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RECONNAISSANCE OF RADIOACTIVE ROCKS OF MAINE

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GEOLOGY AND MINERALOGY

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RADIOACTIVE ROCKS OF MAINE

By

John M. Nelson and Perry F. Narten

ABSTRACT

The state of Maine was traversed with car-mounted Geiger-Mueller equipment in the late summer of 1948 and the radioactivity of approximately 4,600 miles of road was logged.

All samples were analyzed, both in the field by comparing the radioactivity of each sample to the radioactivity of a standard measured with a simple scaling modification of a portable counter, and in the Geological Survey's Trace Elements Section Washington Laboratory. Differences between both types of analyses were negligible. The maximum equivalent uranium content of the most radioactive rocks thus analyzed was 0.008 percent. A 1,400-square-mile abnormally radioactive province in southwestern Maine was outlined.

The outcrop data obtained from car traversing are evaluated statistically. Cumulative frequency distribution curves are drawn to show the distribution of outcrops at various levels of radioactivity, and straight-line extensions are made to show the maximum probable grade for various rock types and areas in Maine. A maximum grade of 0.055 percent equivalent uranium is thus predicted for the entire state. This prediction necessarily is a broad generalization because large areas of Maine are inaccessible for car traversing. A concept of evaluation of an area for possible mineral deposits is proposed on the basis of lithology, and of observed and indicated ranges in grade.

INTRODUCTION

The state of Maine has a total area of 33,000 square miles and is underlain by igneous, sedimentary, and metamorphic rocks of many kinds. Recorded information on the radioactivity of these rocks is limited to published and unpublished statements that minerals containing uranium and thorium occur in noncommercial quantities in some of the pegmatites in the state. In order to obtain a better knowledge of the distribution and variation of radioactivity in Maine, a U. S. Geological Survey field party, using suitable radiometric equipment, systematically scanned about 4,600 miles of roadside rocks, soils, and glacial materials (fig. 1). This work was done on behalf of the U. S. Atomic Energy Commission.

The field party, consisting of J. M. Nelson and P. F. Narten, worked from August 11 to September 9, 1948, at which time Narten left the project. Nelson completed the project on October 28. Much of the compilation and the illustrations were made by R. H. Stewart. The authors are indebted to S. G. Lasky, W. G. Schlecht, J. B. Mertie, Jr., W. A. Guinan, A. P. Butler, Jr., and J. H. Eric for their suggestions and criticisms of the statistical methods that are used.

PROCEDURE AND FIELD EQUIPMENT

The roads traversed were selected so that the radioactivity of the largest number and variety of rocks could be examined in the time allotted to the work.

As the bedrock over much of the area is covered by glacial debris and outcrops therefore are scarce, the lithology, radioactivity, and location of almost all roadside outcrops passed in the car traversing were recorded in order to get as much quantitative data as possible.

These records were kept in notebooks when two men were present and were recorded on a Soundscriber when the party consisted of one man. Rocks showing abnormal _/ radioactivity were examined on foot using portable survey meters, and the more radioactive parts were sampled. Samples of rocks containing less than 0.003 percent equivalent uranium also were collected to evaluate the radioactivity recorded as the car passed the outcrops. No detailed geologic studies were attempted because even the most radioactive rocks were of low grade.

The car-mounted radiometric equipment used in this work consisted of a gamma-ray Geiger tube mounted horizontally on either side of a sedan delivery truck parallel to the long axis of the vehicle. Each Geiger tube is 42 inches long and 2 inches in diameter and will count about 1,500 pulses per minute in an environment of what we shall call "normal radioactivity". The two tubes are connected in parallel to a portable survey meter (Victoreen Model 263A). Changes in the roadside radioactivity are indicated by the microammeter of the instrument. This equipment is sufficiently sensitive to distinguish differences of about 0.001 percent equivalent uranium content in rocks that are exposed for 50 linear feet or more along the traverse route. An alarm circuit was installed that could be adjusted to trigger at any desired ratemeter reading. This device was used to announce abnormal radioactivity, thus permitting the observer to study the roadside rocks, record data, and follow the route and geology on maps. The car-mounted equipment is described in greater detail in another report. _/

_/ Abnormal radioactivity in this report refers to an equivalent uranium content of 0.003 percent or more.

The calibration of the car-mounted equipment and percent equivalent uranium is shown on the scales of the abscissas of figures 3 to 6, and was established by comparing the analytical data obtained from samples of the outcrops to ratemeter readings on the same outcrops. The comparative values apply only to the particular instrument used for the field work in Maine. The use of other instruments, or similar field work in higher areas with the same instrument, would require redeterminations of the correlation between ratemeter readings and percent equivalent uranium. The correlation between grade and ratemeter readings is necessarily based on average values because the size, shape, and distance of the outcrop from the instrument are variable. It will be noted that the scale of equivalent uranium is not linear but varies according to the power law ($y=ax^n$). This nonlinearity is caused by the nonlinear response of the recording instrument used in this field work.

Portable survey meters, equipped with one of the 42-inch gamma tubes or a small beta-gamma tube, were used for foot-traverses and examinations of outcrops prior to sampling. All instruments were checked against a radioactive standard before and after use each day.

Analyses for equivalent uranium of all samples were made in the field using a simple neon scaler attached to a portable counter, a radioactive standard, and a sample container, all designed for the field. The circuit of the neon-scaling attachment to the portable survey meter by which the frequency of the pulses is scaled down to a number that can be conveniently counted is shown in figure 2. These field radiometric analyses served as an immediate check on the materials examined and on the operation of the

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_/ Nelson, J.M., Prospecting for uranium with car-mounted equipment: Trace Elements Investigations Rept. 65, July 1949.

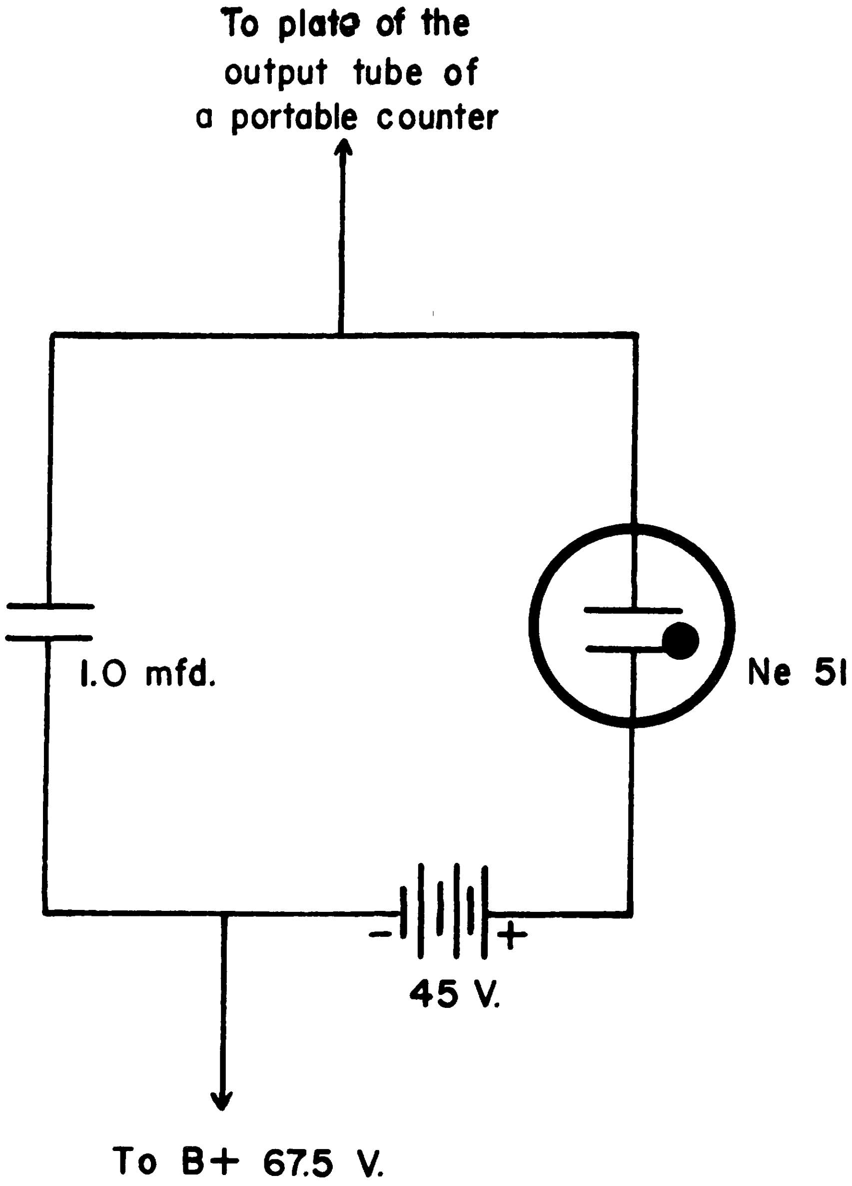

FIGURE 2.— CIRCUIT DIAGRAM OF THE NEON-SCALING ATTACHMENT USED ON A PORTABLE COUNTER.

