Study of Radioactivity in Modern Stream Gravels as a Method of Prospecting

GEOLOGICAL SURVEY BULLETIN 1030-E

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By RANDALL T. CHEW, III

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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The detection of radioactivity anomalies by means of portable instruments of scaler type, and application of the method in locating deposits of radioactive ores in the Colorado Plateau

DEPARTMENT OF THE INTERIOR
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CONTENTS

ILLUSTRATIONS

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

STUDY OF RADIOACTIVITY IN MODERN STREAM GRAVELS AS A METHOD OF PROSPECTING

By Randall T. Chew, III

ABSTRACT

Traverses along some streams of the Colorado Plateau in areas known to contain minable uranium deposits show that anomalous radiation in the stream gravels can be detected with a suitable counter downstream from the deposits. Intensity of radiation is influenced by the size of the uraninum deposit, the size of the drainage area of the stream, the grain size of the sediments, and the lithology of the rocks over which the stream flows.

The spacing of the stations where readings are taken is controlled by the size of the stream, and special readings are also taken just downstream from important tributaries. An anomaly is empirically defined as a 10 percent rise over background.

Radioactive material from large uranium deposits has been detected as much as 1 mile downstream. Radioactive material from smaller deposits is detectable over shorter distances. The method is slow but appears to be a useful prospecting tool under certain conditions.

INTRODUCTION

This report describes investigations of the radioactivity of gravels in modern stream channels undertaken by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The purpose of this study has been to determine whether this radioactivity can be used as a guide in locating uranium and thorium ore deposits or mineralized areas. Some of the ideas presented here are based on assumptions or working hypotheses; further work may change these assumptions. However, the author feels that the assumptions are basically correct, and that radioactivity of stream gravels can be a useful prospecting tool under some conditions.

PREVIOUS INVESTIGATIONS

As early as 1945, the Geological Survey had made investigations of the radioactivity of stream gravels in Alaska. R. S. Cannon, Jr. (unpublished report, 1953) reported that the results of four radiation measurements made in alluvium near uranium deposits in South Dakota indicated a detectable radioactivity anomaly downstream from the uranium deposits.

As a follow-up to Cannon's work, W. E. Bales (personal communication) completed a traverse of about a dozen stations through an intensely mineralized area in South Dakota. Bales found that an anomaly did exist in the stream gravels downstream from the deposits. This anomaly was of about the same magnitude as those described in this report.

Shawe[1] describes a study of stream gravels on the eastern slope of the Sierra Nevada where he measured radioactivity of the gravels with a Geiger counter equipped with a neon light for the counting device and also made a detailed study of the heavy minerals. The sources of the stream gravels described by Shawe are granitic and metamorphic rocks, and the radioactivity in the gravels appears to have monazite as its chief source in some drainages and ilmenite in other drainages. The source rock of the various radioactive minerals is discussed in some detail. Most of the radioactivity detected comes from thorium minerals; no minable uranium deposits have been found in the Sierra Nevada area. Some of the concepts and results described by Shawe may find application as a possible prospecting tool in future study of radioactivity in modern stream gravels.

GENERAL CONSIDERATIONS

The primary purpose of this study was to determine whether uranium ore deposits contribute a measurable amount of radioactive material to the streams that drain them. This material is detected by its radioactivity. Other factors which affect the amount of radioactivity measured must also be considered. These include fluctuations in radiation caused by the diurnal variation in background and differences in the natural radioactivity of various lithologic units. Secondary considerations which influence the validity of the anomalies are: selection of the most suitable radiation instrument for the work, statistical considerations affecting the adequacy of a reading or series of readings, effect of variation in a stream size and drainage area, and effect of variation in grain size of the alluvium.

A scaler type instrument must be used in measuring the radioactivity in modern stream gravels because the scaling circuit records each gamma ray counted by the Geiger-Muller tube. This feature makes small variations in radiation detectable when recorded on a counts-per-minute basis over an adequate period of time. A counter

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[1] Shawe, D. R., Heavy detrital minerals in stream sands of the eastern Sierra Nevada between Lewining and Independence, Calif.: Calif. State Div. Mines Special Rept. in preparation.

equipped with a ratemeter showing only radiation detected over a relatively short time interval will not show these small variations with a sufficient degree of certainty because of the high random variation of gamma rays (both as to intensity and direction) at the low counting rate. A portable scaler equipped with a Geiger-Muller tube with an effective cathode area of 3 square inches was used in this study. At all levels of radioctivity encountered, this tube had sufficiently low sensitivity so that all counts recorded by the tube were shown on the scaling circuit. The Geiger-Muller tube used is similar to those found in most portable counters.

The author made several readings in areas of anomalous and nonanomalous radiation using both a Geiger counter and a scintillation counter equipped with ratemeters. Neither of these instruments showed any anomalies in areas which are considered anomalous on the basis of the scaler readings.

The scaler should make more than 400 counts during the reading period in order that the probable error of the reading be safely within the limits which constitute an anomaly. The formula for percentage probable error mentioned by Faul (1954, p. 22) can be used in computing the number of counts necessary during a single reading period. Faul gives the formula $p=0.6745\sqrt{N}$ where p equals the probable error of a given reading and N equals the number of counts recorded. He then states that the "percentage probable error is the ratio of the absolute probable error to the value of the quantity measured expressed in percent." Stated algebraically, this reduces to $E=\frac{0.6745}{\sqrt{N}}\times100$ where E equals the percentage probable error and N equals the number of counts recorded as before. Faul shows a graph of this percentage probable error. The probable error of 400 counts is ±3.35 percent. Experience has shown that if 8-minute readings are made using an instrument equipped with the Geiger-Muller tube just described, the relative probable error will be ±3.3 percent or less. This relative error is low in comparison with the increase of approximately 10 percent over the normal radioactivity that is considered anomalous; and, if 8-minute readings are made, the statistical error will always be low enough that anomalous readings can be considered valid.

At stations which are obviously giving high readings (more than 100 counts per minute) the reading can be stopped after 500 or 600 counts have been recorded and the average can be computed. If 625 counts are recorded, the probable error is ±2.68 percent. If the reading is obviously anomalous, as shown by a high counting rate, the probable error becomes unimportant.

