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Geophysical and geological investigations of aerial radiometric anomalies in the Paleozoic Tabuk Formation, in northwestern Saudi Arabia: A preliminary report

by

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ABSTRACT

Aerial radiometric anomalies were discovered in the Paleozoic Tabuk Formation in northwestern Saudi Arabia by an airborne gamma-ray spectrometric and proton-precession magnetic survey of the Phanerozoic cover rocks of Saudi Arabia. Ground physical and geological studies located the anomalies and investigated their geologic characteristics during March 1984.

Two belts of anomalies were defined: (1) an equivalent uranium belt that includes (a) an eastern anomaly that occurs about 20 km northwest of Tayma, where it trends northwest for about 80 km and is 5 to 15 km wide, and (b) a western anomaly that begins about 65 km west of the eastern anomaly, trends easterly for about 20 km between N. 37°13' to 37°26' E., and is from 5 to 15 km wide; (2) a multielement belt that is relatively high in all three radioelements (equivalent uranium, equivalent thorium, and potassium), especially equivalent thorium, trends west-northwest from the west edge of the Great Nafud, is 15 to 50 km wide, and includes Tayma.

The ground studies discovered that the radiometric anomalies are stratigraphically controlled; the equivalent uranium belt occurs in a graptolitic, micaceous black shale about 350 m above the base of the Tabuk Formation; and the multielement belt is associated with heavy-mineral zones in beach-placer sandstone about 100 m above the base.

INTRODUCTION

Aerial radiometric anomalies in the Tabuk Formation of Paleozoic age in northwestern Saudi Arabia were investigated by ground geophysical and geological studies during March 1984. The anomalies were discovered during the aerial magnetic and radiometric survey of the "cover rocks" of Saudi Arabia conducted by Geosurvey International Limited between December 1981 and June 1984. Preliminary examination of data while the survey was being flown revealed the Tabuk anomalies, and the ground work was planned and accomplished as Geosurvey was delivering final data from the aerial survey.

This report discusses the aerial survey, verification and enhancement of the radiometric data prior to the ground work, geophysical and geological elements of the investigation, and preliminary conclusions.

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SURVEY

The aerial survey was done by Geosurvey International Limited of London, under contract to the USGS Mission in Jeddah, Saudi Arabia. The work upon which this report is based was conducted in accordance with the terms of a work agreement between the U.S. Geological Survey and the Saudi Arabian Ministry of Petroleum and Mineral Resources. The area surveyed, shown in figure 1, includes the Paleozoic and Mesozoic sedimentary rocks that adjoin the Arabian Shield to the north, east, and south. "Cover rocks" relates to the covering of the Precambrian surface by Phanerozoic sedimentary rocks. The primary intent of the survey was to acquire radiometric and magnetic data that would be used primarily in geologic mapping and mineral exploration of the cover rocks and in mapping the subsurface structure of the cover rock region, and secondarily to complete aeromagnetic surveying of the Shield.

The cover rocks survey area was flown on 2-km-spaced, easterly and northerly flight lines at 120-km above ground level, and tie lines were flown normal to flight lines at 20-km intervals. Lines were flown at 1-km intervals between the regular flight lines in areas where anomalous radioactivity occurred. Anomalies were arbitrarily defined as increases of at least 50% in level of signal per radiometric channel (potassium, uranium, and thorium) for at least 3 km along the flight line. However, supplementary lines were often flown where only 1 channel, usually the uranium, had a significant increase (greater than or equal to 50%) in level of signal.

METHOD

Aerial radiometric surveying focuses on measuring the distribution of natural radioelements at the surface of the ground. Because this distribution is controlled by geologic processes, aerial radiometric measurements can be used in geologic mapping, mineral exploration, and understanding geologic processes. The radioelements K^{40}, U^{238}, and Th^{232} and their decay products produce gamma photons that comprise the surface or terrestrial contribution. Measurement systems are calibrated to monitor the variation of the 1.46-Mev (million electron volts) photopeak of K^{40}, the 1.76-Mev photopeak of Bi^{214} in the U^{238} decay series, and the 2.62-Mev photopeak of Tl^{208} in the Th^{232} decay series.

In addition to the terrestrial contribution, aerial measurements contain contributions from sources that include Rn^{222} in air, cosmic, or extra-terrestrial energy, and material of and within the aircraft. Rn^{222} is a gamma-emitting daughter of U^{238} whose atmospheric contribution is normally removed from aerial radiometric measurements. The Rn^{222} and the cosmic contributions are monitored while surveying and the aircraft contribution is determined by presurveying calibration. All quantities are removed from the measurements during data processing and reduction such that the terrestrial contribution remains as an enhanced data product.

Scintillation detectors are typically used for aerial radiometric measurements, and the detectors with their associated electronic equipment are mounted in aircraft that should follow the contour of the ground with a clearance of no more than 220 m. Aerial radiometric surveys are most often flown at a nominal 120 m above ground level, which has been demonstrated to be adequate for both scientific and safety needs. The low ground clearance is necessary because gamma-rays are absorbed at an exponential rate with atmospheric thickness. Also, because the gamma-rays are absorbed exponentially with increasing thickness of surface materials, the measurements detect radioelement concentrations in the uppermost 0.5 m of rock and soil. At 120 m above ground level,

