A FIELD EXAMINATION OF RADIOACTIVE OCCURRENCES IN THE CADDY LAKE AREA OF MANITOBA

by

E. B. MCGOWAN

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The author dedicates this work to his wife, Linda Wilcox.

ABSTRACT

The Caddy Lake area is located just north of the Trans Canada Highway near the Manitoba-Ontario border. The area surveyed is the eastern and northern contact of a granodiorite batholith intruded into Precambrian volcanic and sedimentary rocks.

The survey consisted of 50 miles of traversing using a gamma-ray spectrometer and 88 radioactive anomalies of various magnitudes were defined. These anomalies are concentrated along contacts between the various rock units in the area. On the basis of the measured spectra and hand specimen examination, none of the anomalies appear to have economic significance.

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CHAPTER 1

INTRODUCTION

Fissionable material (material capable of releasing energy through nuclear chain reaction) can be found in Nature or can be produced from materials found in Nature. These source materials are naturally radioactive, but only three such materials represent a significant source of radiation and they are: Uranium, Thorium, and Potassium.

Radioactive materials can be detected using a variety of methods, but from a practical geophysical approach, interest must lie with the remote techniques; in this case, Gamma Spectrometry (the detection of gamma-ray photons emitted by radioactive materials).

Gamma-ray photons exhibit certain characteristics that make their detection a rather special geophysical technique. As a rule of thumb, geophysical methods are deep-penetrating (on the order of several 100's to 1000's of meters), but due to the properties of rocks and minerals, are generally incapable of discriminating between possible sources of an anomaly. On the other hand, gamma spectrometry offers the capability of distinguishing between possible sources of a given radioactive anomaly, but suffers badly regarding depth of exploration which is typically at most on the order of a couple of meters or less. This is a result of gamma-ray photon absorption on passing through rock and overburden materials. Radiation attributable to deep sources emits from source materials that have been transported to the near surface environment

where detection is possible. This is brought about by the mobility of radioactive minerals accompanied by some geologic process; such as faulting which may provide an open pathway to the surface.

The ability to differentiate becomes very important in dealing with uranium, thorium, and potassium as only one (uranium) is of current economic importance. Before the introduction of gamma spectrometry, the existing tools of the trade yielded the total number of detectable radioactive emissions per unit time. These detectable emissions involved Beta particle and in some cases Alpha particle emissions as well as Gamma-ray photons. Because of an inability to separate and count emissions of varying energies, it was possible only to outline an anomalous area whereupon follow-up was required to determine if indeed there existed an economic potential. The ability of gamma spectrometry to distinguish the source of radioactive emissions allows a direct appraisal of economic potential and the categorization of an area into one of high priority or one of low priority. This entails a much higher degree of confidence; and thus yields more favourable results with a more efficient use of time and reduced expenditures.

The area to be discussed takes in approximately 25 square kilometers of the Whiteshell Provincial Park located some 160 kilometers east of the city of Winnipeg on Highway Number One (Trans Canada Highway). In particular, the area of interest is immediately west of Caddy Lake (Figures 1 and 2).

As a result of past reports regarding radioactive mineral occurrences in the area, the Whiteshell Uranium Syndicate carried out Scintillometer surveys and Sampling programs in 1950. Overburden was removed

in specific areas and a number of deep trenches were cut. A report by G. D. Springer (1952) for the Manitoba Mines Branch suggested that the bulk of analyses fall in a range of 0.01 and 0.05 percent U_3O_8, which the G.S.C. considered encouraging for prospecting. Some of the analyses are in the ore grade range between 0.1 and 1.0 percent U_3O_8.

"Much work remains to be done to determine whether ore of commercial grade and volume is present." This quote from Springer (1952) outlines the basic incentive and motivation behind the survey described in the following pages.

The Field survey involved a large area of ground, which was subjected to a more detailed investigation using a more sophisticated detection device than had previously been used in the area. To be specific, the instrument is a McPhar TV-1A Gamma Spectrometer (Appendix A of this report is the Operations Manual for the instrument as published by McPhar Geophysics).

Past geologic reports covering the area and the Ground Spectrometry carried out as the basic field work were combined to give a better understanding of the radioactive occurrences in the Caddy Lake area of Eastern Manitoba.

Figure 1. Location map of the work area in the Whiteshell Provincial Park near the Manitoba-Ontario border.

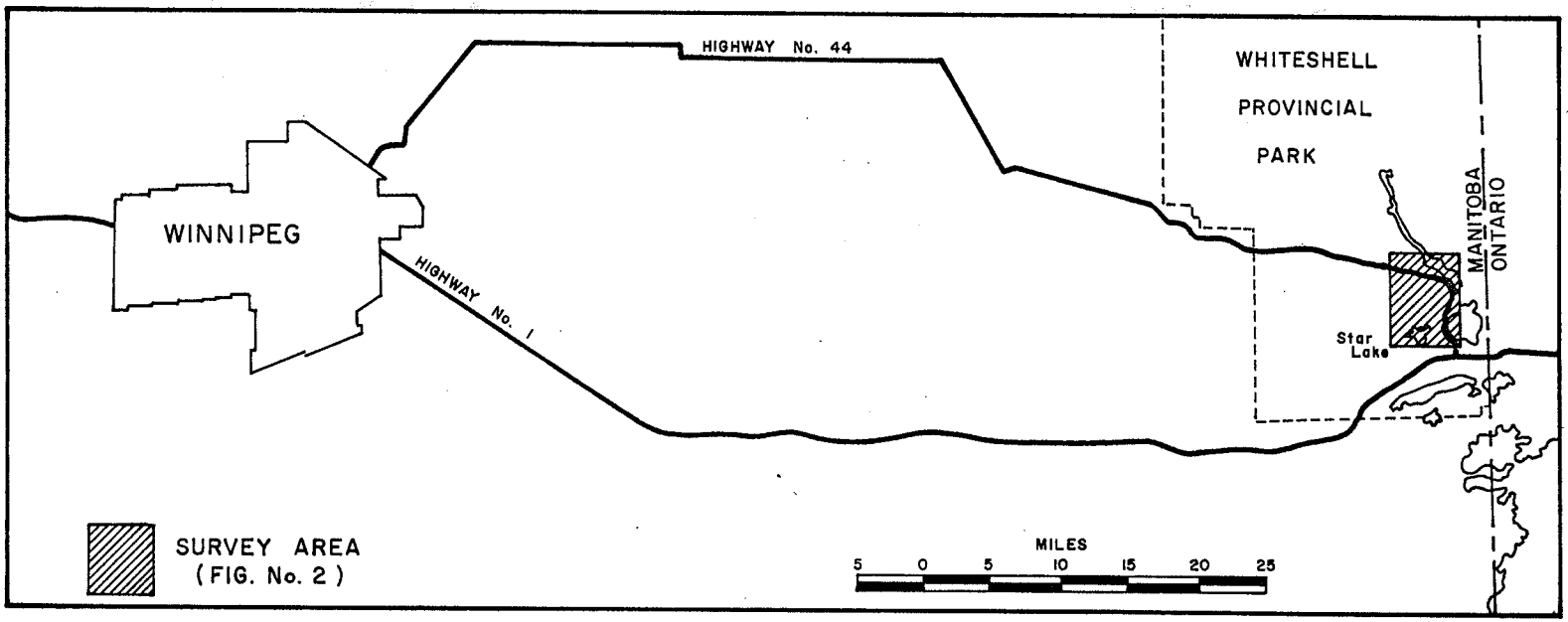
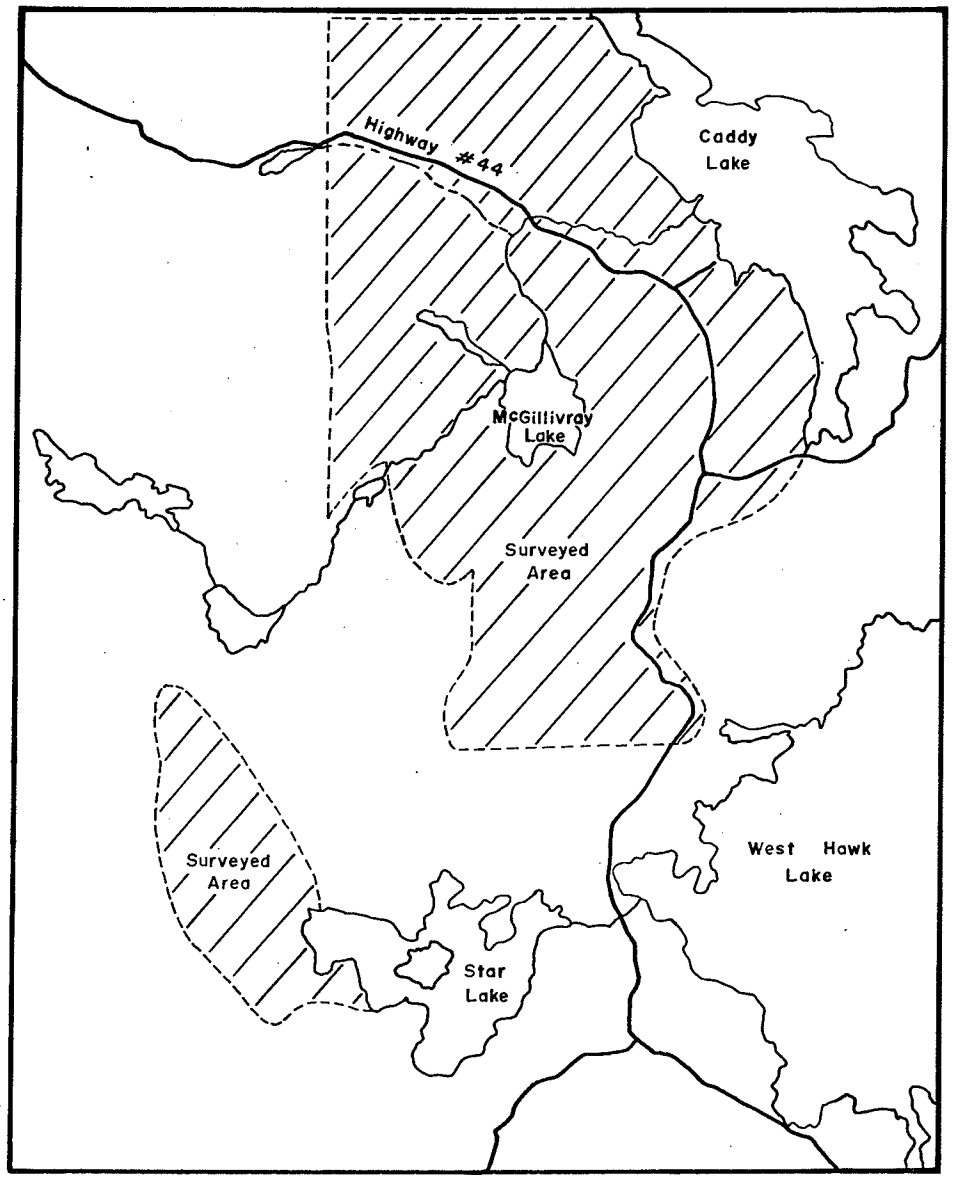

HIGHWAY No. 44
WHITESHELL
PROVINCIAL
PARK
MANITOBA
ONTARIO
WINNIPEG
HIGHWAY No. 1
Star
Lake
SURVEY AREA
(FIG. No. 2)
MILES
5 0 5 10 15 20 25
N

Figure 2. Survey Areas. The map indicates the approximate area of the Gamma Spectrometry survey. This amounted to about 25 square kilometers.



Scale: 1 inch equals 1.609 kilometers (1 mile)

CHAPTER II

PURPOSE

Objectives

1) conduct a reconnaissance style survey employing a gamma spectrometer in an area known to host radioactive occurrences caused in part by uranium mineralization.
2) develop a systematic procedure of field operations, such that rapid ground coverage can be accomplished while maintaining the full capabilities of the equipment. In the process; attempting to outline what would be considered unreliable field procedures to avoid the collection of irrelevant data.
3) provide an appraisal of economic potential for uranium mineralization in the area and recommend further work, if indicated by the reconnaissance survey.

Approach

At the outset of the project traverse lines were set up in much the same manner as a Conventional Grid system. An attempt was made with pace and compass to follow predetermined parallel traverse lines selected from airphotos. In the first area, immediately west of Caddy Lake (Unit #6, Figure 3), this worked quite well as there is a very large portion of outcrop making anything other than a systematic search of the area impractical.

The instrument was operated making use of its greatest sensitivity (lowest scale factor and lowest energy threshold permitting the detection of any gamma flux encountered), while carried at hip level and switched on at all times. In this manner, after preadjusting the instrument to nullify the normal background gamma flux emitted by the host rock, the operator was able to detect any significant increases in radioactivity and would then follow-up with a more detailed local investigation of the occurrence. In addition, readings were taken in areas of nonanomalous radioactivity to determine background values. In all cases the type of rock was noted and in specific radioactive occurrences the approximate size of the surface exposure was estimated, as well as a description of the apparent source rock or material. Wherever possible, samples were collected for analysis.

Throughout the survey, the treatment of individual sample sites, whether background or radioactive occurence, did not change. However, the frequency of the background reading was increased. This modification required that specific background values of the host rock be collected at regular intervals throughout individual traverses. In addition, background values were recorded whenever an anomalous occurrence was encountered. These readings were taken in the local vicinity of the anomaly at positions that would ensure no contribution to the background value by the anomaly.

An attempt to cover a second area using a regular grid similar to that used in the first area described above was not practical. This second area involves a different rock type and is characteristically covered with a great expanse of overburden material combined with dense

foliage. Under these conditions, it is evident that the practice of following predetermined parallel traverse lines will lead to an inadequate coverage of ground. There is very little outcrop and certainly some of the outcrops that should have been investigated would not have been under the previous practices.

It became apparent that the best means with which to cover the second area involved selecting traverses in such a manner as to intersect as many outcrops as possible. These outcrops were located on airphotos and then traverses were established, which would bring about their eventual investigation. This procedure was practiced throughout the remaining survey and resulted in reliable coverage of the ground.

In areas investigated for radioactivity recommendations regarding recording of atmospheric background suggest that samples be taken in locales where the underlying materials be road beds, swamps, lakes, and areas of deep overburden. These surficial features are judged to be composed of materials that will not contribute significant amounts of radiation to measurable atmospheric levels.

Highways and surrounding secondary roads in the Caddy Lake area afforded convenient locations for background samples. However, it became evident very early in the program that despite convenience such sites are totally unreliable as a basis for background values. These road beds as in all of the Canadian Shield are composed of a mixture of various rock types available in the immediate area. The readings taken on the road beds reflected the radiation characteristic of the underlying rock fragments rather than the atmospheric background levels, and appeared very noisy with relatively high amplitude variations.

To verify the cause, a short traverse along the road bed was undertaken. This simple test confirmed the unreliability of road beds as background sites. The variations previously noted occur over short distances along the roads and have amplitudes comparable to those noted between background values representative of specific rock units in the area.

At this point, it was felt that the use of swamps and areas of deep overburden would similarly not provide suitable atmospheric background sites. There would be too many associated unknowns to attempt to explain any variations that may be noted. In the final analysis, the only useful information concerning the interpretations of a radioactive occurrence are atmospheric and host rock backgrounds. Swamps and areas of overburden typically yield values which fall between atmospheric and host rock background values and have no direct influence on any given occurrence found in this program.

Pure uncontaminated atmospheric background radiation is isolated most effectively when the monitoring is done over water. In this case, the few feet of water under the dock at the University of Manitoba Field School Facility located at Star Lake (Figure 2) provided sufficient shielding for the intended purpose.

To determine the atmospheric background, a series of values were recorded in the morning before the day's work and in the evening after the day's work. In all cases, the instrument was allowed to become temperature stable, (i.e. if brought out in the morning, the instrument was given sufficient time to reduce to ambient temperature) and was then completely calibrated as described in the Operations Manual (Appendix A)

before any recording of background values. Temperatures in the mornings and evenings from day to day at this time of the year (September - October) were comparable. Each series of readings comprised ten individual samples taken over several minutes.

In addition to the establishment of atmospheric backgrounds, an attempt was made to measure the effect of drift in the calibration. Mechanical vibration and temperature changes will cause the instrument calibration to drift. This alters the value of specific energy thresholds within the instrument used to discriminate gamma photons. The resultant will be an incorrect estimation of equivalent uranium content derivable from the recorded values. There was no attempt to define the magnitude of the error, simply to establish whether or not it is significant. The results show that any errors derived from drift due to mechanical vibration or temperature change are insignificant; relative to amplitudes associated with radioactive occurrences and general host rock backgrounds. The drift caused by normal survey procedures is a small percent (5 percent) of the atmospheric values and with the exception of Keewatin volcanic rocks, the host rock backgrounds and the numerous anomalous occurrences of radioactivity are orders of magnitude above drift levels.

The approach to be taken with the data that has been collected in the previously described manner will be to initially look at all the recorded background values (atmospheric and host rocks), and determine specific values to attach to each group. This specific value will be the Mean of all background values associated with one source. Accompanying the Mean (Table 7 and 8; Chapter 5) will be a plot of the distribution of background values (Figures 7, 8, 9, 10, and 11), so that there may

be an appraisal of any differences indicated by the Means.

Any distinct differences will be explained using samples collected and the available geological information.

Due to the compositional nature of the rocks in the area, no occurrence will be called Anomalous unless it exhibits a level of radiation at least four times that of the host rock. This rule will also keep the numbers to a manageable level. Each of the six distinct rock units explored will be discussed in turn; relative to those anomalous occurrences within that unit. An effort to explain the anomalies will be made and any anomalies that appear to be caused by uranium mineralization will be compared and discussed as part of Chapter VI (Summary and Conclusions).

CHAPTER III

GENERAL GEOLOGY

Geology Within the Thesis Area

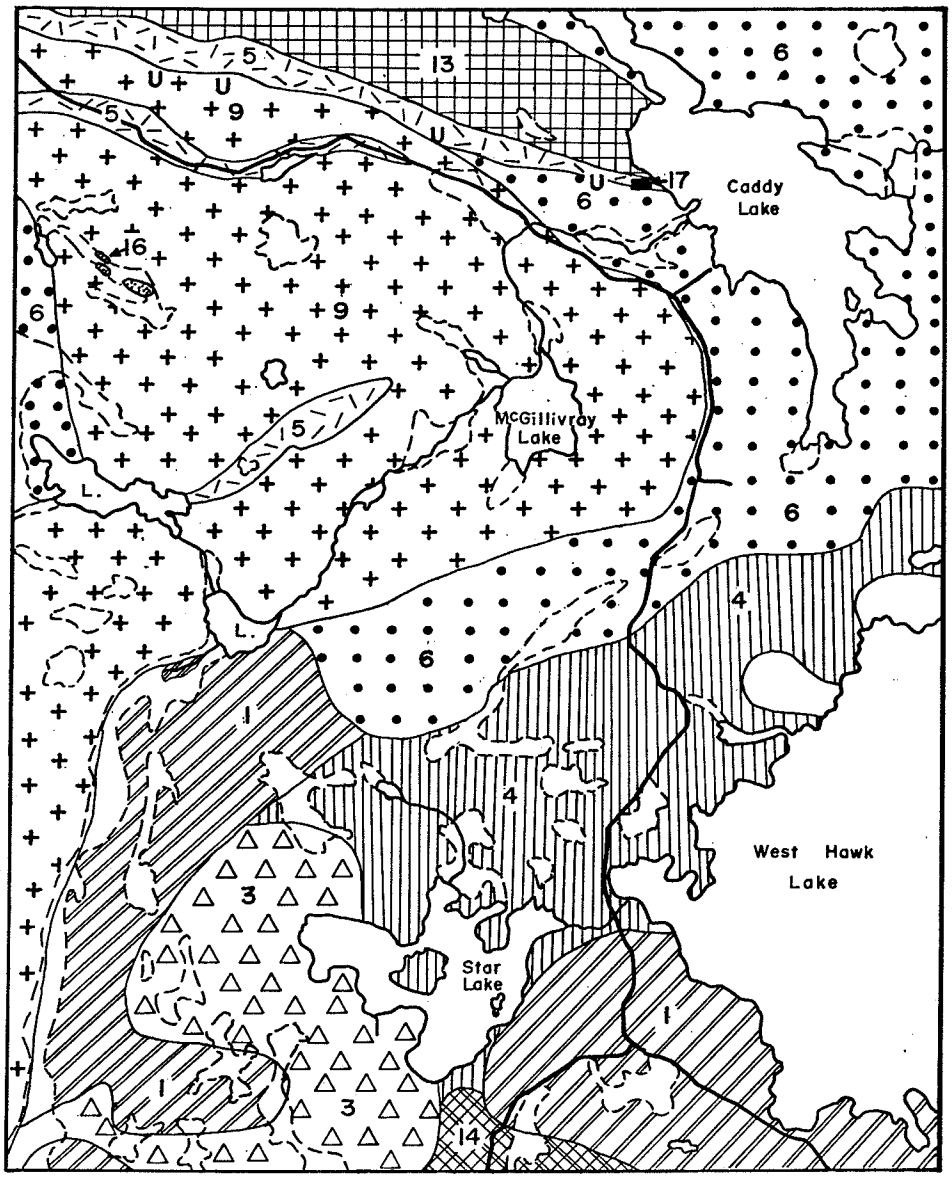
The context of the following geology is taken primarily from Springer (1952) and deals specifically with the area contained within the survey boundaries. It is to be understood that those features mentioned, in most cases, are readily discernable in the field and have been observed by the author during acquisition of data discussed.

