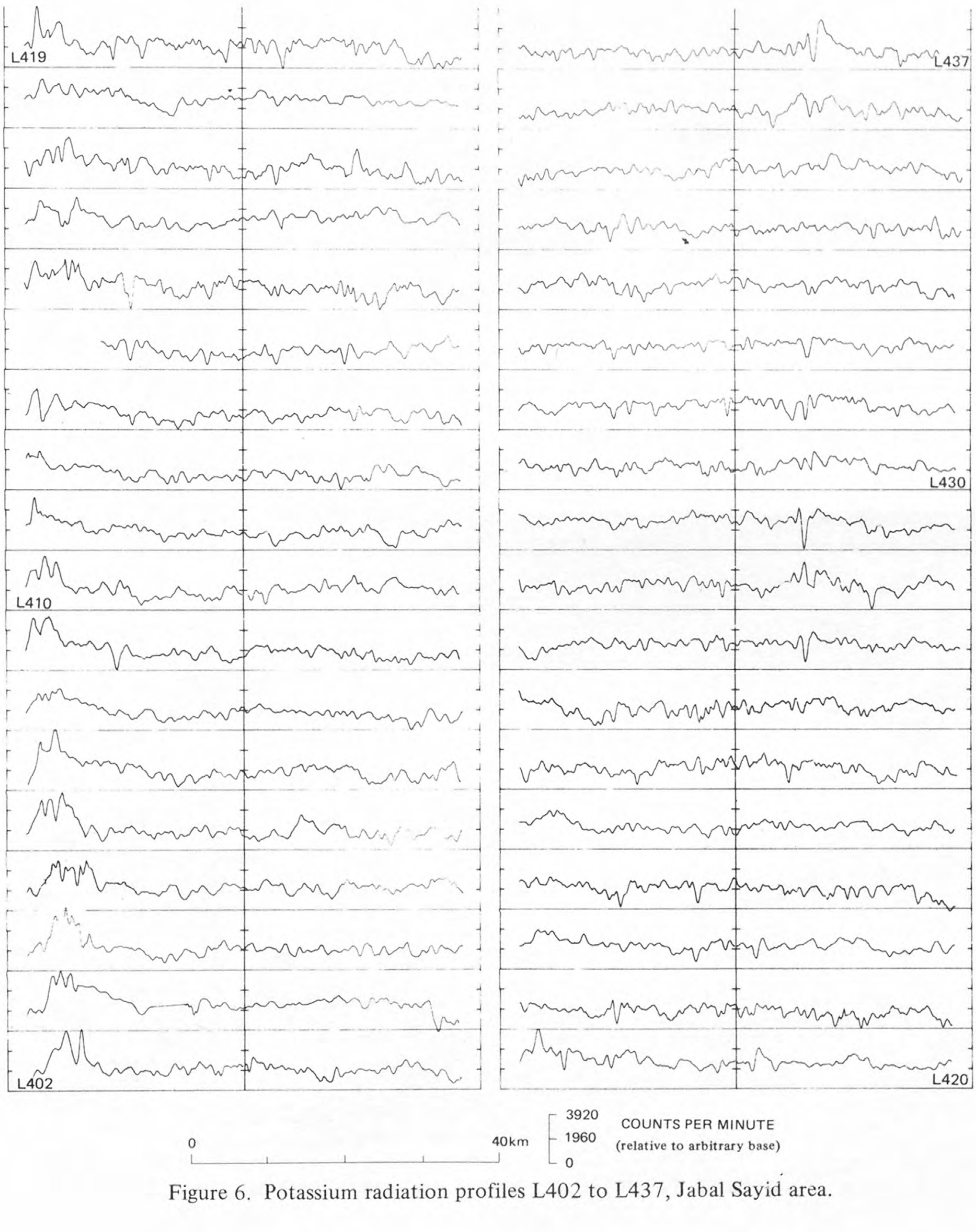

Figure 6. Potassium radiation profiles L402 to L437, Jabal Sayid area.

