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The physical behavior and geologic control of radon in mountain streams

By Allen S. Rogers

Trace Elements Investigations Report 619

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Allen S. Rogers

June 1956

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THE PHYSICAL BEHAVIOR AND GEOLOGIC CONTROL OF RADON IN MOUNTAIN STREAMS

BY ALLEN S. ROGERS

ABSTRACT

Radon measurements were made in several small, turbulent mountain streams in the Wasatch Mountains near Salt Lake City and Ogden, Utah, to determine the relationship between the distribution of radon and its geologic environment.

In this area, the distribution of radon in streams can be used to locate points where relatively large amounts of radon-bearing ground water enter the stream, although other evidence of spring activity may be lacking. These points of influent ground water are marked by abrupt increases (as much as two orders of magnitude within a distance of 50 feet) in the radon content of the stream waters.

The excess radon in the stream water is then rapidly lost to the atmosphere through stream turbulence. The rate of radon dissipation is an exponential function, of different slopes, with respect to distance of streamflow, and depends upon the rate and volume of streamflow, and the gradient and nature of the stream channel.

The higher radon concentrations can be generally related to specific stratigraphic horizons in several different drainage areas. Thus, lithologic units which act as the primary aquifers can be identified. In one area, thrust faults were found to control the influx of ground water into the stream.

Estimates, based on radon concentrations in stream and related spring waters, can also be made of the major increments of addition of ground water to streamflow where conventional methods such as stream gaging are not practical.

The radon in the waters studied was found to be almost completely unsupported by radium in solution.

INTRODUCTION

Physical properties of radon

Radon, (called "radium emanation" and "nitron" by early investigators) belongs to the family of inert noble gases and is the only naturally occurring radioactive gas (traces of radioactive xenon and krypton occur naturally as products of spontaneous and neutron fission). As an element, radon is comprised of three isotopes, each of which disintegrates through alpha emission: Rn^{222} (radon), with a half life of 3.825 days; Rn^{220} (thoron), with a half life of 54.5 seconds; and Rn^{219} (actinon), with a half life of 3.92 seconds. These isotopes are members of the U^{238}, Th^{232}, and U^{235}, families, respectively. Of the three isotopes, the half life of radon (Rn^{222}) is the most convenient for measurement, and Rn^{222} is the only isotope investigated in this report.

The interrelations of half lives of the parent radium and the immediate daughters of radon adds to the convenience of radon measurements. The half life of radium (Ra^{226}) is 1,620 years, and can be considered infinite compared to the 3.825-day half life of radon. Approximately 99 percent equilibrium is established between radon and radium within 25 days.

Radon disintegrates through a series of four short-lived daughter products, with which equilibrium is established in about four hours (Jennings and Russ, 1948, p. 42, and p. 210-211). Pb^{210} (RaD), the next (that is, fifth) daughter product after radon, has a half life of 22 years, which, compared to four hours, is sufficiently long that the effect of Pb^{210} in radon measurements is negligible in the range of radon concentrations discussed in this report.

Being an inert gas, radon is quite susceptible to migration which is accomplished by either gaseous diffusion or solution. The distance of migration depends on the 3.825-day half life, the rate and the medium of migration, and possibly other factors such as absorption of radon on carbonaceous material.

Radon is soluble in many liquids, and the solubility depends upon the nature of the liquid and the temperature. The distribution ratio or solubility coefficient of radon (Rn water / Rn gas) in a gas-water system of equal volumes at various temperatures is shown and compared with selected published data in figure 1. Radon is less soluble in aqueous solutions of electrolytes than in pure water. The distribution ratio of radon in an aqueous solution of NaCl (sp. gr. 1.215) at 17° C is 0.042 (Kofler, 1913). Radon is very soluble in organic liquids. The distribution ratio may be as large as 23 in some liquids (Wahl and Bonner, 1951, p. 157).

This ability of radon to migrate provides possibilities for its use as a tracer in uranium exploration. Perhaps more important are the potential applications of studies of radon concentrations in natural waters to ground-water problems.