The rocks in the area are Precambrian with the oldest being Keewatin (within the period of 1900 - 2700 million years) volcanic and sedimentary rocks. These particular rocks have been intruded by stocks and batholiths of dominantly granodioritic composition (sodic plagioclase predominates over alkalic feldspars), which contain remnants of the older sedimentary and volcanic rocks. Table 1 (Springer, 1952) outlines the classification of rocks within the area.

It is apparent from the geologic map in figure 3 that the area covered by the Spectrometer survey is essentially the Eastern and Northern edge of a granodiorite batholith intruded into volcanic and sedimentary rocks. It was along the northern edge of the batholith (parallel to Highway #44) that uranium occurrences have been previously investigated and sampled in the 1950's.

This area (Figure 3) is composed of six distinct rock types, excluding minor dykes and sills. The following is a brief description of

Figure 3. Geology of Survey Area. The legend accompanying Figure 3 is a reduced version of the entire legend associated with the geology map accompanying the report by Springer, G. D., 1952. Figure 3 represents the portion of that map which is of concern in the thesis study area. For this reason, various rock units not contained within the thesis area have been deleted from the legend, leaving units numbered as high as 17 while only 10 of those units are retained for the purpose of discussion in this thesis.



LEGEND

- 17 — DIABASE AND LAMPROPHYRE DYKES
- 16 — PYROXENITE
- 14 — GRANODIORITE , GABBRO
- 13 — PINK GRANODIORITE AND BIOTITE GRANITE
- 9 — PORPHYRITIC GRANODIORITE
- 6 — GREY GNEISSIC GRANODIORITE AND QUARTZ DIORITE

INTRUSIVE CONTACT

- 1 / 5 — METAVOLCANICS AND METASEDIMENTS
- 4 — GREYWACKE , QUARTZITE , ARGILLITE , SCHIST
- 3 — AGGLOMERATE
- ANDESITE , BASALT , AGGOMERATE
- U — KNOWN URANIUM DEPOSITS

sp→

these individual types. The terminology is that of Springer (1952) and is indicated on the accompanying Geologic map from that report (Figure 3).

(A) Keewatin Volcanic Rocks

The region to the west and south of Star Lake (Figure 3) is underlain by an agglomerate with fragments composed of andesite with some quartzite and vein quartz also present (Unit #3, Figure 3). This unit grades into a typical andesite and basalt agglomerate to the west (Unit #1, Figure 3) with a matrix believed to be of volcanic origin.

(B) Keewatin Sedimentary Rocks

These rocks lie north of Star Lake (Unit #4, Figure 3) and are fine-grained and highly quartzose in composition. Most are dark greywacke with a high percentage of feldspar. These rocks have been metamorphosed to garnetiferous schists and a few argillites. Much of the original fine-grained material has been recrystallized into muscovite, biotite, and rarely amphibole.

Only a small portion of this unit was covered in the subsequent Spectrometer Survey and that area was characteristically covered with overburden and dense foliage, thus making observations virtually impossible.

These Keewatin rocks are portions of a group that make up the north limb of an anticlinal structure that existed prior to intrusions of the granitic rock masses (Springer, 1952).

(C) Metavolcanic and Metasedimentary Rocks

These rocks within the Thesis area (Unit #5, Figure 3) are associated with the contact between a porphyritic granodiorite and a grey gneissic granodiorite and quartz diorite (Unit #6, Figure 3), which are

believed to be old sedimentary and volcanic rocks that have been subjected to a process of Granitization. These metavolcanic and metasedimentary rocks lie in the northernmost portion of the area outlined in Figure 3. The northernmost band is very continuous and can be traced from Caddy Lake west for approximately 22 kilometers (14 miles). It is in this band of rocks that the radioactive occurrences have been investigated. These bands form a major discontinuity along which younger granite and a large amount of pegmatite have intruded. It is the pegmatite that is the carrier of radioactive minerals and numerous radioactive occurrences have been investigated in the northernmost band.

The reported occurrences of the radioactivity in the pegmatite from the work in the 1950's within these metasediments and metavolcanics provided the primary incentive for the investigation described in this Thesis.

(D) Grey Gneissic Granodiorite and Quartz Diorite

These rocks (Unit #6, Figure 3) are situated on the western shore of Caddy Lake and extend westward to Highway #44 and off the south end of Caddy Lake westward beyond McGillivary Lake.

Considered to be one of the oldest granitic rocks in the area, this unit has a definite lineation created by an alignment of ferromagnesian minerals. The average composition is 45% oligoclase, 30% quartz, 10% microcline, 10% biotite, and the remainder accessory minerals.

The granodiorite is believed to have been formed by granitization of old sedimentary and volcanic rocks.

(E) Porphyritic Granodiorite

This rock (Unit #9, figure 3) occupies the Western and Central

portions of the Thesis area. The outstanding feature of the granodiorite is the presence of large phenocrysts of microcline. The groundmass is mostly oligoclase, quartz, and biotite. The rock is typically pink in colour and in places a distinct gneissosity is developed. Pegmatite dykes, many of which contain considerable magnetite, are abundant, but anomalous radioactivity is low and scattered.

(F) Pink Granodiorite and Biotite Granite

These rocks (Unit #13, Figure 3) lie to the immediate north of the band of metavolcanics and metasediments containg the radioactive occurrences (Unit #5, Figure 3). The rocks are pink and fine to medium-grained granodiorite grading to a biotite granite where the percentage of plagioclase drops to a low value. Oligoclase or andesine, microcline, quartz, and biotite are the essential constituents. This rock occurs as dykes in many of the other granitic rocks.

These six rock types: A, B, C, D, E, and F are the individual units found in the area under investigation. Excluding the presence of these rocks either as inclusions or dykes, a breakdown of the relative amounts of each unit found within the Thesis area would be as is shown in Table 1.

TABLE 1

ROCK TYPE (See Figure 3)	PERCENTAGE
Keewatin Volcanic (Units 1 and 3)	15%
Keewatin Sedimentary (Unit 4)	6%
Metavolcanic and Metasediment (Unit 5)	4%
Grey Gneissic Granodiorite and Quartz Diorite (Unit 6)	25%
Porphyritic Granodiorite (Unit 9)	35%
Pink Granodiorite and Biotite Granite (Unit 13).	15%

* Amount of coverage of individual rock types throughout the Thesis area.

As the reported radioactivity is associated primarily with pegmatitic dykes, it is important to consider them as possible carriers elsewhere in the other rock units within this area. There is a particular abundance of pegmatite dykes contained in the Pink Porphyritic Granodiorite. These dykes are composed of feldspars, quartz, and mica. Dykes of a more complex composition containing lithium and beryllium occur to the south of the porphyritic granodiorite, but outside the Thesis area. The radioactive pegmatites along Highway #44 in the Norther region also occur in close proximity to the granodiorite.

There are diabase and lamprophyre dykes scattered throughout the area, but none of these examined by Springer (1952) showed radioactivity.

As mentioned in the introduction, the uranium mineralization so far found does not indicate the possibility of economic potential. The best description of these occurrences is the following:

"Uranium-bearing minerals occur in persistent pegmatite zones, which lie near porphyritic granodiorite and gneissic granodiorite. The pegmatites are associated with altered Keewatin volcanics and sediments. Most of the work done so far as been concentrated on the eastern half of the north band (Section C of this Chapter) where the best indications of radioactivity have been found.

"The pegmatites are composed of microcline, albite or oligoclase, biotite, hornblende, apatite, and garnet. Pyrite and pyrrhotite are present in places. Magnetite is a prominent constituent in faintly radioactive pegmatites, which intrude the porphyritic granodiorite.

"Higher Geiger Counter readings are obtained over most of the places of high concentration of biotite, but good readings are found also

where little biotite is present." (Springer, 1952)

In 1949, some X-ray work done at the University of Manitoba on samples from one claim in the area proved the existence of Uraninite.

The report by G. D. Springer (1952) was selected as the primary reference on which to base the portion of Chapter III as it was the most complete. There is a portion of the Thesis area contained within a report by Davies (1953), but the use of any of that information would have only confused the description. In 1974 - 1975, there was another Geological Mapping program carried out over an area containing the Thesis area. So far, only a preliminary copy of the field mapping by C. F. Lamb has been made available. This preliminary work generally agrees with Springer's work, but is in much greater detail and its adoption would only make the description of the geology in the area of interest unnecessarily lengthy and complicated; however, wherever the detailed information correlates with variations in the gamma spectrometer work, it will be mentioned.

Minerals and Environments

Natural uranium, as it occurs in minerals, is made up of 99.274 percent of U - 238, 0.72 percent of U - 235, and 0.006 percent of U - 234. The remaining decay products are negligible by weight.

Natural thorium occurring in minerals is composed of only one isotope, Th - 232.

Natural potassium is composed of three isotopes of atomic weights 38, 41, and 40 in decreasing order of abundance. Its activity is due solely to the K - 40 isotope estimated to be present to the extent of

0.012 percent. Because of the percent contents of active isotopes, it becomes apparent that the gamma photons from potassium are of very much less intensity and number per unit weight than from an equal weight of uranium or thorium.

Potassium

Natural potassium is contained chiefly in the potash feldspar, which is one of the main constituents of granites, and to a much lesser extent in any muscovite or biotite present. Table 2, G. S. C. (1952) gives estimated percentages of potassium oxide, K_2O.

TABLE 2: Estimated percentages of potassium oxide in some common rock types.

ROCK TYPE	% K_2O
average granite	4.11% in feldspar and mica
potash feldspar of granite	11.7%
potash feldspar of pegmatites	up to 14%

Field studies have shown that the radioactivity of the average granite carrying 4 percent K_2O may be twice the minimum background and other studies have shown this to be equivalent to between 0.001 and 0.002 percent U_3O_8 equivalent activity. Thus, it may be seen that activities of two or three times the lowest background count do not indicate a deposit of possible economic importance, which would require the material to show at least as much as 0.05 percent U_3O_8 equivalent

activity. Anything less than this cannot, on most instances, be considered promising.

Because of the distinct gamma energy displaced by potassium, (Figure 4) the Gamma Detector can be set to eliminate photons of this energy, but commonly a Reconnaissance survey records all radiation. Therefore, the behaviour of potassium permits an evaluation of the relative fraction of the measured radiation level attributable to potassium. Regarding the importance of a given anomaly, this constitutes valuable information.

Thorium

Uranium is by far the most important source material and thorium, the second source material, is only potentially important as a practical source of fissionable material. This potential is a result of the ability to derive a second fissionable isotope of uranium, U - 233, from thorium in a manner similar to the derivation of plutonium from U - 238 by neutron bombardment.

Since both uranium and thorium minerals are frequently found together, it is useful to be acquainted with the thorium minerals even though the primary concern is the search for uranium.

The estimated thorium content ofthe earth's crust is about ten grams per ton of rock which is three to four times that of uranium. Despite this, thorium does not have the chemical properties that permit ease of movement and wide dispersion through the surface rocks of the earth after original deposition, and, as a result, important high-grade deposits are even scarcer than those of uranium.

The number of thorium minerals is small compared to the number of uranium minerals largely because thorium does not readily form, so-called, secondary minerals produced through the process of weathering. Traces of thorium have been found in more than 100 minerals, including most of those containing uranium, but only a few contain in excess of 1 percent thorium.

The thorium minerals occur principally in granites and pegmatites, or in placer deposits derived from these rocks. The occurrence of thorium in vein deposits is rare and negligible in amount. Thorite and thorianite are the only thorium-bearing minerals in which thorium is the major constituent. For example; monazite, xenotime, gadolinite, and allanite contain from 1 to 15 percent thorium.

Monazite is the only mineral of thorium considered to be an ore mineral. This mineral is not directly mined, but rather a by-product of ilmenite, tin, or gold placer mining with thorium, in turn, a by-product of the extraction of rare earths from the monazite.

Monazite [(Ce, La, Th) PO_4] is a phosphate of the rare earths, principally cerium, containing 1 to 15 percent thorium oxide, ThO_2, and from 0.10 to 1 percent U_3O_8. It occurs as pink to brown prismatic crystals or angular fragments in granite, gneiss, and pegmatites. Monazite is sparsely scattered throughout these primary host rocks, and therefore does not occur (in these rocks) in high enough grades to be considered commercial. By processes of weathering, the subsequent breakdown of these primary host rocks permits the transport and eventual concentration of monazite into grades of commercial value. These typically occur with sands and gravels deposited in rivers and on beaches. It is one of the

few radioactive minerals that can be relatively easily recognized in the field.

Although not a commercial source of thorium or uranium, thorianite (ThO_2) and thorite ($ThSiO_4$) are the two minerals in which thorium is the principal constituent. Thorianite may contain up to 90 percent ThO_2 and can be replaced by U_3O_8 up to 33 percent, but when it contains 15 or more percent U_3O_8, it is usually called uranothorianite.

Allanite is probably the most commonly occurring radioactive minerals in Canada. It is mainly a silicate of the rare earths; aluminum, calcium, and iron and the ThO_2 content may reach as much as 3.5 percent, but the U_3O_8 content is rarely more than 0.2 percent. The mineral is common in granitic rocks, especially in any pegmatitic phases and has been known to form very large crystals, usually of long tabular form in pegmatites. When little altered, allanite is black with a glassy lustre, but it alters easily, typically around the margin of the crystals to a brownish material.

Titanite (or sphene) is not ordinarily classed as a radioactive mineral, but samples from some Canadian deposits show appreciable activity due to content of thorium.

These are the more common minerals of thorium of which monazite is the only ore mineral. Descriptions of these minerals and the rest of the thorium minerals can be found in Nininger (1955) and Dake et al (1947).

Uranium

It is customary to divide uranium minerals into two groups; the primary minerals formed in pegmatites, veins, etc., and the secondary

minerals that have been formed as a result of alternation of the primary minerals by near-surface weathering processes. Most of the uranium minerals in pegmatites and placers are refractory; that is, the uranium is present in combinations which are extremely difficult to break down chemically in order to recover the uranium. Recovery is difficult and expensive and the minerals are usually scattered sparsely throughout the deposit. These do not form ore deposits.

Primary Uranium Ore Minerals

These minerals are most commonly found in veins or pegmatites, although extensive, flat-lying deposits of pitchblende have been found in sedimentary rocks. They are generally black or dark brown, noticeably heavy, often showing a shiny or pitch-like luster, and when exposed to weathering at or near the surface, they may be altered to form bright-coloured secondary minerals. There are only three known primary uranium ore minerals and the most important of these, uraninite and pitchblende, are really varieties of the same mineral.

Uraninite (combined UO_2 and UO_3; 50 to 85 percent U_3O_8) is a natural occurring uranium oxide with cubic or octahedral crystal form. It has a specific gravity of 8 to 10.5 (iron is 7.85) and a hardness of 5 to 6, about the same as steel. The mineral has a steel-gray colour containing a greenish cast sometimes and its streak is black to brown-black. Its most widespread occurrence is in pegmatites; however, it is also an important constituent in nearly all important primary deposits, occurring closely associated with its massive variety, pitchblende. Occurrences are numerous in the Canadian Precambrian Shelf, with a typical

occurrence at Bancroft, Ontario.

Pitchblende (combined UO_2 and UO_3; 50 to 80 percent U_3O_8) has no apparent crystal form. It occurs most abundantly in the rich primary vein deposits and is the chief constituent of nearly all high-grade uranium ores, providing the largest part of all uranium produced throughout the world. Pitchblende is lighter than uraninite, having a specific gravity of 6 to 9, but its other properties, except crystal form, are the same. It occurs as irregular masses often with a round layered botryoidal structure.

The principal occurrences of pitchblende are in primary (hydrothermal) vein deposits, usually of the medium temperature and pressure type in igneous and metamorphic rocks and in flat-lying bedded deposits in sedimentary rocks. Pitchblende is commonly associated with one or more of the primary ore minerals of iron, copper, cobalt, lead, silver, and bismuth; and presence of these minerals in a location is one indication of favourable conditions for pitchblende mineralization. It is usually accompanied by bright-coloured secondary uranium minerals due to weathering or other alternation. The commonly associated gangue minerals are quartz and other silica minerals, carbonates, flourite, barite, and hydrocarbons, with quartz, calcite, and dolomite usually the most abundant. In vein deposits, pitchblende is most likely to be deposited in existing open spaces in rock formations, rather than by replacement of the rock itself, and the richest deposits occur where large open fractures were available for filling by the mineralizing solutions.

Deposition of pitchblende is usually accompanied by strong alteration of the wall rock along the veins. The presence of hematite extending

from the pitchblende a few inches to a few feet into the wall rock is the most characteristic feature. The formation of hematite has occurred in all of the major pitchblende vein deposits and other alteration features often associated with pitchblende deposition are formation of kaolin, chlorite, sericite, and silica minerals in the wall rock.

In sedimentary deposits, such as sandstones and conglomerates, the pitchblende is deposited between the around the grains of the rock and in available rock openings. It has also been found in smaller amounts, disseminated in volcanic rocks.

Davidite (rare earth - iron - titanium oxide; 7 to 10 percent U_3O_8) was not considered a significant uranium ore mineral until 1951 when a substantial uranium deposit was discovered in South Australia. It has the same hardness as pitchblende, but is somewhat lighter in weight. It occurs most commonly in angular, irregular masses, sometimes with crystal outlines, but never in round botryoidal shapes like pitchblende. Upon weathering, a thin yellow-green coating of carnotite or tyuyanumite may form on its surface and provides an easy means of tentative identification in the field.

Davidite is deposited in hydrothermal veins, presumably at a higher temperature and pressure than pitchblende, and these veins are found in more basic rocks like gabbro and anorthosite. It is almost never found as the pure mineral, but in complex inter-growths with ilmenite.

Secondary Uranium Ore Minerals

The secondary minerals, instead of the dull black, gray, and brown colours of the primary minerals, present an array of bright yellows,

oranges, and greens with some having the property of fluorescence under ultraviolet light. They occur as earthy or powdery materials or as fine, delicate, needle-like or plate, flake-like crystals.

The secondary minerals have two major modes of occurrence:

1. In the weathered or oxidized zones of primary deposits, where they are formed by decomposition of the primary minerals in place.
2. As irregular, flat-lying deposits in sedimentary rocks, primarily sandstones, but also conglomerates, shales, and limestones, formed by precipitation from solutions that may have carried the uranium some distance away from the original source.