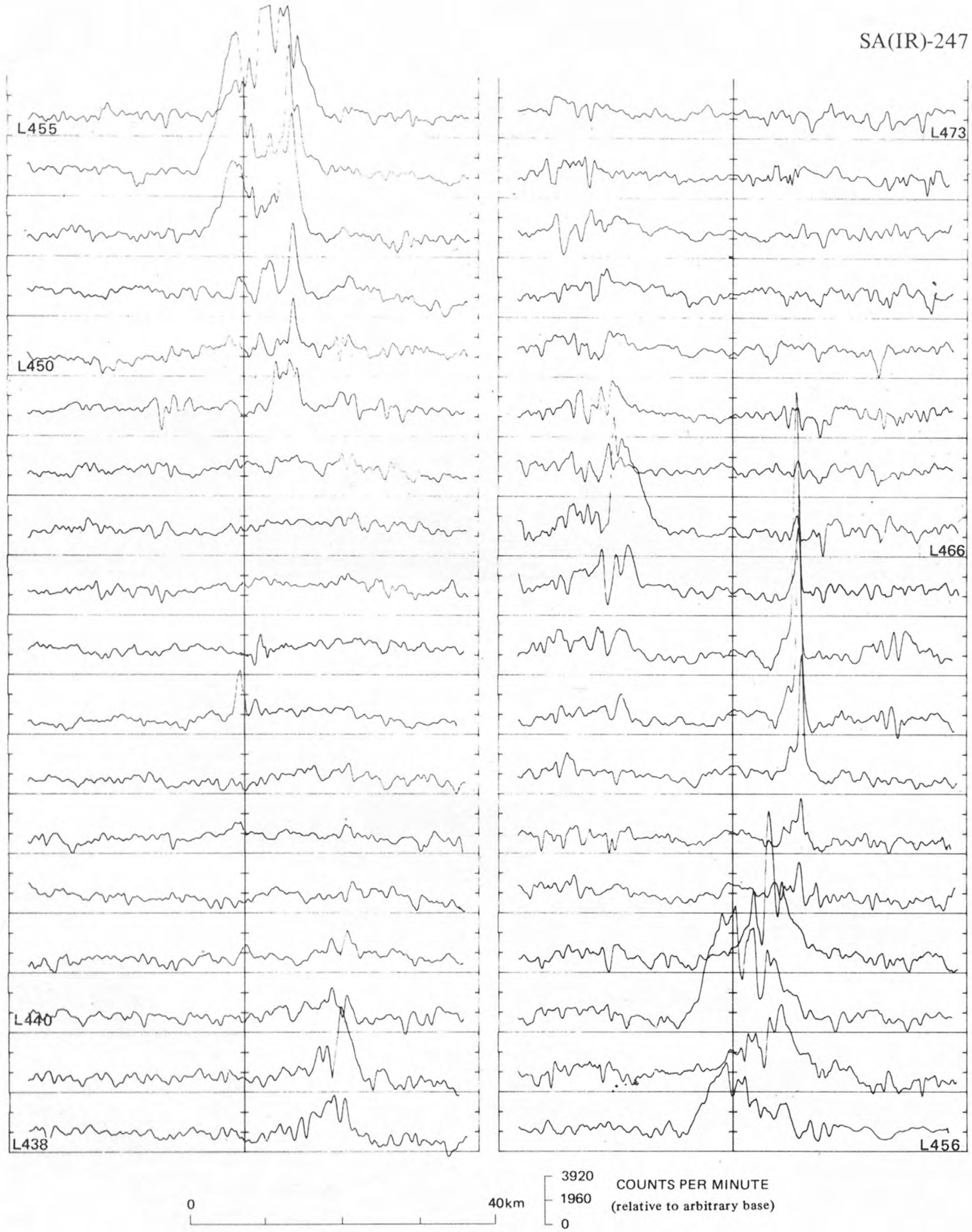

Figure 7 Potassium radiation profiles L438 to L473, Jabal Sayid area.

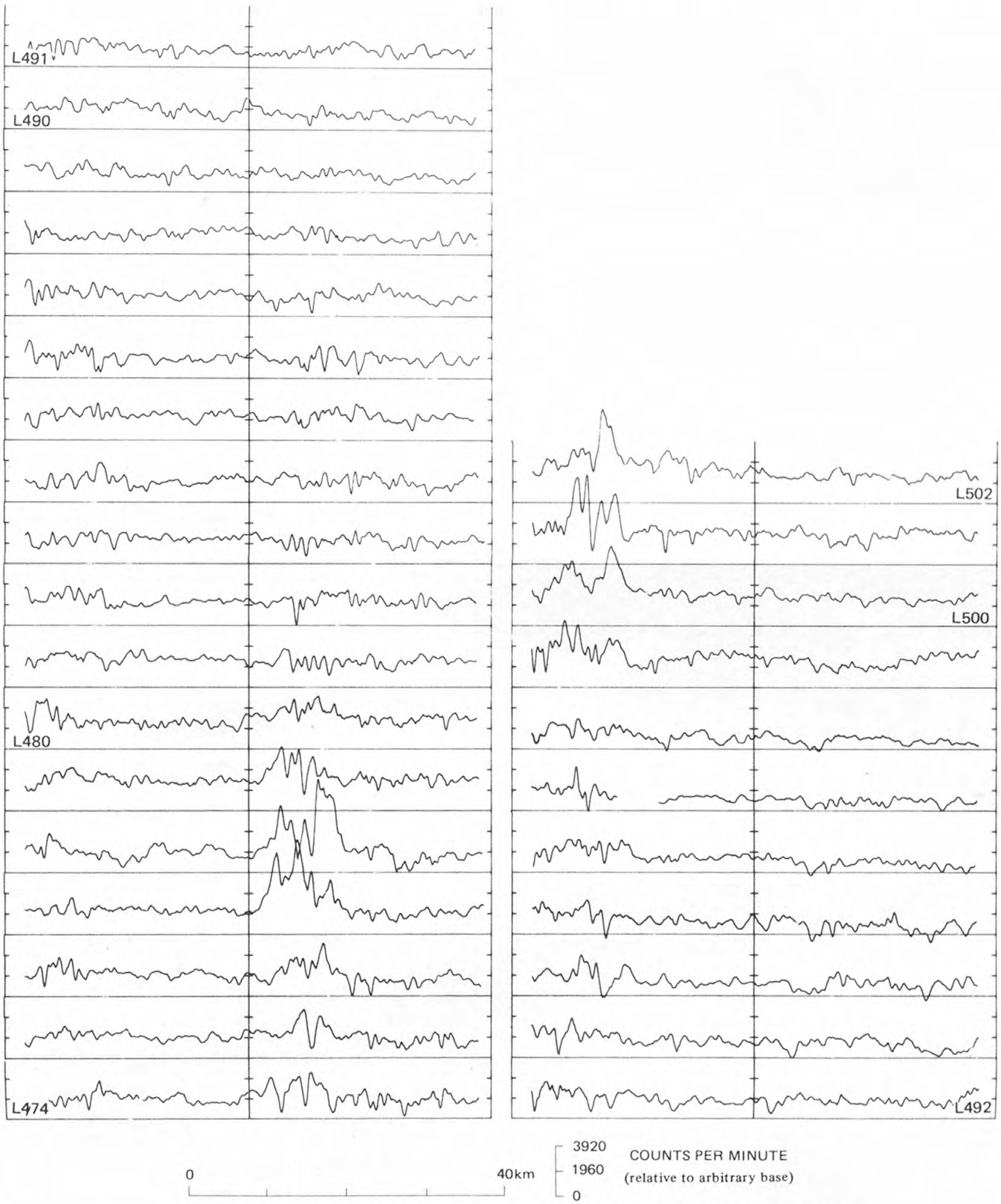

Figure 8. Potassium radiation profiles L474 to L502, Jabal Sayid area.