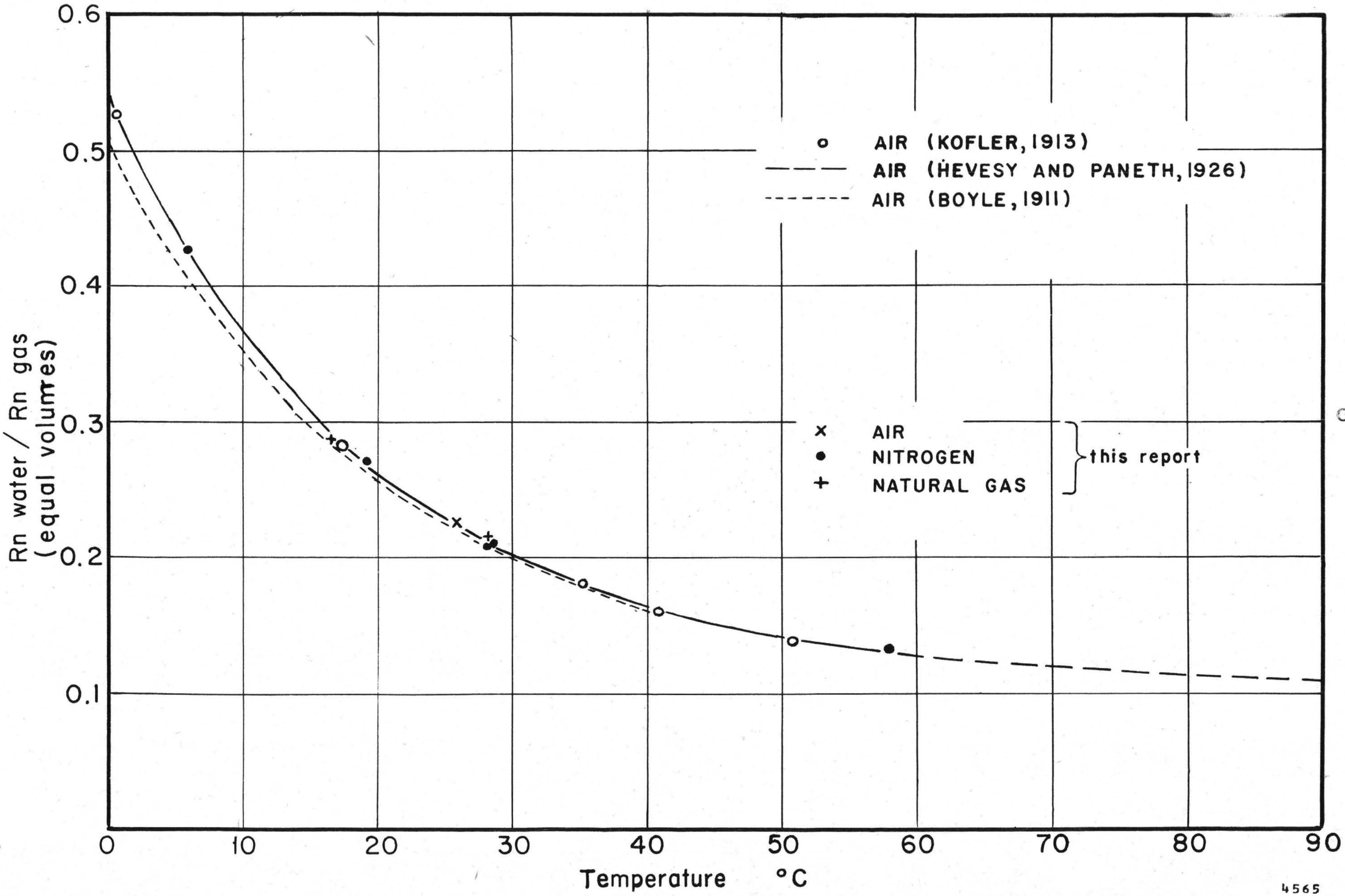

Figure 1. - Radon distribution ratios in a gas-water system.

Radon in natural waters

Previous work

Very little is known concerning the relation of radon in natural waters to geologic conditions. Arndt and Kuroda (1953) conducted a reconnaissance survey of radon in streams and lakes in parts of Garland and Hot Spring Counties, Arkansas. A correlation between radon in streams and the rock types over which the streams flow was suggested where the same rock type crops out over a wide area. The radon content of streams and springs proved higher near known uranium-bearing materials.

An abundance of literature on the radioactivity of spring waters is available. Perhaps the most intensive and complete studies in this country were conducted by Kuroda and his co-workers in Hot Springs National Park and vicinity in Arkansas where radon concentrations in both hot and cold springs and in streams are related to geologic features and known uranium-radium minerals (Arndt and Kuroda, 1953; Kuroda, Damon, and Hyde, 1954). At Yellowstone National Park, radon determinations of gases and waters, and radium determinations of spring deposits, were made by Schlundt and Moore (1909).