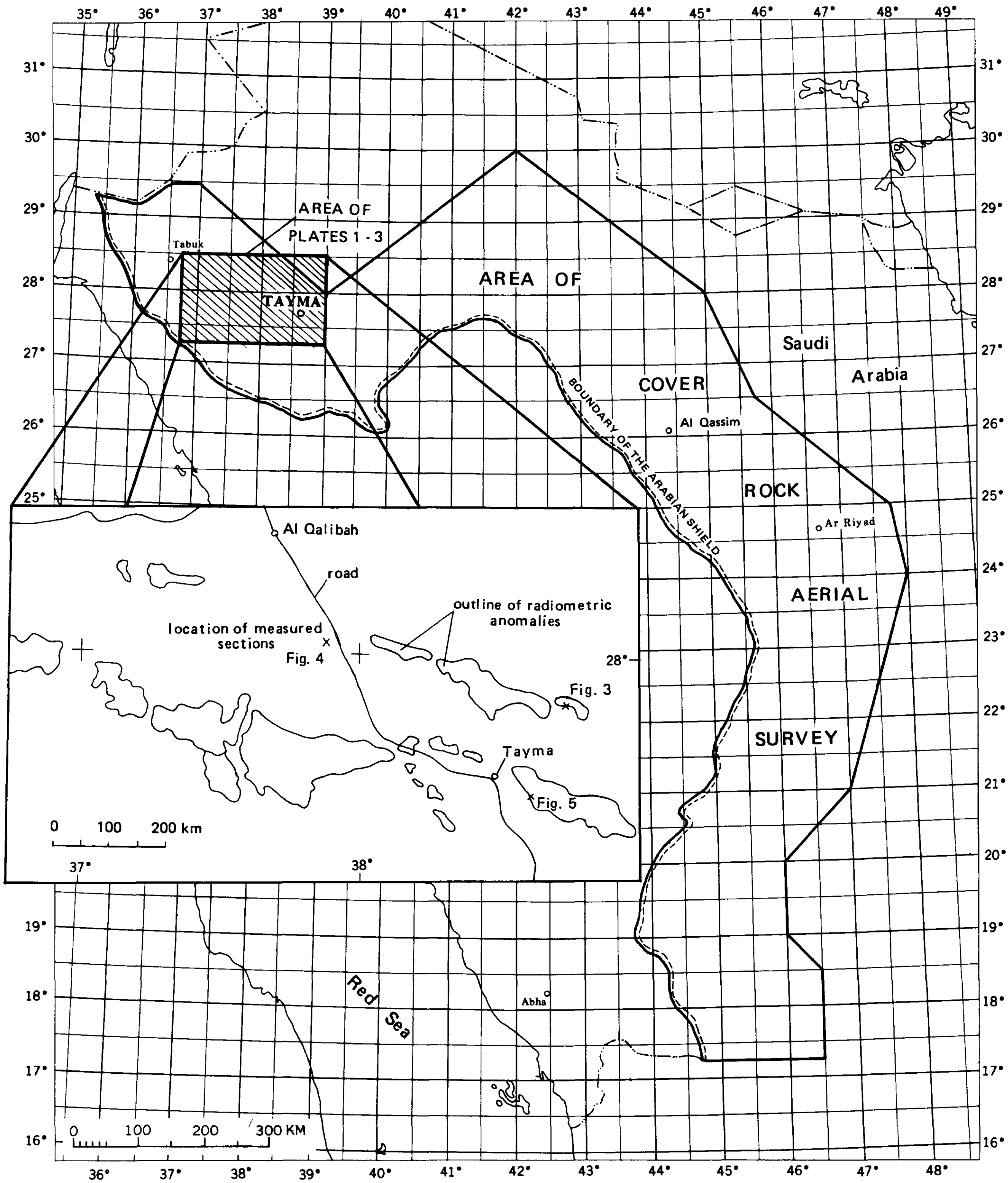

Figure 1--Index map showing area of cover rock aerial survey, area of plates 1-3, and an expanded map of the area of the plates. The expanded map shows a generalized outline of the radiometric anomalies, primarily derived from the eU map (pl. 1), and the location of measured sections (figs. 3, 4 and 5).

the effective area of response measured by an aerial radiometric system is a strip along the flight line approximately 240 m wide.

The cover rock aerial survey also acquired magnetic data, which were not used in the ground investigation of the Tabuk anomalies, and will not be discussed in detail. Complete details of the survey are given in the contractor's final report (Geosurvey International Limited, 1984).

EQUIPMENT

The equipment used for the cover rock survey included 256-channel gamma-ray spectrometers and proton precision magnetometers installed in twin-engine aircraft. Signals from these instruments and signals from doppler navigation systems, radar and barometric altimeters, atmospheric temperature and pressure sensors, and clock and fiducial systems were recorded on magnetic tape by computer-controlled digital recording and acquisition systems. System sampling for digital recording was doppler controlled at one second or 60-m intervals along flight traverse. Aircraft flight paths were photographed by 35-mm tracking cameras.

Each spectrometer included a gamma-ray detector of 58.7 liters of sodium iodide (thallium-activated) crystals. The detector consisted of two arrays of crystals: (1) a 4-pi array of 50.3 liters that accepted gamma photons from all sources, and (2) a 2-pi array of 8.4 liters that was shielded to accept gamma photons only in the solid angle above the horizontal plane of the aircraft, thereby acting as a monitor of Rn^{222} in air.

Spectrometer data recorded on magnetic tape for each detector array included a 256-channel (128-channel 2-pi) full spectrum for 0.40 to 3.0 Mev and a cosmic or extra-terrestrial channel from 3.0 to 6.0 Mev. Also recorded on magnetic tape were real-time signals for windows in the natural spectrum calculated by the on-board computer from the 4-pi full spectrum at 1.37 to 1.58-Mev for K^{40}, 1.66 to 1.87-Mev for Bi^{214} in the U^{238} decay series, 2.42 to 2.83-Mev for Tl^{208} in the Th^{232} decay series, and 0.41 to 3.0-Mev for total count. An analog recorder displayed these signals and two magnetometer signals (fine and coarse), the 2-pi total count (Rn^{222} monitor), and aircraft height above ground level as determined by the radar altimeter, for visual inspection during and after surveying. These records were examined daily during the survey to determine any need for infill surveying.

DATA REDUCTION AND PRESENTATION

The geophysical data were processed by the contractor to obtain contour maps of the apparent surface concentrations of potassium (K), uranium (eU), thorium (eTh), total count, and the residual total magnetic field. The e (for equivalent) prefix denotes the potential for disequilibrium in the U- and the Th-decay series.

Corrections applied to the radiometric data include background subtraction of counts due to cosmic rays and sources within the aircraft, as previously stated, and normalization to the nominal survey altitude (120 m) to compensate for variations in ground clearance. These corrected data were reduced to apparent concentrations of the radioelements by applying calibration data obtained at the Saudi Arabian Aerial Test Range (Young and Cowan, 1982) and at the calibration pads located at Ottawa, Ontario, Canada (Grasty and Darnley, 1971).

The aerial contractor routinely presents the fully corrected radioelement data for the entire survey as contour maps and stacked profiles at scale 1:250,000. The maps are keyed to the Landsat image map series of 1 1/2° longitude by 1° latitude quadrangles of the Arabian peninsula prepared by the USGS. For this report, radioelement contour maps have been composited from adjacent parts of contractor-prepared maps for 1:250,000-scale quadrangles 27B, 27C, 28B, and 28C. Plates 1, 2, and 3 are, respectively, the composited eU, eTh, and K maps of the area of radiometric anomalies in the Tabuk Formation at and northwest of Tayma, northwestern Saudi Arabia.

VERIFICATION AND ENHANCED PRESENTATION OF RADIOMETRIC DATA

The decision to investigate radiometric anomalies in the Tabuk Formation was based on preliminary data analysis while the survey was being flown. These data were made available to the Deputy Ministry for Mineral Resources and to the other missions in an administrative report (Pitkin, 1983).

Prior to the actual ground work, the radiometric data for the area of the Tabuk anomalies were examined in detail to verify the anomalies and to obtain precise locations. Preliminary editions of the radioelement contour maps for the anomaly area were examined and the anomalies to be investigated were defined. An anomaly with expression only in the eU data (pl. 1) occurs about 20-km north of Tayma, where it trends west-northwest. This anomaly is about 80 km long and 5 to 15 km wide, and is here designated as the eastern eU anomaly. Another anomaly with only eU expression occurs in the northwest part of the study area (pl. 1), here designated as the western eU anomaly, trends east-west for about 20 km between long. 37° 13' and 37° 26' E. and is 5 to 10 km wide. The two eU anomalies are about 65 km apart (pl. 1). Another anomaly, here designated as the multielement anomaly, with expression in all three radioelements and especially in eTh (pl. 2), occurs in the approximate lower half of the study area where it includes Tayma, trends west-northwest and is 15 to 50 km wide. The primary target of the ground study was the eU anomalies; an initial interpretation suggested that the source of the multielement anomaly was the same as similar anomalies on the northeast side of the Shield (Matzko and others, 1978).

The maps were examined further and specific flight lines that crossed the eU and multielement anomalies were chosen for individual examination. For these lines, data for the full spectrum (0.40 to 3.0 Mev) from the 4r detector array were averaged for 10-second sections of data within and outside the anomalies. An example is flight line 40686 (pls. 1, 2, and 3), for which spectra for 5 intervals were computed and are shown in figures 2A, 2B, 2C, 2D, and 2E. Referring to the locations shown on the plates, figures 2A, 2C, and 2E show spectra outside the anomalies and figures 2B and 2D show spectra within the anomalies. In figure 2B (eastern eU anomaly), the Bi214 (U238 10 decay series) photopeaks at 1.12- and 1.76-Mev show greater amplitudes compared to the same photopeaks in figures 2A and 2C (outside anomalies), thereby substantiating the eastern eU anomaly of plate 1. Also, there is no appreciable increase in amplitude in the K40 (1.46-Mev) and T1208 (2.62-Mev, Th232 decay series) photopeaks in figures 2A, 2B, and 2C that would indicate increased concentrations of K and eTh, respectively. Similarly, figure 2D (multielement anomaly) shows appreciable increases in amplitudes especially in eTh comparative to the spectra of figures 2C and 2E. The spectrum of figure 2E shows appreciably lesser K comparative to the K of all the other spectra (figs. 2a - 2d) which substantiates the appreciably lesser K (pl. 1) of the southern part of the study area.