The secondary minerals in the weathered zones of primary deposits have contributed significant uranium production in some places where weathering has been deep, but such occurrences are usually considered important as indicators of the presence of primary mineralization.

The flat-lying deposits in sedimentary rocks represent the most important occurrence of the secondary minerals, specifically the carnotite deposits of the Colorado Plateau of Coloradu, Utah, Arizona, and New Mexico.

Only a few secondary ore minerals occur together in groups of several of both the ore and non-ore minerals, but in carnotite deposits the one mineral is predominant. The dominant colours of the secondary uranium ore minerals are yellow and green, orange being confined primarily to the non-ore minerals.

Carnotite ($K_2O\ 2UO_3\ V_2OS\ nH_2O$; 50 to 55% U_3O_8) is the most important of the secondary uranium ore minerals, having provided some 90

percent [Nininger (1955)] of the uranium production from secondary deposits. It is lemon-yellow with earthy luster, yellow streak, specific gravity of about four, and a hardness of two to three (easily scratched with the fingernail). It occurs most commonly in soft powdery aggregates of fine crystalline material or thin films or strains, on rocks of other minerals.

Carnotite is found in sandstones in flat-lying, irregular, partially bedded ore bodies with most deposits ranging in grade from 0.10 percent to 0.50 percent U_3O_8.

The most common other secondary uranium mineral found associated with carnotite is tyuyamunite and the most common non-uranium minerals found associated with it are the vanadium minerals.

Tyuyamunite is closely related to carnotite, having a chemical formula that is the same except that calcium substitutes for the potassium (Ca --- K_2). Its physical properties are the same as carnotite except for a slightly greener colour and a very weak yellow-green fluorescence not found in carnotite. It is more abundant where there is an appreciable amount of calcium, usually in the form of calcite or limestone.

Torbernite and meta-torbernite ($CuO\ 2UO_3\ P_2Os\ nH_2O$; 60% U_3O_8) are hydrous copper uranium phosphates, the only difference between the two being the number of water molecules. Their physical properties are identical and they have a bright emerald colour, pearly luster, hardness of two to two point five, and specific gravity of about 3.5. They occur in flat, square, translucent crystals, which usually fluoresce with a faint green colour.

Autunite and meta-autunite ($CaO\ 2UO_3\ P_2Os\ nH_2O$; 60% U_3O_8) have

the same composition as torbernite except calcium substitutes for copper. The colour is predominantly lemon or sulpher-yellow, although occasionally apple-green, and a brilliant yellow to greenish-yellow fluorescence in ultraviolet light is observed.

The greatest significance of autunite lies in the fact that it is the most common uranium mineral in the oxidized secondary deposits in igneous rocks of Arid regions, both those related to primary mineralization and those of unknown origin.

The other two uranium secondary minerals considered to be ore minerals are: uranophane, a hydrated calcium uranium silicate; and schroeckingerite, a complex hydrated sulfate, carbonate, and fluoride of calcium, sodium, and uranium [Nininger (1955)]. They are very minor, and schroeckingerite barely qualifies as an ore mineral.

More complete descriptions of the uranium minerals can be found in Dake et al (1947) and Nininger (1955). For a description of Canadian minerals, consider G. S. C. (1952), and Lattanzi et al (1974).

Uranium Deposits in Granitic Rocks

It has been noted in the review by Nishimani et al (197-) that there are certain geological features, which characterize low-grade uranium deposits in granitic rocks. The following list is 12 recognized criteria as quoted directly from that review:

Summary of Generally Favourable Criteria

1. Areas of provinces where the earth's crust has undergone extensive reworking, appear to be a highly favourable

environment for both vein and igneous uranium deposits. Remobilization and concentraion of uranium can be triggered by the processes of Granitization (Metamorphism) and Anatexis (melting of pre-existing rocks).

2. Uranium deposits in pegmatites and aplites (granitic aplite, consisting essentially of quartz, potassium, feldspar, and acid plagioclas) occur in areas where numerous other varieties of uranium deposits have been found. Good areas for future prospecting are those in which pre-existing deposits have been recognized or where there is known bedrock enrichment in uranium.
3. Quartz monzonite, granite, alaskite granite (granite containing only a few part of dark minerals) and syenite (dominance of alkalic feldspars; orthoclase, microlite or perthite) are favourable host rocks for deposits of the "porphyry" or pegmatite-alaskite-gneiss uranium association. The ore-bearing pegmatites are characteristically in or at the margins of these host granitic rock types and may inject the surrounding country rock.
4. Economic concentrations of uranium in pegmatites and alaskites are almost exclusively developed in and around granites, which lie in upper-amphibolite and amphibolite grade (moderate to high pressure and temperature) metamorphic facies. Thus, deeply eroded mobile belts are more favourable for this type of uranium mineralization than uneroded or slightly eroded.

5. Ore localization generally clusters around structural traps, where the late-stage, uranium-rich differentiates may have migrated during the advanced stages of cooling of the magma. The crests of major anticlines or other folds are particularly favourable zones.
6. Metasomatized pegmatites are favoured over unaltered varieties. evidence at Bancroft and Rossing suggests that uranium mineralization was contemporaneous with metasomatism or metasomatic growth in the pegmatites.
7. If local faults of shear zones exist in the vicinity of uranium-mineralized pegmatites and aplites, these areas may be favourable areas to search for lenses or pods of uranium minerals, which represent the residue of ore solutions that have migrated to zones of dilatancy.
8. The uranium deposits in pegmatites at Bancroft and Rossing are accompanied by nearby calcite-fluorite-apatite and quartz-fluorite veins. Vein uranium deposits of this type in the vicinity of granite bodies may indicate favorability for uranium mineralization in the granites and pegmatites.
9. In general, hydrothermally altered zones around uranium-rich granites are the most favourable areas to seek uranium mineralization.
10. In addition to the radioactive elements, uranium deposits in igneous rocks are associated with variable, but small amounts of molybdenum and fluorine. (Fluorine is believed to form mobile complexes of uranium under magmatic and hydrothermal conditions).

Thus, fluorine-rich granites, pegmatites and veins may constitute higher-probability host rocks than fluorine-poor varieties. Much additional geochemical work is needed before any positive statements can be made on the characteristic elemental associations of uranium deposits in granites.

11. Archean terranes are unfavourable areas to search for uranium deposits in igneous rocks. Aside from conglomerate deposits, which may range in age up to 2.7 billion years, there are no known uranium deposits of Archean Age.
12. Abundant secondary enrichment of pegmatites and alaskites in uranium minerals may be due to the effects of unusual climatic conditions.

Referring to the study area (Figure 2), the only member of the above list indicating unfavourable conditions for uranium mineralization is number eleven. Number eleven is viewed as negative under the assumption that any uranium present is a remnant of primary mineralization formed at the same time as the host rock. Given the half-life of uranium, most primary uranium mineralization of Archean age will have decayed to a stable end product leaving amounts to minute to form economic deposits. The other implication to consider is simply because of Archean age, the much longer period of time over which other processes have available in which to act toward the removal of uranium from the host rock.

CHAPTER IV

GAMMA-RAY SPECTROMETRY

Radiation

All radioelements--including uranium, thorium, and potassium--as they decay, give off one or more of three types of radiation: Alpha, Beta, and Gamma.

(1) Alpha Particle (α)

This particle is a helium nucleus having two protons and two neutrons. An example of alpha decay is the isotope U - 238 in natural occurring uranium. The decay is written:

$$_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}\alpha^{4}$$

The loss of alpha particle characteristically reduces the atomic number of the parent isotope (U - 238) by two units and the atomic weight by four units.

A characteristic of alpha emission that serves to identify the emitter is discreet alpha particle energies. Each alpha emitter will have a set of these energies that distinguish it from other emitters. For example, consider U - 238; when observing energies of alpha particles it is found that during 23 percent of the disintegrations 4.13 Mev. particles are emitted. No other energies are observed, and this set is characteristic of U - 238.

(2) Beta Particle (β)

A beta particle is an electron, but rather than coming from the electrons surrounding the nucleus, it comes from within the nucleus. The overall effect is to convert a neutron into a proton, which increases the atomic number by one unit. As an example, consider Cs - 137:

$$_{55}Cs^{137} \longrightarrow {}_{56}Ba^{137m} + \beta^-$$

The small "m" following the atomic weight of the barium (Ba - 137m) indicates that this daughter Ba - 137m atom is formed in a metastable state.

In contrast to alpha particles, beta particles are emitted over a continuous energy distribution. Each beta emitted has a maximum beta energy characterizing it. All the emitted particles can range in energies from this maximum down to zero.

(3) Gamma-ray Photon (γ)

This is a quantum of electromagnetic radiation like visible light, X-rays, radiowaves, etc. In most instances, the daughter nucleus resulting from the alpha or beta particle emission is left in an excited state, i.e., it possesses energy above its normal state. This excess energy is released as gamma-ray photons immediately following the alpha or beta decay. This gamma emission produces no change in the atomic number or atomic weight.

An example of gamma-ray photon emission is:

$$_{55}Cs^{137} \longrightarrow {}_{56}Ba^{137m} + \beta^-$$

THEN

$$_{56}Ba^{137m} \longrightarrow {}_{56}Ba^{137} + \gamma$$

After the parent Cs - 137 atom beta decays, the daughter Ba - 137m atom is a metastable state of Ba - 137. The Ba - 137m decays to the stable state of Ba - 137 by emitting a gamma photon with a characteristic energy.

Gamma-ray photons can be affected in a variety of ways by interactions with atoms. Sometimes a gamma-ray photon may be completely absorbed by an atom, which then ejects an electron. This phenomenon, called the photoelectric effect, is important in the detection and measurement of these photons. Another process called Pair Production occurs when a gamma photon is absorbed by the coulombic fields around and in the atom, causing a positron (e^+) and an electron (e^-) to be produced. This is a direct production of mass from energy and has the greatest probability of occurring with gamma-ray photons of energies greater than or equal to 1.02 Mev. One other important process is Compton Scattering. A gamma photon collides with an atom, causing ejection of an electron, but only a portion of the photon energy is transferred to the electron. This also occurs with free electons in a medium. The photon in this case transfers only a portion of its energy to the electron and afterwards continues on an altered path with reduced energy. This is the single most significant means of attenuation of gamma photons in rocks, air, and water, and is, therefore, important in spectrometic assaying.

Range, Penetration, and Rate of Decay

TABLE 3: A Comparison of the Range and Penetration of Alpha, Beta, and Gamma Radiation

RADIATION	RANGE IN AIR	PENETRATION OF METAL
ALPHA PARTICLE	0.09 meters	Stopped by aluminum foil
BETA PARTICLE	3.00 meters or more	0.65 cm. of aluminum
GAMMA PHOTON	800 meters	90% stopped by 21 cms. of aluminum

In addition to Table 3, something should be said for penetration to be expected in the field during a survey. When considering gamma radiation from uranium or thorium ores only, it takes about 30 cm. of rock or 75 cm. of water to shield the radiation. These degrees of shielding are, however, dependent on the density and atomic structure of the shielding material and the intensity (energy) of radiation below it. There have been discoveries over 120 cm. of snow; however, if the snow has a high moisture content, the same shielding effects as overburden may be observed, meaning that 60 to 90 cm. will shield radiation. Little is said about alpha and beta radiation, since Table 3 reflects their very limited range and penetration without further mention.

Each radioelement has characteristic types of emissions as well as energy magnitudes of those emissions and the higher the energy the greater the penetration and range. Table 3 shows values that tend toward effects displayed by higher energy radiations.

The faster an element decays, the more radiation it produces for

a given weight in a given time and the more energy its radiation has. Each individual radioelement decays in a way and at a rate that is characteristic, producing radiation of a certain energy or range of energies that is also characteristic for the element. These trends are displayed by the relative half-lives of elements shown in Table 4.

TABLE 4: Some Element Half-lives

ELEMENT	HALF-LIFE
K - 40	14.1 billion years
U - 238	4.5 billion years
TH - 232	13.9 billion years
U - 235	707.0 million years

Radioactive Equilibrium and Decay Series

One particular question involved with the detection and estimation of amounts of a radioactive element in a mineral is whether or not the element is in equilibrium. This equilibrium problem applies to elements that have a decay series; such as, shown in Table 5, which is the series for uranium.

A decay series is a set of elements (nuclides) composed of a parent element, a number of daughter products, and a stable end product. As an example, consider uranium given in Table 5. The parent element is U - 238. As can be seen, during the decay of U - 238 to its stable end product Pb - 206 (lead) at the bottom of the table, it goes through 14 different types of decay involving 13 different elements. These elements are the daughter products of U - 238 and these elements and their related decay sequence make up the decay series of U - 238 to Pb - 206. Each of

TABLE 5. The Uranium Decay Series

Name of Nuclide	Atomic Number	Nuclide	Half-Life	Energy of Gamma Rays Emitted by Nuclide (MeV)[1]
Uranium Group				
Uranium 1	92	U 238	4.5×10^9 y.	0.047 (?)
Uranium X1	90	Th 234	24.1 d.	0.093
Uranium X2	91	Pa 234	1.18 m.	0.394, 0.782, 0.806 0.820
Uranium II	92	U 234	2.6×10^6 y.	0.060, 0.093, 0.118
Ionium	90	Th 230	8.0×10^4 y.	0.068, 0.140, 0.190, 0.228, 0.240
Radium Group				
Radium	88	Ra 226	1,600 y.	0.188
Radon	86	Rn 222	3.825 d.	-----
Radium A[2]	84	Po 218	3.05 m.	-----
Radium B	82	Pb 214	26.8 m.	0.053, 0.242, 0.259, 0.295, 0.351
Radium C	83	Bi 214	17.9 m.	0.063, 0.191, 0.426, 0.498, 0.609, 0.766, 0.933, 1.120, 1.238, 1.379, 1.520, 1.761, 1.820, 2.200, 2.420
Radium C'	84	Po 214	164×10^{-6} s.	-----
Radium D	82	Pb 210	22 6.	0.007, 0.023, 0.032, 0.037, 0.043, 0.047, 0.065
Radium E	83	Bi 210	5.0 d.	-----
Radium F	84	Po 210	138 d.	0.084, 0.790
Radium G	82	Pb 206	Stable	-----

TABLE 6. The Thorium Decay Series

Name of Nuclide	Atomic Number	Nuclide	Half-Life	Energy of Gamma Rays Emitted by Nuclide (MeV)
Thorium	90	Th 232	1.4×10^{10} y.	0.055, 0.075
Mesothorium 1	88	Ra 228	6.7 y.	0.030
Mesothorium 2	89	Ac 228	6.13 h.	0.060, 0.135, 0.184, 0.038, 0.462, 0.533, 0.590, 0.913, 0.969
Radiothorium	90	Th 228	1.9 y.	0.087
Thorium X	88	Ra 224	3.64 d.	0.241
Thoron	86	Rn 220	54.5 s.	-----
Thorium A	84	Po 216	0.16 s.	-----
Thorium B	82	Pb 212	10.6 h.	0.115, 0.176,0.238 0.249, 0.299
Thorium C	83	Bi 212	60.5 m.	0.040, 0.144, 0.164, 0.288, 0.328, 0.432, 0.452, 0.472, 0.720, 0.830, 1.030, 0.340, 1.610, 1.810, 2.200
Thorium C'	84	Po 212	0.3×10^{-4} s.	-----
Thorium C"	81	Tl 208	3.1 m.	0.277, 0.510, 0.582 0.859, 2.620
Thorium D	82	Pb 208	Stable.	-----

the 13 elements can be considered a parent of the one immediately following it in Table 5. Table 6 is the decay series of thorium. As can be seen, it has a different number of different daughter products than uranium.

In radioactivity, the condition of equilibrium requires that the rate of decay of the parent nuclide is exactly matched by the rate of decay of every intermediate daughter nuclide or it may be said that the rate of decay is constant, but the quantities of each member element are not. For example, for two elements "A" and "B" to be in equilibrium, if "A" decays to O and does so at a decay rate twice that of "B", then equilibrium is maintained if there is twice as much "B" as "A".

When equilibrium has been established, the relative concentrations of intermediate daughters remain virtually constant.

U - 238, U - 235, and Th - 232 represent the only three natural occurring decay series. Potassium is not included because its radioactive member, K - 40, decays immediately in one step by emission of gamma-ray photons to a stable end product. U - 235 is the only natural occurring fissionable material and is associated with the source material U - 238 in natural uranium in the proportion of one part in 140 parts.

Each daughter product of a series emits radiation from each of its atoms that decays. For this reason, the total radiation from any given quantity of uranium or thorium old enough to have attained a state of Equilibrium (dependent on the half lives of daughter product) is several times greater than that of an equal quantity of pure uranium or thorium of a relatively young age, essentially free from its daughter products. Thus, most of the radiation from uranium or thorium minerals in equilibrium

actually comes from the daughter products even though the amount of disintegration products by weight relative to the uranium or thorium present is so minute as to be negligible. This has a bearing on prospecting, and is especially important in the estimation of uranium and thorium content by radiometric methods.

The problem of equilibrium arises because the radiation measured does not come primarily from the uranium or thorium, but from its daughter elements. When a radioactive mineral or element is in equilibrium, a certain relative proportion of each daughter element is present no matter what the grade of the mineral or ore, and there is a theoretical level of radiation for a given amount of uranium or thorium. Under these conditions the amount of radioactivity measured is directly dependent upon the amount of uranium or thorium present and provides a reliable indication of the grade.

The minerals encountered in nature are often not in equilibrium. This is because the minerals may have been attacked by chemical weathering, which will separate out some daughter products and insufficient time has elapsed to restore equilibrium through the process of radiation, decay, and formation of new elements to replace the ones removed. The most important cause of a lack of equilibrium is that of primary minerals becoming dissolved and then removed by solutions, such as ground water, and later redeposited as secondary minerals. Uranium primary minerals are particularly susceptible to this, and, as a result, are not in equilibrium and have many secondary deposits, also not in equilibrium. On the other hand, the thorium series is nearly always found in an equilibrium state, since the decay products are not very mobile under weathering

conditions and since the half-lives of the daughter elements are quite short.

There are some advantages to be gained by a non-equilibrium state. Since only about 25 cm. of rock or 60 cm. of water will effectively mask all gamma radiation from natural sources beneath, there is little chance of finding any surface evidence of buried deposits. There is, however, a chance that there may be surface radioactivity related to uranium concentrations at depth if some of the soluble daughter products have been taken into solution and moved to surface. For example, since bismuth - 214 (Bi - 214) occur after radon - 222 (Rn - 222, a gas) in the uranium decay series (Table 5), we could expect to find a Bi - 214 anomaly if there has been migration of Rn - 222. In fact, instruments do make use of this fact, and other instruments are designed to "sniff out" radon gas.

The equilibrium or non-equilibrium of a deposit will ultimately depend on what mineral it is, what environment the mineral is in, and what processes are known to be acting on that environment. It is a distinction that may be made in the field with some degree of certainty.

Uranium, Thorium, and Potassium Gamma Radiation

U - 238 and Th - 232 in pure form (no daughter products) decay by emission of alpha particles. All beta, gamma, and most alpha radiation from old uranium and thorium minerals comes from the highly active daughter products. Potassium decays to a stable product in one step by emission of gamma rays.

Gamma radiation, because of its longer range and penetration characteristics, compared to α and β radiation, is the most effective

Figure 4. Gamma photon spectrum of potassium.