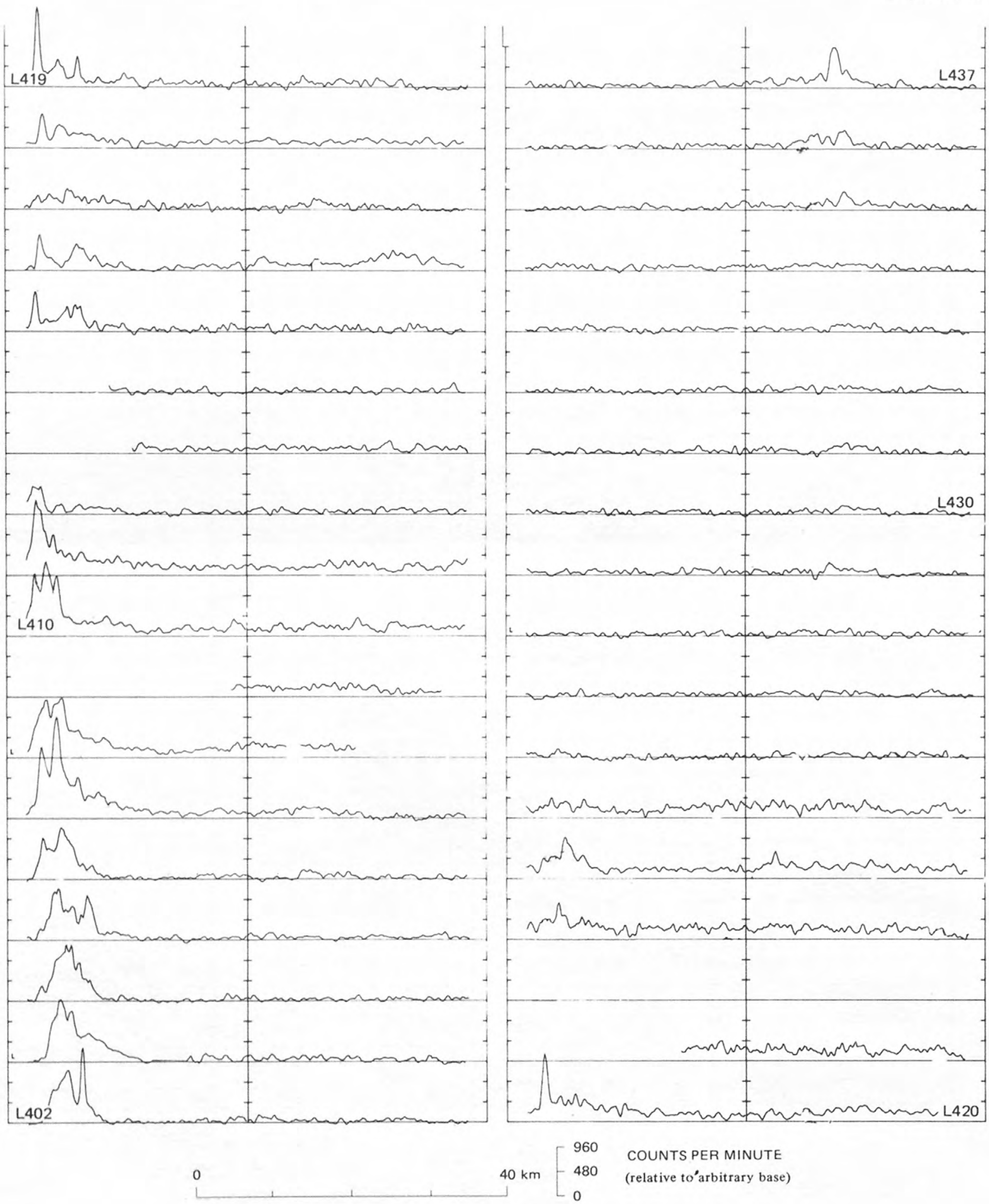

Figure 9. Thorium radiation profiles L402 to L437, Jabal Sayid area.

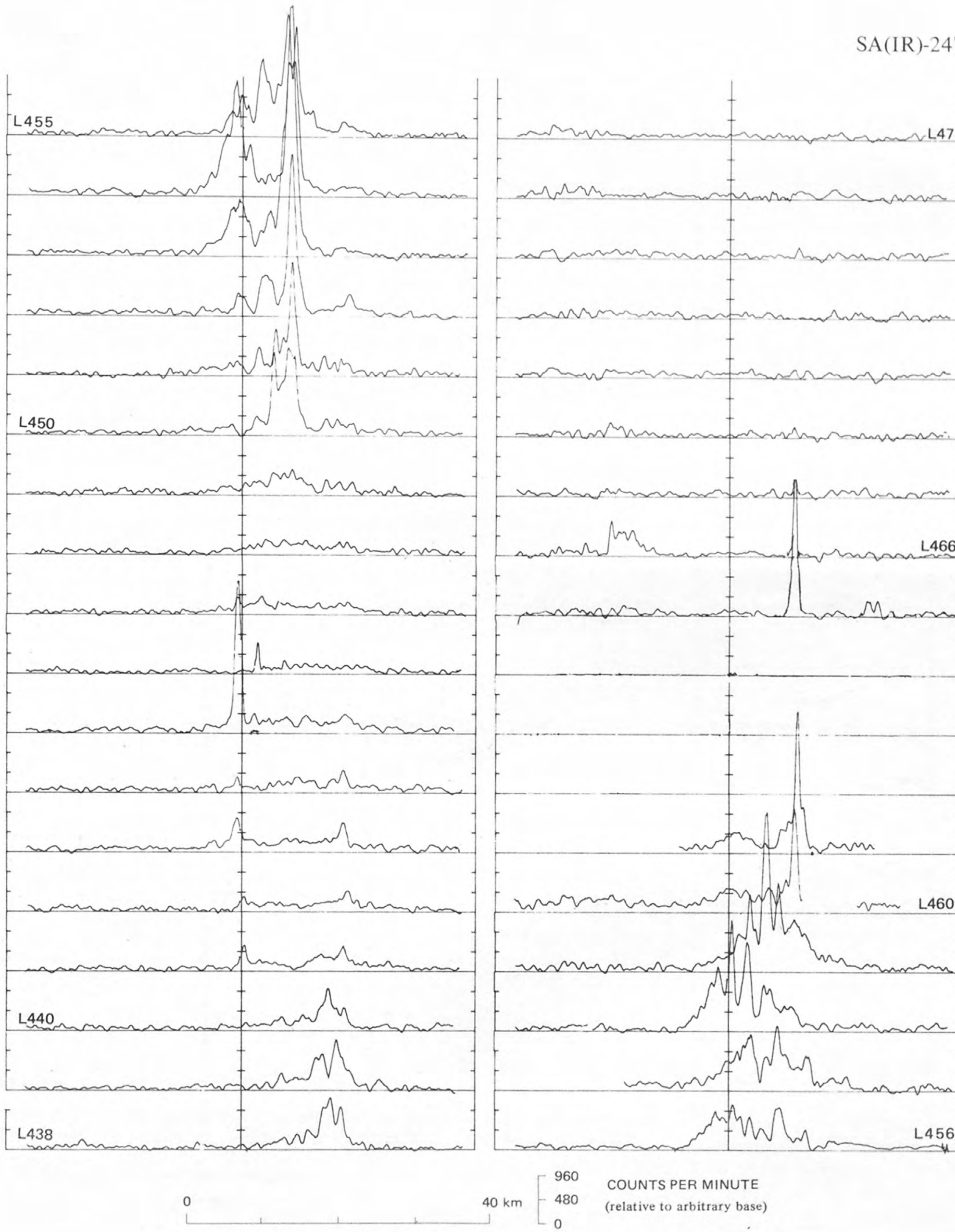

Figure 10. Thorium radiation profiles L438 to L473, Jabal Sayid area.