Variations in radioactivity over a limited geographical area are unimportant. The table below shows the results of two traverses made to show variation in readings obtained by moving the probe slightly between readings. Three readings were taken at each station, but the probe was moved slightly between readings. At six stations the readings were taken on a triangular grid with the corners about 4 feet apart. At two stations the readings were spaced about 4 feet apart in a line parallel to the stream flow. The readings show a maximum range of 24 counts per minute (about 50 percent) caused by moving the probe slightly between readings. In general, the range is least where the radiation is at the lowest level and greatest where radiation is at the highest level. The range is great enough that probably no single reading less than 20 percent above average should be considered anomalous. Three or more stations with readings of more than 10 percent above average can be considered anomalous. Apparently a longer low peak is more likely to occur downstream from a uranium deposit than a single high one.

Average reading (counts per minute) and range of three readings taken in closely spaced holes at each station, Seven Mile area, Grand County, Utah

Station No.	Average	Range
Seven Mile Canyon traverse		
1	59	58–61
2	57	52–63
3	53	51–56
4	53	49–58
5	54	53–55
Corral Canyon traverse		
3	107	92–116
4	84	80–87
5	99	97–101

In Corral Canyon, Seven Mile area, Utah, (fig. 33), the range in a series of reading shown in figures 34–37 illustrates the error made possible by readings of insufficient duration. The probe setting numbers at the top of each graph denote the same setting of the probe on each graph. Stations 3, 4, and 5 consist of three readings in different holes within about 4 feet of each other. An 8-minute reading was taken in each hole. While the measurements were being taken, the scaler was read at 2-minute intervals to obtain data for the shorter readings. Figure 34 shows the average and range of four 2-minute readings. The others show the ranges of two readings except figure 36 which shows only one reading.

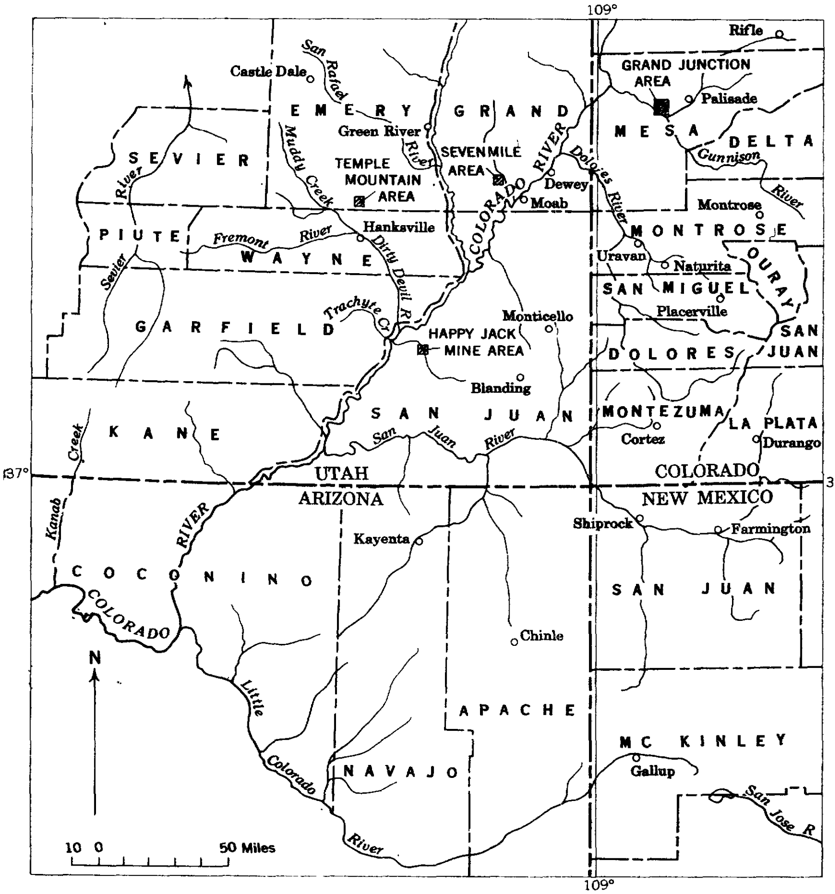

FIGURE 33.—Index map of part of Colorado Plateau showing areas where radioactivity of modern stream gravels was studied.

The dashed line connects the same readings on each graph. The readings connected by the dashed line have been arbitrarily selected but might have been obtained in a traverse where only one reading of the duration shown on each graph was taken at each station. The dashed line shows two reverses in pitch as the result of the theoretically improved "sampling." The first change is between stations 1 and 2 and the other is between stations 3b and 4b.

To some extent, an anomally is influenced by the size of the deposits and the size of the stream draining the area. A deposit in the drainage area of a small stream will give a larger anomaly than the same size deposit in the drainage area of a large stream because the greater amount of barren sediments in the large stream tend to mask any anomalous radioactivity. On the basis of reserve estimates and pro-