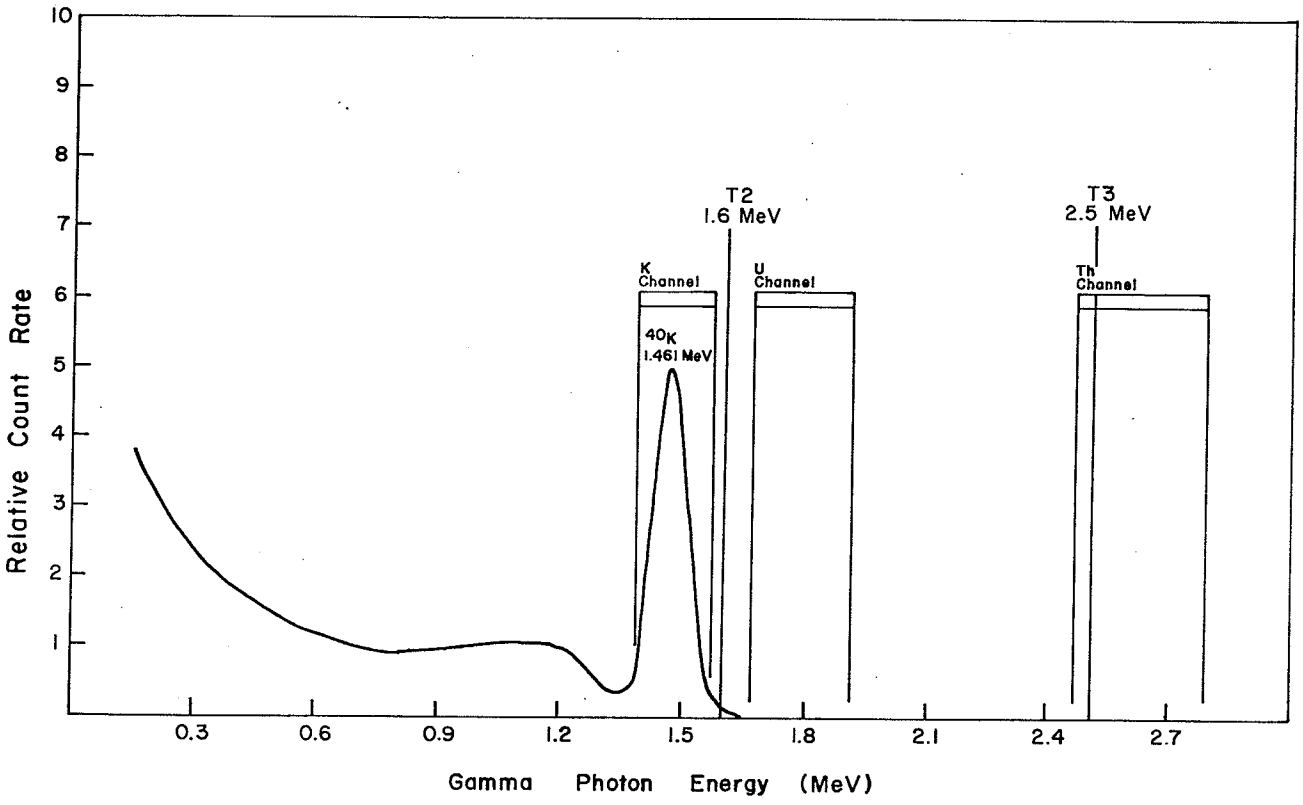

Relative Count Rate
10
9
8
7
6
5
4
3
2
1
T2
1.6 MeV
T3
2.5 MeV
K
Channel
U
Channel
Th
Channel
40K
1.461 MeV
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
Gamma Photon Energy (MeV)

Figure 5. Gamma photon spectrum of uranium ore.

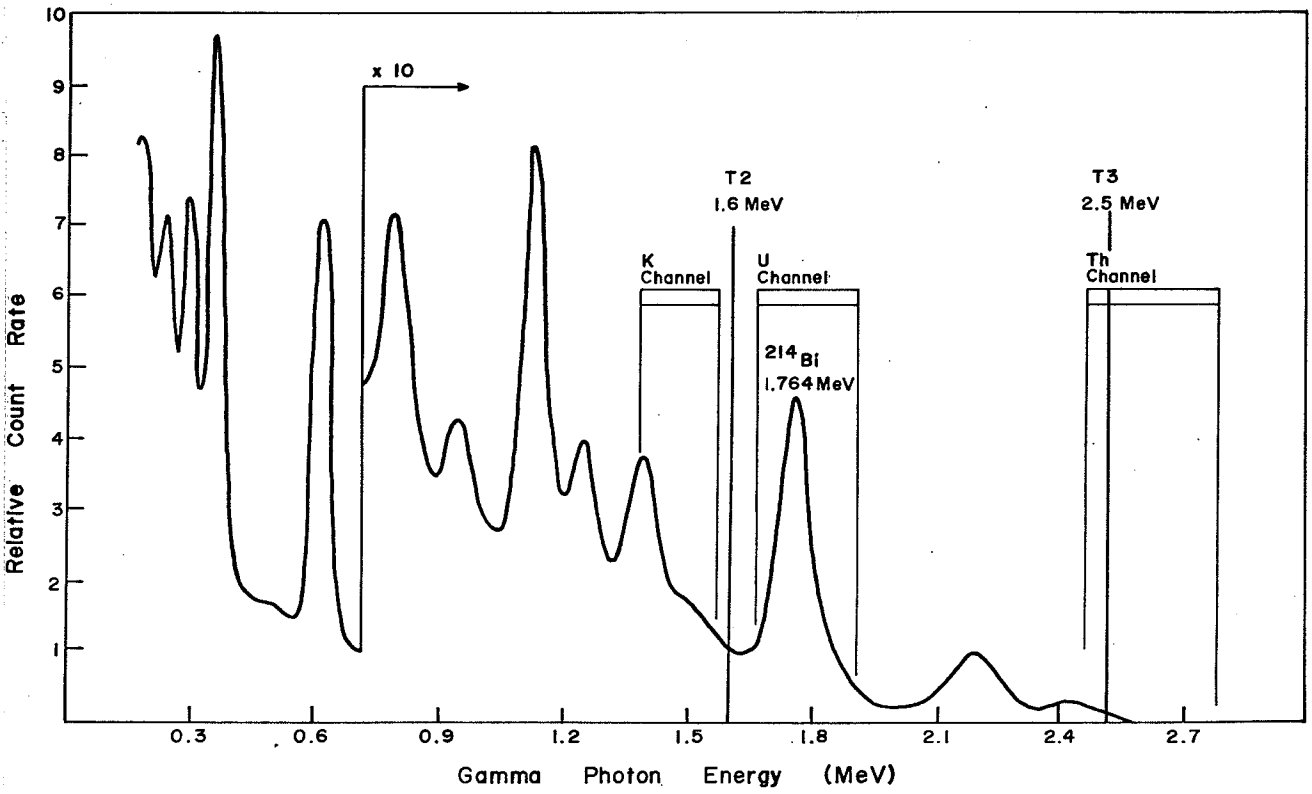
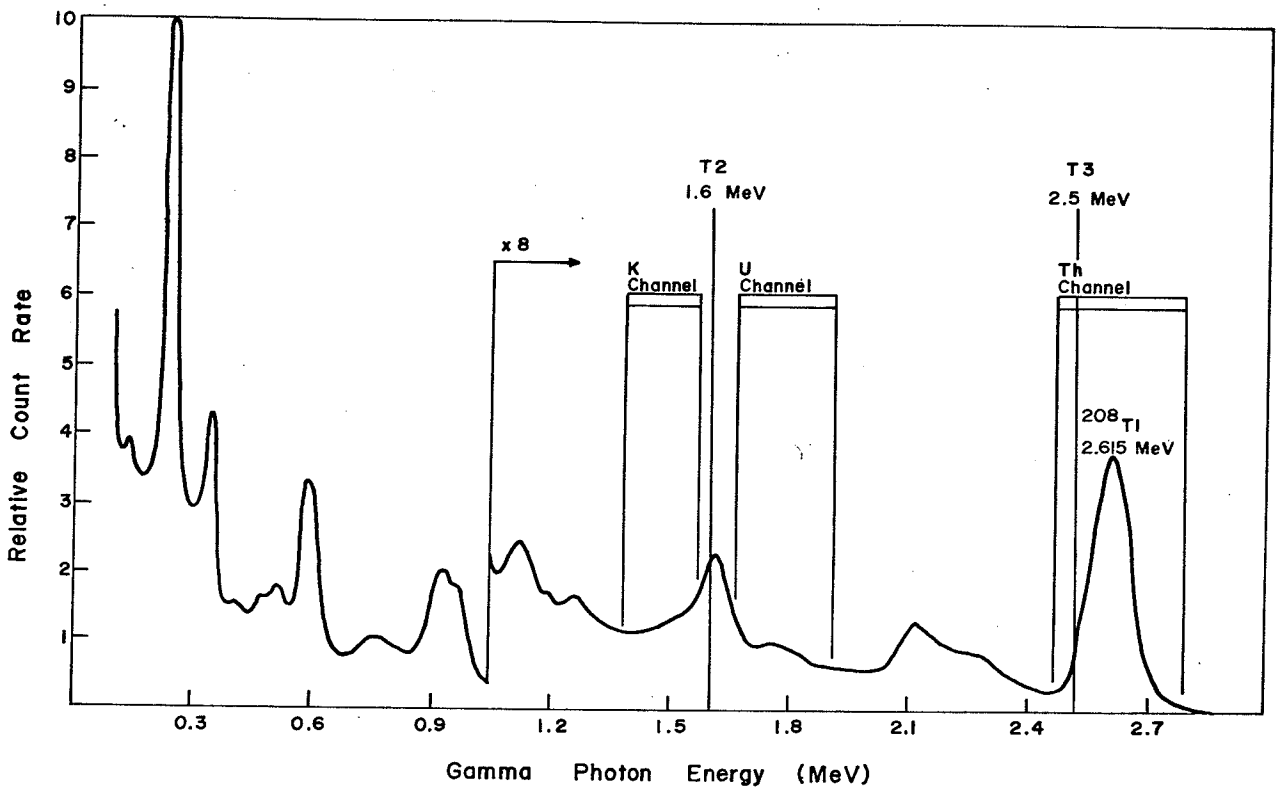

x 10
T2
1.6 MeV
T3
2.5 MeV
K
Channel
U
Channel
Th
Channel
214 Bi
1.764 MeV
Relative Count Rate
Gamma Photon Energy (MeV)
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7
1
2
3
4
5
6
7
8
9
10

Figure 6. Gamma photon spectrum of thorium


Relative Count Rate
Gamma Photon Energy (MeV)
T2
1.6 MeV
T3
2.5 MeV
x 8
K
Channel
U
Channel
Th
Channel
208 Tl
2.615 MeV

in looking for these elements. Figure 4, 5, and 6 from Baird et al (1975) show the characteristic gamma ray energy spectrums for potassium, uranium, and thorium. Since potassium decays in one step, its energy spectrum is a single peak. The complex nature of the uranium and thorium spectrums reflect the decay sequences of their decay series. The characteristic nature of these spectra have permitted discrimination by instrument in the field of these elements. There are three specific characteristic gamma photon energies associated with potassium, uranium, and thorium , which are of interest in geological surveying and radio-chemical analysis. These energies are represented in Figure 4, 5, and 6 by channel K for potassium, channel U of uranium, and channel Th for thorium. If these channels are compared in Tables 5 and 6, also from Baird et al (1975), it can be seen that channel U corresponds to Bi - 214 uranium daughter product gamma emissions and channel Th corresponds to Tl - 208 thorium daughter product gamma emissions. The decay series representative of thorium emits gamma photon energy exceeding 215 Mev., of which potassium and uranium have no such levels. The potassium emits essentially no photons of energies above 1.6 Mev. Instruments make use of these three energies by having the ability to cut out all energies below 1.6 Mev., which removes the effect of potassium and also cuts out all energies below 2.5 Mev., which removes the effect of potassium and uranium. With proper application of these features, it is possible to get individual values of intensity of uranium and thorium gamma radiation, and if the source is suspected of being in equilibrium, then it is possible to obtain an assumed estimate of amount of uranium and thorium present.

CHAPTER V

FIELD RESULTS

Backgrounds

The procedure employed to determine the atmospheric background levels of gamma radiation is described in Chapter 2. Figure 7 shows the distribution of those background values. Table 7 lists the mean atmospheric background values for the various energy thresholds characteristic of the gamma spectrometer. In each case, the mean represents the total number of gamma photons counted that have energies above that of the indicated threshold.

TABLE 7: Mean atmospheric background radiation levels associated with the three energy thresholds: T1, T2, and T3.

	Threshold (Mev.)	Mean (Counts/Min.)
T1 (Total Count)	0.2	315
T2 (U + Th)	1.6	38
T3 (Th)	2.5	32

The above values are used throughout the data whenever a correction for atmospheric background radiation is required.

Figures 8, 9, 10, and 11 are of the distributions of host rock backgrounds. The calculated Means of these backgrounds are displayed in Table 8.

Figure 7. The distribution of 140 samples of atmospheric background radiation. T1, T2, and T3 represent the various energy thresholds, recording respectively total radiation, uranium and thorium radiation, and thorium radiation.

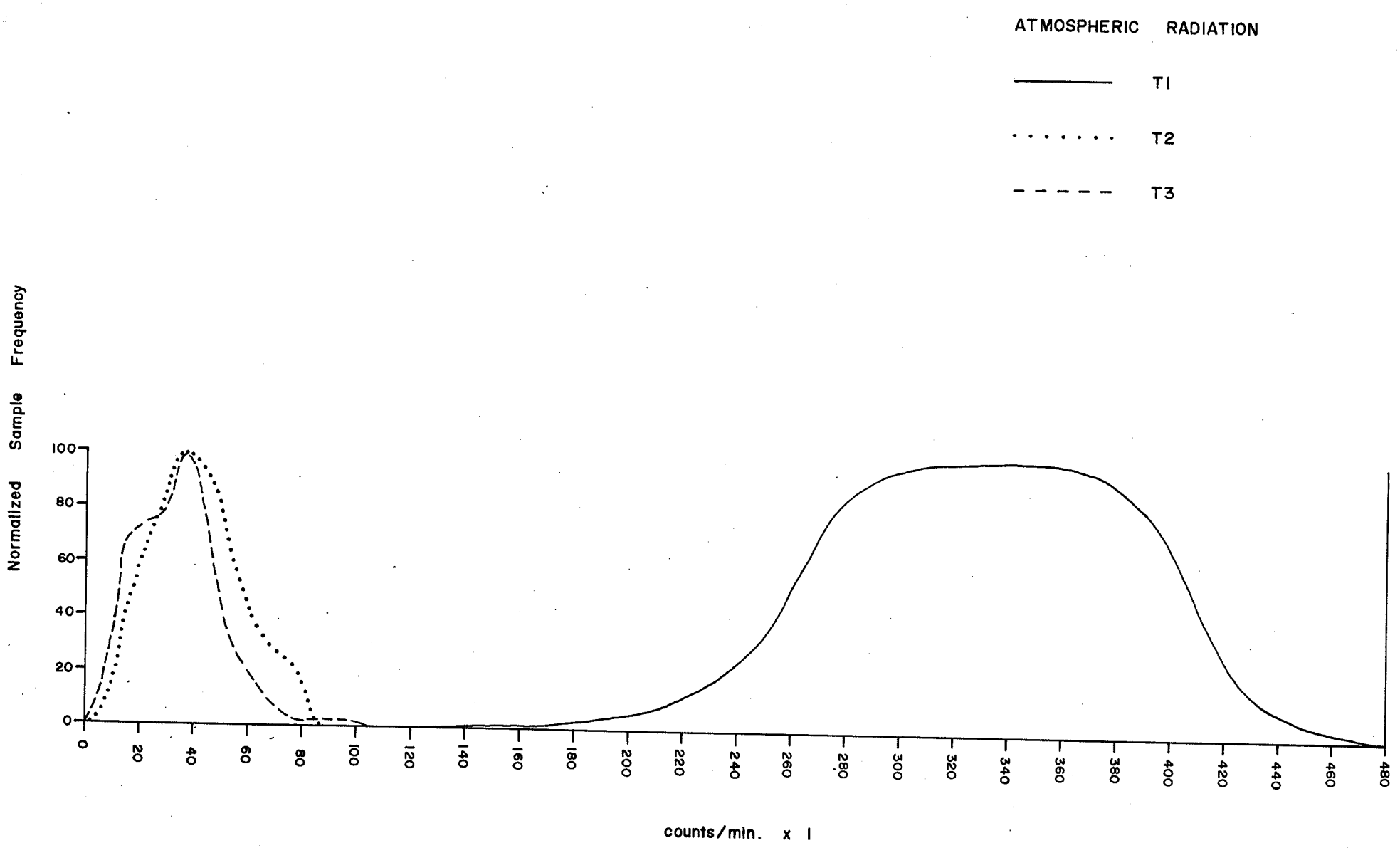

ATMOSPHERIC RADIATION
T1
T2
T3
Normalized Sample Frequency
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
480
counts/min. x 1

Figure 8. The distribution of 12 samples of background radiation from Keewatin volcanic rocks. T1, T2, and T3 represent the various energy thresholds recording respectively total radiation, uranium and thorium radiation, and thorium radiation.

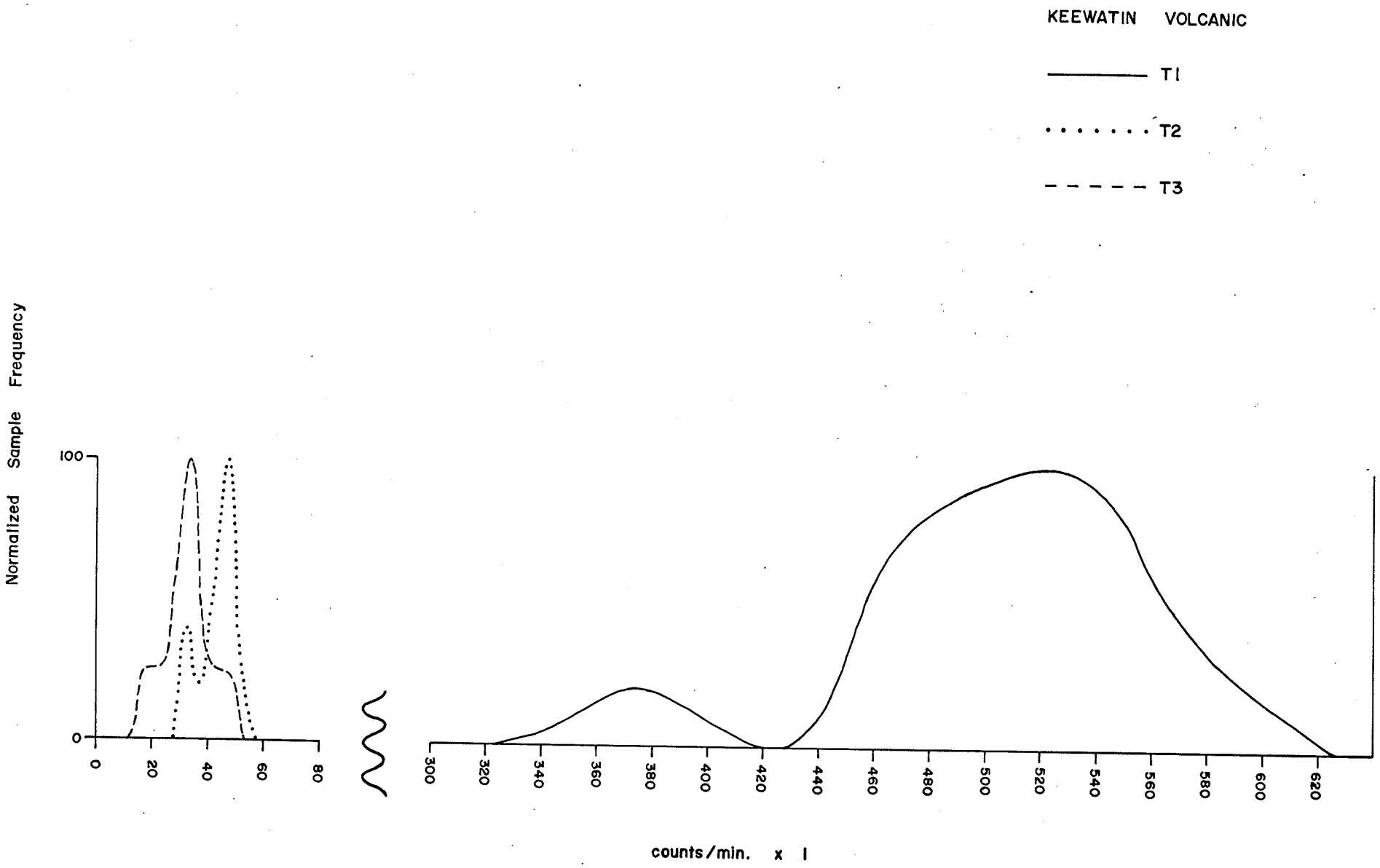

KEEWATIN VOLCANIC
T1
T2
T3
Normalized Sample Frequency
100
0
0
20
40
60
80
300
320
340
360
380
400
420
440
460
480
500
520
540
560
580
600
620
counts/min. x 1

Figure 9. The total count (Tl, 0.2 Mev.) host rock background distribution for: grey gneissic granodiorite and quartz diorite, porphyritic granodiorite, pink granodiorite and biotite granite, and Keewatin sedimentary rocks.