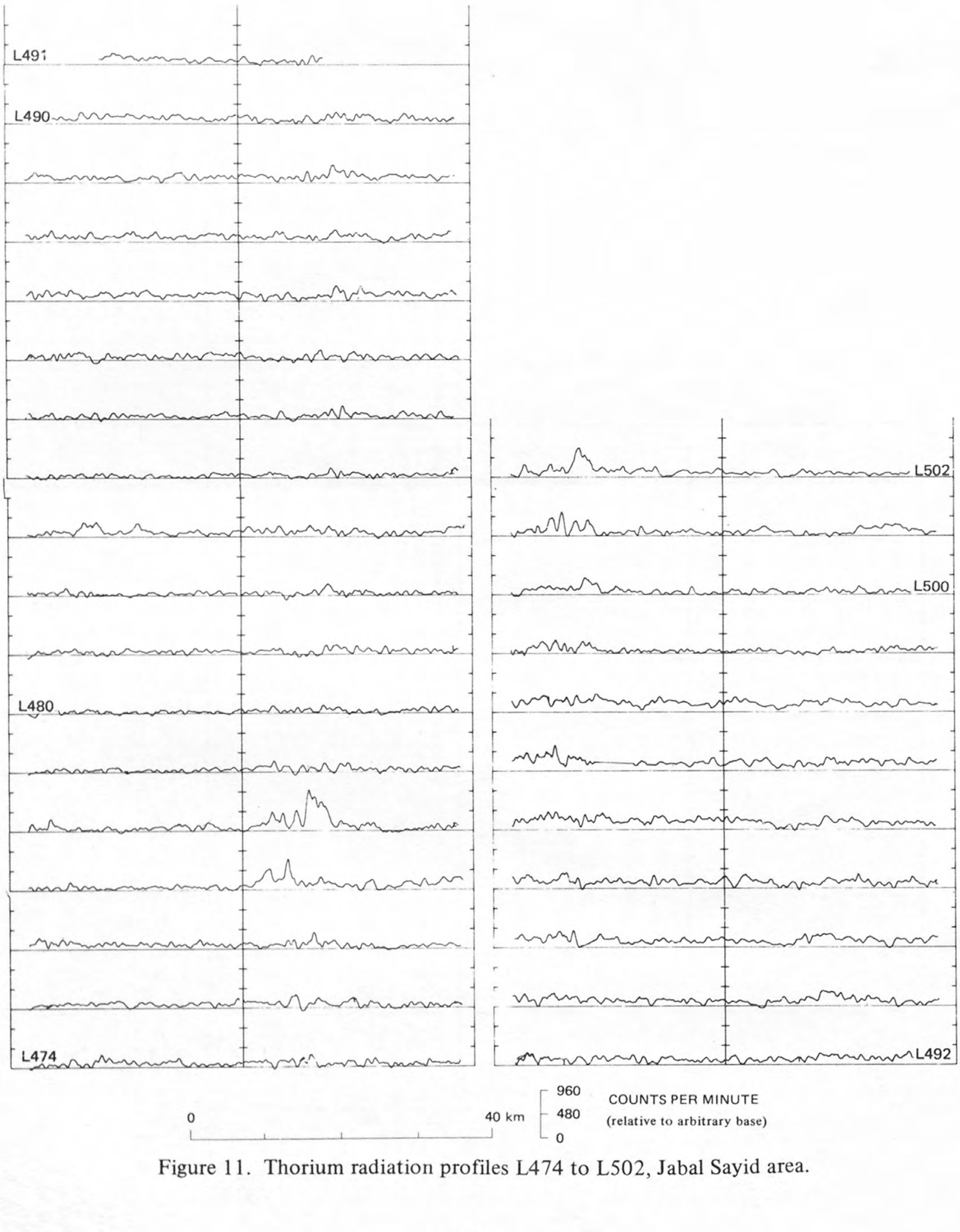

Figure 11. Thorium radiation profiles L474 to L502, Jabal Sayid area.