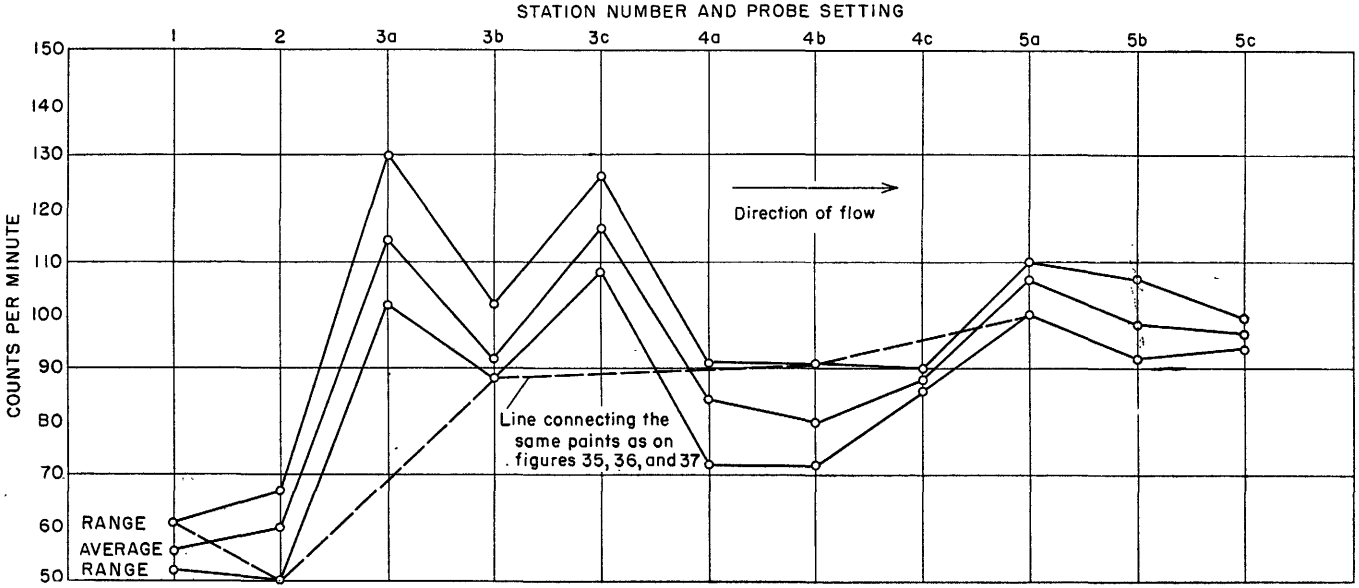

FIGURE 34.—Radioactivity in modern stream gravels—range and average of four 2-minute readings at each probe setting, Corral Canyon, Seven Mile area, Grand County, Utah.

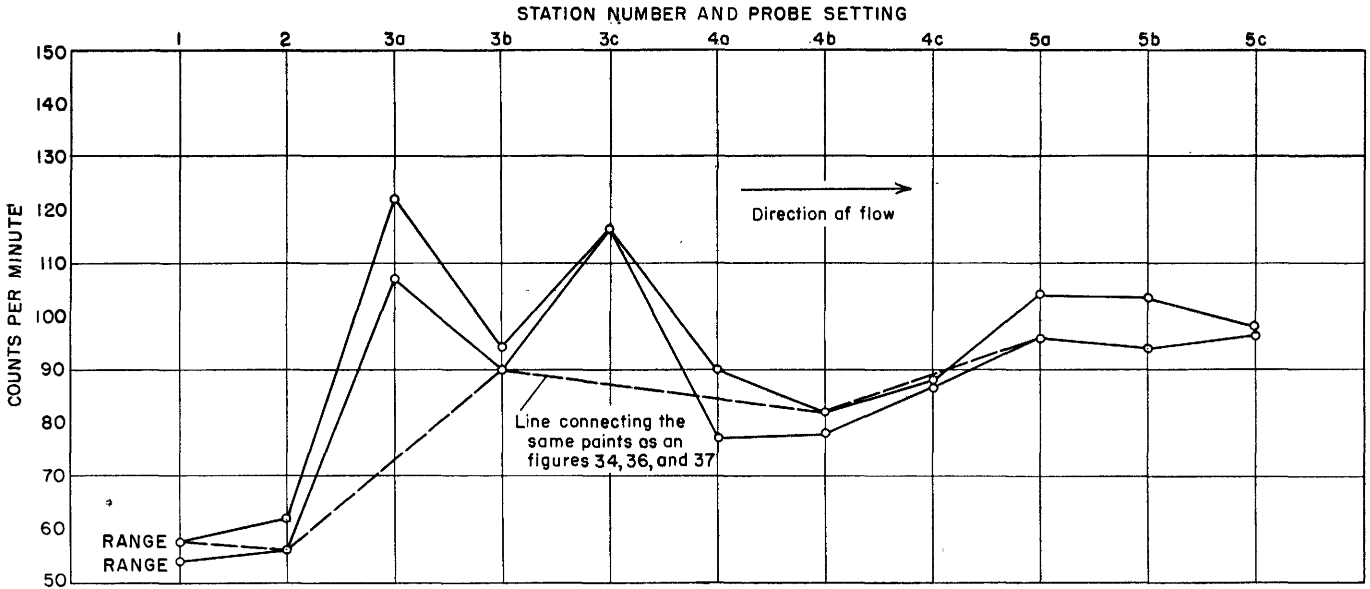

FIGURE 35.—Radioactivity in modern stream gravels—range of two 4-minute readings at each probe setting, Corral Canyon, Seven Mile area, Grand County, Utah.

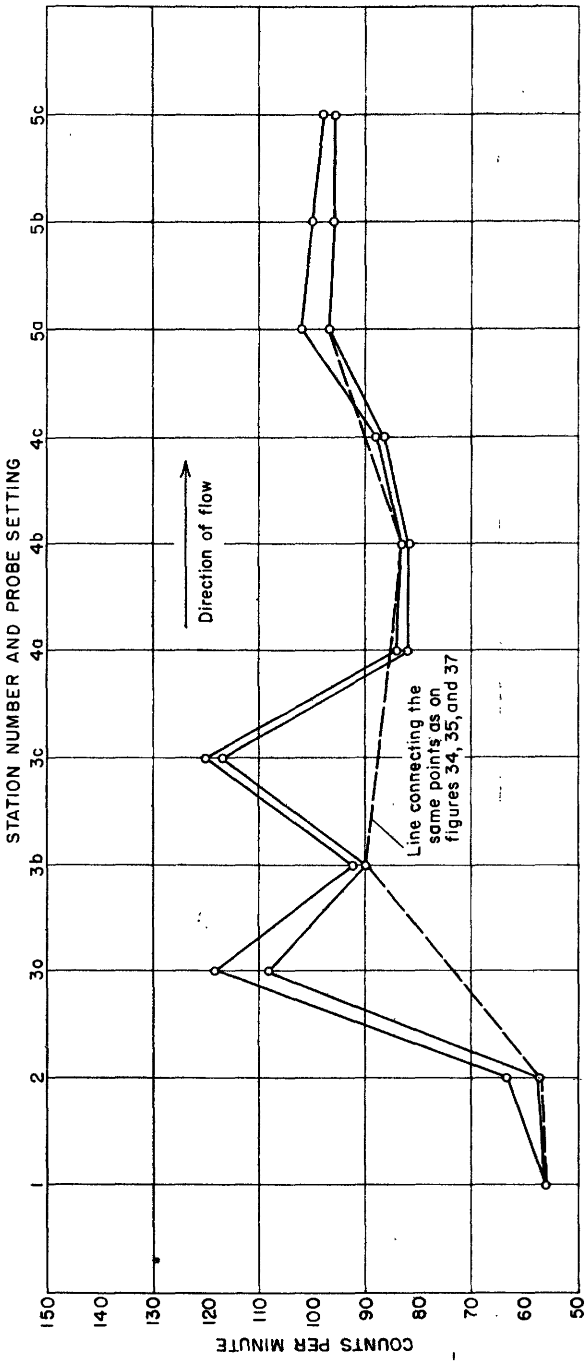

FIGURE 36.—Radioactivity in modern stream gravels—range of two 6-minute readings at each probe setting, Corral Canyon, Seven Mile area, Grand County, Utah.