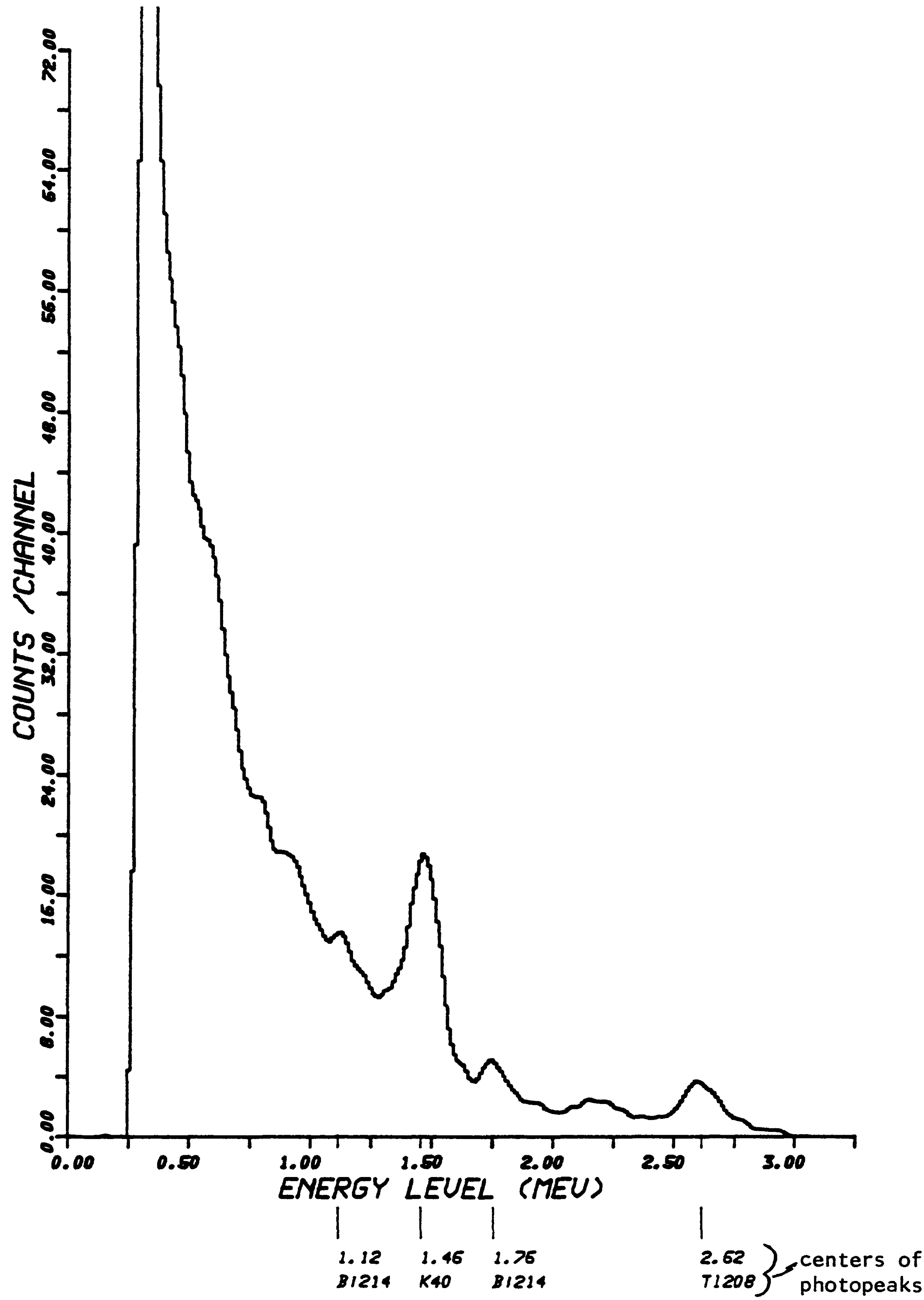

Figure 2A--Summed spectrum for fiducial interval 5020 to 5030, flight line 40686, north of eastern eU anomaly. Location shown on plates 1-3. COUNTS in arbitrary units, MEV = millions of electron volts.

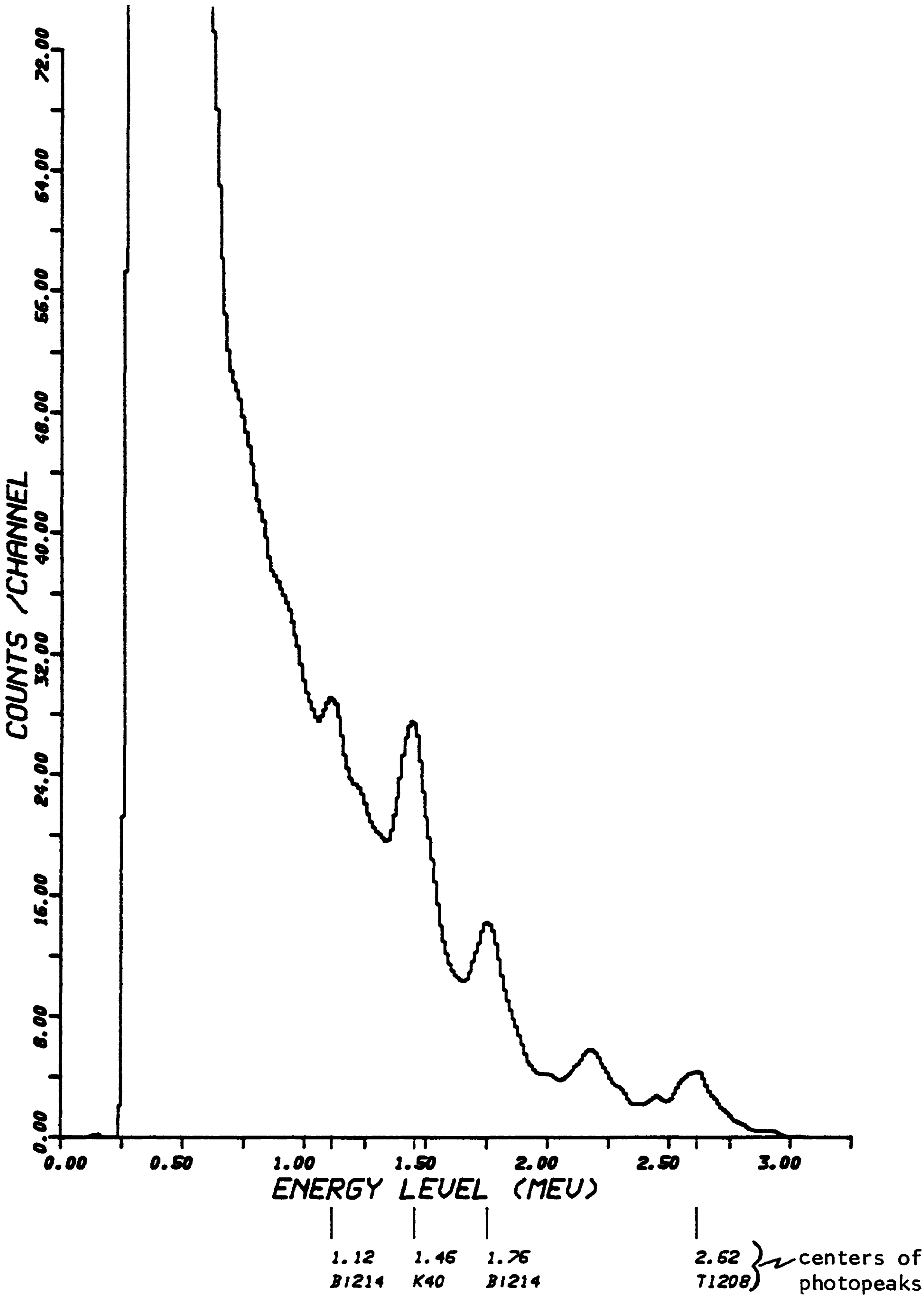

Figure 2B--Summed spectrum for fiducial interval 5112 to 5122, flight line 40686, across eastern eU anomaly. Location shown on plates 1-3. COUNTS in arbitrary units, MEV = millions of electron volts.