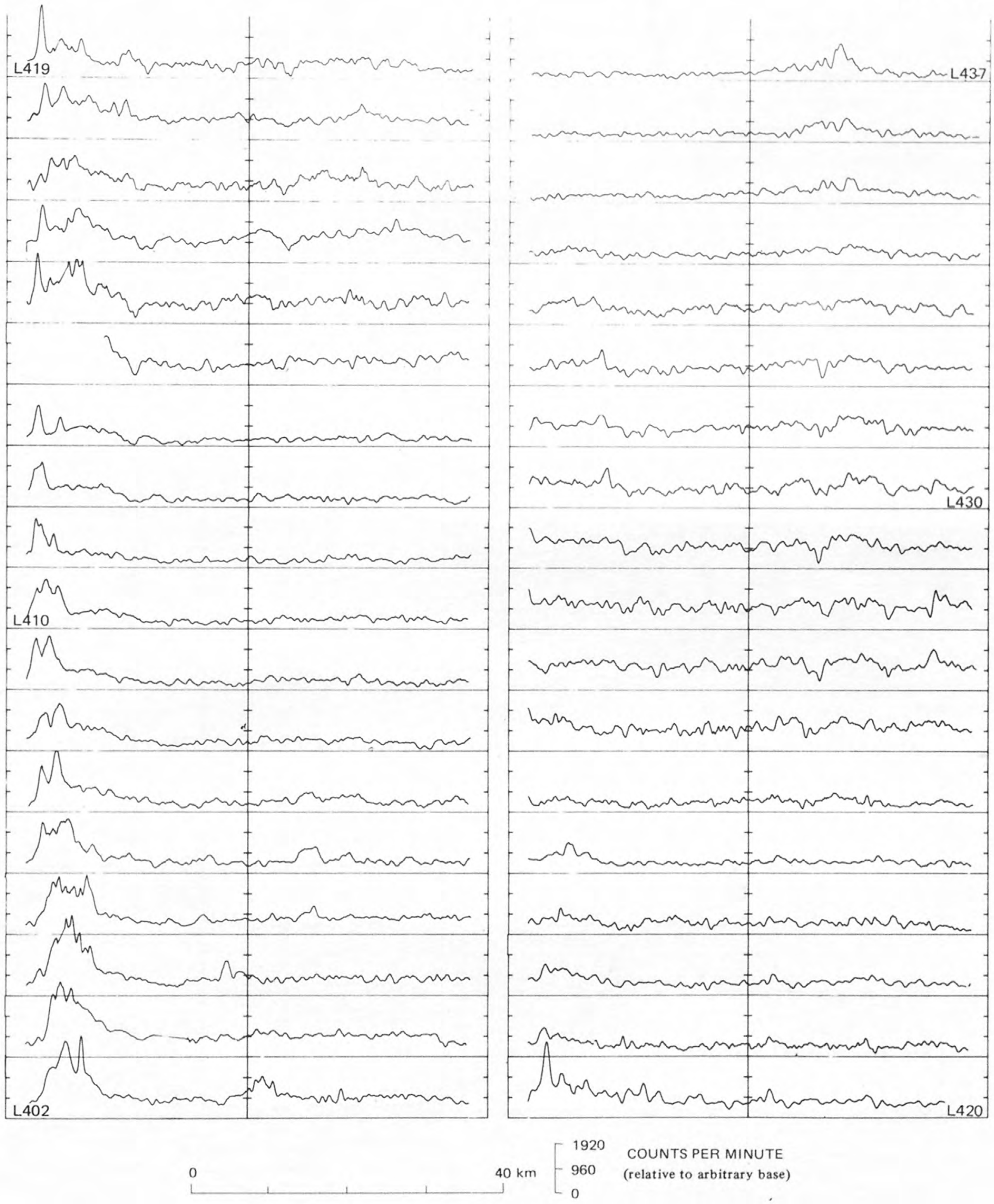

Figure 12. Uranium radiation profiles L402 to L437, Jabal Sayid area.

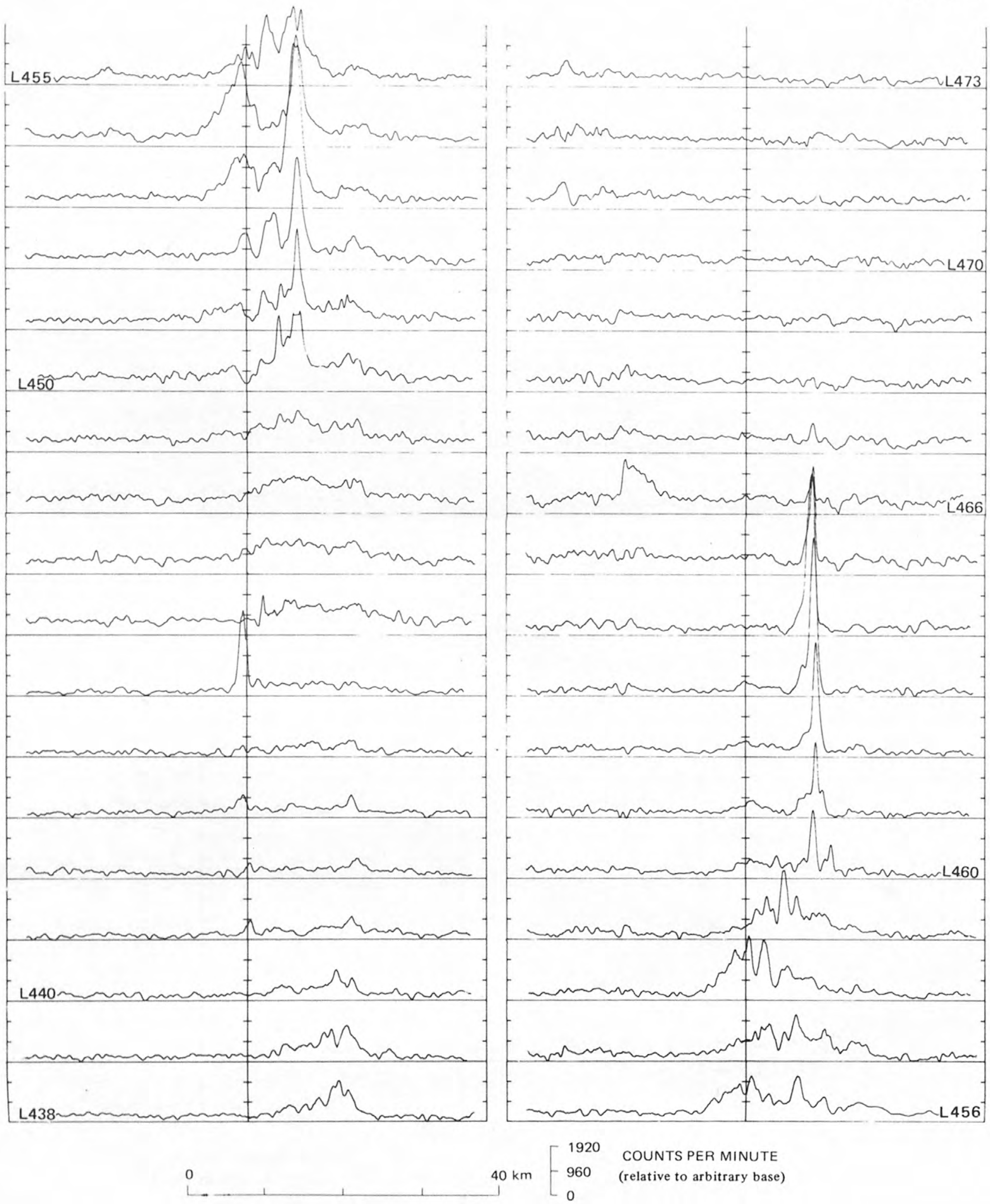

Figure 13. Uranium radiation profiles L438 to L473, Jabal Sayid area.