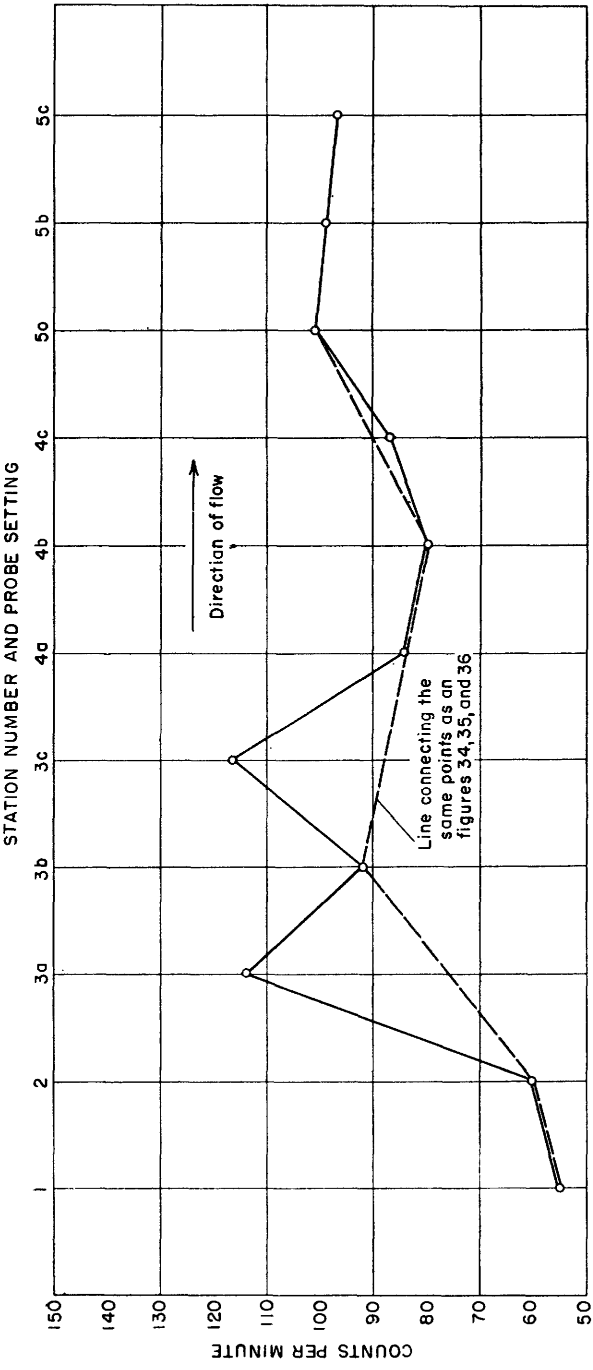

FIGURE 37.—Radioactivity in modern stream gravels—one 8-minute reading at each probe setting, Corral Canyon, Seven Mile area, Grand County, Utah.

duction records, deposits have been considered for this report to be either "small" deposits containing less than 1,000 tons of ore, or "large" deposits containing more than 1,000 tons. Streams were classed as "small," having a width of less than 10 feet where its width is not controlled by the local topography; "intermediate," with a width of from 10 to 35 feet; and "large," with a width greater than 35 feet. This width reflects, to some extent, the size of the drainage area of the stream and the amount of sediment carried by it.

The grain size of the rock probably has some effect upon the radiation through the "mass effect." Sediments of a small median grain size show higher radioactivity than sediments of similar composition and larger median grain size. Apparently this is caused by close packing of the small material around the probe.

It was believed, early in the work, that diurnal variations in the cosmic-ray background radiation might affect the readings; therefore, a reading of the background was taken at every station. Readings of the background radiation were also taken in several areas at about 1-hour intervals over several days. This was done to obtain some record of the diurnal variations in background radiation and also to determine the effects of background readings on the radiation recorded from stream gravels. These background readings were about the same as or slightly lower than readings in barren gravels and seem to have no adverse effect on the readings taken in the gravels. Readings taken with the probe buried 6 inches in the gravels probably record gamma radiation derived from both cosmic rays and radioactive material in the sediments. The radiation recorded is the sum from these two sources and thus the cosmic-ray background radiation has no practical effect on the readings in the gravels.

FIELD METHODS

In this study the intensity of gamma radiation was measured at stations along streams that cross known deposits and also along streams that cross no known deposits. Spacing of the stations was determined by the size of the stream, but in many places this spacing was reduced where the amount of radioactivity detected in the gravels began to approach the anomalous level.

On small streams, the stations can be spaced at 0.2 mile intervals with spacing narrowed to 0.1 mile where an anomaly is suspected. Intermediate streams can have the stations spaced at intervals of half a mile. These can be narrowed to 0.2 mile intervals where an anomaly is suspected. Readings from stations spaced 0.1 mile apart on streams of intermediate size will probably not give any additional useful information.

A somewhat different technique is necessary on large streams, especially perennial ones, because the amount of radiation seems to vary significantly on opposite banks of a large stream. In wide streams it appears possible to determine from which side of the stream the radioactive material is introduced by taking closely spaced readings on each side. For ordinary reconnaissance work on large streams, stations on one side of the stream are sufficient; stations can be spaced 1.0 mile apart and narrowed to 0.5 mile where an anomaly is suspected. If readings are made on each side of the stream, it appears practical to narrow the spacing to 0.2 mile. This may give additional information as to the source of an anomaly. In an entirely unexplored region, stations spaced at wider intervals might give some useful information as to the location of large areas for more intense exploration. Stations spaced at intervals of 2 to 3 miles might conceivably have some significance in an entirely untried area, but more closely spaced stations should generally be used. A traverse along the Colorado River from Rifle, Colo., to Moab, Utah, using stations spaced at intervals of 5.0 miles, gave readings which have been interpreted as too unsystematic to be useful.