Miholic (1952) analyzed water from 26 springs in Yugoslavia and found that the waters from Carboniferous and Cretaceous strata contain more radon than the waters from sedimentary rocks of other periods.

A detailed investigation of radon and helium in the West Panhandle Gas Field of Texas, the Hugoton gas field of Kansas, and other gas fields in the Mid-Continent region is being made (Faul and others, 1954; Pierce, Mytton and Gott, 1956).

Kovach (1944, 1945, 1946) has described a series of measurements at Fordham University of radon in soil gas. He noted variations in radon content that are attributable to depth and meterological effects, such as rain, snow cover, barometric pressure, and wind velocity. A similar study by Norinder, Metnieks, and Siksna (1953) was made at Uppsala, Sweden.

A relationship between the radon content of soil gas and the heavy mineral content of the soil was observed by Clark and Botset (1932).

Acknowledgments

The work described in this report is part of a program of investigations being carried on by the U. S. Geological Survey on behalf of the Division of Research of the U. S. Atomic Energy Commission. Space and other facilities were made available by the University of Utah where during part of the time the writer was studying under a Shell Oil Company Research Fellowship in Geophysics. John H. Feth and Herbert A. Waite of the Geological Survey cooperated in the investigation in the lower Weber River area. Water analyses were made by Ignace Sekula of the Geological Survey.

METHODS OF STUDY

Instruments and methods of measurement

Radon can be measured by the ionization produced by alpha emission in an ionization chamber. The degree of ionization is a measure of the radon present in the chamber, and can be measured by the rate of fall of a charged gold leaf of an electroscope, or by a suitable device capable of counting individual pulses, or by measuring the total ionization current produced by the alpha emission.

The unit of measurement most commonly used in radon determinations is the curie, but because the curie is a very large unit, the millimicrocurie (10^{-9} curie) or micromicrocurie (10^{-12} curie) is conventionally used. The curie is defined as the amount of radon in equilibrium with one gram of radium. It has been further defined as 3.7×10^{10} radioactive disintegrations per second. A curie, in terms of volume of radon at standard temperature and pressure, is 0.66 mm^3. Thus, 0.66×10^{-12} mm^3 of radon gas, which is equivalent to one micromicrocurie, gives an indication of the minute quantities of radon that can be quantitatively measured. Other units that have been used are the Mache unit, which is equal to 3.6×10^{-10} curie per liter, and the Eman unit, which is equal to 1×10^{-10} curie per liter. (Hevesy and Paneth, 1926, p. 178).

For the radon measurements given in this paper, a slow ionization chamber was used, collecting positive ions, with an attached vibrating-reed electrometer to measure total ionization current. Radon was boiled out of liquid samples into an evacuated ionization chamber, while argon was simultaneously bubbled through the boiling liquid sample in order to carry the radon from the sample into the chamber. The radon was isolated in the chamber for a 4-hour period, during which time equilibrium was established with its short-lived daughter products, and the total ionization current was then measured by the vibrating reed electrometer. A continuous record of the amplified current was recorded on a one-milliampere graphic strip-chart recorder.

The currents produced by the unknown samples were compared directly with the current produced by a known amount of radon evolved from a standard radium solution. The radon content of the 10.5×10^{-12} g standard radium solution, obtained from the National Bureau of Standards, is measured periodically for calibration. The average of 20 such measurements is 25.7 milliamperes $\pm$ 0.6 (standard deviation) and gives a conversion factor, in terms of micromicrocuries per milliampere.

Background measurements using "dead" argon were made periodically, and subtracted from all measurements. The smallest amount of radon that can be measured by this apparatus is about one micromicrocurie per liter.

Radium contents of liquids are determined in a similar fashion, except that two boilings of the liquid sample are necessary. First, all radon is driven from the sample either by making a radon determination, or by boiling it to the atmosphere. The sample is sealed in its original boiler and several days later, the radon which evolved from the radium in the sample is driven into an ionization chamber and measured. The amount of radon evolved gives a measure of the amount of the radium in the sample.

Time is an important factor in both radon and radium determinations. The amount of radon that decayed during the time between sampling and determination must be determined. Because of the 3.825-day half-life, radon determinations are generally made within a day or two after sampling. In radium measurements, the time of radon evolution or buildup must be accurately known.