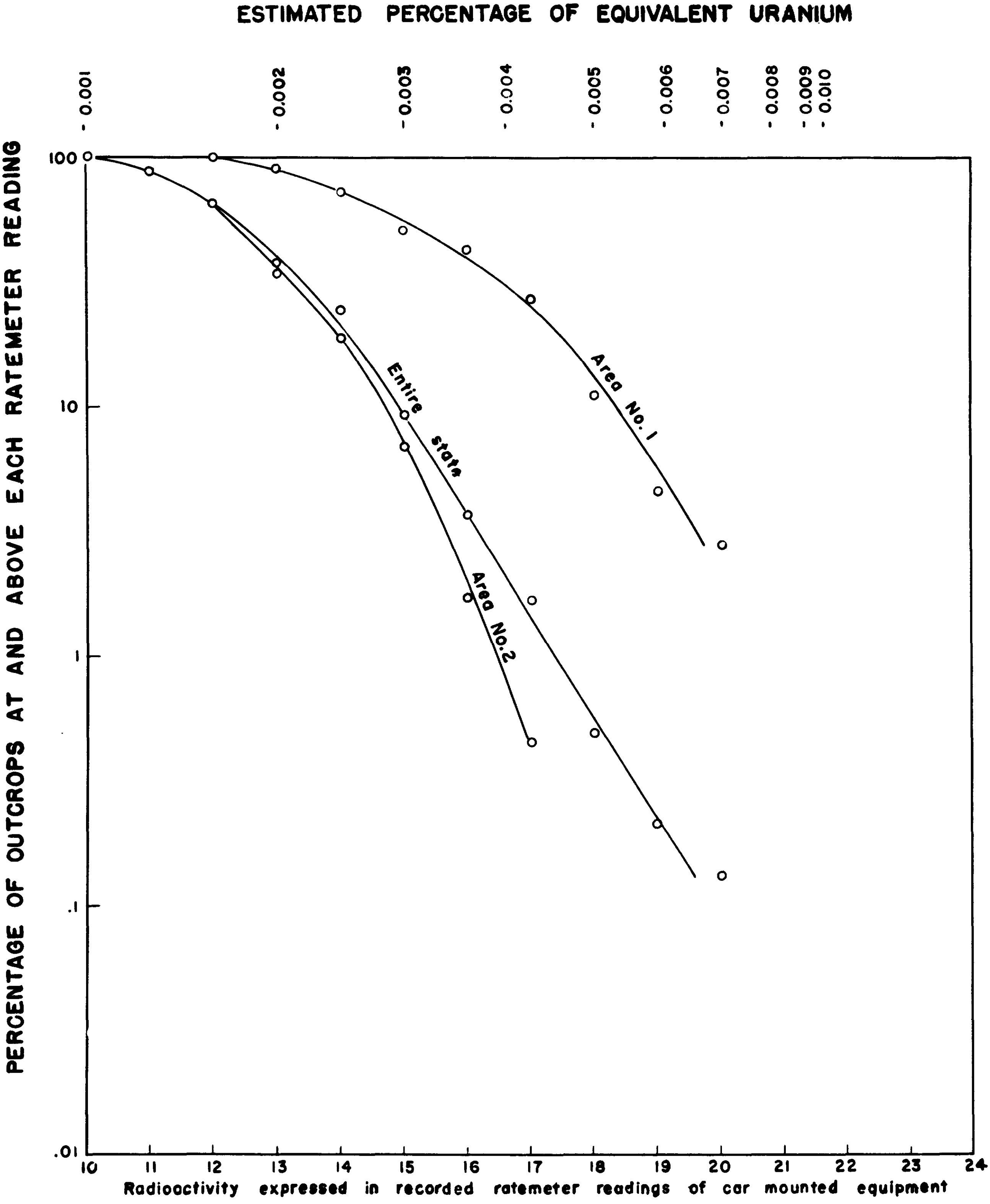

FIGURE 3.- CUMULATIVE FREQUENCY DISTRIBUTION CURVES OF OBSERVED RADIOACTIVITIES IN PARTS OF MAINE

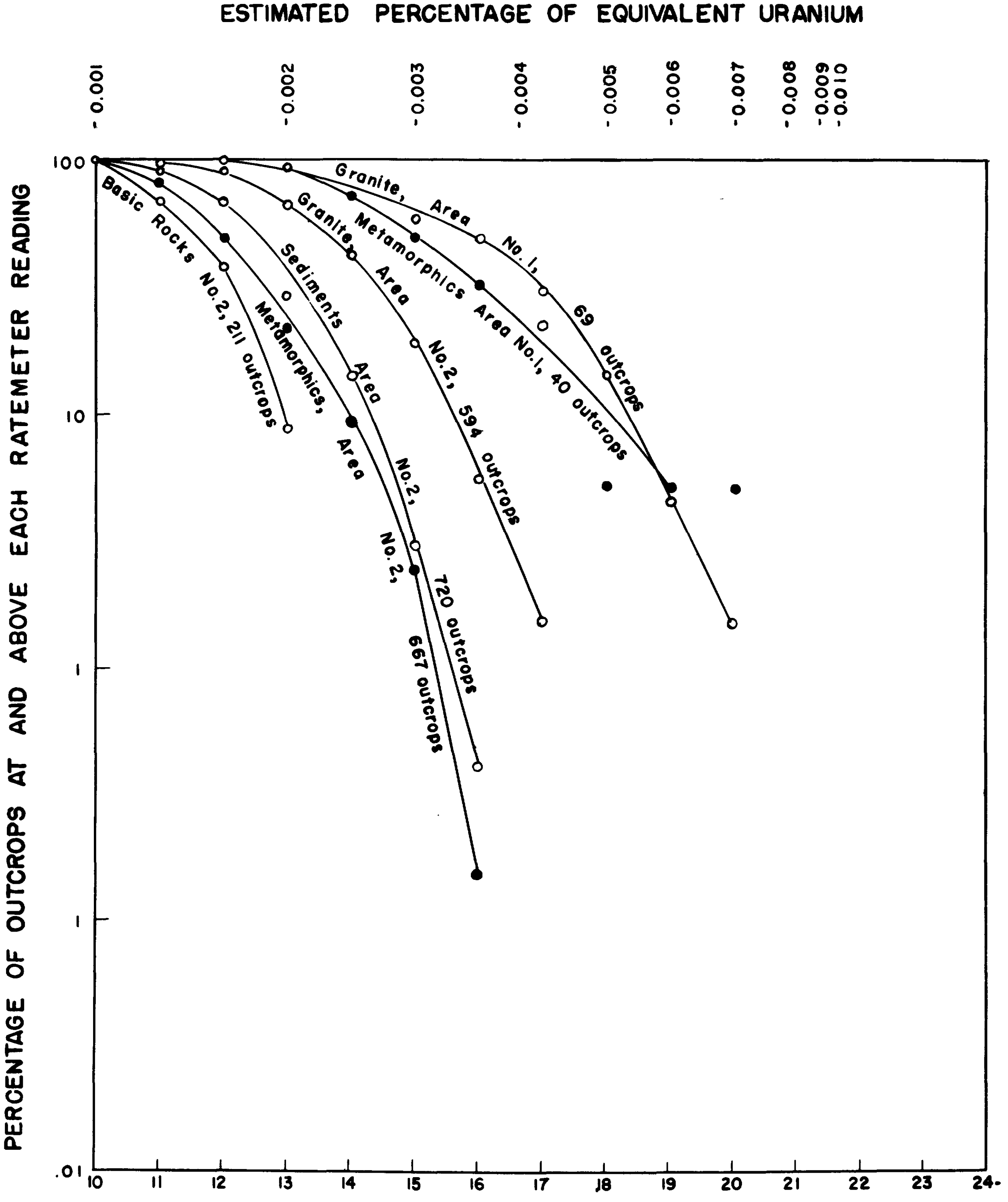

FIGURE 4.- CUMULATIVE FREQUENCY DISTRIBUTION CURVES OF OBSERVED RADIOACTIVITIES IN SEVERAL ROCK TYPES IN MAINE

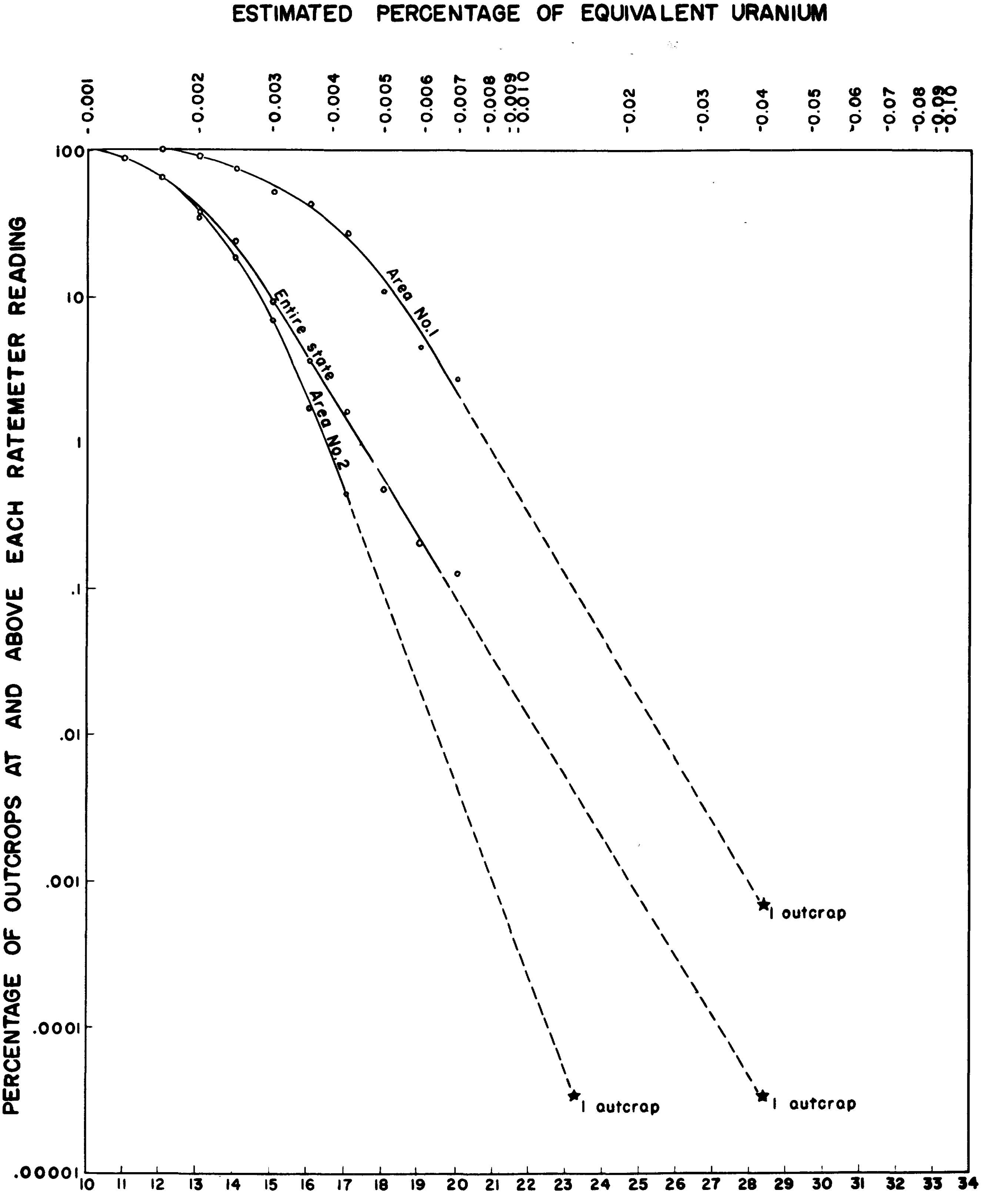

FIGURE 5.- CUMULATIVE FREQUENCY DISTRIBUTION CURVES OF PROBABLE RADIOACTIVITIES IN PARTS OF MAINE

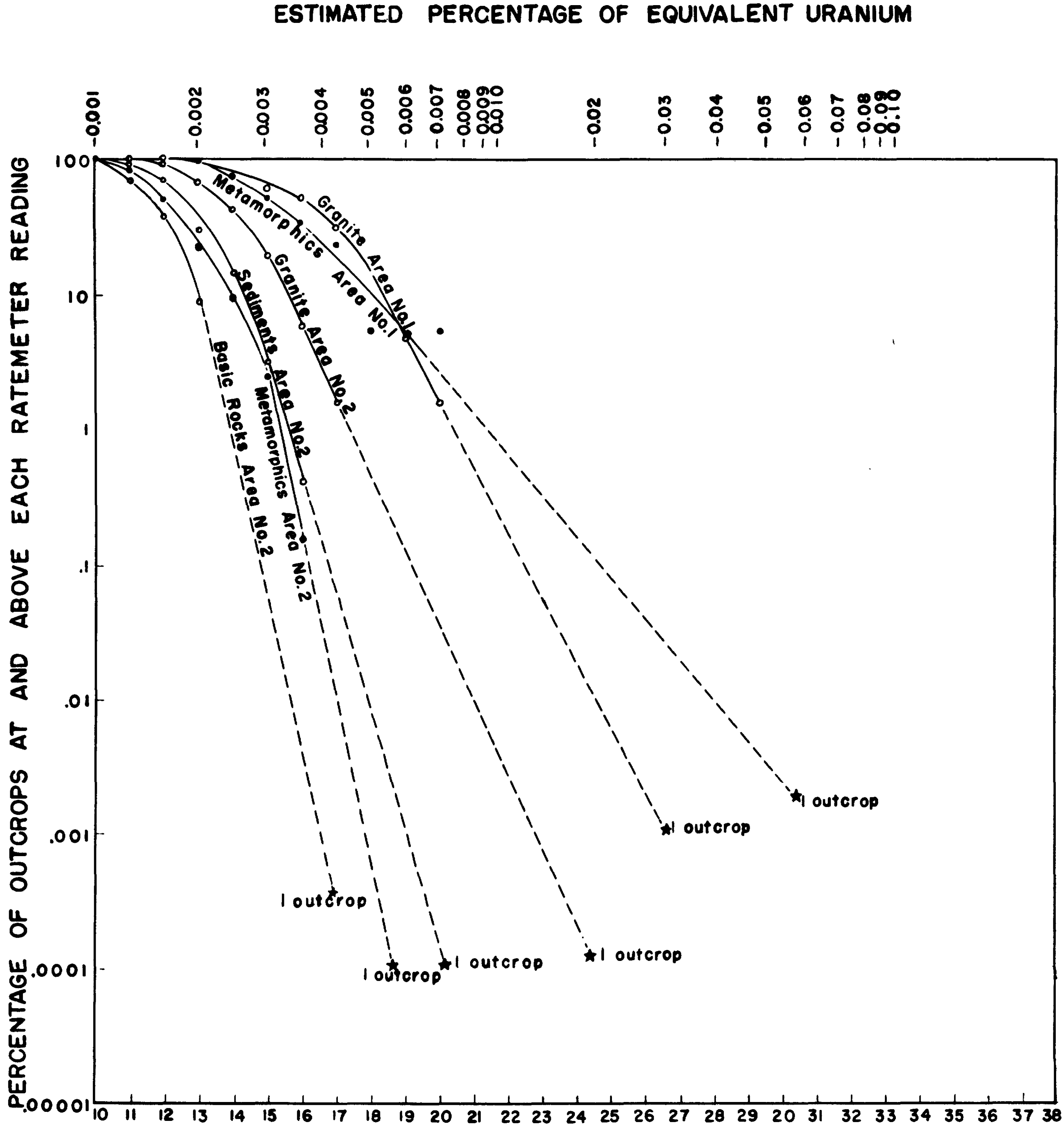

FIGURE 6.- CUMULATIVE FREQUENCY DISTRIBUTION CURVES OF PROBABLE RADIOACTIVITIES IN SEVERAL ROCK TYPES IN TWO AREAS IN MAINE

car-mounted Geiger tubes. The samples were also analyzed for equivalent uranium and uranium by the Geological Survey's Washington Laboratory at the end of the field season. Comparison of the field and laboratory analyses for equivalent uranium content for 22 samples (table 2) shows that the maximum difference is 0.002 percent equivalent uranium.