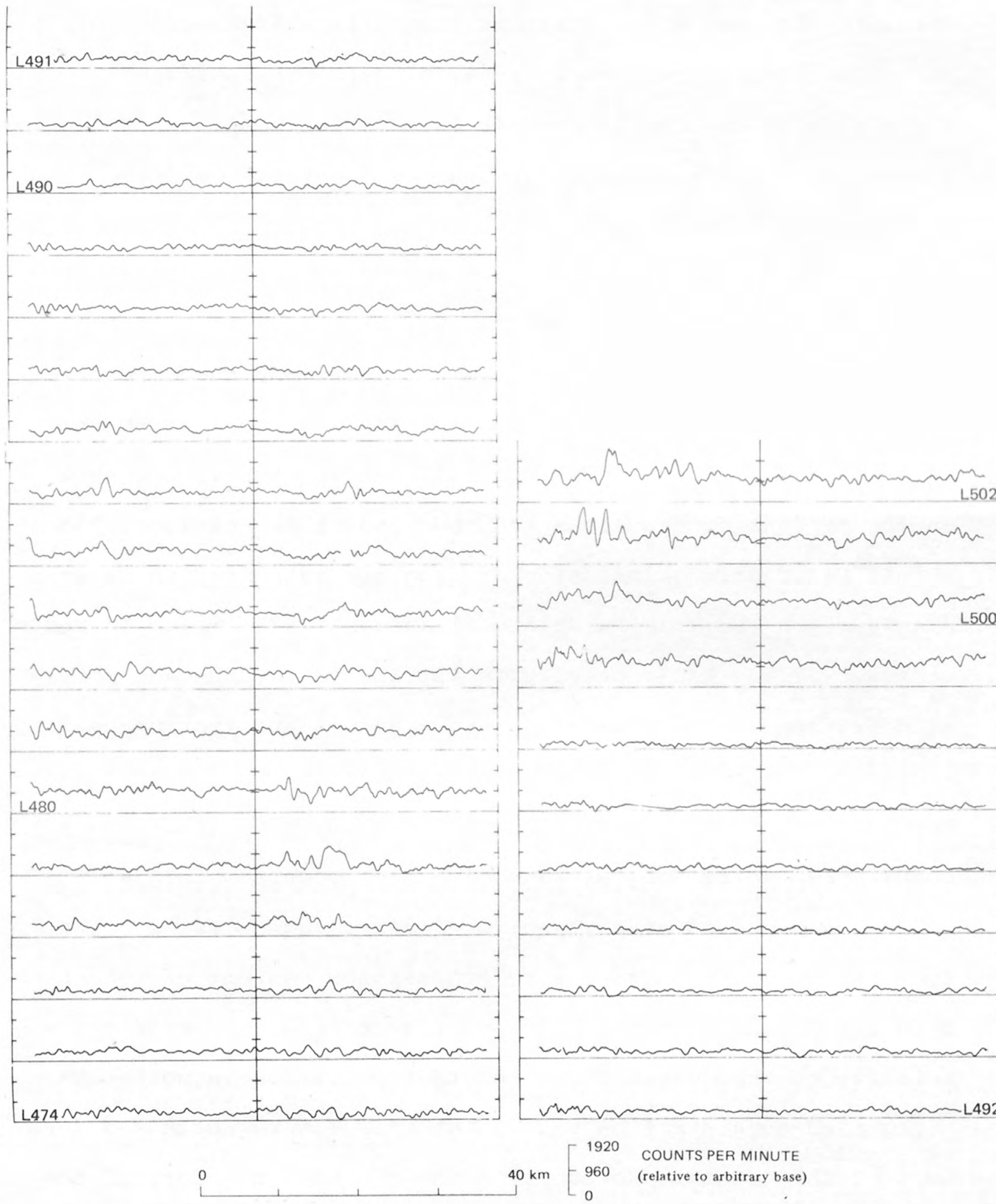

Figure 14. Uranium radiation profiles L474 to L502, Jabal Sayid area.

wedge of rhyolitic metavolcanic rock in which hydrothermal alteration has developed sericite, chlorite, and pyrite. Specifically, the mineralization occurs in tuffaceous rhyolite and rhyolite breccia (Campi, 1969, p. 29). The surface expression of the copper deposit is a gossan composed of siliceous limonite laced with veins of hematite (Delfour, 1970b, p. 25).

The Jabal Sayid deposit was crossed by flight lines 460 to 477 (figs. 4, 5, 6, 7, 10, 11, 13, and 14). The gossan lies on the northwest periphery of the radioactive high correlative with the granitic rocks of the Jabal Sayid pluton and their detrital dispersion halo. This radioactive high is not shown on figure 2 as an anomalous zone because it is considered the normal radioactive expression of granitic intrusive rocks seen elsewhere on the Arabian Shield (Flanigan, 1974; Theobald and others, 1973). Radioactivity is attributed to abundant potassium feldspar, potassium mica, and uranium- and thorium-bearing accessory minerals such as monazite, allanite, and zircon. North of the gossan, a distinct spectrometry low (that is, a comparative deficiency of radioelements) occurs within volcanic rocks mapped as rhyodacite, dacite, and andesite. The spectrometry data suggest a relatively low content of potassium feldspar in these rocks. The position of the radiometric low relative to the gossan indicates that potassium is not above background concentration within the area 1.5 km north and 3 km west of the gossan. However, on the northern boundary of the area outlined around the Jabal Sayid copper deposit (fig. 2), an anomalous potasium high has been detected. In this area potassium (K^{40}) increases 2400 counts per minute (cpm), uranium (Bi^{214}) 480 cpm, and thorium (Tl^{208}) 160 cpm. The resulting radioelement count-rate ratio is K:Th, 15:1, and K:U, 2.9:1. Compared to radioelement count-rate ratios over basic rocks these data indicate that potassium-rich minerals are abundant. The potassium anomaly is centered over an east-west wadi drainage system and may reflect the presence of potassium minerals in the wadi alluvium, which is composed of detritus weathered from granite mapped east of the anomaly. Two other potassium anomalies lying 5-6 km west of Jabal Sayid correlate with small exposures of alkalic granite that apparently intrudes metavolcanic rocks. A group of uranium-potassium anomalies about 10 km northeast of the Jabal Sayid prospect are on the northern edge of the Jabal Sayid pluton and may reflect slope wash and detritus from the more radioactive pluton.