The probe was buried 6 inches below the surface in the stream gravels and covered as well as possible. Complete burial of the probe is important. If it is not well covered, the readings will be lower than the true radioactivity of the station. Where the ground is frozen or boulders make burial difficult, a small mound of loose material should be piled over the probe to simulate burial.

Because apparently they do not affect the radioactivity of the alluvium, moisture content and abundance of organic matter need not be noted in prospecting. Topographic features such as constrictions in the streams and the location of the station in relation to major bends which might affect deposition of gravels should be noted.

A sketch map of the stream is useful in interpreting the results of the traverse. The map can be made by using a compass and some means of measuring distance—either the odometer of a car or pacing—and stratigraphy, structure, and topography can be plotted in relation to the location of the stations while the readings are made. To make anomalous areas more easily recognizable the readings are plotted on graph paper. The distances between stations and the various geographic check points are plotted on the abcissa and the readings, in average counts per minute, are plotted on the ordinate. Readings both in gravels and in country rocks, the average size of the smallest grains, and points where the contact between distinctive stratigraphic units are crossed can be plotted on the graphs.

ANOMALIES

The number of counts per minute defined in this section as constituting an anomaly is empirical and is based on the field work. These figures have proven sufficiently consistent within the limits given here. Traverses have been conducted only over barren rock, mill tailings piles, and uraninite-type deposits. No traverses have been made over vanadium-bearing carnotite-type deposits or oxidized deposits that do not contain vanadium. A significant variation from the figures cited here may occur in the amount of radioactive material in sediments downstream from these other types of deposits, especially if the source of the radiation in the gravels is detrital uranium minerals. These minerals have differing solubilities and this may produce various amounts of radiation.

Barren gravel shows radioactivity ranging from 55 to 65 counts per minute regardless of grain size. However, single readings as high as 72 counts per minute should not be considered anomalous. A continuous series of readings at several stations averaging less than 55 counts per minute should be questioned as the scaler may not be functioning properly.

Single readings of more than 80 counts per minute, or three or more consecutive stations giving readings of more than 72 counts per minute can be considered anomalous. An area which gives unequal readings of 65 to 75 counts per minute at several stations may be anomalous and should be investigated further. This irregularity has been noticed near smaller deposits that do not show definite high counts, and is most common in small streams.

In summary, a rise of 10 percent in the average number of counts per minute above the average background can be considered anomalous. This figure of 10 percent is a convenient one derived from the statements in the preceding paragraphs, that is, multiple readings of 72 counts per minute is considered anomalous over an average of 65 counts, a rise of 7 counts or about 10 percent.

The amount of radiation recorded from the gravels tends to rise slowly as the deposit is approached from the downstream side, reaches a peak where sediments from the deposit are added, and falls off very sharply upstream. The best example of this tendency obtained in the present study is shown in figure 38, which shows readings taken near the Grand Junction, Colo., mill of the Climax Uranium Company. Wet tailings from the mill are emptied into a marsh near the river bank. The curve of the actual readings taken is shown on the graph, and the projected curve is shown also. The maximum number of counts per minute at the mill as shown on the projected

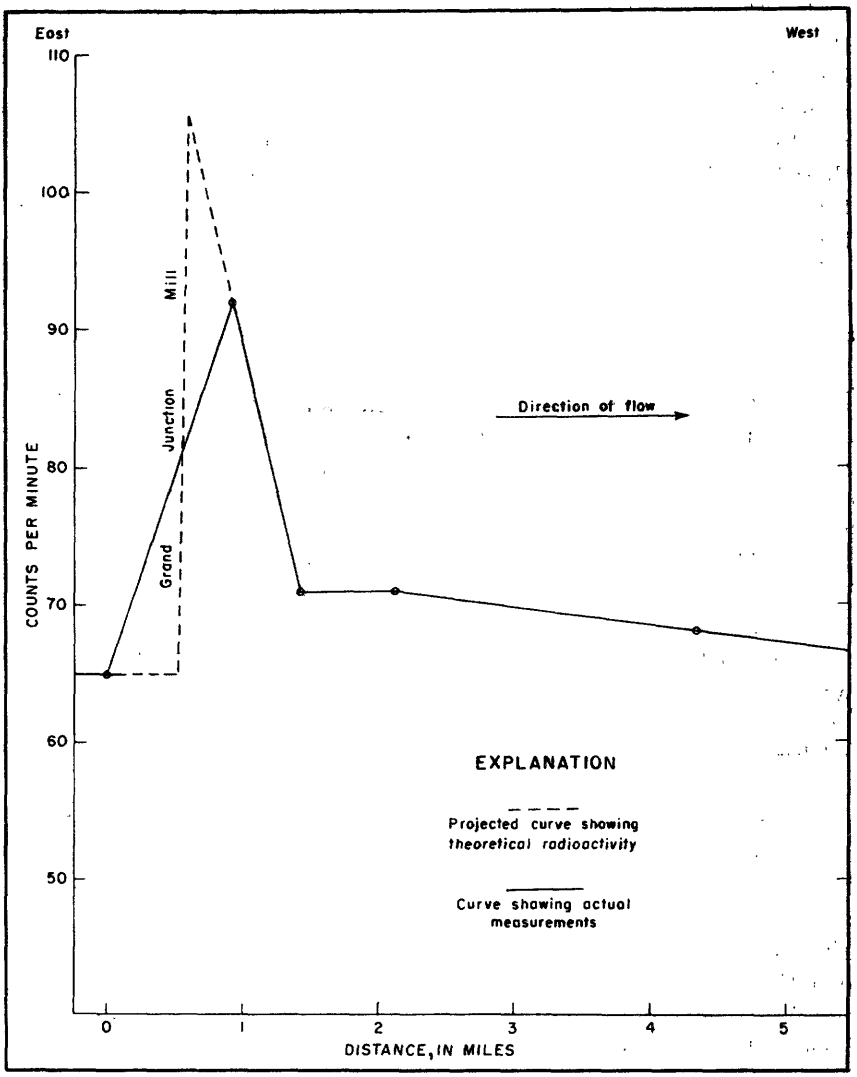

FIGURE 38.—Radioactivity of Colorado River gravels near Climax Uranium Company mill, Grand Junction, Colo.

curve are, of course, conjectural. Most curves are much more irregular, but they follow this general pattern.