The standard used in calibrating the neon scaler was made by thoroughly mixing an essentially nonradioactive cement with a small amount of pitchblende which had been ground to minus-200 mesh. Then nonradioactive colored pigment was thoroughly mixed with the cement for identification purposes, and the cement was cast. The hardened cement was ground to pass through a 1/8-inch screen, the fines winnowed, and analyzed in the laboratory for equivalent uranium. The resulting standard contained about 0.015 percent equivalent uranium and showed no measurable change in two years.

The sample container for field analyses was made from a brass cylinder 6½ inches high and 2-3/4 inches in diameter, in the center of which was mounted a thin-walled beta tube. This sample container and tube had a sensitivity of about 38 pulses per minute per 0.001 percent equivalent uranium and a background of about 30 pulses per minute in Maine. A one-minute count thus was sufficient to analyze a sample containing 0.002 percent equivalent uranium with an accuracy of ± 0.001 percent equivalent uranium.

The samples were first crushed in a portable jaw crusher to the approximate size of the standard and poured into the container. Ten consecutive one-minute counts were recorded and averaged, and the results compared directly with results obtained for the standard sample. The background count was subtracted from the unknown sample and standard sample counts when comparing them, and was determined before and after any material was poured into the container.. The background counts also served as a check on the operation of the Geiger tube and on the cleanliness of the container.

GEOLOGY AND RADIOACTIVITY

General

According to Keith _/ the coastal belt and the western border of Maine consist largely of pre-Cambrian mica gneisses and schists, cut by many pegmatities, and intruded by pre-Cambrian, Devonian, and Carboniferous granitic rocks. Fisher _/ has assigned an early Paleozoic age to the metamorphic rocks and a late Paleozoic age to the granitic rocks in the Lewiston region. The remainder of the state, according to Keith, is underlain by middle and upper Silurian argillaceous sedimentary rocks with bands of northeasterly striking Lower and Middle Devonian and Cambro-Ordovician sedimentary rocks. Mississippian sedimentary rocks occur only in two areas, one in the northeastern part and the other in the most eastern corner of the state along the coast. Pennsylvanian sedimentary rocks in the southwest corner of the state are the youngest rocks exposed. All the Paleozoic sedimentary rocks have been subjected to varying degrees of metamorphism ranging from low-to high-grade, and have been intruded by widely scattered Silurian diabase, Devonian volcanics, and Carboniferous granites._/. Mafic dikes of Triassic age were mapped by Fisher._/.

_/ Keith, Arthur, Preliminary geologic map of Maine, Maine Geol. Survey, map, scale 1/1,000,000, 1933.

_/ Fischer, L. W., Structure and metamorphism of Lewiston, Maine, region: Geol. Soc. America Bull., vol. 52, Pl. 1, p. 153, 1941.

_/ Keith, op. cit.
_/ Fisher, op. cit.

Uraninite and other uranium-bearing minerals have been described in many publications on the pegmatites of Maine, but the occurrences probably are of mineralogic rather than economic interest. As an example, a square yard of pegmatite surface, showing a uranium mineral which is 1/4-inch square and containing 40 percent uranium, would have a radioactivity attributable to the mineral of only 0.002 percent equivalent uranium per square yard. Such a pegmatite surface might prove profitable to a mineral collector, but not to a mine operator.

The state is divided into two areas on the basis of radioactivity (fig. 1, red numbers 1 and 2).

Area 1 is an abnormally radioactive area of approximately 1,400 square miles extending from Lewiston westward to New Hampshire. Keith mapped the rocks as pre-Cambrian gneisses and schists much intruded by pegmatites and granites _/, but more detailed work by Fisher and Hanley indicates a Paleozoic age _/. Glacial materials cover most of the bedrock, and roadside observations were made only on 128 rock outcrops. The rocks in these outcrops are estimated to contain from 0.001 to 0.008 percent equivalent uranium and to average 0.0035 percent equivalent uranium. The maximum uranium content of the eight samples (table 2) from Area 1 is only 0.003 percent. The difference between equivalent uranium and uranium content of the rocks would suggest that thorium might be present in the order of 0.0X percent; chemical analyses of three of the samples, however, show a maximum content of only 0.004 percent thoria. Analysis for radium made on one sample of granite (No. *152) indicates that the sample is out of equilibrium. No additional laboratory tests have been made to determine whether or not

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_/ Keith, Arthur, op. cit., map

_/ Fisher, L.W., op. cit.
_/ Hanley, J.B., Personal communication.

other samples are out of equilibrium.

Area 2, comprising the rest of the state, is essentially normally radioactive. Granitic rocks containing a maximum of 0.005 percent equivalent uranium were found sporadically within the 40-mile-wide coastal belt of pre-Cambrian rocks and later intrusives. In the remainder of the traversed portions of the state, only nine localities contained "abnormally" radioactive rocks. Samples from the most radioactive of these localities contained only 0.004 percent equivalent uranium as determined by field analysis.

A study of Keith's map _/ and observations of roadside outcrops suggest that small granitic stocks are most abundant in Area 1, and a rough correlation exists between the amount of radioactivity and the areas where the granitic intrusions are most numerous. The abnormally radioactive areas containing abundant granitic intrusions form a belt that extends in a west-northwesterly direction to the Canadian border _/. The trend of this belt is across the strike of the intruded metamorphic and sedimentary units. Granitic intrusions, which occur in the costal belt of Area 2, are generally much larger and the coastal belt is less radioactive. The remaining portion of Area 2 has the fewest granitic intrusions and is the least radioactive.

The relationships outlined in the proceeding paragraph suggest that the probability of finding concentrations of radioactive minerals will be greatest in areas containing a large number of small granitic intrusions. Such relationships might be partially explained by assuming that the additional heat generated by the radioactive elements would cause an intrusive body to

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_/ Keith, Arthur, op. cit.

_/ McKeown, F. A., Reconnaissance of radioactive rocks of Vermont, New Hampshire, Connecticut, Rhode Island, and southeastern New York: Trace Elements Investigations Rept. 67, July, 1951.

stay fluid longer and thus enable it to rise higher in the intruded rocks. This concentration of the radioactive elements in granitic rocks could be the result of magmatic differentiation, the formation in place from rocks orginally high in radioactive components, or a combination of these factors. Ingham and Keevil,_/ in a detailed study of the radioactivity of some Canadian granitic batholiths, have described the concentration of radioactivity on the outer margins of intrusions and hypothesize a similar role for the associated radiogenic heat contribution.

The above explanation is recognized as "possible" rather than "probable" as the other factors that influence the formation of granitic intrusions are unknown, such as depth of burial, sub-crustal heat supply, stress, and lithology. The suggested relations, however, do seem to apply to the more radioactive parts of the Bear Mountain area of New York, and the northwestern Adirondacks, and these relations may be worthy of further consideration.

The areas that contain high-grade metamorphic rocks tend to be more radioactive than areas containing low-grade metamorphic rocks. The most radioactive metamorphic rocks found in Maine are the high-grade gneiss and schist in the area west of Lewiston. The widespread exposures of slate in northern Maine, in comparison, exhibited the lowest average radioactivity.

Table 1 lists the location, estimated radioactivity, and observed and mapped rock types of all localities showing "abnormal radioactivity" (0.003 percent equivalent uranium or more).