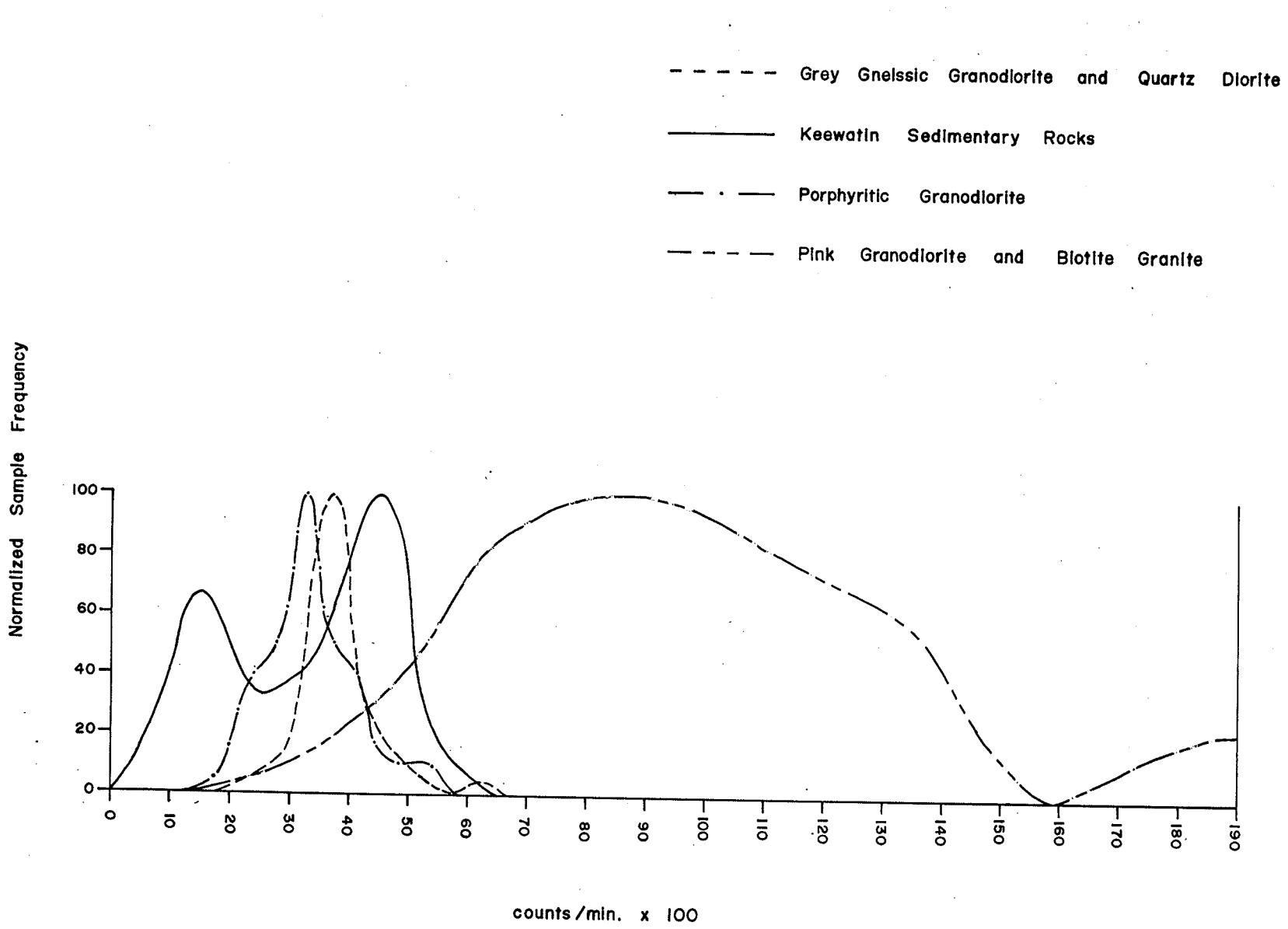

Grey Gneissic Granodiorite and Quartz Diorite
Keewatin Sedimentary Rocks
Porphyritic Granodiorite
Pink Granodiorite and Biotite Granite
Normalized Sample Frequency
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
counts/min. x 100

Figure 10. The uranium and thorium (T2, 1.6 Mev.) host rock background radiation distribution for: grey gneissic granodiorite and quartz diorite, porphyritic granodiorite, pink granodiorite, and biotite granite, and Keewatin sedimentary rocks. This energy threshold excludes gamma photons originating from a potassium source.

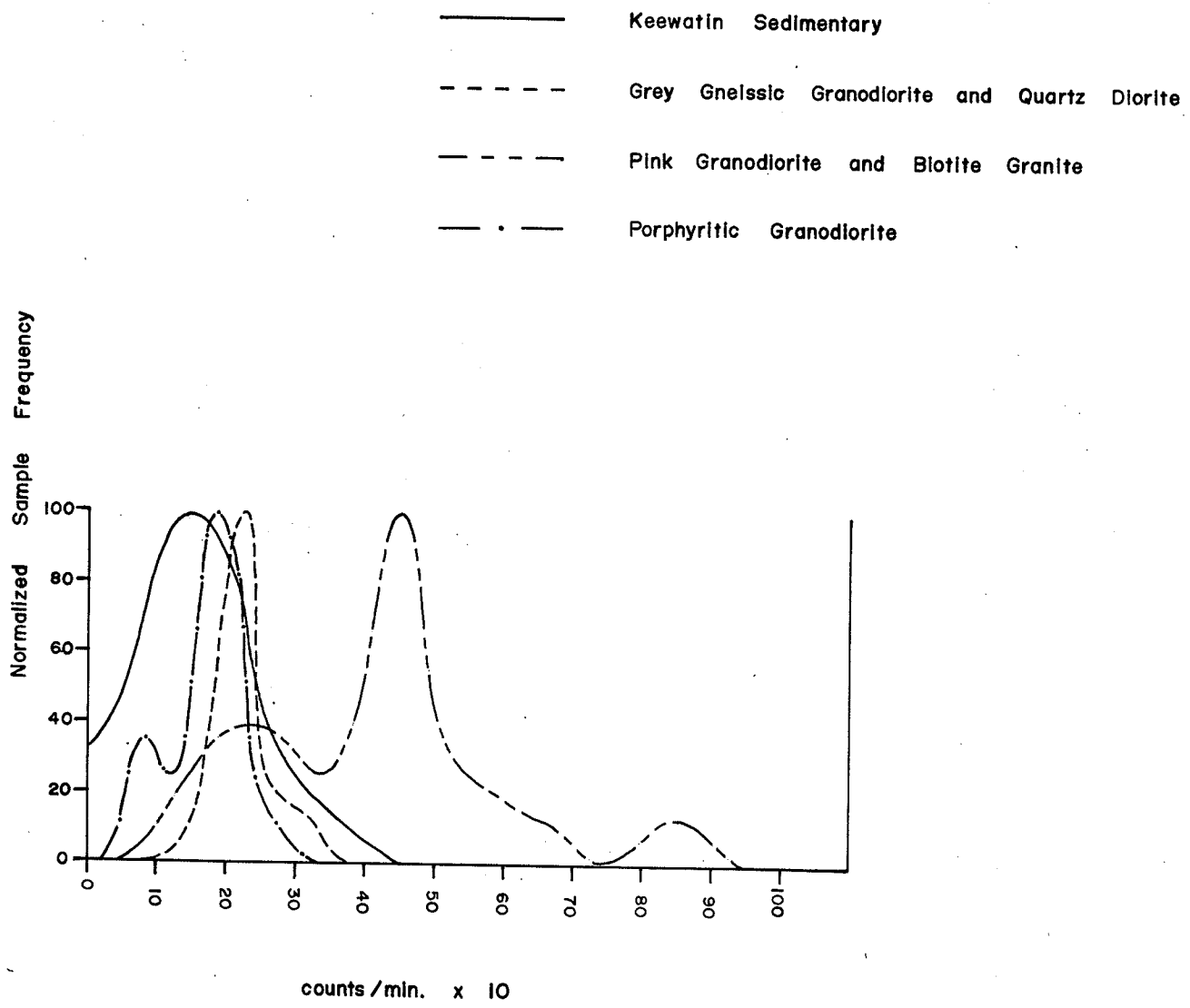

Keewatin Sedimentary
Grey Gneissic Granodiorite and Quartz Diorite
Pink Granodiorite and Biotite Granite
Porphyritic Granodiorite
Normalized Sample Frequency
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
counts / min. x 10

Figure 11. The thorium ($T3_{\gamma}$, 2.5 Mev.) host rock background radiation distribution for: grey gneissic granodiorite and quartz diorite, porphyritic granodiorite, pink granodiorite and biotite granite, and Keewatin sedimentary rocks. This energy threshold excludes gamma photons originating from a potassium and/or uranium source.

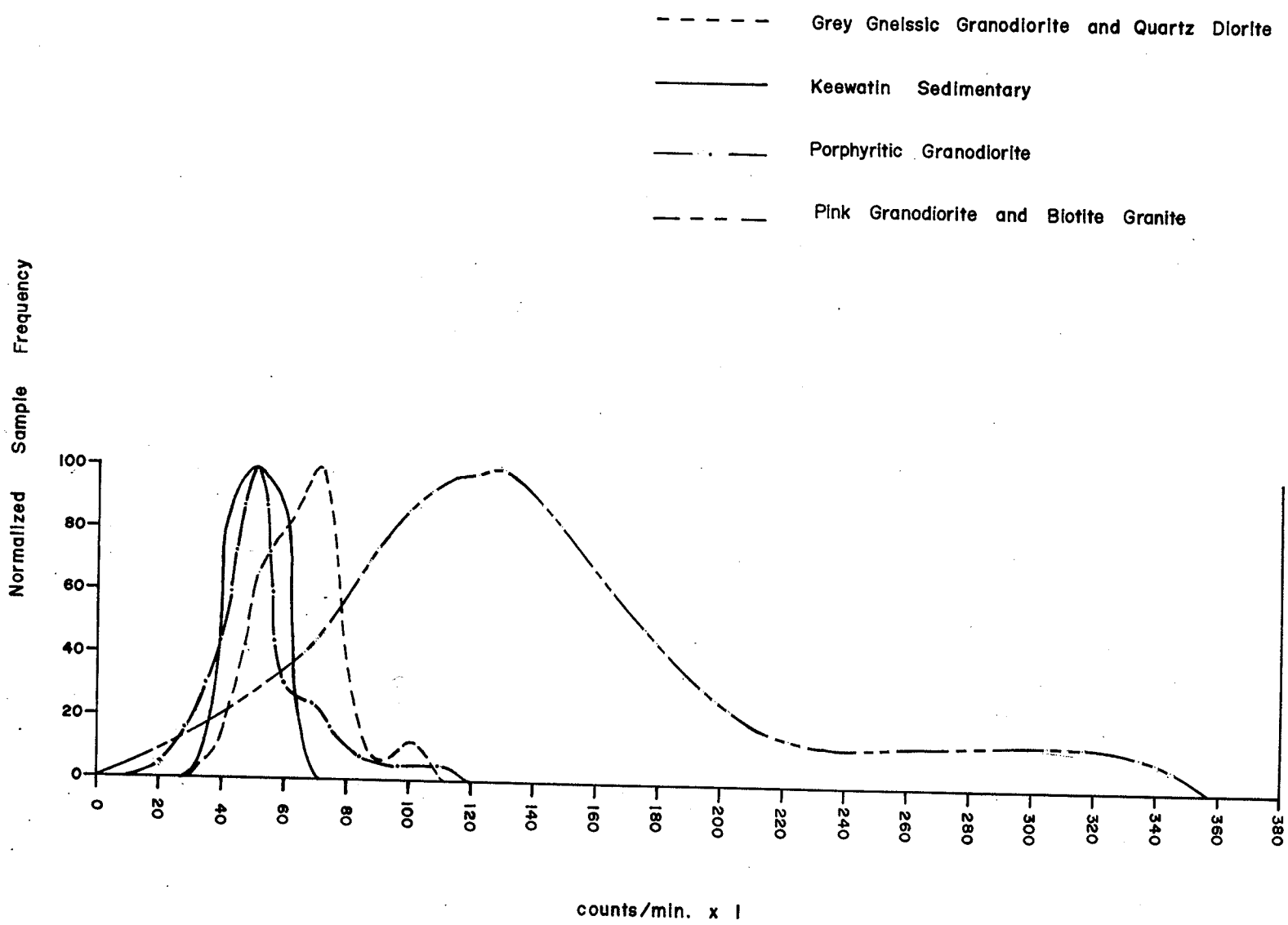

Grey Gneissic Granodiorite and Quartz Diorite
Keewatin Sedimentary
Porphyritic Granodiorite
Pink Granodiorite and Biotite Granite
Normalized Sample Frequency
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
counts/min. x 1

TABLE 8: The Mean background levels of the host rocks. These levels have not been corrected for atmospheric radiation.

HOST ROCK	Mean Background Levels (counts/min.)		
	Total Count	U + Th	Th
Keewatin Volcanic	500	43	33
Keewatin Sedimentary	3040	160	51
Grey Gneissic Granodiorite and Quartz Diorite	3540	209	63
Porphyritic Granodiorite	3260	160	54
Pink Granodiorite and Biotite Granite	9260	420	130

There are distinct differences in the composition of the various rocks. These differences are reflected, in part, by varying amounts of feldspar, or, in particular, dominance of either sodiac feldspar (plagioclase series) or potassium feldspars (alkali feldspare series) over each other. This compositional difference can, therefore, be seen reflected in the background radiation levels of the various host rocks. Examination of Table 8 indicates three distinct groups showing characteristic levels of radiation due primarily to potassium. Using the lowest energy threshold (T1, 0.2 Mev.), the Keewatin volcanoc rocks form one group (500 counts/min.), the Keewatin sedimentary, grey gneissic granodiorite, and the porphyritic granodiorite form a second group (3040 - 3540 counts/min.) with the pink granodiorite and biotite granite forming a third group (9260 counts/min.).

If the defined atmospheric correction is applied to the Keewatin volcanic rocks, the counts over the T2 (uranium and thorium) and T3 (thorium) thresholds correct to zero and the total count T1 threshold reduces to 200 counts/min., indicating a very low potassium content. This is expected with this type of rock.

The second group of rocks are within a few hundred counts/min. of each other. There are significant counts shown in the higher energy levels after an atmospheric correction (Table 9) and as portions of the uranium and thorium decay series are measured by T1 and not by T2 or T3, it is reasonable to assume that the variations observed through group two with reference to T1 may be due to uranium and thorium. Aside from that possibility, if the variations observed are due to variations in potassium, then these degrees of variation are not readily observable in the feldspars contained in the individual rock units.

Table 9: The host rock background concentrations of uranium and thorium in parts per million. These values are determined by applying atmospheric radiation corrections to the values in Table 8, and removing the portion of radiation recorded in T2 that is due to thorium. The relationship between gamma counts/min., and concentrations in ppm's outlined in Table 11 are then applied and an estimate of uranium and thorium results. This assumes that the uranium and thorium minerals occur in the equilibrium state.

HOST ROCK	Concentration (ppm)		Uranium/Thorium
	U	Th	
Keewatin Volcanic	0	0	
Keewatin Sedimentary	11	13	0.85
Grey Gneissic Granodiorite and Quartz Diorite	13	21	0.62
Porphyritic Granodiorite	9	15	0.60
Pink Granodiorite and Biotite Granite	8	65	0.12

The third group, the pink granodiorite and biotite granite, display a very high background value (9260 counts/min.). This is approximately three times the highest background previously discussed. In the field, such a variation would constitute an anomaly depending on the host rock. The other rock units (Group 2) host this unit and this is the cause of a great deal of the recorded anomalies. Because of this high background value associated with this rock, anomalies were not considered unless they showed total counts at least four times that of the hosting material. Measuring the potassium feldspar content is a simple test to define or measure the relative potassium content. This is done by cutting the rock samples and immersing the cut surface in hydrofluoric acid, etching the potassium feldspars. The cut surface is then immersed in a solution of sodium cobaltinitrite, which stains the potassium feldspars a bright yellow. Figures 12, 13, and 14 show the representative samples of the rocks comprising Group 2 and Group 3. There was no collection of Keewatin sedimentary or volcanic rock samples as there were no indications of anomalous radioactivity. Figures 12, 13, and 14 display samples of host rocks that contained numerous occurrences of anomalous radioactivity.

The pink granodiorite and biotite granite showing the highest level of radioactivity is composed of about 40 percent potassium feldspars and quartz (Figure 12). Relative to the other samples shown (Figures 13 and 14), the pink granodiorite and biotite granite has higher percentages of potassium feldspars, which typically is distributed rather uniformly throughout the rock. The estimated potassium feldspar content of the remaining samples range from 0 percent in the quartz diorite

Figure 12. Representative samples of Unit 13 (Figure 3), the pink granodiorite and biotite granite. The samples have been stained to reveal potassium feldspars (yellow). The right hand stained side contrasted with the left hand unstained side. The samples top to bottom are 145-84 and 143-145. The sample sites are indicated in Figure 17.

Figure 13. Representative samples of Unit 6 (Figure 3), the grey gneissic granodiorite and quartz diorite. The samples have been stained to reveal potassium feldspars (yellow). The right had stained side is contrasted with the left hand unstained side excluding sample 156-45B. The samples top to bottom are 156-45B, 130-125, and 149-168. The location of the sample sites are indicated in Figure 17.


B

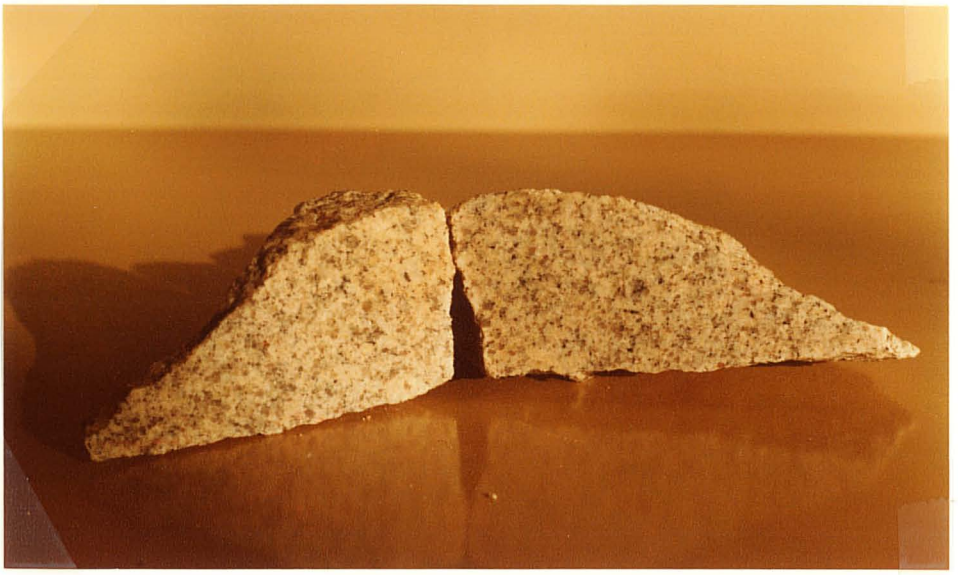


Figure 14. Representative sample of Unit 9 (Figure 3), the porphyritic granodiorite. The sample has been stained to reveal potassium feldspars (yellow). The left hand stained side is contrasted with the right hand unstained side. Sample 117-51 is shown. Its location is indicated in Figure 15.