Geomorphic control of radioactivity does not seem important. Anomalous radioactivity is apparently not affected by the rate of flow or the location of bends in the channel.

The most important outside influences on the variation of the amount of radioactivity in stream gravels are the introduction of material by side streams and the lithologic variations of the country rock. Special stations should be placed immediately below large side streams because a high reading below an important side stream would indicate that it should be investigated. Any radioactivity of sediments from a side stream is, within a short distance, masked by the greater amount of nonradioactive sediments in the main stream; therefore, the reading should be taken within a hundred yards below the confluence. On a large stream, the reading should be taken on the side on which the side stream enters.

The gravels in streams over some stratigraphic or lithologic units may show abnormally high radioactivity over wide areas which do not contain any minable deposits. The stream gravels on the Mancos shale of Late Cretaceous age exhibit this property wherever they have been checked during this investigation. At least 30 percent of the readings in stream gravels over the Mancos shale have exceeded 70 counts per minute; the highest reading was 84.

The tributary streams that flow into the Colorado River from the north between Palisade, Colo., and Dewey, Utah, cross the Mancos shale. These tributaries give high readings and might give the impression of being anomalous if this special characteristic of the country rock were not taken into account. However, there is no noticeable increase in the radioactivity of the Colorado River alluvium in this area. Apparently the amount of alluvium from the Mancos contributed to the river gravels is too small in relation to the amount of less radioactive gravels already present to affect noticeably the radioactivity of the river gravels.

Where the country rock is thought to be abnormally radioactive, a few readings should be taken on fresh outcrops. If they are abnormally radioactive, the number of counts per minute considered necessary to constitute an anomaly should be revised upward. A 10-percent rise in the number of counts per minute over the higher background can then be considered anomalous. Thus, where 85 is the average number of counts per minute in the gravels, 93 or more counts could be called anomalous.

AREAS STUDIED

The results of two traverses are explained here in detail because they demonstrate all the controlling factors discussed in preceding sections of this paper.

Traverses in the Temple Mountain region, Utah, revealed three areas that show anomalous radioactivity (fig. 33, pl. 8). One is the main Temple Mountain uranium deposit, which is drained by the stream here referred to as the north wash (fig. 39). This wash is of intermediate to large size and drains a large area of nonmineralized rock

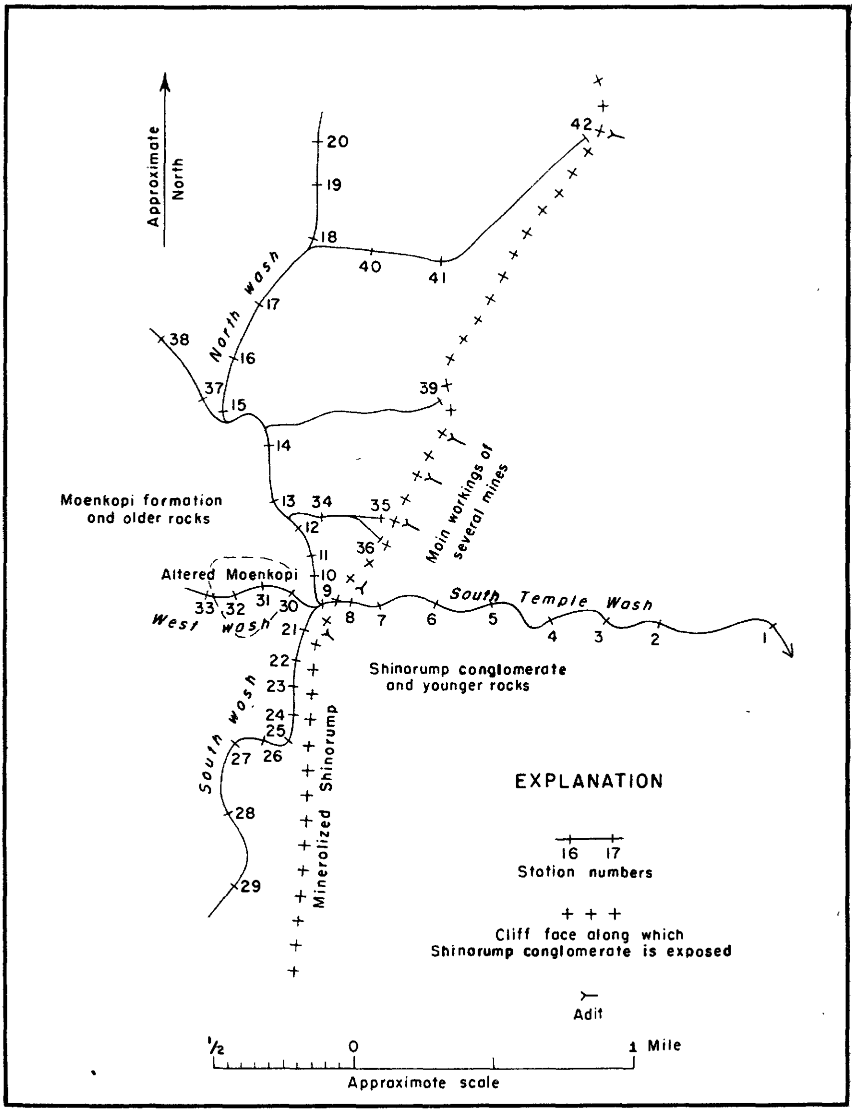

FIGURE 39.—Diagrammatic sketch of the Temple Mountain area, San Rafael district, Emery County, Utah, for use with plate 8.

in addition to the main workings. The readings are irregular (pl. 8) without being definitely anomalous. The gravels of the side streams gave anomalous or nearly anomalous readings. A side stream that drains only areas of unaltered Moenkopi gave readings (pl. 8, sta. 37, 38) well below the average for the north wash as a whole. The irregularity of the graph showing the amount of radioactivity in the gravels in the main stream and the general high count of the gravels in the side streams is indicative of anomalous radioactivity and, if the area were new, would suggest need for further exploration.

South wash (fig. 39, pl. 8) drains an area of mineralized Shinarump conglomerate that has been thoroughly prospected, but contains only the one minable deposit shown in figure 39 near the confluence of the three washes. The amount of Shinarump in the drainage area is fairly large, and the radioactivity anomaly is more pronounced than that on the north wash. If the area were new, this type of anomaly would warrant further exploration.