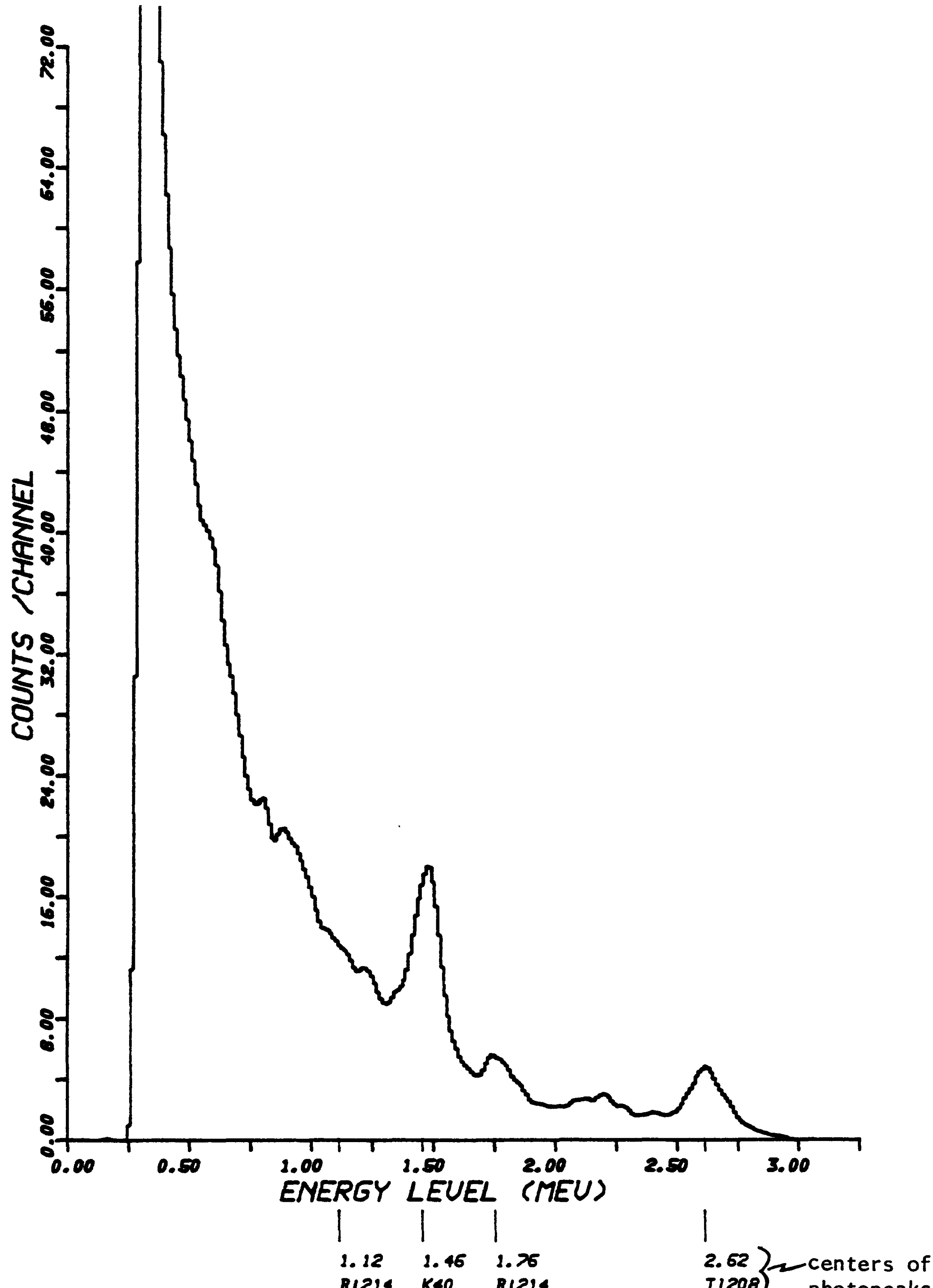

Figure 2C--Summed spectrum for fiducial interval 5250 to 5260, flight line 40686, south of eastern eU anomaly and north of multielement anomaly. Location shown on plates 1-3. COUNTS in arbitraryt units, MEV = millions of electron volts.

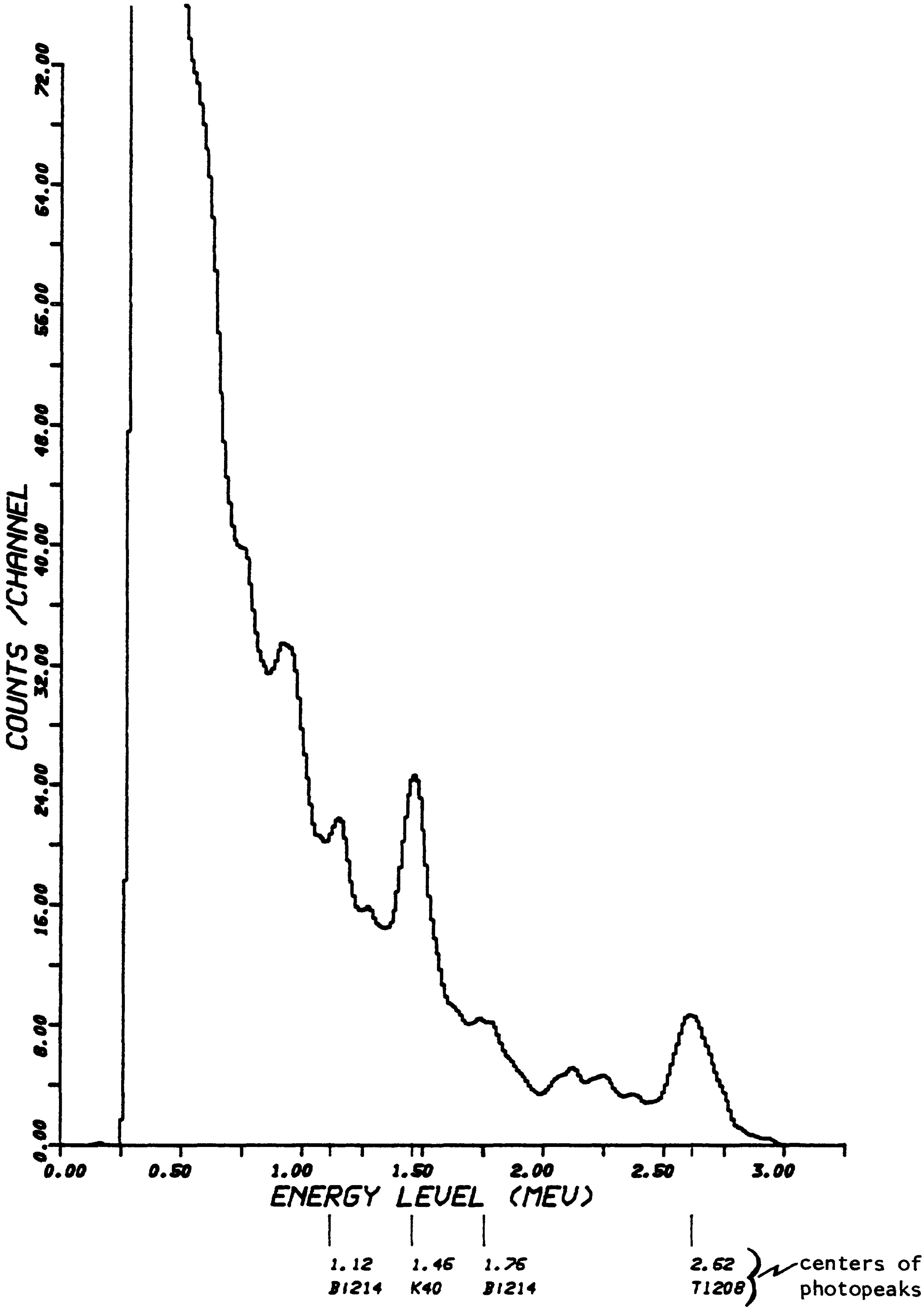

Figure 2D--Summed spectrum for fiducial interval 5344 to 5354, flight line 40686, across multielement anomaly. Location shown on plates 1-3. COUNTS in arbitrary units, MEV = millions of electron volts.