(Figure 13) to an upper limit of about 25 percent in the porphyritic granodiorite (Figure 14).

It is apparent that the very high background of the pink granodiorite is due primarily to increased amounts of potassium contained within potassium feldspars.

Another method of comparing differences between backgrounds of various rock units is to compare uranium-thorium ratios and by attempting to recognize characteristic ratios or in detailed analysis, relating these ratios to the composition of the rock. In order to do this, the backgrounds must be corrected for atmospheric radiation (procedure outlined in Appendix A).

The use of uranium-thorium ratios is very important in the discrimination of true uranium anomalies. As mentioned previously, uranium minerals are generally much more mobile than thorium minerals and are most often found not in equilibrium. The stability of thorium minerals suggests they are found in equilibrium and, therefore, provides a constant measuring standard with which to compare measured uranium content. It has been shown (Mero, 1960) that a chemically refined thorium oxide reached equilibrium in less than 20 years, so that the time to recover equilibrium is very short. Because of this, thorium is assumed constant; therefore, a reduction in U/Th ratios indicates a loss of uranium minerals and an increase in the ratio suggests a buildup of uranium. This becomes important because it provides another dimension in which to consider anomalies. Anomalies having low count rates may have very high ratios indicating a concentration of uranium, whereas due to the count rate, the anomaly may seem uninteresting. Uranium is generally found

with thorium in nature in a ratio of about ten parts of thorium to one part of uranium (Mero, 1960). This means that any ratio other than 0.10 may be considered anomalous.

As can be seen in Table 9, the only two rock types that have comparable uranium/thorium ratios are the grey gneissic granodiorite (and quartz diorite) and the porphyritic granodiorite. This is not unexpected, as it can be seen from Figures 13 and 14. The grey gneissic granodiorite is very similar to the porphyritic granodiorite. Lamb (1974-75) in fact, calls the grey gneissic granodiorite a marginal phase of the porphyritic granodiorite indicating similar composition.

Note that the Keewatin sedimentary rocks are not separated from the other two rock units that (with the Keewatin sedimentary rocks) comprised a group characterized by a similarity of total count radiation due primarily to potassium. This group is now subdivided based on relative concentrations of thorium and uranium.

The pink granodiorite (and biotite granite) shows an anomalous ratio relative to the other units. It is the only rock unit in which there is more radiation from thorium sources than uranium sources. The very high total count background (associated with concentrations of potassium) and this anomalous ratio (U/Th = 0.12, indicating much more thorium than uranium) suggests that many of the anomalies observed due to pink granodiorite (and biotite granite) may in fact be nothing more than local concentrations of either thorium, potassium, or both.

Anomalous Occurrences of Radioactivity in the Porphyritic Granodiorite

The Mean Background value established for this host rock is 3260 counts/min. above the total count threshold (Table 8); therefore, any radioactive occurrence having total counts greater than 12,000 counts/min. is considered anomalous. Examination of the data turned up 52 anomalous sites (Table 10). The distribution of these anomalies in plan (Figure 15) indicates that they become more numerous along or near contacts with grey gneissic granodiorite as noted by Springer (1952).

These anomalies can be separated into two types; those associated with dykes of pink granodiorite intruding the porphyritic granodiorite, and those that are either pegmatites or associated with fracturing (and/or foliation). Often the pegmatites and fracturing occur together.

The dykes of pink granodiorite represent 72 percent of the recorded anomalies while pegmatites and fracturing compose the remaining 29 percent. This leads to a false impression that the pink granodiorite is the most important target; however, if the most interesting anomalies are considered (those showing total counts greater than 50,000 counts/min.), then 33 percent of the occurrences associated with pegmatites and/or fracturing are anomalous, while only 10 percent of the occurrences associated with pink granodiorite are anomalous. If a similar approach is taken with the U/Th ratios greater than 1.00, then 36 percent of pegmatites and/or fraturing are anomalous and only 17 percent of pink granodiorite dykes are anomalous. This demonstrates that pegmatites and fracturing are the most important targets to investigate. A U/Th ratio greater than 1.00 was selected as anomalous, based on Figure 16. The majority of the

TABLE 10: Radioactive occurrences in porphyritic granodiorite. Table of anomalies showing the counts/min. of the radiation due to thorium (Th) and uranium (U). These values are then converted to uranium and thorium in parts per million (ppm.) using Table 11. The U/Th is a ratio of the apparent concentration in ppm's of uranium and thorium.

Anomaly #	Total Counts X 1000	Radiation Counts/Min.		Concentration p.p.m.		
		U	Th	U	Th	U/Th
1 *	88	1029	746	206	497	0.41
2 *	17	229	146	46	97	0.47
3 *	39	179	446	36	297	0.12
4 *	65	< 0	1346			
5 *	36	329	346	66	231	0.29
6 *	33	404	296	81	197	0.41
7	28	219	206	44	137	0.32
8	63	654	596	131	397	0.33
9 *	23	284	216	57	144	0.40
10 *	28	559	166	112	111	1.01
11 *	38	354	396	71	264	0.27
12	68	1129	346	226	231	0.98
13	20	309	66	62	44	1.41
14 +	20	429	146	86	97	0.89
15 *	26	119	206	24	137	0.18
16 *	86	< 0	1246			
17 *	45	629	346	126	231	0.55
18 *	85	1454	396	291	264	1.10
19 *	26	< 0	126			
20 *	68	979	446	196	297	0.66
21 *	33	< 0	346			
22 *	23	< 0	246			
23 *	26	609	66	122	44	2.77
24 *	36	754	196	151	130	1.16
25	90	1919	206	384	137	2.80
26	96	1279	646	256	430	0.59
27 +	43	899	126	179	84	2.14

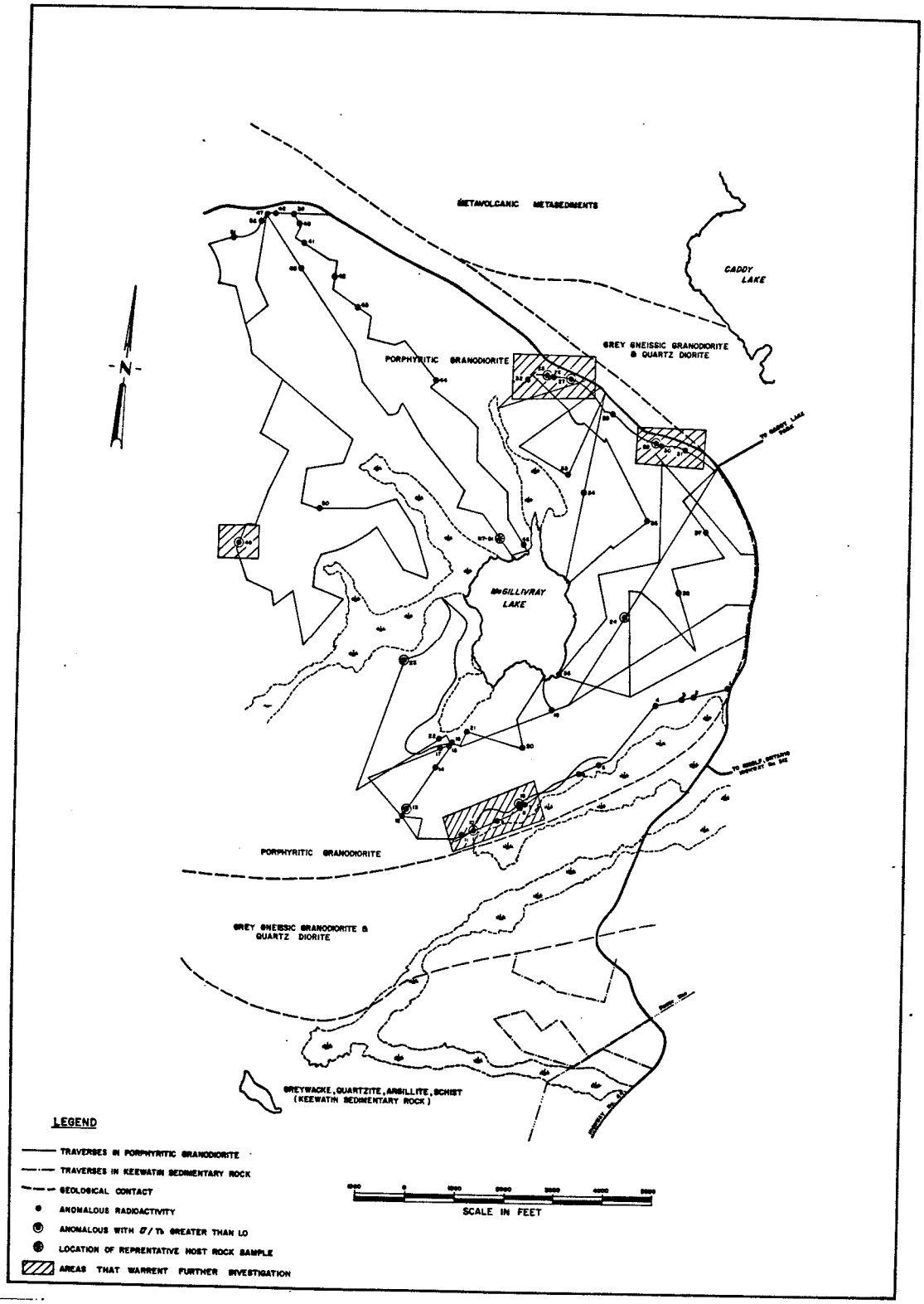
28 +	21	89	186	18	124	0.15
29 +	38	869	106	174	71	2.45
30 *+	23	269	106	54	71	0.76
31 *	Off Scale	3529	1546	706	1031	0.68
32 *	46	< 0	646			
33 *	18	124	176	23	117	0.21
34 *	32	< 0	546			
35 *	22	129	146	26	97	0.27
36 *	20	29	146	6	97	0.06
37 *	31	< 0	446			
38 *	24	< 0	346			
39 s	Off Scale	779	1446	156	924	0.16
40 *s	19	319	206	64	137	0.47
41	48	584	416	117	277	0.42
42 *	16	< 0	206			
43	18	< 0	166			
44 *	30	< 0	446			
45 *s	88	1579	646	316	431	0.73
46 *	23	154	196	31	131	0.24
47 *	36	79	446	16	297	0.05
48 *	24	< 0	346			
49 +s	33	549	26	110	17	6.47
50 *	13	144	56	29	37	0.78
51 *	34	< 0	346			
52 *s	46	579	246	116	164	0.71

Pegmatite
+ Fracturing and/or Foliation
* Pink Granodiorite
s sample collected

TABLE 11. Equivalent content in parts per million of uranium and thorium relative to the observed counts/min. attributed to uranium and thorium. Taken from Appendix A (Operations Manual for McPhar TV-1A Spectrometer), these values are in-situ measurements on outcrops (2π geometry).

Grade (p.p.m.)	Uranium (counts/min.)	Thorium (counts/min.)
10	50	15
100	500	150
1000	5000	1500

Figure 15. Rock contacts, survey traverse lines, and locations of radioactive occurrences associated with the porphyritic granodiorite. Also, shown are the traverses covering the Keewatin sedimentary rocks. There were no anomalies found in this unit. Areas that warrant further investigation have been selected based on a localization of anomalies and/or U/Th ratios greater than 1, and indications that the area has anomalies that may be effectively delineated yielding important information regarding structure and interrelationships of those anomalies.

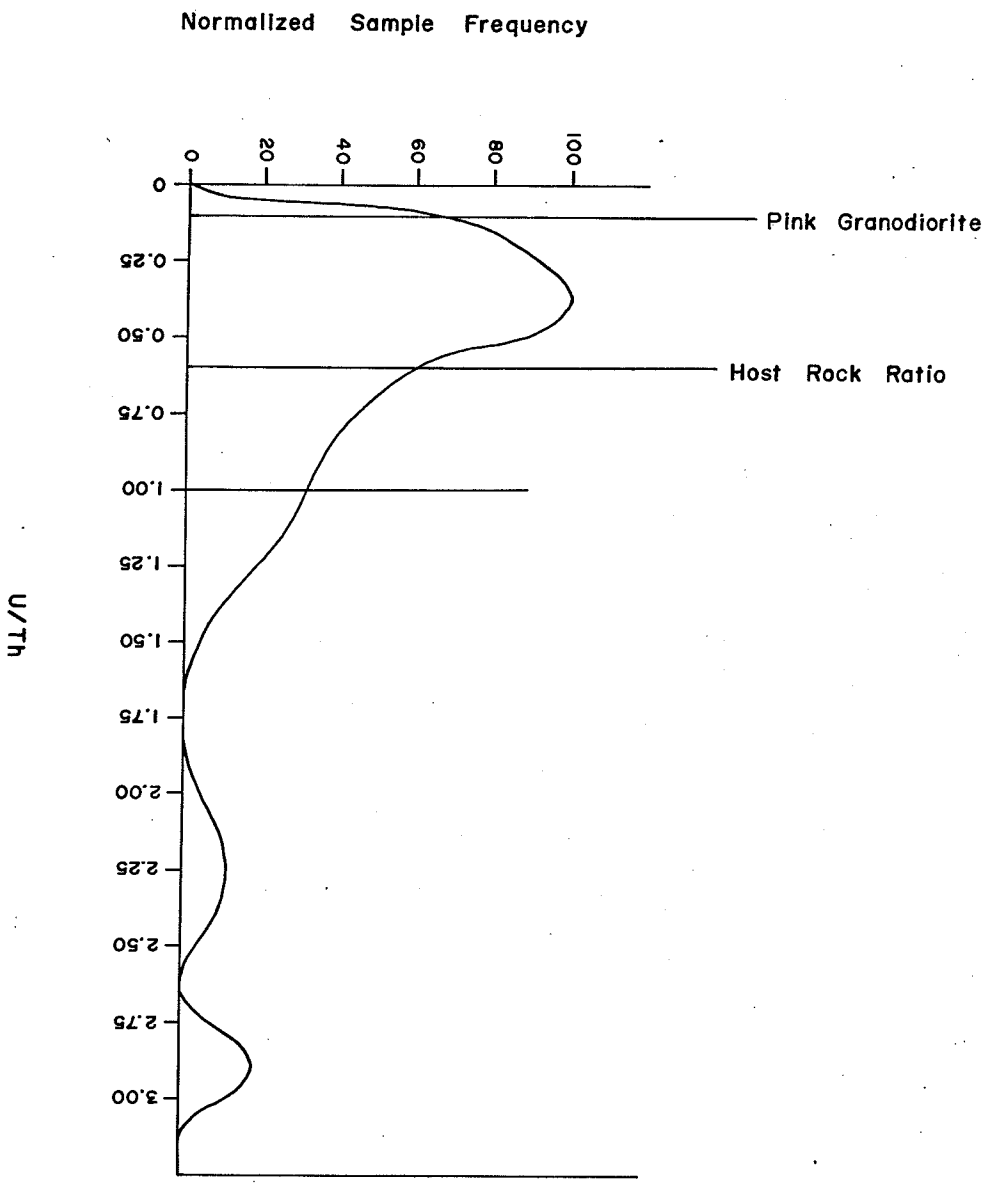

METAVOLCANIC METASEDIMENTS
CADDY LAKE
PORPHYRITIC GRANODIORITE
GREY GNEISSIC GRANODIORITE & QUARTZ DIORITE
GILLIVRAY LAKE
PORPHYRITIC GRANODIORITE
GREY GNEISSIC GRANODIORITE & QUARTZ DIORITE
GREYWACKE, QUARTZITE, ARGILLITE, SCHIST (KEEWATIN SEDIMENTARY ROCK)
N
LEGEND
TRAVERSES IN PORPHYRITIC GRANODIORITE
TRAVERSES IN KEEWATIN SEDIMENTARY ROCK
GEOLOGICAL CONTACT
ANOMALOUS RADIOACTIVITY
ANOMALOUS WITH Ø / Th GREATER THAN 10
LOCATION OF REPRENTATIVE HOST ROCK SAMPLE
AREAS THAT WARRENT FURTHER INVESTIGATION
SCALE IN FEET

anomalies fall between U/Th ratios, typical of the pink granodiorite and the porphyritic granodiorite. In general, it can be said that intrusions of pink granodiorite dykes have picked up minor amounts of uranium minerals. The source for this material may, in fact, be the porphyritic granodiorite, as it typically has a greater concentration of uranium than the pink granodiorite (Table 9, U/Th ratios). There are nine anomalous U/Th ratios greater than 1.00 (Figure 16). Their locations are indicated on Figure 15. In particular, anomaly #49 (Table 10) shows the highest ratio (6.47), which is about 65 times the excepted normal state of 0.10. This anomaly warrants further consideration.

There are numerous anomalies throughout that showed negative counts/min. from a uranium source (Table 10) when corrected for backgrounds. This indicates a situation in which the thorium minerals are not in equilibrium and, that is contradictory to the basic assumption that thorium is in equilibrium. This effectively defines the limitations on the reliability of the data.

When using the Spectrometer, the T2 threshold records gamma photons that originate from both thorium and uranium. In order to determine how much of the recorded count is due to uranium, the instrument is calibrated and tested using the thorium source; counts above the T2 threshold are 3.5 times the number recorded above the T3 threshold. The thorium source used for calibration is known to be in equilibrium; therefore, if the assumption that thorium in Nature (in the field) is, also equilibrium, the portion of counts recorded above the T2 threshold due to thorium will be 3.5 times whatever the counts are above the T3 threshold after correc-

Figure 16. The distribution of U/Th ratios for radioactive anomalies (total counts greater than 12,000 counts/min.) in porphyritic granodiorite. This is produced from the 38 samples contained in Table 10. The distribution indicates a peak at a ratio of 0.35, which is greater than the established background ratio of pink granodiorite, but less than that for porphyritic granodiorite. This may reflect a general characteristic ratio of pink granodiorite intruded into porphyritic granodiorite and does not represent a true anomaly. Ratios genuinely anomalous are all greater than 1.00.


Normalized Sample Frequency
0
20
40
60
80
100
0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
U/Th
Pink Granodiorite
Host Rock Ratio

tion for background levels.

If there is no uranium present, the counts/min. related to photons having energies above the T2 threshold will be exactly 3.5 times the counts/min. above the T3 threshold. This will occur if the thorium is in equilibrium and the correction for the portion of energies above T2 due to thorium will yield zero. This requires, however, that there be sufficient counts due to thorium daughters that have decay energies below T3 and above T2. If some of these daughters are removed or out of equilibrium, then there will be less than the expected counts/min. based on equilibrium, and the correction is the subtraction of a larger number of counts/min. than were actually measured.

This disequilibrium in thorium presents a problem as the validity of using U/Th ratios may be questioned. There are more sophisticated Spectrometers available employing energy windows rather than energy thresholds and generally more numerous in number than three. This type of instrument can be used to determine the degree of disequilibrium and provide enough information to determine if a specific U/Th ratio is, in fact, due to build-up or removal of uranium or thorium. An instrument like this, unfortunately, does not conform or is not suitable for a Reconnaissance Style survey. The instrument used (TV-1A) is suitable for just such a purpose and can be used very effectively to define specific locales exhibiting anomalous character. To determine the importance of an anomaly, all aspects must be considered no matter how suspicious the results may appear.