West wash (pl. 8) has a drainage area of less than 1 square mile and is underlain by the Moenkopi formation. About one-half of this area is composed of interbedded sandstones and siltstone of the Moenkopi showing some alteration under the sandstone beds. This entire unit is slightly radioactive. The large amount of slightly radioactive material caused a very sharp anomalous reading. However, the country-rock reading, not shown on the graph, was exactly the same as that in the stream, and it was obvious that the anomaly was more apparent than real. Upstream from this slightly radioactive area the readings are below the anomaly level. If the region were unexplored, further investigation would be justified. Careful observation and note-taking while traversing the west wash showed the anomaly in the Moenkopi to be of small extent and low grade.

The smoothness of the curve (pl. 8) below station 9, which represents the confluence of the three washes, is noteworthy. Temple Wash is outside the mineralized area, and any sediments contributed to it below station 9 are not significantly radioactive.

The graph also shows, below station 9, that the radioactivity tends to decrease to a constant with increasing distance downstream from an ore deposit. The constant here averages about 63 counts per minute.

Figure 40 shows the graph of the traverse along Corral Creek in the Seven Mile area, Grand County, Utah. The Shinarump No. 3 mine is located on the east side of Corral Creek Canyon. The stream is of intermediate size. This was the first traverse made and 2-minute readings were taken at each station. The possible relative error ranged from ±7.6 to ±9.2 percent. These figures show that the observation time was too short; statistically the chances are about even that the average number of counts would show either an anomaly where none existed or would miss an anomaly where one did exist. Apparently, however, the average number of counts obtained at each station was somewhat nearer the number that would have been obtained with a longer counting period than the probable relative error formula shows; thus, the graph has some value. This occurred purely

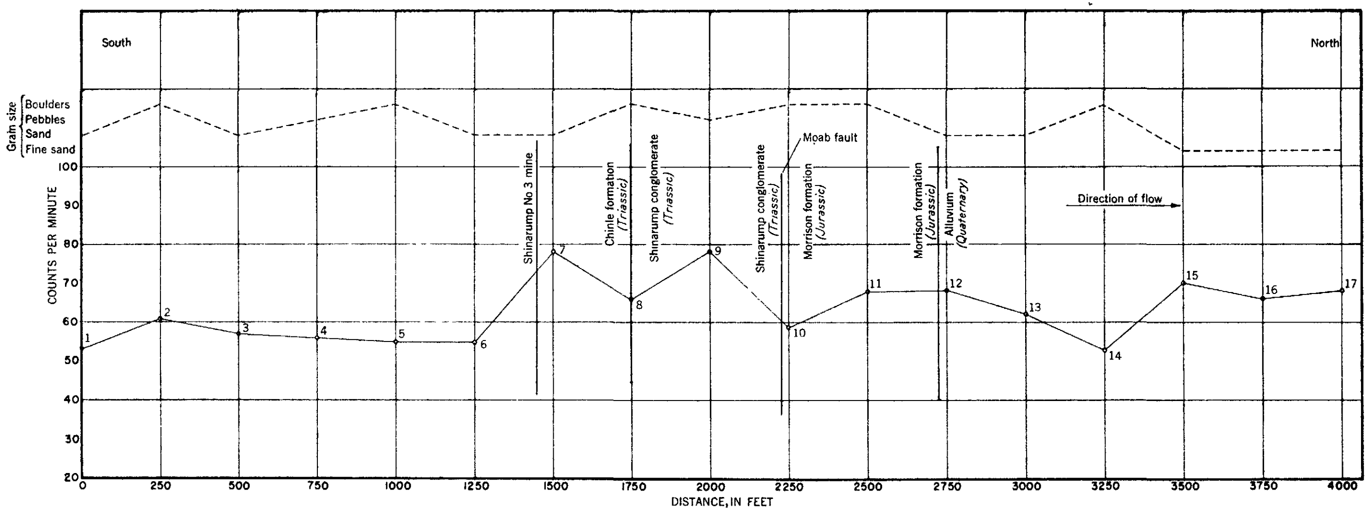

FIGURE 40.—Graph showing radioactivity in stream gravels and a comparison of radioactivity to grain size of sediments, Corral Creek, Seven Mile area, Grand County, Utah. Grain-size designations are based on work of Wentworth (1922) but modified in that "fine sand" includes all sizes smaller than fine sand, "sand" includes all sizes from very coarse sand through medium sand, "pebbles" includes granules, and "boulders" includes all sizes larger than pebbles in the Wentworth scale. Grain-size designation is based on the smallest class forming an important (> 10 percent) component of the alluvium.

by chance. The curve showing radioactivity is probably much more irregular than it would have been had longer readings been taken.

This graph includes a line showing grain size of the stream gravels plotted above the line showing the radioactivity. The relation between grain size and the amount of radioactivity is well shown, especially from stations 10 to 17. Especially high readings were obtained from stations 15 to 17 where the alluvium consists of fine sand. A low reading was obtained from station 14 where the alluvium consists of boulders.

The double peak in the graph just below the mine may be significant. The Shinarump outcrop is almost 500 feet wide where the stream crosses it. Since the traverse was made, miners have stripped the gravel from this outcrop and mined some of the underlying Shinarump bedrock as ore. This concentration of ore-grade rock immediately under the gravels may account for the double peak and the elongate shape of the anomaly.

The Moab fault and the rocks of the Morrison formation of Jurassic age apparently have no effect on the radioactivity of the gravels.

RESULTS, AND EVALUATION OF THE METHOD

The investigation has shown that a recognizable radioactive anomaly occurs in alluvium downstream from both large and small uranium ore deposits. A large deposit in the drainage area of a small stream will cause anomalous readings as much as a mile downstream. A large deposit in the drainage area of an intermediate stream will cause anomalous readings not more than 0.1 to 0.2 mile downstream. A small deposit in the drainage area of a small stream will cause anomalies 0.1 to 0.2 mile downstream, but a small deposit in the drainage area of a large stream would probably not give an anomalous reading unless a station were set by chance exactly upon the point where the deposit contributed to the stream gravels.