Table 2 is a list of sampled localities and the analytical results.

_/ Ingham, W. N., and Keevil, N. B., Radioactivity of the Bourlamaque, Elzevir, and Cheddar Batholiths, Canada: Geol. Soc. America Bull., vol. 62, no. 2, p. 147, 1951.

Statistical evaluation

The outcrop data obtained from the car-traverse method and consisting of the radioactivity, lithology, and location of each outcrop are amenable to a partial statistical evaluation. Although the available data cannot validly be used rigorously to compute the standard deviations of the separate and composite variables, the cursory treatment given them here suggests the possibility of predicting the probable upper limit of radioactivity in an area or in a particular rock type.

The percentage or fraction of outcrops with equivalent radioactivities above a given value are plotted as a cumulative frequency distribution curve; the curves for the total outcrops examined in Areas 1 and 2, and for granites, metamorphic, sedimentary (includes low-grade metamorphic) and mafic rock types are shown in figures 3 to 6. These curves are drawn to fit the observed ratemeter response of the car-mounted Geiger tubes so that both the observed and extended portions of the curves are based upon these ratemeter responses.

On the basis of radioactivity of the observed outcrops, the state is divided into two areas (fig. 1). In Area 1 the average radioactivity of the granitic and metamorphic rocks is much higher than that of similar rocks of Area 2 (fig. 4). It is also evident from figure 4 that the granites have the highest radioactivity in their respective areas. The slope of the higher-grade portion of the granite curve in Area 1, however, is steeper than the corresponding slope of the metamorphic curve. From the steepness of slope, it is inferred that granitic rocks in Area 1, although they have the highest bulk content of radioactive elements, are least likely, and the metamorphic rocks are most likely, to contain high-grade deposits.

The sedimentary rocks (with which have been included the low-grade metamorphic rocks) and the mafic rocks are present in Area 2 but are very rare in Area 1. Figure 6 shows that the sedimentary rocks are slightly more radioactive than the high-grade metamorphic rocks in Area 2. The slope of the extended portion of the sedimentary rock curve also is less steep than that of the metamorphic rock curve and therefore, the sedimentary rocks may be considered more favorable hosts for radioactive elements. The mafic rocks have the lowest average radioactivity and the slope of the curve indicates a low probability for the mafic rocks to be a host for radioactive elements.

Similar curves have been constructed for glacial material _/ in both Area 1 and Area 2, but are not included here because of their erratic character. However, the radioactivity of glacial materials is of about the same general magnitude as that of the rock in the areas (fig. 3) where they are found. It would thus seem that the glacial debris from the eroded rocks of Maine has not been transported great distances.

The probable number of outcrops of a specific grade can be calculated for each rock type in an area or in those portions of an area for which sufficient control data are available. The mechanics of such calculations are similar to those used in estimating ore tonnages of any grade from a distributed number of samples. The accuracy of such calculations depends upon two factors: (1) how representative of the whole are the samples, and (2) what portion of the whole was sampled.

In applying such calculations to the state of Maine, it must be assumed that the size of outcrops was uniform and that the coverage of roads was equal for the entire state. The relative geometry of each outcrop is not known. Each observed outcrop was considered regardless of its size; the

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_/ All areas of no outcrop were termed "glacial" as regolithic material probably represents only a small fraction of the soils and overburden of Maine.

very long outcrops in general were subdivided arbitrarily on the basis of length and lithology. Although such nonselection of outcrop size disregards the effective area scanned by the Geiger counters, it is thought that the outcrops are generally representative of rock type and area.

The density of road coverage per unit area is roughly twice as great in Area 1 as in Area 2, and even greater differences in density of road coverage exist within Area 2. Several methods of weighting the number of outcrops and length of traverse for each area were attempted, but the nature of the field data would make any method inherently faulty. The net effect of weighting by these various methods was to change the probable number of outcrops shown in table 3. The predicted highest grade was not changed significantly. For the purpose of simplicity of illustration, therefore, the same factor (1/1,300) is used for the entire state.

The ratio of the area radiometrically tested to the total area of Maine is approximately 1/1,300. _/. Insofar as the tested area is representative of Maine, the number of outcrops of each grade in the tested area multiplied by 1,300 gives the probable number of such outcrops for the entire state. It is unlikely that the most radioactive outcrop is among those recorded. The probable number of outcrops of any higher grade then those recorded is estimated by extrapolation of the distribution curves shown in figures 3 and 4. Figures 5 and 6 are extrapolated curves.

The curves are extended as straight lines because they approach straight

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_/ The practical effective range of car-mounted equipment has been checked many times and is estimated to be 15 feet on either side of the center of the car. This is an average traverse width of 30 feet or 1/176 mile. The average traverse width multiplied by the traverse length, 1/176 x 4,600 miles, indicates that approximately 26 square miles have been tested. The ratio of the tested area, 26 square miles, to the area of the state, 33,000 square miles, is approximately 1/1,300.

lines in the portion of the highest recorded radioactivities. Mathematical expressions for these curves could be derived but the nature of the recorded data do not warrant such treatment.

In figures 5 and 6, the curves are extended to a point representing a single outcrop. The ordinate representing a single outcrop is obtained by multiplying the reciprocal of the probable number of outcrops in any curve by 100 to yield percentage _/.

_/ Example: Granite curve, Area 1, figure 6-

Observed number of outcrops	69
Probable number in Area 1 (69 x 1,300)	89,700
Calculation, (1/89,700 x 100)	0.0011%

Thus one outcrop of granite is represented at an ordinate value of 0.001 percent, and the ratemeter value at the intersection of the curve with this ordinate value is about 26.5.

The observed and probable number of outcrops with respect to areas and rock types are shown in table 3. The radioactivity is expressed both in ratemeter units, as recorded in the field, and in the estimated percent equivalent uranium.

Table 2 shows that the most radioactive outcrops sampled in Maine contain a maximum of 0.008 percent equivalent uranium, 0.003 percent uranium, and 0.004 percent thoria. Projections of the curves in figure 6 show that the most radioactive outcrop in the state probably contains only about 0.055 percent equivalent uranium. These maxima of grades are too low to be of economic interest. This technique, however, can be applied to any area to determine the highest grade of radioactive material to be expected, thus evaluating the area economically. For example, this technique was used in the Bear Mountain Area, New York. Projections of curves from data collected at Bear Mountain, where roadside outcrops have been found to contain as much as 0.033 percent equivalent uranium, indicate that outcrops may be found in the area which will contain 0.X percent equivalent uranium.

SUMMARY AND CONCLUSIONS

The most radioactive outcrops sampled in Maine contain a maximum of 0.008 percent equivalent uranium, 0.003 percent uranium, and 0.004 percent thoria. From a statistical study it can be shown that there may be 1,300 such outcrops and that the most radioactive outcrop in the state has a probable content of only 0.055 percent equivalent uranium.

Although the areal survey for radioactive materials in Maine was disappointing because no high-grade deposits were found, the car-traverse method proved again to be a valuable tool in rapidly scanning a large area in a short time. At the same time, this field technique also provided sufficient data to indicate that statistical treatment of properly controlled radiometry may be used to evaluate an area or rock type.

In conclusion, a statistical approach has been used to study the distribution of radioactive materials in an area, whereby the area is evaluated economically on the basis of observed and indicated ranges in grade rather than on the basis of average grade. This method is applicable either to an economic or scientific study of an area, to a geologic province, or to a lithologic or structural unit. It is best suited, however, to areas where the radioactivity is higher than that exhibited in Maine. The ranges in grade of radioactive rocks determine the shape of the distribution curves, but the slope of these curves is the most significant factor in an economic appraisal of the material or area.

Table 1.—Log of localities estimated to contain 0.003 percent equivalent uranium (eU) or more, and all sampled localities.