Of particular interest are the interwoven potassium-uranium anomalies on the eastern side of the Jabal Sayid granite pluton. Previous work by Hummel and Hakim (1965) in the area near Hail, lat 27°38'N., long 41°41'E., showed that the Jabal Aja granitic pluton intrudes metavolcanic rocks of the Halaban group west of Hail. Geochemical samples collected by Hummel and Hakim were found to be radioactive, and further work in the area revealed that pegmatitic dikes presumably associated with the Jabal Aja intrusion contained significant quantities of titanium, niobium, and rare-earth minerals (Meissner, 1970, written commun.). The full extent of this type of mineralization in the Hail area has not been determined. Inasmuch as the Jabal Sayid pluton is known to contain concentrations of niobium rare-earth minerals (Shepherd, 1965), it seems possible that dikes similar to those at Jabal Aja may occur at Jabal Sayid.

A series of potassium-uranium anomalies (labeled I on fig. 2) lies over a belt of rock mapped as a diorite-granodiorite complex. The trend of the radiation anomalies generally follows northwest-trending dikes and suggests that these dikes and dike swarms may contain potassium minerals and uranium-bearing rare-earth minerals. Other potassium and uranium anomalies are seen to border the radiometric high associated with the Jabal Hadeb granite body in the south-eastern corner of the survey area (fig. 2), and may indicate another area of interest for prospecting for rare-earth minerals.

A series of spectrometrically anomalous areas along the eastern edge of the study or survey area (labeled II on fig. 2) evidently contain sufficient potassium and uranium mineral-ization to give rise to anomalous radioactivity. These anomalies have been recorded over rocks mapped as rhyolite and rhyolite tuff. The normal high potassium content of rhyolite may account for the potassium anomaly, but the cause of the uranium high is not readily apparent. Flight line 402 (fig. 15) shows the combined spectrometer response over this rhyolite unit. Near the center of the flight line the count rate in the uranium window increases about 1450 cpm, thorium increases about 150 cpm, and potassium about 1550 cpm. These relative increases in count rate yield a ratio for K:Th of about 10:1, and for K:U a ratio of about 1:1. The count-rate ratios do not necessarily indicate that potassium, thorium, and uranium actually exist in the outcrop in these relative concentrations; they do indicate, however, that potassium exists in greater abundance than in the areas around the anomaly.

The Mahd adh Dhahab gold mine area (labeled III on fig. 2) has a radiometric pattern similar to that of the anomaly just described, that is, a potassium-uranium anomaly associated with rhyolitic rocks. Flight line 482 (fig. 15) illustrates the composite radiometric response over the Mahd adh Dhahab area located approximately on the southern end of the flight line. Here the relative increase in the potassium and uranium count rates yield ratios of 1.6:1 for K:U and 16.3:1 for K:Th. Very likely the rhyolitic intrusive rocks in this area explain the potassium high, but the cause of the uranium anomaly is not known. A detailed ground gamma-spectrometer survey and geochemical sampling in the Mahd adh Dhahab area confirm the potassium anomaly but leave unanswered the question of whether anomalous quantities of uranium-bearing minerals are present (Alageel, 1974, oral commun.). Roberts (1974, written commun.) believes that mineralization at the Mahd adh Dhahab mine may be associated with the intrusive rhyolite. If this relationship exists, then other areas having approximately the same radiation pattern may be prime areas for prospecting for similar mineral deposits. One such area about 1 km in diameter, marked