If a question regarding the truth of interpreted results arises due to just such a problem as disequilibrium in thorium, then the operator

must consider this carefully and make recommendations for detailed work in specific areas defined as anomalous before walking away from an area. This may involve using a more sophisticated instrument or sampling and chemical assay.

In this case, recommendations would have to take into account total count values as well as ratios. High total count anomalies showing disequilibrium in thorium cannot be ignored.

Anomalous Occurrences of Radioactivity in the Grey Gneissic Granodiorite and Quartz Diorite

The Mean Background value established for this host rock (Unit #6, Figure 3) is 3540 counts/min. (Table 8); therefore, only those sites emitting radiation greater than 12,000 counts/min. total counts will be considered anomalous.

Examination of the data revealed 32 Anomalous sites (Table 12). The distribution of these anomalies in plan (Figure 17) indicates a concentration of anomalies along the west shore of Caddy Lake.

As can be seen from Table 12, pegmatitic zones are the most prevalent zones of anomalous radioactivity. Like the occurrences in the porphyritic granodiorite (Table 10), the uranium-thorium ratio best defines build-up of uranium. Of course, some limitations regarding disequilibrium of thorium can be applied to these rocks. As with the porphyritic granodiorite (Figure 16), a ratio of 1.00 seems to mark a division between non-anomalous and anomalous ratios. Six anomalies stand out as having ratios greater than 1.00. In this case, however, the host rock has a ratio of 0.62 (Table 9), and it is questionable as to whether

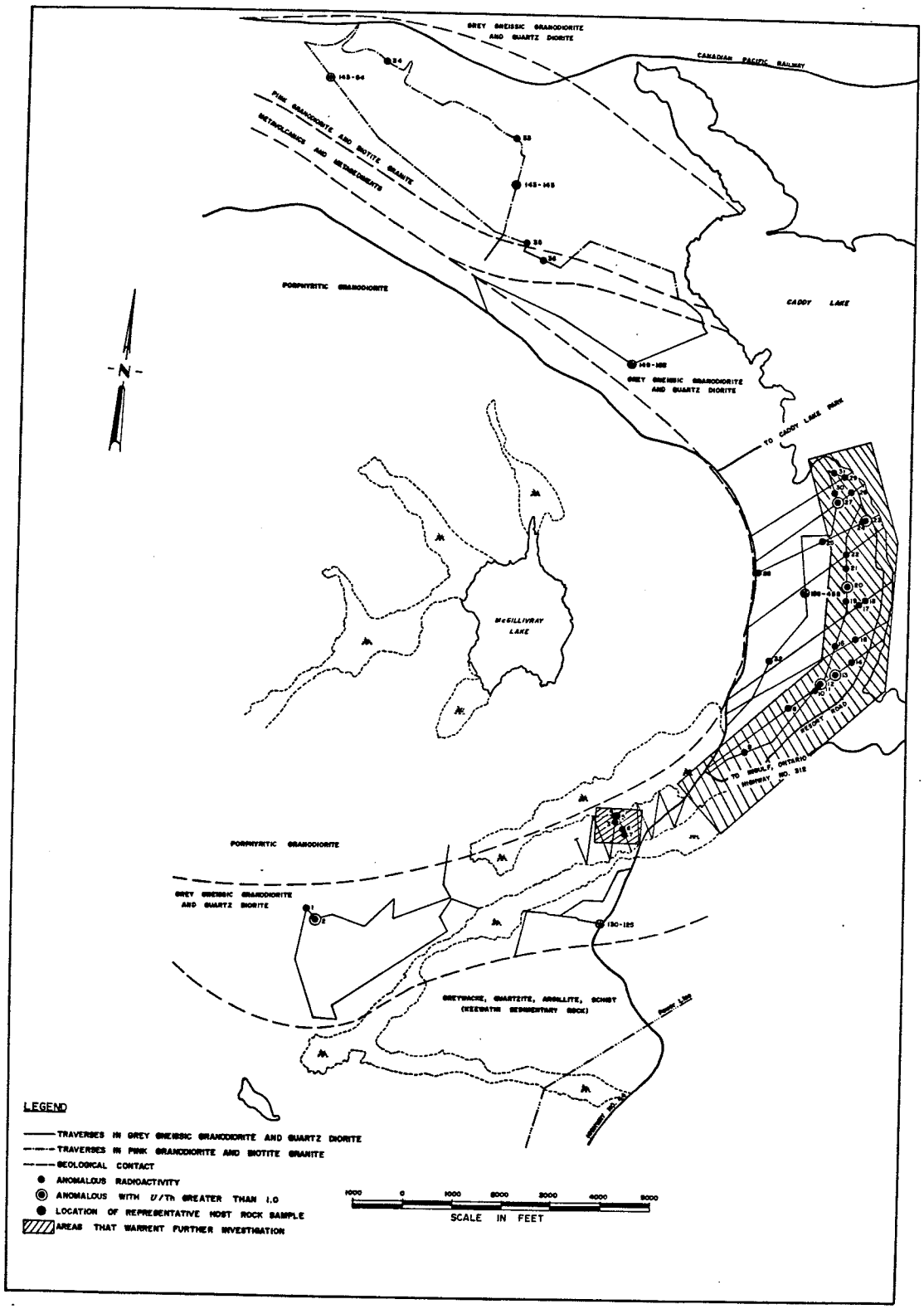
TABLE 12: Radioactive Occurrences in Grey Gneissic Granodiorite and Quartz Diorite. Table of anomalies showing the counts/min. of the radiation due to thorium (Th) and uranium (U). These values are then converted to uranium and thorium in parts per million (ppm.) using Table 11. The U/Th is a ratio of the apparent concentration in ppm's of uranium and thorium.

Anomaly #	Total Counts X 1000	Radiation Counts/Min.		Concentration p.p.m.		
		U	Th	U	Th	U/Th
1 +	80	937	387	187	258	0.72
2	64	1162	237	232	158	1.47
3	20	137	187	27	125	0.22
4 +	60	512	537	102	358	0.28
5 *	Off Scale	1062	1237	212	825	0.26
6	15	187	87	37	58	0.64
7	36	357	267	71	178	0.40
8	20	< 0	287			
9 *	27	62	237	12	158	0.08
10	48	462	237	92	158	0.58
11	98	1012	537	322	358	0.90
12 *	30	512	137	102	91	1.12
13 Ø	45	962	237	192	158	1.22
14	17	12	137	2	91	0.02
15 *	46	712	337	142	225	0.63
16	19	112	137	22	91	0.24
17	25	< 0	187			
18	17	12	137	2	91	0.02
19	Off Scale	1812	937	362	625	0.58
20	21	661	37	132	25	5.28
21 *	33	12	337	2	225	0.01
22 *	25	262	237	52	158	0.33
23	35	936	187	187	125	1.50
24	45	262	437	52	291	0.18
25	50	712	537	142	225	0.63
26	46	587	487	117	325	0.36
27	32	812	137	162	91	1.78

28	25	< 0	337			
29	15	12	137	2	91	0.02
30 *	53	312	537	62	358	0.17
31	20	< 0	237			
32 *	37	< 0	537			

Pegmatite
+ Fracturing and/or Foliation
* Pink Granodiorite
Ø Quartz Vein
s Sample collected

Figure 17. Rock contacts, survey traverse lines, and locations of radioactive occurrences associated with the grey gneissic granodiorite (and quartz diorite), Unit #6, Figure 3, and the pink granodiorite (and biotite granite), Unit #13, Figure 3. Areas that warrant further investigation have been selected based on a localization of anomalies and/or U/Th ratios greater than 1, and indications that the area has anomalies that may be effectively delineated yielding important information regarding structure and interrelationships of these anomalies.


GREY GNEISSIC GRANODIORITE AND QUARTZ DIORITE
CANADIAN PACIFIC RAILWAY
PINK GRANODIORITE AND BIOTITE GRANITE
METAVOLCANICS AND METADIORITE
PORPHYRITIC GRANODIORITE
CADDY LAKE
GREY GNEISSIC GRANODIORITE AND QUARTZ DIORITE
TO CADDY LAKE MINE
McGILLIVRAY LAKE
SECOND ROAD
TO KENORA, ONTARIO
HIGHWAY NO. 515
PORPHYRITIC GRANODIORITE
GREY GNEISSIC GRANODIORITE AND QUARTZ DIORITE
GREYWACKE, QUARTZITE, ARGILLITE, SCHIST (KEEWATIN SEDIMENTARY ROCK)
LEGEND
TRAVERSES IN GREY GNEISSIC GRANODIORITE AND QUARTZ DIORITE
TRAVERSES IN PINK GRANODIORITE AND BIOTITE GRANITE
GEOLOGICAL CONTACT
ANOMALOUS RADIOACTIVITY
ANOMALOUS WITH U/Th GREATER THAN 1.0
LOCATION OF REPRESENTATIVE HOST ROCK SAMPLE
AREAS THAT WARRENT FURTHER INVESTIGATION
1000 0 1000 2000 3000 4000 5000
SCALE IN FEET

ratios less than twice as large can actually be considered anomalous. Some doubt may develop, but until more detailed work is done with chemical assay, etc., it is not valid to assume that as with total counts, the value must be four times background to define anomaly. Anomaly 20, having a ratio of 5.28, is certainly anomalous, and warrants further investigation.

Anomalous Occurrences of Radioactivity in the Pink Granodiorite and Biotite Granite

The Mean Background value established for this host rock (Unit #13, Figure 3) is 9260 counts/min. (Table 8); therefore, only those sites emitting radiation greater than 36,000 counts/min. total counts will be considered anomalies.

Under this constraint, examination of the date revealed three anomalies (Table 13), but one anomaly two times background is included in the table as well. All other sample sites did not exceed a maximum of 14,000 counts/min. The location of anomalies can be found in Figure 17.

Two of the four anomalies show counts due to uranium as negative, indicating, as previously discussed, that thorium is not in equilibrium.

All the anomalies occur in pink granodiorite, but in the case of anomaly 34, the host rock for the pink granodiorite is the metavolcanics and metasediments (Unit #5, Figure 3). It is along the contact of the metasediments and metavolcanics with the porphyritic granodiorite that uranium occurrences have been found (Springer, 1952).

The established ratio associated with the background of pink granodiorite is 0.12 (Table 9). The one sample is very close to this value

Table 13. The anomalous radioactive occurrences in Unit 13 (Figure 3), the pink granodiorite (and biotite granite). Shown are the counts/min. due to thorium (Th) and uranium (U), which are converted to a concentration of uranium and thorium in parts per million (Table 11). The U/Th is a ratio of the apparent concentrations (ppm's) uranium and thorium.

Anomaly #	Total Count X 1000	Radiation (Counts/Min.)		Concentration (ppm.)		U/Th
		U	Th	U	Th	
33	18	< 0	145		97	
34	46	235	470	47	313	0.15
35	58	< 0	770	157	513	
36	64	785	370		247	0.64

and may be an anomaly due to equivalent build-up of uranium and thorium or simply a concentration of potassium feldspar or both. Anomaly 36 indicates a slight build-up of uranium; however, if the previously established division (ratio of 1.00) between anomaly and non-anomaly is considered, then there are no anomalous occurrences of uranium.

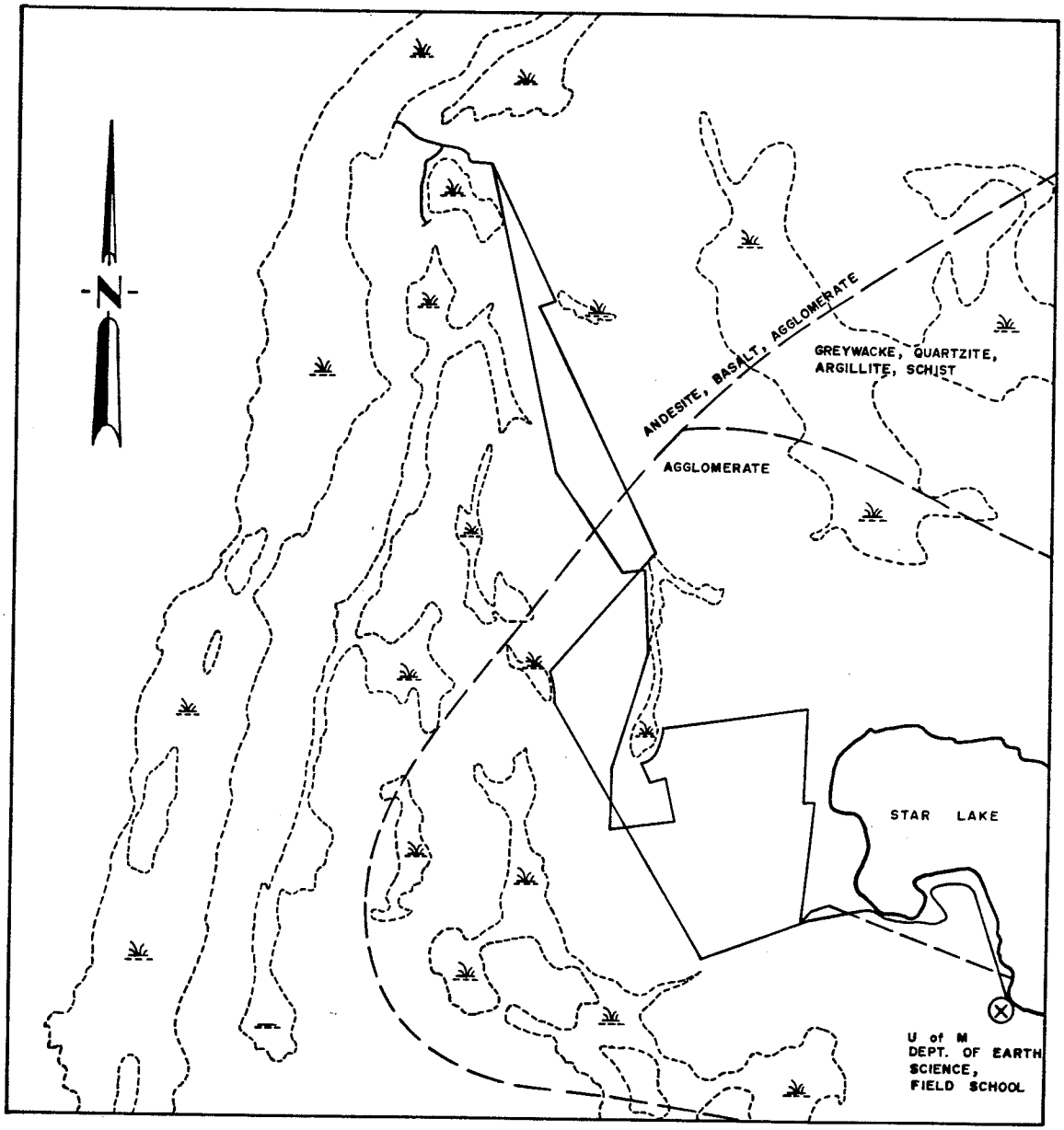
Remaining Host Rock Unit

The term "host rock" is not applicable to either the Keewatin sedimentary rocks or the Keewatin volcanic rock, as no anomalous occurrences of radioactivity were found.

Figure 18 shows the survey coverage for the Keewatin volcanic rocks. To classify as an anomaly, occurrences of only 2,000 counts/min. (four times background, Table 7) were required, but none were found.

A similar situation was found for the Keewatin sedimentary rocks (Figure 17), except that an anomaly would have to be at least 12,000 counts/min.

Figure 18. Survey traverse lines carried out in Keewatin volcanic rocks. No anomalous radioactivity.



LEGEND

——— TRAVERSES IN KEEWATIN VOLCANIC ROCKS

— — — ROCK CONTACT

1000 0 1000 2000 3000 4000 5000

SCALE IN FEET

CHAPTER VI

SUMMARY AND CONCLUSIONS

This survey involved 50 miles of traversing that was carried out discontinuously through the Summer and early Fall of 1977. Eighty-eight anomalies of various magnitudes were defined and found to be distributed among three out of five possible host rock units. These anomalies are concentrated along contacts between the various host rocks; however, none of the anomalies based on the information collected can be said to be of significant economic importance.

The concentration of radioactive occurrences in the vicinity of the contact between gneissic granodiorite and porphyritic granodiorite as well as the most important anomalies being pegmatites were observations noted in previous work (Springer, 1952).

The first two objectives (Chapter 2) of the program have been met. The survey was conducted in a systematic manner, so as to maximize ground coverage and the possibility of finding occurrences that would show anomalous quantities of uranium.

Table 14 is a representation of the distribution of so-called exploration intensity. The intensity is purely a relative number and it points out that the exploration interest focused around the porphyritic granodiorite and the grey gneissic granodiorite. This conforms to the knowledge that in the past, it was noted that uranium occurrences

TABLE 14. "Effort or intensity of exploration" expended in each rock unit within the Survey area. The "effort" is the survey footage divided by the relative proportion of rock units in the Survey area (Table 1). Survey footage is the accumulated footage from traverses.

ROCK TYPE	SURVEY FOOTAGE (ft.)	"EFFORT OR INTENSITY"
eewatin edimentary	11,000	1,833
eewatin olcanic	30,000	2,000
rey Gneissic ranodiorite and Quartz Diorite)	71,000	2,840
orphyritic ranodiorite	129,000	3,685
ink Granodiorite nd Biotite anite)*	21,000	1,105

also includes the metavolcanic and metasediments (Table 1, and Figure 3).

are associated with the contact between these two rock types (Springer, 1952).

The third objective is somewhat inconclusive. No significant uranium mineralization was found. What was found is radioactivity originating from what appears to be localized concentrations of potassium feldspars. This was evident in some of the samples that were stained for potassium. In addition, some samples typically characterized by a significant portion of biotite showed high counts both in the field and in hand sample. This character was also noted by Springer (1952).

Because of no obvious mineralization (i.e., not visible) and the very high portions of potassium rich minerals present, an attempt was made to interpret uranium-thorium ratios in the hope that a build-up in uranium might be seen in the ratios and indicate an area promising for uranium mineralization not observable at the surface. Instead, thorium in a few samples was found not to be in equilibrium, which raises questions regarding the validity of studying ratios in this area.

The third objective (economic appraisal) was, in part, accomplished. Any significant high-grade showing, if present, would have been found. The radiation observed is due to localized concentrations of potassium, which in most cases is accompanied by similar increases in uranium and potassium. This process of concentration does not seem to be one to produce ore zones or as was observed, no obvious accumulations of uranium. However, given the limitations of the survey and the problems encountered, it must be said that although no significant mineralization was detected, enough interesting radioactive occurrences were defined to

warrant further investigation with new tools. These tools could be a sampling program followed with precise assay or a survey of specific anomalous areas already outlined using a much more sophisticated instrument.

The type of tool used on this program, the McPhar TV-1A Spectrometer, is a reconnaissance instrument designed to look at low levels of radiation. It is a "first look" tool, and, as such, could only be used to define anomalous areas in which to maximize the intensity of search.

Figures 15 and 17 indicate specific areas of anomalous radioactivity which warrant further investigation. In this sense, the overall objectives of the thesis were met. It would have been fortuitous to find a high-grade showing, but the fact that no such zones were found represents, to a degree, an economic appraisal of the area. In lieu of actually finding a high-grade zone, the procedures adopted and the instrument used were capable of defining areas of specific interest. This narrows the "field of vision" and provides an opportunity for further detailed work to adequately determine the economic potential of the area.

In concluding, the author recognizes that the types of survey performed will certainly outline uranium mineralization of significant proportions; however, negative results do not necessarily disqualify an area regarding the possibility of uranium mineralization. In this case, the Operator (holding Company) must use the information gathered to select a new method or tool with which to carry out detailed follow-up on specific anomalies.