Observed rock types	Age and rock type as mapped*	Estimated equivalent uranium (percent)	Location	Remarks
Granite	Pre-Cambrian to Upper Paleozoic granite 1/	0.003	3.7 miles north of East Lebanon on unnumbered highway to Milton Mills.	
Porphyry	do.	0.003-0.004	3.9 miles north of East Lebanon on unnumbered highway to Milton Mills.	
Granite	do.	do.	4.8 miles north of East Lebanon on unnumbered highway to Milton Mills.	
Glacial	Granite 1/ Pennsylvanian sediments, shale, sandstone, conglomerate, quartzite, etc. 5/	0.003	5.3 miles northwest of Springvale on Highway 109.	
Granite	Pre-Cambrian to upper Paleozoic granite 1,5/	0.002-0.003	3.2 miles northwest of Springvale on Highway 109.	
Granite	do. 1,5/	do.	2.3 miles northwest of Springvale on Highway 109.	
Granite	do. 1,5/	0.003	Outcrop in Springvale.	

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* It is recognized that references to the geology obtained from small-scale maps are necessarily very general and that in many places local geology may differ markedly.

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Gneiss	Pre-Cambrian gneiss & schist 1/	0.003	Outcrop in Limerick.	
Glacial	do.	do.	2 miles southwest of Limerick on Highway 11.	
Gneissic rocks	do.	do.	5.2 miles southwest of Limerick on Highway 11.	
Glacial	do.	0.003-0.004	5.7 miles southwest of Limerick on Highway 11.	
Do.	do.	0.002-0.004	8.2 miles southwest of Limerick on Highway 11.	
Do.	do.	0.005-0.006	8.7 miles southwest of Limerick on Highway 11.	
Glacial	Pre-Cambrian to Upper Paleozoic granite 1/	0.006	2.3 miles west of West Newfield on Highway 110.	
Do.	do.	0.003-0.005	From junction of Highway 153 and 110, 2.9 miles west of West Newfield northward on Highway 153 to Effingham.	
Do.	do.	0.003-0.004	4.5 miles west of Kezar Falls on Highway 25.	
Do.	do.	0.002-0.004	2.6 miles west of Kezar Falls on Highway 25.	

Table 1.—(Continued)

Observed rock type	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Glacial	Pre-Cambrian gneiss and schist 1/	0.003-0.005	4.2 miles north of Kezar Falls on Highway 160.	
Do.	do.	0.001-0.005	4.2 to 6.0 miles north of Kezar Falls on Highway 160.	
Granite and pegmatite	Pre-Cambrian to Upper Paleozoic granite 1/	0.003	7.6 miles north of Kezar Falls on Highway 160.	
Do.	do.	0.003-0.004	9.7 miles north of Kezar Falls on Highway 160.	
Glacial	do.	0.002-0.004	0.1 miles east of Cornish at junction of Highways 5 and 25.	
Do.	do.	0.002-0.005	2.1 miles east of Cornish at junction of Highways 5 and 113.	
Do.	do.	0.002-0.003	6.5 miles east of Cornish on Highway 11, 0.1 miles north of junction of Highways 11 and 113.	
Do.	Pre-Cambrian gneiss & schist 1/	do.	At Hiram.	
Do.	do.	do.	3.1 miles east of Hiram on unnumbered road to Sebago.	
Do.	do.	do.	4.5 miles east of Hiram on unnumbered road to Sebago.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Granite	**Pre-Cambrian to Upper Paleozoic granite 1/**	0.003	1.2 to 2.0 miles north of Hiram on Highway 117.	
Glacial	do.	0.002-0.003	Brownfield to East Brownfield on Highway 160.	
Do.	do.	0.002-0.005	East Brownfield to Fryeburg on Highways 5 and 113.	
Granite	Pre-Cambrian gneiss & schist 1/	0.003	4.7 miles northwest of East Brownfield on Highways 5 and 113.	
Road metal	do.	do.	Fryeburg west to Conway, N.H., on Highway 302.	
Granite and pegmatite	Pre-Cambrian to Upper Paleozoic granite 1/	do.	1.8 miles east of Fryeburg on Highway 302.	
Glacial	do.	0.002-0.005	Fryeburg to Bridgton on Highway 302.	Granite in west; gneiss and schist in east; road metal up to 0.008% eU.
Do.	**Pre-Cambrian gneiss & schist 1/**	0.001-0.003	1 mile south of Lovell on Highway 5.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Glacial	Pre-Cambrian gneiss and schist 1/	0.002-0.003	At North Fryeburg.	
Pegmatite, and gneiss	do.	0.003-0.004	0.4 miles north of Stow on Highway 113.	
Gneiss	do.	0.002-0.003	9.0 miles north of Stow on Highway 113.	
Gneiss, and pegmatite	do.	do.	9.3 miles north of Stow on Highway 113.	
Gneiss, and schist	do.	0.003-0.004	10.4 miles north of Stow on Highway 113.	
Do.	do.	do.	10.5 miles north of Stow on Highway 113.	
Phyllite schist, and pegmatite	do.	0.003-0.005	10.7 miles north of Stow on Highway 113.	
Gneiss, and schist	do.	0.003-0.004	11.0 miles north of Stow on Highway 113.	
Do.	do.	0.004-0.007	11.2 miles north of Stow on Highway 113.	
Dark gray gneissic rock	do.	0.002-0.003	13.0 miles north of Stow on Highway 113.	

Table 1.--(Continued)

Observed rock types	Age and Rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Gneiss, schist, and pegmatite	Pre-Cambrian gneiss and schist 1/	0.003-0.004	15.9 miles north of Stow on Highway 113.	
Do.	do.	0.003	17.1 miles north of Stow on Highway 113.	
Crystalline	do.	0.002-0.003	18.9 miles north of Stow on Highway 113.	
Glacial	do.	0.001-0.003	6.0 miles of road from Gilead to North Bethel on Highway 2.	
Metamorphic	do.	0.003	2.5 to 2.6 miles west of West Bethel on Highway 2.	
Granite, pegmatite, lime silicate rocks	Pre-Cambrian to Upper Paleozoic Granite 1/	0.002-0.003	6.3 miles northwest of North Newry on Highway 26.	
Glacial	do.	0.003	19.2 miles west of Oquossoc on Highway 16.	
Do.	Silurian phyllite and schist 1/	do.	9.1 miles west of Oquossoc on Highway 16.	
Phyllite and schist	do.	do.	8.6 miles west of Oquossoc on Highway 16.	
Schist	do.	do.	5.5 miles north of Houghton on Highway 17.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Glacial	Silurian phyllite and schist 1/	0.003-0.004	3.8 to 4.8 miles north of Houghton on Highway 17.	
Do.	Pre-Cambrian gneiss and schist 1/	0.003	0.7 miles south of Houghton on Highway 17.	
Do.	Pre-Cambrian to Upper Paleozoic granite 1/	do.	2.0 miles south of Roxbury on Highway 17.	
Do.	Pre-Cambrian gneiss and schist 1/	0.002-0.003	1.2 to 1.5 miles north of Rumford Point on Highway 5.	
Gneiss	do.	do.	3.0 miles north to Rumford Point on Highway 5.	
Do.	Pre-Cambrian to Upper Paleozoic granite 1/	do.	4.7 miles north of Andover on Highway 5.	
Granite	do.	0.003	8.5 miles east of Andover on Highway 120.	
Glacial	Pre-Cambrian gneiss and schist 1/	0.002-0.006	4.0 miles of road north of Waterford on Highway 35.	
Granite	do.	0.004	0.3 miles north of Waterford on Highway 35.	
Do.	do.	do.	At Waterford on Highway 37.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Glacial	Pre-Cambrian gneiss and schist 1/	0.003-0.004	East Waterford to Waterford on Highway 37.	
Do.	do.	0.004-0.006	Norway Lake to East Waterford on Highway 118.	
Do.	do.	0.002-0.005	On Highway 302 west from Bridgton 0.1 miles to junction of Highways 302 and 117, south on 117 to junction of Highways 117 and 107.	
Granite	do.	0.004-0.007	3.4 to 3.8 miles south of Bridgton on Highway 107.	
Do.	do.	0.003-0.005	5.3 miles south of Bridgton on Highway 107.	
Glacial	do.	0.002-0.004	5.9 miles south of Bridgton on Highway 107.	
Do.	do.	do.	1.0 to 1.2 miles south of South Bridgton on Highway 107.	
Granite	do.	0.004-0.005	3.8 miles south of South Bridgton on Highway 107.	
Do.	do.	0.003-0.006	5.0 miles south of South Bridgton on Highway 107.	
Do.	do.	0.004-0.005	5.7 miles south of South Bridgton on Highway 107.	