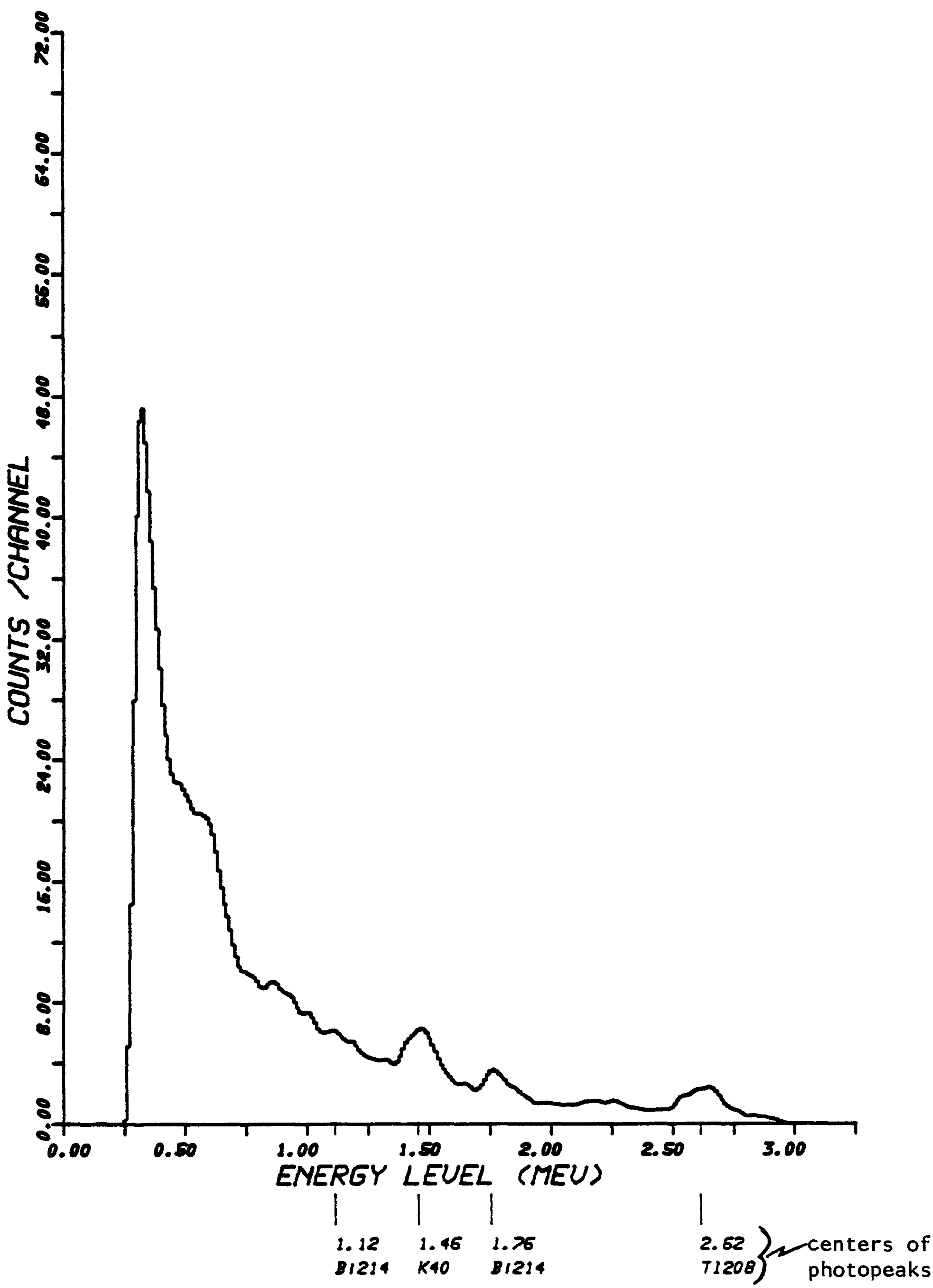

Figure 2E--Summed spectrum for fiducial interval 5490 to 5500, flight line 40686, south of multielement anomaly. Location shown on plates 1-3. COUNTS in arbitrary units, MEV = millions of electron volts.

Flight-line location maps for the cover rock survey were routinely supplied by the aerial contractor for Landsat quadrangles at a scale of 1:250,000. Where available, the contractor used 1:100,000-scale photomosaics (U.S. Geological Survey, 1980b) to plot flight line positions and later transferred these data to the 1:250,000-scale Landsat base maps. Contractor plotting at a scale of 1:100,000 was available for the study area and was replotted on 1:50,000-scale photomosaics (U.S. Geological Survey, 1980a), which were used for control during the ground work.

GEOPHYSICAL ELEMENTS OF THE GROUND STUDY

The radioelement contour maps (pls. 1, 2, and 3) and the 1:50,000-scale flight-line plots were used to determine where the ground work would be done. Helicopter landing sites were chosen within and outside both anomalies and targets of geologic interest. The goals were to locate the anomalies, to determine the source of the anomalies, and to place the anomaly sources in the Phanerozoic sedimentary section of northwestern Saudi Arabia.

A hand-portable gamma-ray spectrometer, calibrated to monitor the same photopeaks as the airborne spectrometer, was operated at landing sites for 5-minute counting intervals. The portable instrument, quantitatively calibrated at Grand Junction, Colorado, (Ward, 1978), included a 0.35-liter sodium iodide (thallium-activated) crystal that was suspended within a tripod about 1/2 m above ground level. The ground measurements effectively measured gamma energy from an area more than 1 m in diameter and as much as 1/2 m in depth. Because of the unequal dimensions of the areas being compared, these localized data were not directly relatable to the airborne data, which per 1-second interval at 120 m above ground level measured gamma energy from a circle more than 240 m in diameter and from a depth of as much as 1/2 m. However, the ground measurements, which provided a measure of K, eU, and eTh concentrations, were invaluable in guiding the ground study.

Rock and soil samples were obtained at selected ground spectrometer sites for laboratory gamma-ray and delayed-neutron analyses. These data were not available when this report was prepared.

GEOLOGICAL ELEMENTS OF THE GROUND STUDY

GEOLOGICAL SETTING

The radiometric anomalies occur in the Upper Ordovician to Lower Devonian Tabuk Formation between the towns of Tabuk and Tayma and within the Tabuk segment of the interior homocline on the Arabian shelf (Powers and others, 1966, pl. 2). Tabuk is located about 15 km west of the northwest corner of the study area (pls. 1, 2, and 3, fig. 1) and Tayma is in the southeast part of the area. The Tabuk Formation within the study area has strikes ranging from westerly to northwesterly and dips varying between $1/2^{\circ}$ and 1° to the north-northeast. A series of northwest-trending faults generally parallel to the Red Sea Rift system was mapped with the regional geology by Bramkamp and others (1963) and Brown and others (1963), but offsets are small and difficult to measure (Bigot, 1970, p. 12).

In the Tabuk-Tayma area the Tabuk Formation is approximately 1050 m thick and consists of sandstone, siltstone, and shale (Powers and others, 1966). It weathers to a surface of generally low relief with individual sandstone units forming cuestas, mesas, and dissected plateaus 50 to 200 m high. The basal contact with the Cambrian and Ordovician Ram and Umm Sahm Sandstones, undivided, is poorly exposed and has been called both conformable (Powers and others, 1966, p. 25) and paraconformable (Bigot and Lafoy, 1970, p. 30). The 600-m-thick Ram and Umm Sahm Sandstones, equivalent in part to the Saq Sandstone, exhibit a characteristic orthogonal jointing system, and weather to a flat surface interrupted by widely spaced bosses and stacks in the upper part.

The Tawil Member of the Tabuk Formation forms a rough irregular escarpment at the top of the Tabuk Formation. East of the study area the Tawil Member is conformably overlain by the Devonian Jauf Formation which is dominantly silty shale interbedded with sandstone near the base and with limestone in the upper part. The Jauf Formation is approximately 200 m thick (Powers and others, 1966, p. 26) east of the study area.