Measuring the radioactivity of modern stream gravels as a prospecting method is slow compared to other reconnaissance methods such as the use of airborne and carborne scintillation counters. Measuring the radioactivity of the stream gravels only, it is possible to cover about five stations per hour. At 0.1 mile intervals this is somewhat less than a half a mile per hour or about 3½ miles per day. Using a 1-mile spacing on larger streams, probably only four stations per hour could be read because of the time consumed in moving from station to station. About 30 miles per day could be covered under ideals conditions.

The greatest usefulness of the method probably would be in areas of poor outcrop and moderate relief that had been explored by airborne scintillometer. Here the scaler could be used in checking anomalous radioactivity detected by the scintillation counter. The method would be used to limit the area of search for the deposit and might show the presence of a deposit that is covered by soil.

Another somewhat specialized use would be applicable along a dissected cliff face such as is common on the Colorado Plateau. The small restricted drainages flowing out onto the fan at the foot of the cliff could be checked with one or two stations in each wash. A traverse along such a cliff front could be made at the rate of several miles per day and might show the presence of a relatively small deposit which otherwise would not be found except by the examination of many miles of outcrop. This method was tried at the large deposit of the Happy Jack mine in the White Canyon area of Utah (fig. 33), and the results are shown in figure 41. Two small streams were studied. The anomaly shown in the gravel 0.5 mile below the mine is very large, over 100 counts per minute. A smaller ore body occurring in a similar area would also be noticed though the magnitude of the anomaly would naturally be smaller. The drop in radioactivity below the point where the two small streams coalesce is very sharp. In using this method of prospecting, the prospector must be careful to check each individual stream above the point where it coalesces with another.

There are probably other uses for this prospecting method that have not come to light. Under ideal conditions anomalies have been noted in stream gravels as far as 1 mile from the nearest known outcrop of radioactive material in large deposits. Small deposits will cause detectable irregularities in radioactivity that can be traced over several hundred feet of stream gravels. Even though the method is slow, deposits can apparently be detected farther away than by the other means of reconnaissance prospecting; thus the measurement of the radioactivity of modern stream gravels would seem to be useful in certain instances.

SUGGESTIONS FOR FUTURE WORK

The work reported in this paper shows only that study of the radioactivity in modern stream gravels appears to be a useful tool in prospecting for uranium deposits. Additional work must be done before the applicability of the method under all conditions will be completely proved.

The traverses described in this paper and from which the conclusions stated herein have been drawn were all made over uraninite-type deposits that predominantly contain primary uranium minerals. No traverses have been made over carnotite-type deposits that predominantly contain oxidized minerals. Additional traverses over other

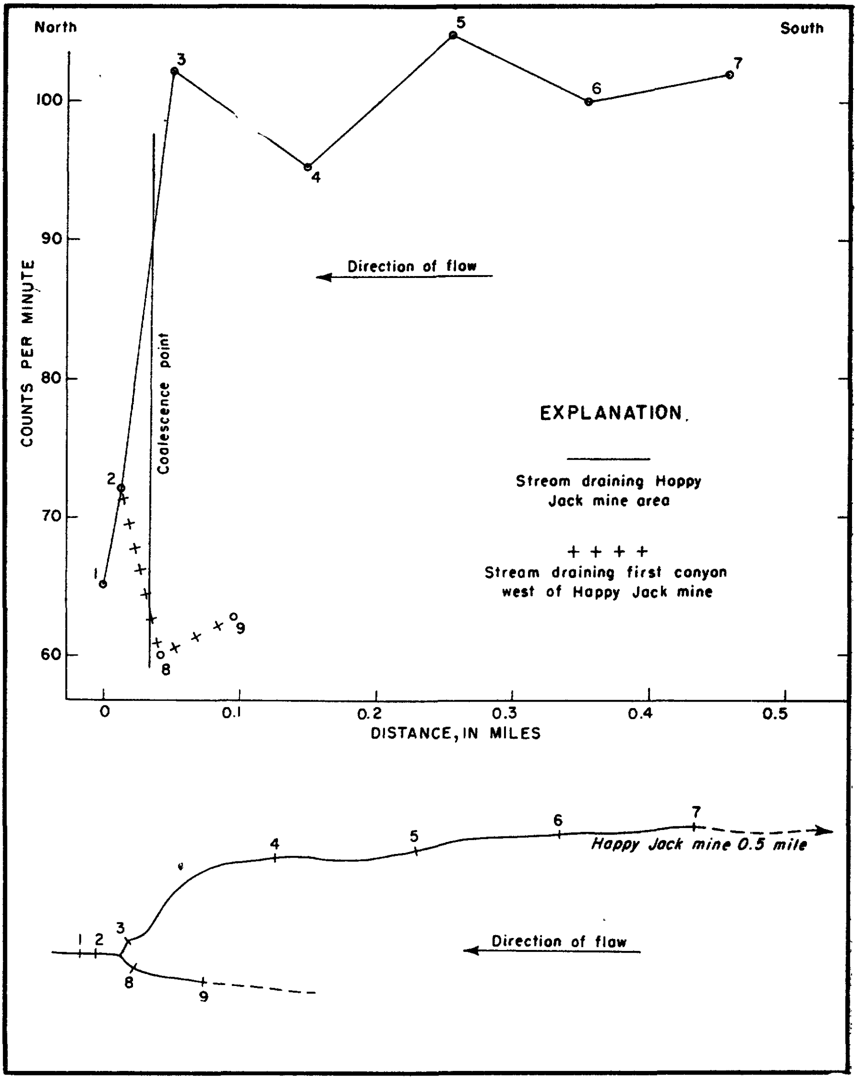

FIGURE 41.—Radioactivity of gravel in washes draining Happy Jack mine and first canyon west, White Canyon area, San Juan County, Utah.

types of deposits in igneous and metamorphic rocks as well as in sedimentary rocks are necessary before the adequacy of the method under all field conditions has been proved.

The source of the radioactivity in the stream gravels is not known. It may be detrital uranium or thorium minerals in the gravels, or uranium or radium salts coating the sand grains and filling pore spaces. The radioactivity may come from both sources or from others.

If the source varies with the different types of deposits, gravel downstream from oxidized deposits might produce different amounts of radioactivity from those described here.

One method of determining the source of the radioactivity is through the use of the nuclear-track plates as described by Stieff and Stern (1952). The radioactive particles can be located on the plates, but it will probably be necessary to use X-ray photographs and chemical tests to identify the minerals (T. W. Stern, written communication, 1954).

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