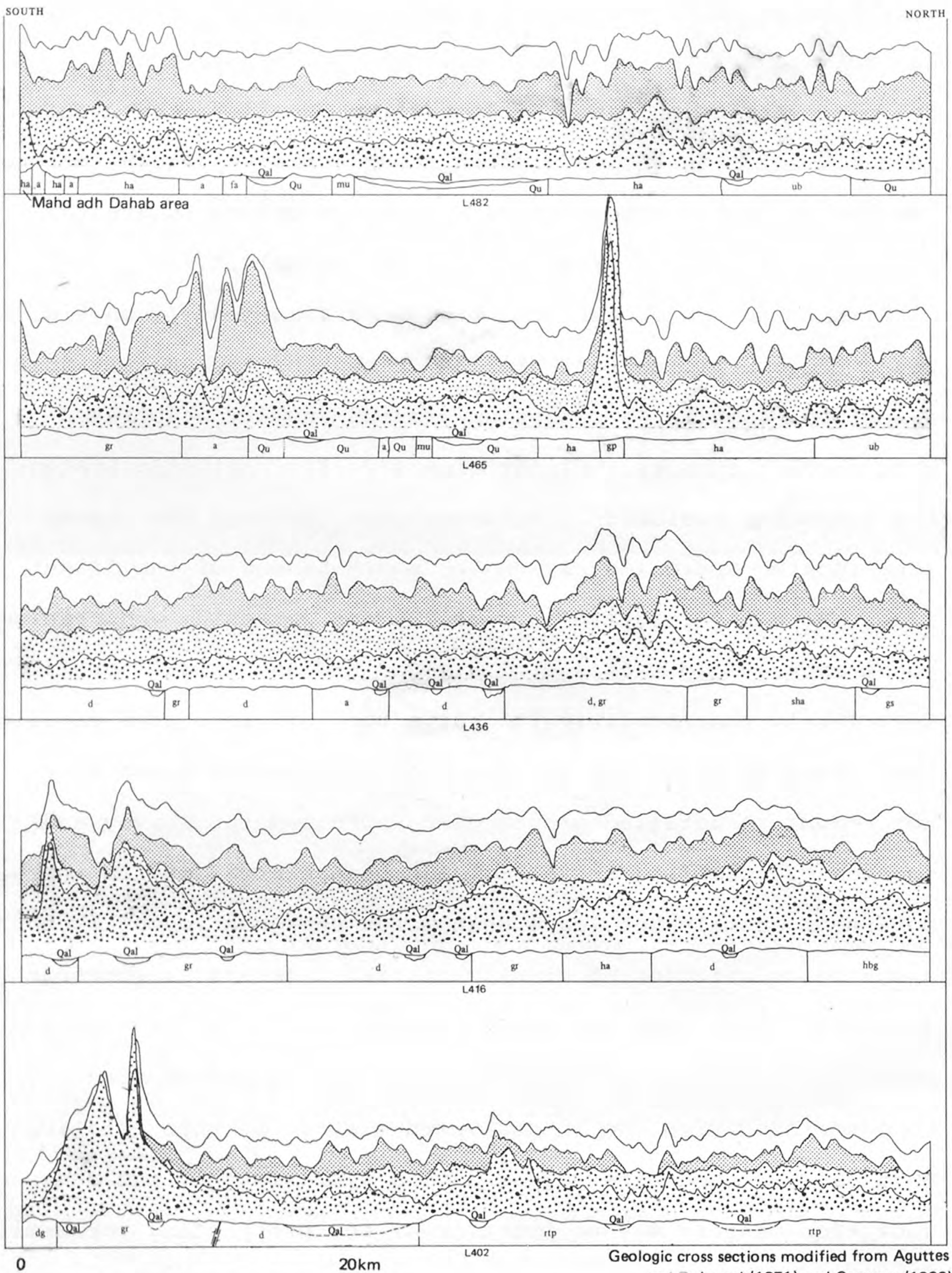

Figure 15. Selected radiation profiles and geologic cross sections across the Jabal Sayid area.

EXPLANATION

RADIATION

	TOTAL COUNT TRACE – vertical scale 20,000 counts per minute per centimeter (cpm/cm)
	POTASSIUM COUNT TRACE – vertical scale 1960 cpm/cm
	THORIUM COUNT TRACE – vertical scale 480 cpm/cm
	URANIUM COUNT TRACE – vertical scale 960 cpm /cm
L402	NUMBER OF RADIATION PROFILE

GEOLOGY

Qal	WADI ALLUVIUM, SILT, SAND, AND GRAVEL
Qu	SILT AND GRAVEL
gp	GRANITE – Alkalic to peralkalic
mu	MURDAMA FORMATION – Undifferentiated
ha	HALABAN GROUP – Undifferentiated
gr	RED GRANITE
d	DIORITE AND QUARTZ DIORITE
a	ANDESITE
gs	GREENSCHIST
fa	GRANOPHYRIC COMPLEX – Andesite, dacite, and rhyolitic breccia
ub	OPHIOLITIC LAYERED COMPLEX – Serpentinite, marble, and jasper
d, gr	DIORITE AND GRANITE COMPLEX
sha	ANDESITE AND SCHIST
hbg	AMPHIBOLITE, HORNBLENDE SCHIST, AND GNEISS
dg	DIORITE AND GRANODIORITE
rtp	RHYOLITE, RHYOLITE TUFF, AND AGGLOMERATE

Order of listing of geologic units does not indicate their relative age.

predominantly by a potassium high, is about 3 km west of the Mahd adh Dhahab mine area. Here, radioelement ratios are 3.7:1 for K:U and 14:1 for K:Th. Comparison of these ratios with those over the Madh adh Dhahab area shows that potassium is slightly more abundant at this location. Rocks in this area are part of the metavolcanic and metasedimentary rocks of the Mahd adh Dhahab sequence and are mapped as siltstone. Explanation of the potassium anomaly would require ground checking.

Twelve other potassium and potassium-uranium anomalies are within an 18 km radius north of Madh adh Dhahab (fig. 2). Flight line 465 (fig. 15) includes one of these anomalies (labeled IV on fig. 2). The anomaly lies over rocks mapped as andesite and specifically occurs over pediment alluvium probably derived from a nearby granitic body. The count rate in the potassium window increases about 500 cpm and the rates in the thorium and uranium window increase about 240 and 430 cpm, respectively. The count-rate ratio of K:Th is 24:1 and that of K:U is 11.6:1.

Twenty-two km farther north along flight line 465, a sharp rise in count rate has been recorded over an outcrop mapped as alkalic to peralkalic granite. Here the relative increases in count rates are: potassium, 7640 cpm; uranium, 4800 cpm; and thorium, 2640 cpm. The ratios are: 2.8:1 for K:Th and 1.6:1 for K:U. The relative count-rate ratios over rock mapped as red granite (gr) on the south end of flight line 416 (fig. 15) are 4:1 for K:Th and 1.5:1 for K:U.

Comparison of the count-rate ratios of the potassium anomaly at area IV (fig. 15) on flight line 465 with those over the two types of granitic rocks indicates that potassium is clearly in abundance in area IV and that the anomaly probably does not originate from granitic rocks.

No detailed discussion of the other potassium-uranium anomalies within the 18 km radius of Mahd adh Dhahab is warranted because the sources of the anomalies are not readily apparent. Goldsmith (Goldsmith and Kouther, 1971) mapped several outcrops of rhyolitic rocks within this area that seem to correlate with some of the potassium anomalies, but it is uncertain whether these rocks are intrusives, such as those at Mahd adh Dhahab, or are instead extrusives.

On the western margin of the surveyed area (fig. 2) a rock mapped as rhyolitic tuff correlates reasonably well with a potassium anomaly and probably accounts for the anomalous radioactivity.

CONCLUSIONS AND RECOMMENDATIONS

The study of the gamma-spectrometry data of the Jabal Sayid area suggests the following:

1. In a rectangular area of 1.5 x 3 km immediately north of the Jabal Sayid gossan, no anomalous concentrations of potassic minerals, such as can occur in areas of hydrothermal alteration, were detected. Furthermore, the gossan associated with the Jabal Sayid pluton and its detrital dispersion

halo, and any anomalous radioelement concentration in the gossan is masked.

2. Several potassium-uranium anomalies in the survey area may represent areas of rhyolitic intrusion and(or) hydrothermal alteration. Ground checking of the anomaly detected at the Mahd adh Dhahab mine indicates that the anomaly is associated with rhyolitic intrusive rocks. Thus some of the potassium-uranium anomalies may represent unmapped rhyolitic rocks and may be considered as potential economic exploration targets.
3. The potassium-uranium anomalies east of Jabal Sayid may indicate niobium-rare earth-bearing minerals occurring in dikes and pegmetitic veins similar to those known at Jabal Aja near Hail.
4. It is suggested that further testing of the gamma-ray spectrometry technique be made over areas well-mapped geologically and known to contain hydro-thermally altered rocks.

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