The Cambrian to Devonian sequence exposed in the Tabuk segment of the Arabian shelf records several transgressive and regressive cycles over a nearly horizontal surface. The Tabuk Formation contains graptolite-bearing marine shale, coastal barrier sandstone, fluvial channel sandstone, and overbank mudstone in several deltaic and alluvial plain cycles. Little detailed work has been done in the area, however, and an in-depth discussion of the regional relationships is beyond the scope of this study.

GEOLOGY OF ANOMALIES

The radiometric anomalies occur in the lower part of the Tabuk Formation and are stratigraphically controlled. Both of the eastern and western eU anomalies occur in a graptolitic, micaceous black shale about 350 m above the base of the Tabuk Formation. The multielement anomaly occurs approximately 100 m above the base of the Tabuk Formation and is associated with concentrations of heavy minerals that are beach placer deposits. Both anomalous zones were inspected in a large number of localities and traced by helicopter along most of their exposure in the study area. Sections were measured and sampled at three localities (pls. 1, 2, and 3); one within the eastern eU anomaly (fig. 3), one between the eastern and western eU anomalies (fig. 4), and one within the multielement anomaly (fig. 5). Total gamma radioactivity was measured along the sections (figs. 3, 4, and 5) and at other sites with a portable scintillometer having a 0.174 liter sodium iodide (thallium-activated) detector. The scintillometer occasionally guided positioning of the spectrometer for the K, eU, and eTh measurements.

Both zones of anomalies could extend to the east of the study area, beneath the eolian sands of the Great Nafud. The west boundary of the Great Nafud occurs at the southeast side of the study area, as shown by abrupt lows in all radioelements (pls. 1, 2, and 3) that are due to the sand deposits overlying bedrock of the Tabuk Formation. The multielement zone, following Paleozoic regional strike, extends out of the study area to the west and northwest, and also occurs on the northeast side of the Shield (Matzko and others, 1978) southeast of the Great Nafud.

EASTERN AND WESTERN URANIUM ANOMALIES

The marine shale that hosts the eU anomalies is laterally continuous over short distances and is quite variable in thickness. Where measured, the shale varied from 6 to 12 m thick, but at other localities along strike the thickness was estimated at nearly

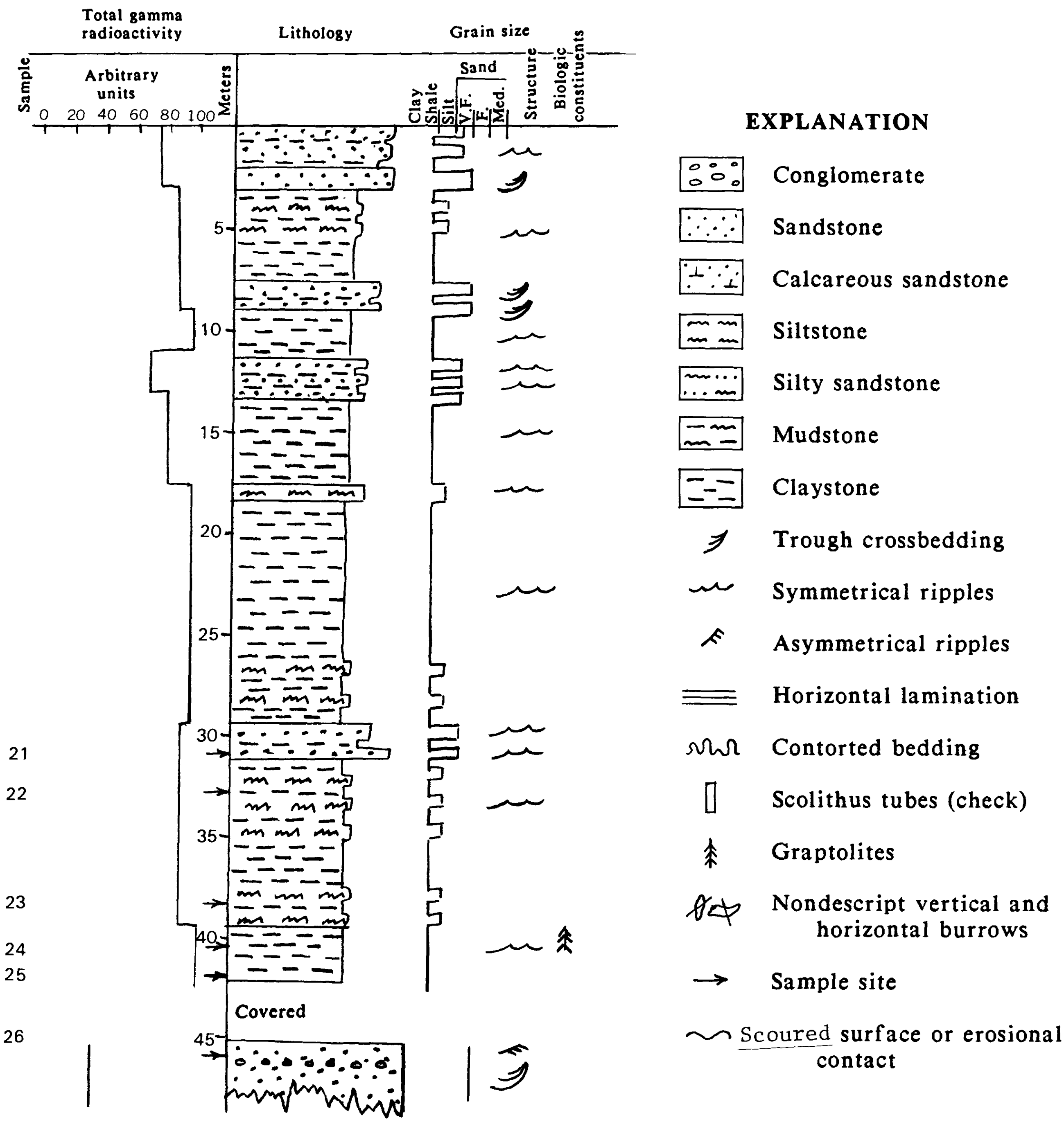

Figure 3--Measured section in eastern eU anomaly area.