Table 1.--(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Granite	Pre-Cambrian gneiss and schist 1/	0.002-0.003	6.1 miles south of South Bridgton on Highway 107.	
Glacial	do.	0.003-0.004	7 miles south of South Bridgton on Highway 107	At town of Sebago (not shown on map).
Outcrop	Pre-Cambrian to Upper Paleozoic granite 1/	0.003	0.3 miles southwest of East Sebago on Highway 11.	
Glacial	do.	0.002-0.003	3 miles of road southwest of East Sebago on Highway 11.	
Do.	Pre-Cambrian granite, gneiss and schist 1/	0.002-0.004	Along road from East Sebago to Naples on Highways 11 and 114.	
Outcrop	Pre-Cambrian gneiss and schist 1/	0.005-0.007	3.2 miles north of North Sebago on Highways 11 and 114.	
Glacial	do.	0.003-0.007	2.5 miles of road beginning at Naples and going northward on Highway 302.	
Granite	do.	0.004	6.1 to 6.2 miles south of Bridgton on Highway 302.	
Do.	do.	0.005	7.2 miles south of Bridgton on Highway 302.	

Table 1.—(Continued)

Observed rock type	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Pinkish Granite	Pre-Cambrian gneiss & schist 1/	0.004	2.7 miles south of Bridgton on Highway 302	Bridgton Locality Sample *163 contains 0.006% eU, 0.001% U., and 0.002% ThO_2
Glacial	do.	0.004-0.007	Harrison to Naples on Highway 35	
Unidentified	do.	0.003	2.3 miles south of Harrison on Highway 35.	
Gneiss & Schist	do.	do.	2.8 miles south of Harrison on Highway 35.	
Do.	do.	0.003-0.006	5.5 miles south of Harrison on Highway 35.	
Do.	do.	0.008	6.0 miles south of Harrison on Highway 35.	Long Lake Locality Sample *151 contains 0.007% eU, 0.003% U., and 0.001% ThO_2
Do.	do.	0.006-0.007	6.5 miles south of Harrison on Highway 35.	
Do.	do.	0.003	0.6 miles north of Naples on Highway 35.	
Granite, gray to pink	do.	0.004	0.7 miles east of Naples drawbridge on Highway 11.	Naples Locality Sample *164 contains 0.003% eU., 0.001% U.

Table 1.—(Continued)

Observed rock type	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Glacial	Pre-Cambrian gneiss & schist 1/	0.002-0.006	0.6 miles southeast of Naples on Highway 11 to junction of Highways 11 and 35.	
Do.	do.	0.004-0.006	2.0 miles south from junction of Highways 11 and 35, on Highway 35 1 mile east of Naples.	
Unidentified.	do.	0.005-0.007	3.2 miles southeast of Naples on Highways 35 and 302.	
Granite and pegmatite	do.	0.003	3.3 miles southeast of Naples on Highway 302.	Average for glacial debris in vicinity is 0.003% eU.
Gneiss	do.	0.004	5.2 miles southeast of Naples on Highway 302.	
Do.	Pre-Cambrian to Upper-Paleozoic granite 1/	do.	5.3 miles southeast of Naples on Highway 302.	
Gneiss & schist	do.	do.	5.4 miles southeast of Naples on Highway 302.	
Granite	do.	0.003	5.6 miles southeast of Naples on Highway 302.	
Do.	do.	do.	7.3 miles southeast of Naples on Highway 302.	
Unidentified.	Pre-Cambrian gneiss & schist 1/	0.004-0.007	4.4 to 4.7 miles east of junction of Highways 11 and 121, on Highway 11, just west of Crescent Lake.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Unidentified	Pre-Cambrian to Upper Paleozoic granite 1/	0.005-0.007	4.3 miles east of junction of Highways 11 and 121 on Highway 11 just west of Crescent Lake.	
Gneiss	Pre-Cambrian gneiss & schist 1/	0.002	1.0 miles west of Crescent Lake Post Office on Highway 11.	Crescent Lake Locality A, Sample *167 contains 0.002% eU., by field analysis, Quartz, feldspar, medium-to fine-grained biotite gneiss.
Unidentified.	do.	0.006-0.007	1.5 miles west of Cresent Lake on Highway 11.	
Granite	do.	0.004	1.6 miles west of Crescent Lake Post Office on Highway 11.	Crescent Lake Locality A, Sample *166 contains 0.003% eU., and 0.001% U. Medium coarse grained, gray to pink, some pegmatitic zones.
Gneiss	do.	0.004+	1.9 miles west of Crescent Lake Post Office on Highway 11.	Crescent Lake Locality A, Sample *165 contains 0.004% eU. Medium coarse, gray to pink, some pegmatitic zones.
Glacial	do.	0.004-0.007	Crescent Lake southwest on Highway 11, then north on Highway 121 to Casco.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Unidentified	Pre-Cambrian gneiss & schist 1/	0.004	1.1 miles north of Casco on Highway 121.	
Glacial	do.	0.003-0.004	From Casco north to Otisfield on Highway 121.	0.007% eU. at Otisfield.
Pegmatite, diorite, granite	do.	0.005-0.006	1.5 miles north of Otisfield on Highway 121.	
Glacial	do.	0.002-0.004	From East Otisfield to point 3.1 miles north of East Otisfield on Highway 121.	
Do.	do.	0.003-0.005	2.2 and 3.5 miles south of Oxford on unnumbered highway along east side of Thompson Lake.	
Do.	do.	0.004-0.007	From junction of above road and Highway 11 west to Crescent Lake.	
Granite	do.	0.005	1.0 miles northeast of Crescent Lake Post Office on Highway 11.	Crescent Lake Locality B, Sample *168 contains 0.005% eU., 0.000% U., and 0.004% ThO_2
Glacial	do.	0.002-0.006	From Mechanic Falls to Welchville along Highway 26.	
Do.	do.	0.004-0.006	In the town of Norway.	

Table 1.—(Continued)

Observed rock types	Age and Rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Gneiss and pegmatite	Pre-Cambrian gneiss & schist 1/	0.003	5.2 to 5.3 miles north of South Paris on Highway 26.	
Glacial	Pre-Cambrian to Upper Paleozoic granite 1/	0.003-0.004	3.6 and 4.3 miles northwest of Hebron on Highway 119.	
Granite	do.	0.004	3.3 miles northwest of Hebron on Highway 119.	
Do.	do.	0.008	0.7 miles northwest of West Minot on Highway 124.	West Minot Locality, Sample *152 contains 0.008% eU., 0.002% U., and 0.001% ThO_2.
Glacial	do.	0.003	At West Minot at junction of Highways 119 and 121.	
Do.	do.	0.003-0.004	From Minot to West Minot on Highway 119.	
Do.	Holowell granite 3/	0.003	6.0 miles east of Augusta Bridge on Highway 202.	
Do.	do.	do.	7.7 miles east of Augusta Bridge on Highway 202.	
Do.	do.	do.	8.3 miles east of Augusta Bridge on Highway 202.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Granite porphyry	Holowell granite 1,2/	0.004	12.1 miles west of Ellsworth on Highways 3 and 1.	East Orland Locality, Sample *169 contains 0.004% eU, and 0.000% U.
Do.	Pre-Cambrian to Upper Paleozoic granite 1,2/	0.003	5.7 miles west of Ellsworth on Highways 3 and 1.	
Granite	do.	do.	4.2 to 4.3 miles north of the junction of Highways 3 and 198 on Mt. Desert Island about 7 miles north of Seal Harbor.	
Coarse porphyritic granite	do.	do.	16.0 miles west of Cherryfield on Highway 182.	
Granite	do.	do.	13.3 miles west of Cherryfield on Highway 182.	
Do.	do.	do.	11.6 miles west of Cherryfield on Highway 182.	
Do.	do.	0.004	6.6 miles west of Cherryfield on Highway 182.	Large boulders.
Do.	do.	do.	6.2 miles west of Cherryfield on Highway 182.	
Do.	do.	0.003	4.7 miles west of Cherryfield on Highway 182.	