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APPENDIX A

Model TV-1A
Spectrometer
(McPhar Geophysics)

NOTE: Appendix A is an exact reproduction of the manual for the instrument as provided by the manufacturer (McPhar Geophysics Ltd.).

CONTENTS

SECTION 1

INTRODUCTION

Model TV-1A is a three threshold spectrometer. Measurements are based on the spectral characteristics or energy levels of gamma radiation from radioactive elements. Selection of the operating threshold is made by means of the threshold selector switch.

The instrument is designed primarily for reconnaissance. The selective thresholds however provide the capability to differentiate between gamma radiations emanating from uranium and thorium and to provide quantitative information relating to each.

The meter is calibrated to display zero to 100 counts per minute. A four position scale multiplier switch provides four full scale ranges of 100, 1000, 10,000 and 100,000 counts per minute. A fifth position on this switch is employed to test the condition of the batteries.

The variable time constants are tied in with the threshold selector switch. In the wide open (maximum sensitivity) operation, a fast or slow time constant may be selected. In the upper thresholds (lower net count), the long time constant only is in effect.

The detecting element is a 1.5 by 1.5 inch sodium iodide crystal coupled to a photomultiplier tube. These are hermetically sealed, magnetically shielded and mounted in the forward end of the spectrometer housing.

A speaker provides a variable pitch output with changing radiation levels. A speaker control, mounted on the top of the instrument, can be used to adjust the pitch for any given level of radiation.

SECTION 2

SPECIFICATIONS

2 - 1 THRESHOLD POSITIONS

T_1 at 0.2 MEV. - measures the total count across the entire gamma energy spectrum for maximum sensitivity.

T_2 at 1.6 Mev. - measures characteristic uranium and thorium radiations.

T_3 at 2.5 Mev. - measures diagnostic thorium radiations only.

2 - 2 MEASUREMENT RANGES

Range Switch Position	Full Scale Counts
x 1	100
x 10	1,000
x 100	10,000
x 1000	100,000

2 - 3 TIME CONSTANTS

T_1 F (Fast) - 1 second

T_1 S (Slow) - 10 seconds

T_2 - 10 seconds

T_3 - 10 seconds

2 - 4 SPEAKER

A speaker is mounted in a top compartment of the instrument. The variable pitch output of the speaker is governed by the intensity of radiation and can also be adjusted by a speaker pitch control.

2 - 5 BATTERY SUPPLY

The instrument operates from two "c" size flashlight type cells, located in the handle. Ordinary zinc carbon cells may be used. From the standpoint of longer life and low temperature operation, the alkaline type should be employed wherever available.

Both the high and low voltages, generated internally to operate the instrument, are regulated to a high degree of stability. The batteries can be allowed to drop to one half of their initial voltage without any effect on the operation of the instrument.

2 - 6 SENSITIVITY

The instrument, on threshold 2, registers approximately 50 counts per minute on an in-situ measurement, (2π geometry) over homogeneous material containing 5 parts per million uranium or thorium.

2 - 7 TEMPERATURE RANGE

The instrument has been designed to operate over the temperature range of -35 to +55 degrees centigrade. Low temperatures require the use of alkaline type batteries.

2 - 8 DETECTOR CRYSTAL

The sodium iodide crystal is 1.5 inch in diameter and 1.5 inches thick. The crystal is coupled to the photomultiplier in a permanent hermetically sealed housing.

2 - 9 WEIGHT

The total wieght of the instrument is 3 pounds. (1.4 Kg)

2 - 10 DIMENSIONS

The length including rubber end guards is 13 inches. (33 cm)

The maximum height is 8 inches. (20 cm)

2 - 11 ACCESSORIES

The spectrometer is supplied with a leather belt holster, a thorium calibrating source, spare batteries and an instruction manual.

SECTION 3

GENERAL DESCRIPTION AND APPLICATIONS

The gamma ray detecting principle lies in the sodium iodide crystal. Gamma rays entering the crystal, interact with the crystal atoms, resulting in free electrons and light emission. The optically coupled photomultiplier converts the light emission to electrical pulses. The magnitudes of the electrical pulses bear a relationship to the energy levels of the intercepted gamma rays.

Various radioactive elements have characteristic gamma energy spectrums. The nature of the spectrum for a given element can be used to advantage in identifying it in the presence of other radioactive elements. Figure 1 shows spectral curves for the three main elements of interest in radioactive surveys; potassium, uranium and thorium.

Thorium emits gamma rays with energy levels exceeding 2.5 Mev. The highest energy radiation from potassium is about 1.6 Mev. The three vertical lines marked T_1, T_2 and T_3 show the location of the threshold settings of the TV-1A spectrometer after the instrument has been calibrated. Threshold T_3 at 2.5 Mev. allows only those electrical pulses to be registered whose amplitudes correspond to gamma rays with energy levels above 2.5 Mev. T_2 similarly responds to gamma energy levels above 1.6 Mev. When both thorium and uranium are

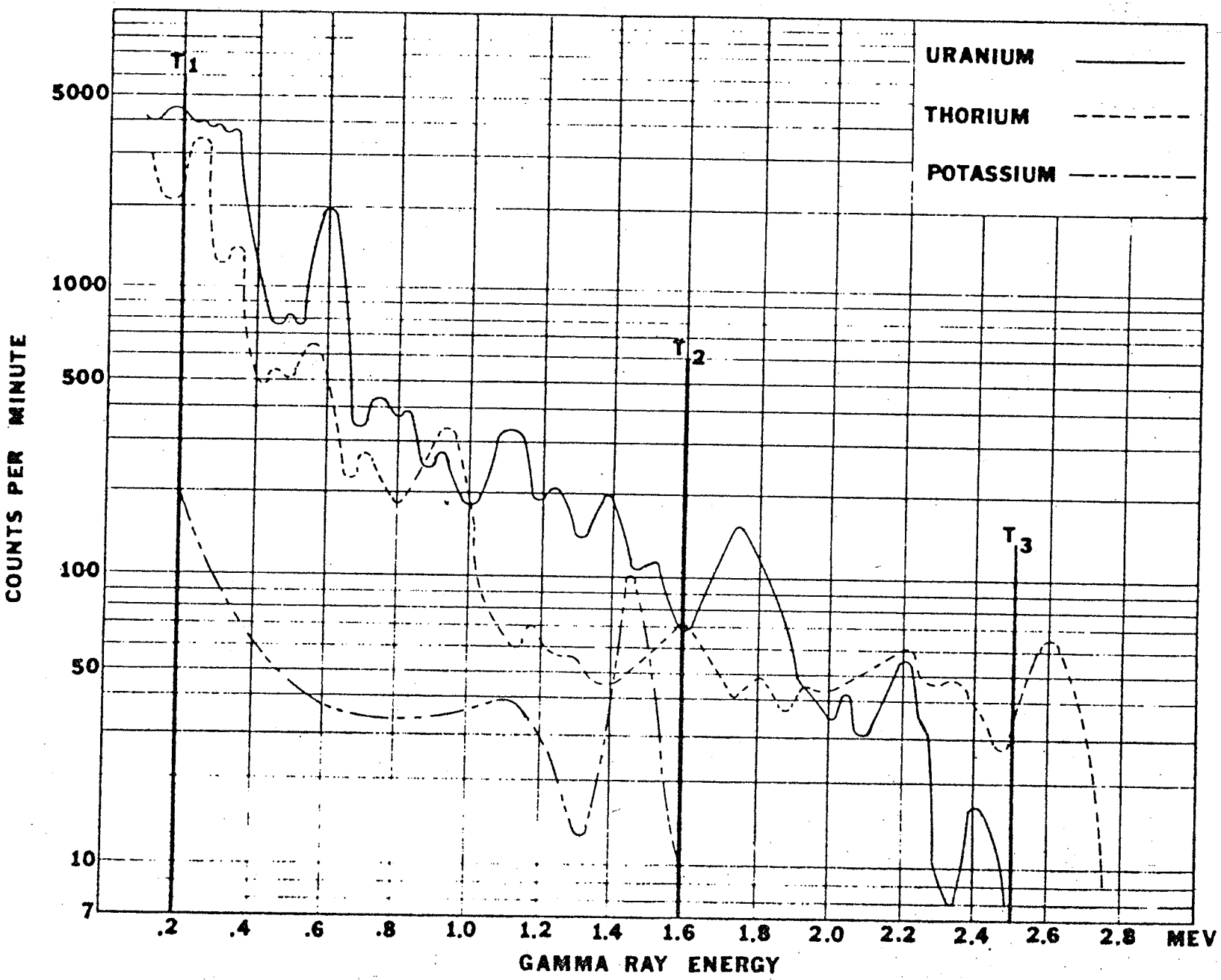

FIG-1

GAMMA RAY SPECTRA FROM NAT''RAL ORES OR THEIR CONSTITUENTS

present during a measurement, then the reading at T_2 contains counts resulting from both during a measurement, then the reading at T_2 contains counts resulting from both elements whereas T_3 contains counts from thorium only.

It is possible then, to subtract the count due to thorium in the T_2 reading, leaving the count from uranium only. The count representing thorium in the T_2 reading is a fixed multiple of the T_3 reading. In the TV-1A spectrometer, this multiple is 3.5. That is, the count in T_2 due to uranium is T_2-3.5 T_3. A thorium calibrating source and calibration procedure, provided with the instrument, ensures that this is always the case.

Once the count in T_2 has been resolved into net count for uranium, it is possible to arrive at a quantitative estimate of the material grade. This requires reference to certain conditions described in section 6-3.

SECTION 4

OPERATING INSTRUCTIONS

4-1 INSPECTION

After the instrument is unpacked, it should be carefully inspected for possible damage received during transit. If any shipping damage is detected, immediately file a claim for damage in shipment with the carrier.

4-2 CONTROLS AND THEIR FUNCTION

There are six controls on the instrument. Their functions are described below.

4-3 OFF-ON SWITCH

This is a slide switch located under the front barrel. The instrument is permanently turned on while this switch is in the on position.

4-4 TRIGGER SWITCH

This is a spring return on-off switch. Pulling the trigger will turn the instrument on. The instrument turns off when the switch is released.

Note: The trigger switch will over-ride the off-on slide switch when the slide switch is in the off position. The purpose of the trigger is to act as a battery saver when the instrument is used intermittently. The slide switch can be left in the OFF position.

4-5 METER SCALE SWITCH

This is a five position switch. Four positions are used to change the meter scale and the fifth is used to check the battery supply.

4-6 THRESHOLD SWITCH

This is a four position switch. The first two positions are used to select either the fast or slow time constant to be employed with threshold T_1. The remaining two positions select thresholds T_2 and T_3 to which the slow time constant, only, is applied.

4-7 SPEAKER CONTROL

This is a potentiometer control located at the top of the instrument. Rotation of this control performs the function of setting the sound pitch for any given radiation level. The setting of the control is at the operator's option and can be set to give zero output or a pitched

tone output at background levels. After a setting is selected, changes in repetition rate or frequency will indicate a change in background level.

4-8 CALIBRATION CONTROL

This control is concealed under the left hand vinyl covered panel. To expose the control, lay the instrument flat with the handle toward the operator and the meter to the right. Remove four panel retaining screws and note that there are two short screws and two long screws. The long screws fit the top and bottom holes. Lift the panel clear. This exposes the calibration control which is a small 10 revolution trimpot. A small screw driver is provided with the instrument to fit the adjustment screw on the potentiometer.

4-9 CALIBRATION PROCEDURE

1. Set the spectrometer on a flat surface with the calibration control facing up and the meter in an easily read position.
2. Turn the instrument ON with the slide switch.
3. Set the scale switch on the X 100 position.
4. Set the threshold switch on T_2.
5. Rest the thorium source on the barrel of spectrometer and move it forward or backward until the meter reads 90 divisions. This is 9000 counts per minute and well above the influence of any background.
6. Switch the threshold switch to T_3 and read the meter. It should read 25 divisions to have the necessary ratio of $\frac{T_2}{T_3} = 3.5$

7. If the meter does not indicate 25 divisions then adjust the calibration until a reading of 25 is obtained.

8. Return the threshold switch to T_2 and note that the T_2 reading will have changed. Shift the thorium source to again obtain a reading of 90 and again recheck T_3.

9. This is a back and forth adjustment procedure with the object of obtaining a ratio of 3.5 for T_2/T_3. The numbers of 25 and 90 are only used for convenience. Any set of figures may be used.

10. When a ratio of $\frac{T_2}{T_3} = 3.5$ is arrived at, the instrument is calibrated.

A first time calibration may appear lengthy and awkward, however, future calibrations will be considerably speeded up if the following is observed. Immediately following a calibration procedure, place the thorium source, with the small diameter side, up against the end of the spectrometer. Take a reading on T_3. Record this reading and refer to it in future calibration checks. If the future readings are high or low then calibration will be effected by adjusting the calibration control to obtain the same reading again.

SECTION 5

BATTERY TEST AND REPLACEMENT

To test the condition of the batteries, set the meter scale switch to the battery test position. Pull the trigger switch and read the meter.

Fresh batteries will read at or near full scale. When the meter reading drops below the red line, replace the batteries.

An additional feature has been incorporated into the speaker drive system such as to give an audible warning that the batteries are approaching the end of their useful life. The audible warning is in the form of an interrupted tone. When this warning tone occurs, it does not impair the operation of the instrument.

Alkaline batteries have a tendency to recover after a rest period and additional usage may be obtained if they are not discarded.

To replace the batteries, turn the knob at the bottom of the handle in a counterclockwise direction until it comes off. The batteries are now free to drop out. Insert new batteries, positive end first, and replace the battery cap.

When the spectrometer is to lay idle for a long time, remove the batteries to avoid corrosion problems which might result from battery leakage.

SECTION 6

DETERMINATION FOR URANIUM, THORIUM

6-1 EXPLANATION OF T_1, T_2 AND T_3 READINGS

Following a calibration procedure, the three thresholds are established on the gamma energy spectrum, in the positions shown in Figure 1.

T_3 is set at 2.5 Mev. and from the curves of the three elements displayed, it is noted that only thorium contains gamma radiation with energy levels above 2.5 Mev. The use of T_3 then forms the basis of a diagnostic test for thorium. The number of counts, measured under controlled conditions, can also form the basis of a quantitative evaluation for thorium.

T_2 is at 1.6 Mev. and from the curves, it is apparent that this threshold provides a diagnostic test for the presence of both uranium and thorium.

T_2 is at 1.6 Mev. and from the curves, it is apparent that this threshold provides a diagnostic test for the presence of both uranium and thorium. The number of counts due to uranium in a sample containing both is readily established by subtracting 3.5 times the T_3 counts. The difference represents the counts relating to uranium. The subtraction of 3.5 times the T_3 count is valid since this is the basis of the calibration procedure with the thorium source. The count remaining after the subtraction can further be related to the quantity of uranium (in equilibrium) that is present.

T_1 is at 0.2 Mev. and measurements with this threshold will include gamma counts from all three elements of potassium, uranium and thorium. This is the most sensitive threshold position since it includes practically the entire energy spectrum. It is common therefore to employ threshold one for general reconnaissance.

6-2 BACKGROUND MEASUREMENTS

So far, the influence of natural background radiation has not been introduced. It is recognized however, that measurements on any sample material include count contributions from background radiation. When the count yield from a sample or in-situ measurement is low, it is necessary to subtract the background count prior to any attempt at qualitative or quantitative evaluation.

For survey work, the background count on all thresholds should be recorded at an area away from any known source of radioactivity. For sample work, the background should be taken at the location of the measurement site but with radioactive samples removed to such a distance that random position changes of the samples do not influence

the general background level. In all cases, no radioactive articles, personal or otherwise, should be in the vicinity of the instrument. Background count levels are generally low and difficult to establish to any high degree of accuracy, particularly in the upper threshold settings. Extra care should be taken to measure the background. Fortunately the background does not have to be measured frequently so a longer time can be taken to arrive at a more accurate measurement. The background is recorded and subtracted from future readings. The background should be rechecked from time to time but the frequency of rechecking depends on the nature of the work.

6-3 ISOLATING URANIUM

From a sample or outcrop containing both uranium and thorium, the net count due to uranium is obtained as follows.

1. Measured background counts at $T_3 = C_{3B}$
   and background counts at $T_2 = C_{2B}$
2. Measured counts on sample at $T_3 = C_3$
   and counts on sample at $T_2 = C_2$
3. Counts at T_3 due to thorium = $C_3 - C_{3B} = C_{3Th}$
   Counts at T_2 due to thorium and uranium = $C_2 - C_{2B} = C_{2(U + Th)}$
4. Counts at T_2 due to uranium only

$$= C_{2U} = C_{2(U+Th)} - 3.5\ C_{3Th}$$

C_{2U} = Net counts per minute in threshold 2 due to uranium after the subtraction of all background and thorium counts. C_{2U} can then be applied toward a quantitative estimate of grade as per Section 6-4.

C_{3Th} = Net counts per minute in threshold 3 due to thorium after the subtraction of the background counts.

6-4 QUANTITATIVE EVALUATION

The relationship between the counts per minute obtained from radioactive material and the assay grade of the material is subject to many variables.

Among these are; geometry of the material, distribution of the radioactive elements in the material, volume, density, distance of probe to source, background changes, and equilibrium state. The most dependable method of quantitative evaluation includes the control of as many of the variables as possible by establishing fixed procedures. The measurements on test samples are then related to accurately assayed samples of preferably the same or near the same grade as the grade of the test samples. In-situ measurements are more difficult to relate because of lack of control on the source. However, several considerations can be applied to minimize the variables.

To enhance the usefulness of the instrument on initial applications, an approximate relationship between counts per minute and grade is tabulated below. The operator is cautioned to use these as approximations only until verification with assayed samples can be obtained. Assumption is made that the uranium is in equilibrium.

TEST CONDITIONS

5 lb. Sample: The diameter of the container containing 5 lbs. of crushed material was 4-1/2 inches.

The probe was brought into contact with material through the top of the container.

In-Situ

The readings shown in the in-situ column were extrapolated from the approximate emperical relationship between hand samples and the same material of homogeneous consistency in-situ, as follows:

5 lb. Sample (probe in contact with sample material	2π Geometry (probe in contact with flat outcrop of the same material)	4π Geometry (probe recessed in ground so crystal is considered completely covered)
1 c. p. m.	10 c. p. m.	20 c. p. m.

GRADE LEVELS (Parts per million)

Uranium p.p.m.	T_2 c.p.m. 5 lb. sample	T_2 c.p.m. 2π Geometry	Thorium p.p.m.	T_3 c.p.m. 5 lb. sample	T_3 c.p.m. 2π Geometry
10	5	50	10	-	15
100	50	500	100	15	150
1,000	500	5,000	1,000	150	1,500

T_2 = net counts for uranium = C_{2U} (Section 6-3)

T_3 = net counts for thorium = C_{3Th} (Section 6-3)

SECTION 7

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INTERNAL INSPECTION
OF INSTRUMENT

Where it is necessary to examine the instrument internally the following procedures can be used to get at any part of the instrument.

The instrument is laid out in three sections. The main section is contained in the square tube and contains all the components and circuits important to the operation of the instrument. The speaker and speaker drive circuits are housed in the top compartment. The batteries and off-on switches are located in the lower or handle section.

To remove the main section lay the instrument flat and remove the panel concealing the calibration control. This also exposes a plug through which the battery and speaker connections are made. Carefully pull out the plug. This removes all electrical contact to the internal circuits. Next unscrew four studs which act as stops for the threshold switch and the meter scale switch. Slide off the rubber meter guard and lift the engraved escutheon or dial plate. Remove the rubber seal by lifting it out of position. Now, by grasping the two switch shafts at the threaded areas, pull towards the meter end. All the internal components are mounted on a tray and the tray will slide completely out of the tube.

To inspect the top and bottom compartment it is necessary to remove six screws that are exposed when the vinyl panel is removed. The instrument is then turned over on the other side and six additional screws are removed after lifting the vinyl panel. All parts of the spectrometer have now been exposed.