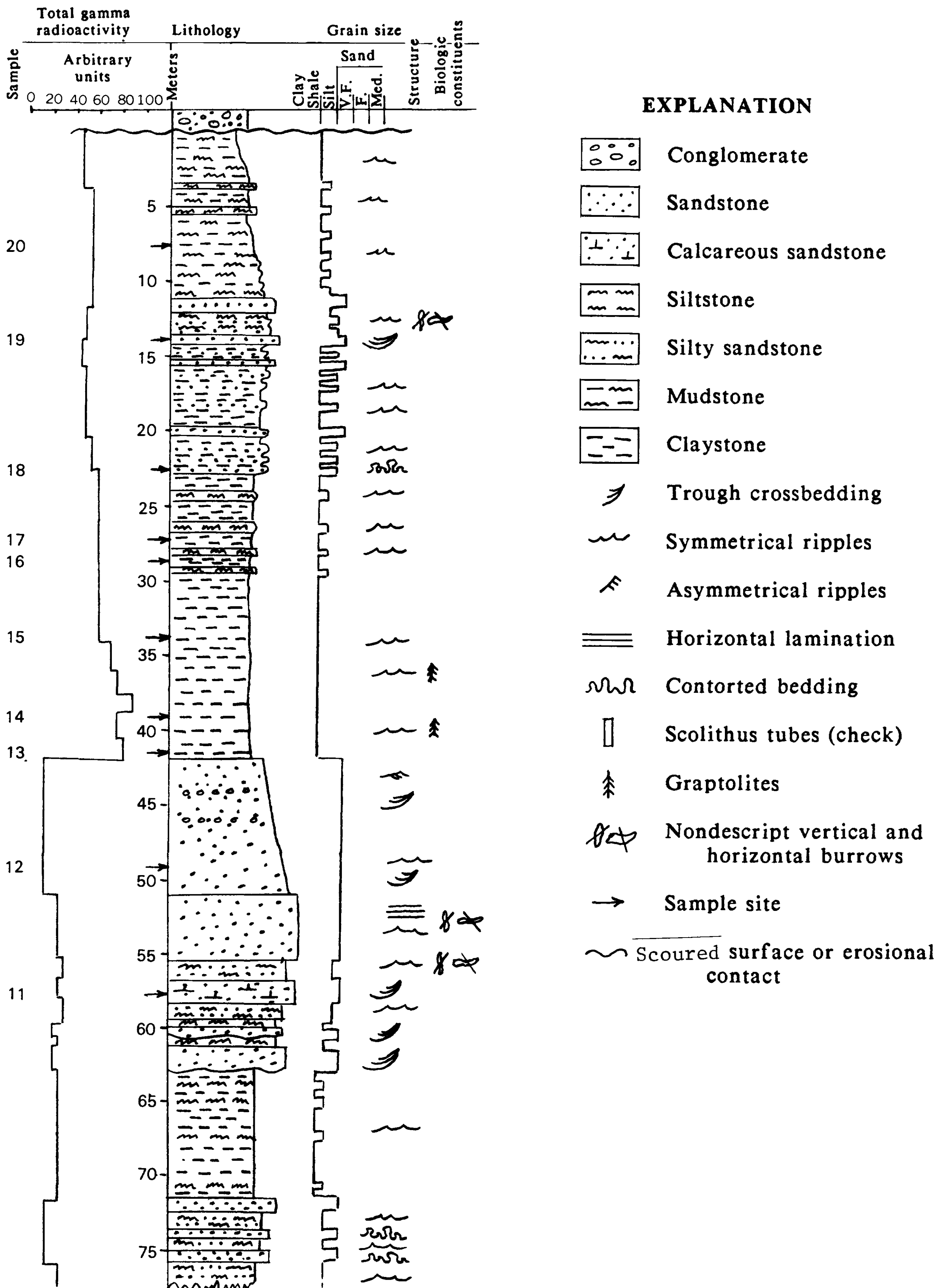

Figure 4--Composite measured section between and along strike of eastern and western eU anomalies.

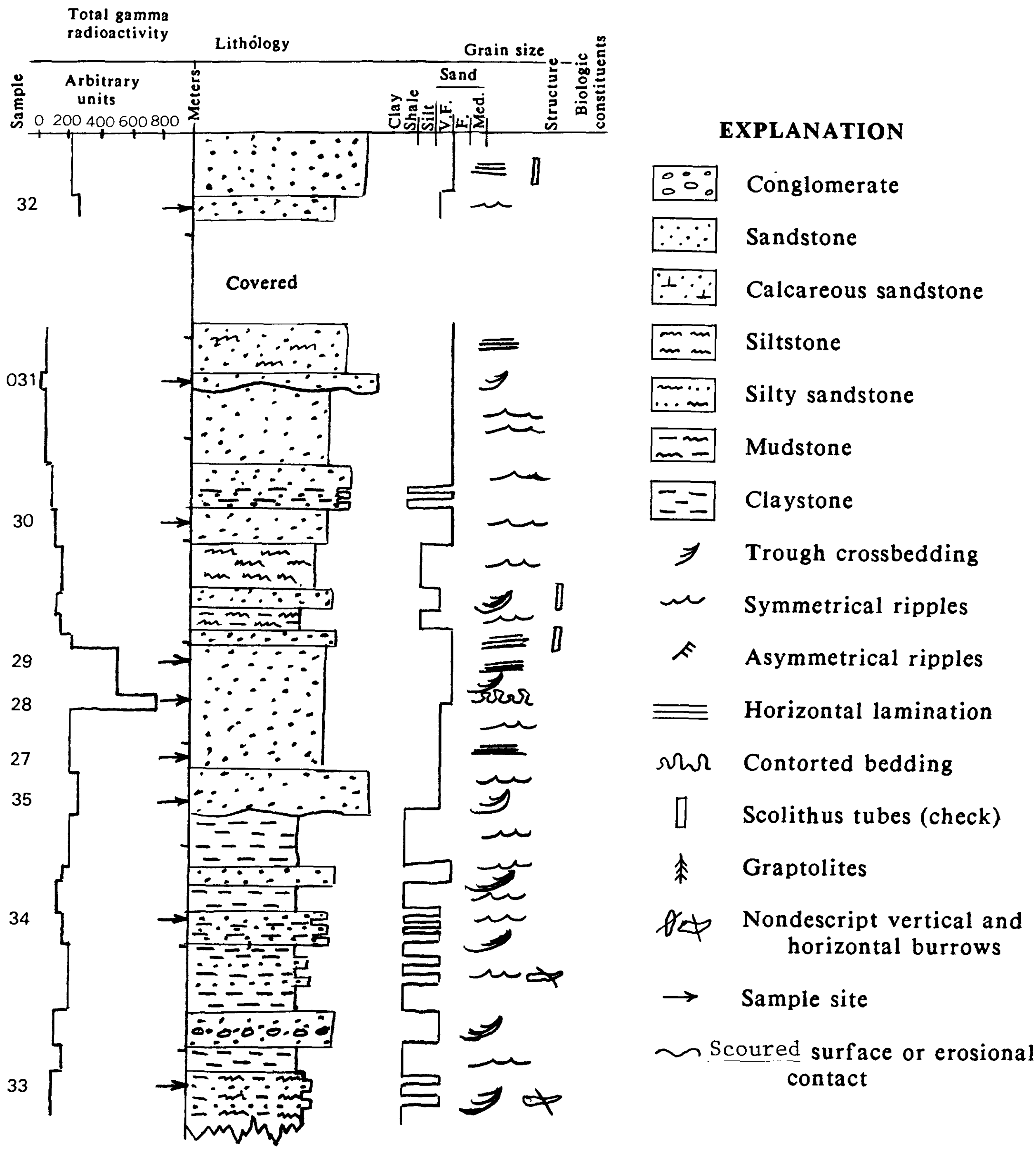

Figure 5--Composite measured section in multielement anomaly area southeast of Tayma.

30 m. Powers and others (1966, p. 111) measured 18 m in the type locality near Tabuk, but the regional continuity is unknown. It weathers to light gray (N8), pinkish gray (5YR8/1), pale red (10R6/2), and dusky red (5YR3/2) and only appears black or grayish brown (5YR3/2) in fresh exposures. It is easily eroded and commonly forms wadis.

Several graptolite-bearing horizons occur in the shale, but the most abundant horizons are near the base. Powers and others (1966) reported both *Didymograptus protobifidus* and *Diplograptus* from the Tabuk Formation, but no identifications have been made on the occurrences in the shale unit. The highest concentrations of uranium are associated with the greatest concentration of well-preserved graptolites at the base of the shale.

The basal contact with the underlying sandstone is either sharp or gradational over a thickness of 15 cm, and is commonly covered. Where the contact appears gradational, the underlying sandstone is fine grained, well sorted, subrounded, and micaceous with organic material on the laminations and symmetrical ripples in the upper part. Where bounded by a sharp contact, this sandstone contains beds of granule conglomerate, is asymmetrically rippled and trough crossbedded, and locally is capped by a well-cemented, ferruginous layer.

The upper part of the shale is completely gradational with a coarsening-upward unit, 30 to 35 m thick, of interbedded shale, siltstone, and very fine to fine-grained sandstone. Most of the siltstone and sandstone beds are 3 to 15 cm thick, rippled, and locally burrowed. The shale beds contain sparse graptolites commonly oxidized and poorly preserved.

On the basis of detailed observations made at a small number of localities and a reconnaissance study along the outcrop of the shale unit, we interpret the sequence to be one of interdistributary bay fill along a delta margin. The source of uranium is unknown at the present. Two origins appearing most likely are: 1) weathering of crystalline rocks on the Shield and transport by distributary streams, and 2) syndepositional volcanic activity to the west. The volcanic source is considered least likely because of the apparent absence of ash or volcanic debris in the sediment. Petrographic, heavy-mineral, and geochemical studies are under way to confirm this observation. The cause of the low eU values between the east and west highs is also unknown.