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Porphyritic granite	Pre-Cambrian to Upper Paleozoic granite 1,2/	0.004	4.7 miles west of Cherryfield on Highway 182.	
Porphyritic pink granite	do.	do.	4.0 miles west of Cherryfield on Highway 182.	Cherryfield Locality, Sample *170 contains 0.004% eU., and 0.000% U.
Porphyritic granite	do.	0.003	3.4 miles west of Cherryfield on Highway 182.	
Granite	Pre-Cambrian to Upper Paleozoic granite 4/	do.	13.2 miles north of railroad crossing in Perry on Highway 1.	
Do.	do.	do.	12.7 to 12.8 miles north of railroad crossing in Perry on Highway 1.	Red Beach Locality, Sample *171 contains 0.003% eU., and 0.000% U.
Do.	do.	do.	10.9 miles north of railroad crossing in Perry on Highway 1.	
Do.	do.	do.	10.7 miles north of railroad crossing in Perry on Highway 1.	
Do.	do.	do.	10.5 miles north of railroad crossing in Perry on Highway 1.	Red Beach Locality, Sample *172 contains 0.004% eU., and 0.001% U.
Do.	Pre-Cambrian to Upper Paleozoic granite 1/	do.	2.3 miles north of Topsfield on Highway 1.	Topsfield Locality, Sample *162 contains 0.003% eU., and 0.001% U.

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Massive granite	Pre-Cambrian to Upper Paleozoic granite 1/	0.003	4.4 miles southeast of Camp Phoenix on Baxter State Park road.	Harrington Lake Locality C, Sample *156 contains 0.003% eU, and 0.000% U.
Do.	do.	do.	2.3 miles southeast of Camp Phoenix on unnumbered dirt road to Baxter State Park.	Harrington Lake Locality B, Sample *157 contains 0.003% eU, and 0.000% U.
Phyllite	Silurian phyllite 1/	do.	7.5 miles west of Camp Phoenix on unnumbered dirt road to Baxter State Park, near west end of Harrington Lake.	Harrington Lake Locality A, Sample *158 contains 0.003% eU.
Quartzite conglomerate with greenstone matrix	Silurian to Devonian diabase schist & greenstone 1/	Qtzte 0.001 Mtx 0.004	About 0.1 miles southwest of the Ripogenus Dam on Chesuncook Lake on unnumbered dirt road.	Chesuncook Lake Locality, Sample *159 contains 0.003% eU, and 0.001% U. Consists of chloritized basic pyroclastics in greenstone section.
Gray granite	Pre-Cambrian to Upper Paleozoic granite 1/	0.003	2.2 miles west of Yoke Pond on an unnumbered dirt road east of Kokadjo.	Yoke Pond Locality, Sample *161 contains 0.003% eU., and 0.000% U.
Black phyllite	Silurian schist 1/	0.003	5.3 miles north of Kokadjo on unnumbered dirt road.	Kokadjo Locality Sample, *160 contains 0.002% eU., and 0.000% U.
Phyllite	Ordovician and Silurian schist and phyllite 1/	do.	14.0 miles north of Seboomook Lake on an unnumbered dirt road from Seboomook Lake to Caucomgomoc Lake.	Seboomook Locality, Sample *153 contains 0.002% eU., and 0.001% U.

Table 1.—(Continued)

Observed rock types	Age and rock type as mapped	Estimated equivalent uranium (percent)	Location	Remarks
Phyllite	Silurian slate and phyllite 1/	0.003	15.0 miles north of Monson on Highway 15.	Monson Locality, Sample *154 contains 0.003% eU. and 0.000% U.

1/ Keith, Arthur, Preliminary geologic map of Maine 1/1,000,000: Maine Geol. Survey, 1933.

2/ Li Ching, Yuan, Genesis of some ore deposits of southeastern Maine: Geol. Soc. American Bull., vol. 53, pl. 1, 1942.

3/ Trefethen, H. T., The Hollowell intrusives: Maine Geol. Survey, 2nd. Ann. Rept., map, 1932.

4/ Smith, G. O., and White, David, Geology of the Perry Basin in southeastern Maine: U. S. Geol. Survey Prof. Paper 35, pl. 1, 1905.

5/ Katz, F. J., Stratigraphy in southwestern Maine: U. S. Geol. Survey Prof. Paper 108, pl. 61, 1917.

Table 2.—Field and laboratory analyses of samples from various localities in Maine

Sample Number (Lot 1604)	Area and locality name on Figure 1	Type of material sampled	Field Analysis	Laboratory Analyses		
			eU 1/ (percent)	eU 1/ (percent)	U (percent)	ThO_2 (percent)
	Area 1					
*151	Long Lake	Granite, gneiss & schist	0.008	0.006 0.007	0.002 0.003	0.001
*152	West Minot	Granite	0.008	0.008	0.002	0.001
*163	Bridgton	Pink granite	0.007	0.008 0.006	0.001	
*164	Naples	Pink granite	0.004	0.003	0.001	
*165	Crescent Lake A	Pink granite	0.005	0.004	0.001	
*166	Crescent Lake A	Gray granite	0.004	0.003	0.001	
*167	Crescent Lake A	Biotite gneiss	0.002			
*168	Crescent Lake B	Gray granite	0.005	0.004 0.005	0.000	0.003 0.004
	Area 2					
*153	Seboomook	Gray phyllite	0.003	0.002	0.001	
*154	Monson	Black phyllite	0.003	0.003	0.000	
*156	Harrington Lake C	Massive granite	0.003	0.003	0.000	
*157	Harrington Lake B	Massive granite	0.003	0.003	0.000	
*158	Harrington Lake A	Black phyllite	0.003	0.003		
*159a	Chesuncook Lake	Greenstone tuff matrix	0.004	0.003	0.001	

Table 2.—(Continued)

Sample Number (Lot 1604)	Area and locality name on Figure 1	Type of material sampled	Field Analysis	Laboratory Analyses		
			eU 1/ (percent)	eU 1/ (percent)	U (percent)	ThO_2 (percent)
	Area 2					
*159b	Chesuncook Lake	Quartzite pebbles	0.001	0.001	0.000	
*160	Kokadjo	Black phyllite	0.003	0.002	0.000	
*161	Yoke Pond	Granite	0.003	0.003	0.000	
*162	Topsfield	Red granite	0.005	0.003	0.001	
*169	East Orland	Porphyritic granite	0.005	0.005	0.000	
*170	Cherryfield	Pink granite	0.004	0.004	0.000	
*171	Red Beach	Red granite	0.004	0.003	0.000	
*172	Red Beach	Red granite	0.004	0.004	0.001	

1/ Equivalent uranium

Table 3.—Distribution of outcrop radioactivities with respect to area and lithology

Outcrops	RADIOACTIVITY IN RECORDED RATEMETER UNITS											
	9	10	11	12	13	14	15	16	17	18	19	20
Total State												
Recorded	23	243	501	672	392	258	128	46	27	6	2	3
Probable	29900	315900	651300	873600	509600	335400	166400	59800	35100	7800	2600	3900
Area 1												
Recorded				8	21	20	14	17	18	6	2	3
Probable				10400	27300	26000	18200	22100	23400	7800	2600	3900
Area 2												
Recorded	23	243	501	664	371	238	114	29	9			
Probable	29900	315900	651300	863200	482300	309400	148200	37700	11700			
Granite, Area 1												
Recorded				6	12	11	7	13	11	6	2	1
Probable				7800	15600	14300	9100	16900	14300	7800	2600	1300
Metamorphic rocks, Area 1												
Recorded				2	9	9	7	4	7			2
Probable				2600	11700	11700	9100	5200	9100			2600
Granite, Area 2												
Recorded	1	7	39	146	150	137	80	25	9			
Probable	1300	9100	50700	189800	195000	178100	104000	32500	11700			
Metamorphic rocks, Area 2												
Recorded	15	107	221	190	69	48	16	1				
Probable	19500	139100	287300	247000	89700	62400	20800	1300				
Sedimentary rocks, Area 2												
Recorded	3	64	164	281	134	53	18	3				
Probable	3900	83200	213200	365300	174200	68900	23400	3900				
Basic rocks, Area 2												
Recorded	4	65	77	47	18							
Probable	5200	84500	100100	61100	23400							
	0.001			0.002		0.003		0.004		0.005		0.006

ESTIMATED EQUIVALENT URANIUM (PERCENT)