MULTIELEMENT ANOMALY

The multielement anomaly corresponds to a heavy-mineral-rich horizon approximately 100 m above the base of the Tabuk. The anomaly is strongest where the heavy minerals are concentrated in beach placer deposits, but the anomaly can also be traced through other environments such as back beach and shoreface. Where measured southeast of Tayma (fig. 5), the sandstone body containing the greatest concentration of heavy minerals is 8 m thick and was deposited in both shoreface and foreshore environments. The highest gamma radioactivity values measured by the scintillometer occur in the upper 3 m in the foreshore beds.

The heavy-mineral-bearing sandstone is grayish red (5R4/2) to light brownish gray (5YR6/1), very fine grained, well sorted, subrounded, micaceous, low-angle trough-crossbedded, and rippled in the lower 5 m and pale brown (5YR5/2), fine-grained, well sorted, subrounded, micaceous, parallel laminated, and low-angle trough-crossbedded in the upper 3 m. Between those two lithologies is a 30-cm-thick, light-olive-gray (5Y6/1), massive to contorted, poorly sorted, micaceous sandstone bed with black opaques concentrated on remanent laminations and bedding. Capping the entire assemblage is a 30-cm-thick, fine-grained, well-sorted, parallel-laminated sandstone with abundant Scolithus tubes.

Beneath the heavy-mineral-bearing sandstone body is a transitional zone of interbedded sandstone and silty shale at least 15 m thick. The sandstone beds are typically 30 cm to 1 m thick, grayish red (10R4/2), very fine grained, well sorted, micaceous, burrowed, rippled, and low-angle trough-crossbedded with a scour base. The silty shale is light olive gray (5Y6/1), ripple laminated, and micaceous.

Immediately overlying the mineral-bearing sandstone body is a 4-m-thick sequence of interbedded sandstone, siltstone, and mudstone. The sandstone is very fine grained, silty, ripple laminated, low-angle trough-crossbedded, with Scolithus tubes. Both the siltstone and mudstone are moderate yellowish brown (10YR5/4), micaceous, and ripple laminated. Above the interbedded unit is a 7-m-thick, ripple-laminated sandstone. The entire sandstone is fine grained, well sorted, subrounded, and micaceous. The color varies from pale red (10R6/2) to grayish orange (10YR7/4) with a 1-m-thick, dark-reddish-brown (10R3/4), iron and manganese concretionary zone in the middle. We interpret the sequence above the heavy-mineral-bearing sandstone to be tidal flats overlying back beach deposits.

The ripple-laminated sandstone is scoured by a 30-cm-thick, conglomeratic, fine-grained sandstone that is trough crossbedded in the lower part and asymmetrically rippled at the top. The conglomeratic sandstone is overlain by a 3-m-thick, grayish-orange (10YR7/4), fine-grained, well-sorted, horizontally laminated sandstone. Bedding planes near the base contain current lineations trending N. 15° E. The upper contact and vertical relationships are obscured by a 5-m-thick, laterally extensive, covered interval containing predominantly fine-grained, non-resistent beds where exposed. The covered interval is followed by a 1-m-thick, moderate-reddish-brown (10R4/6), horizontally laminated and rippled, very fine grained sandstone that is conformably overlain by a 3-m-thick, pale-red (5R6/2), fine-grained, well-sorted, horizontally laminated sandstone with abundant Scolithus tubes.

Based on detailed measurement at one location and limited reconnaissance observations, we tentatively conclude that the heavy-mineral-rich sediment was deposited in a wave-dominated delta with considerable tidal influence. This interpretation results primarily from comparison of the measured section with facies models presented in Coleman and Wright (1975), Galloway (1975), and Miall (1979).

The heavy-mineral horizon is in approximately the same stratigraphic position as that described by Matzko and others (1978) in the Al Qassim area, approximately 490 km east-southeast of Tayma, on the northeast side of the Shield (fig. 1). Although we have not yet completed the mineralogic and geochemical studies on the samples from the Tayma area, the thorium and uranium values by delayed neutron activation (table 1) are very similar to those reported by Matzko and others (1978, table 1). Similarities in the source terrain for the two areas as shown on the Geologic Map of the Arabian Peninsula (U.S. Geological Survey and Arabian American Oil Co., 1963) also suggest that the two occurrences are comparable, and perhaps correlative or even coeval.

TABLE 1.--*Uranium (U) and thorium (Th) analyses of total bulk samples from measured sections.*

[Sample-site localities are shown in figures 3, 4, and 5. Values are in parts per million (ppm). Delayed neutron activation analyses by USGS, Denver, Colorado, 1984.]

SAMPLE NO.	Th (ppm)	U (ppm)	SAMPLE NO.	Th (ppm)	U (ppm)
11	4.66	1.31	26	2.1	0.654
12	3.5	1.57	27	27.9	6.37
13	8.4	16.5	28	221	25.5
14	15.7	9.57	29	25.2	5.38
15	18.1	13.9	30	7.48	1.92
16	4.1	2.19	31	9.90	2.11
17	8.90	2.09	32	64.6	26.7
18	6.93	1.33	33	9.29	1.75
19	7.63	1.61	34	11.9	3.26
20	16.9	3.58	35	42.8	6.56
21	14.8	2.63			
22	11.7	4.20			
23	15.4	3.10			
24	13.2	4.17			
25	13.2	5.59			

CONCLUSIONS

The ground investigation of the Tabuk Formation aerial anomalies successfully located the anomalies by utilizing large-scale aerial photography and by operating a hand-portable gamma-ray spectrometer. Re-examination of the radiometric data for specified flight lines prior to the ground work verified that the anomalies existed, and detailed plotting of flight line locations on large-scale photomosaics enabled accurate positioning of helicopter landing sites at localities within and outside the anomalous areas. Operation of a quantitatively calibrated portable spectrometer at landing sites gave values for K, eU, and eTh concentrations that, while not directly comparable to aerial values because of differences in areas measured, documented radioelement distribution at the sites and guided site selections.

Geologic examination and section measurement at follow-up landing sites confirmed that the anomalous zones, both eU and multielement, occur in the Tabuk Formation. The eU zone occurs about 350 m above the base of the Tabuk in a graptolitic, micaceous black shale. The shale is laterally continuous because it hosts both the eastern and western anomalies, but varies in thickness from 6 to nearly 30 m. The reason for the 65-km separation between the two anomalies is not known. Preliminary results from laboratory analysis of field samples indicates that the highest concentrations of uranium occur at the base of the shale where well-preserved graptolites are most abundant.

The multielement anomaly is associated with sandstone that contains heavy mineral concentrations as beach placer, back beach, and shoreface deposits. The anomaly (pls. 1, 2, and 3), which crosses the study area from east to west-northwest and varies in width from 15 to 50 km, suggests an abundance of heavy minerals in the source areas. However, available information from one measured section and other limited reconnaissance suggests that the anomaly pattern reflects the varying near-horizontal dip of a relatively thin geologic unit. The measured section (fig. 5) shows the greatest concentration of heavy minerals to occur in a zone of sandstone 8 m thick. Scintillometer measurements also showed this zone to have the highest total radioactivity.

The source of the radioactive minerals is not known; however, a reasonable hypothesis would be that during the Ordovician, thorium- and uranium-enriched crystalline rock in the Shield was the source of sediment that was deposited and concentrated in the deltas and perhaps in the distributary streams as well. Anomalies similar to the multielement anomaly occur to the northwest of the study area, follow regional strike of Paleozoic rocks, and occur on the northeast side of the Shield (Matzko and others, 1978). Studies are underway to define the petrographic, heavy-mineral, and geochemical characteristics of these anomalous sediments to identify the source terrain and better understand the depositional system.

DATA STORAGE

All field and laboratory data for this report are stored in Data-File USGS-DF-05-09 (Pitkin and Huffman, 1985) in the USGS offices of the authors in Golden, Colorado. No updated information was added to the Mineral Occurrence Documentation System (MODS) data bank, and no new files were established.

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