The equipment (figs. 2 and 3) consists of a bank of three 500-milliliter reflux boilers and two 4.2-liter stainless steel ionization chambers with a connecting gas transfer system. The system consists of two parts: the intake line from the boilers with attached U-tube desiccator and vacuum gage, and the exhaust line with its vacuum pump and thermocouple vacuum gage. The ionization chambers are connected to both lines. The two lines are connected by a "bridge" stopcock. When the

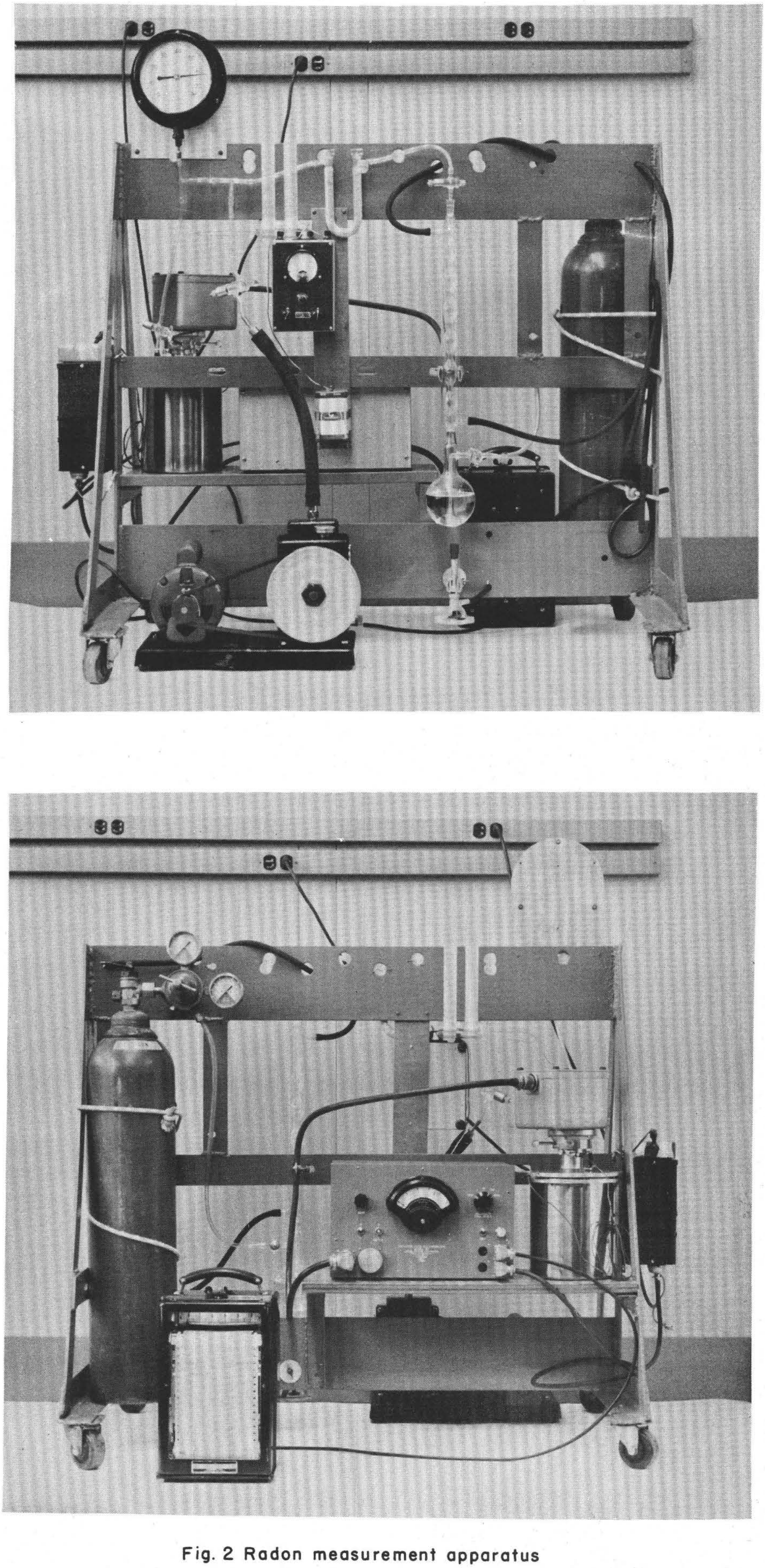

Fig. 2 Radon measurement apparatus

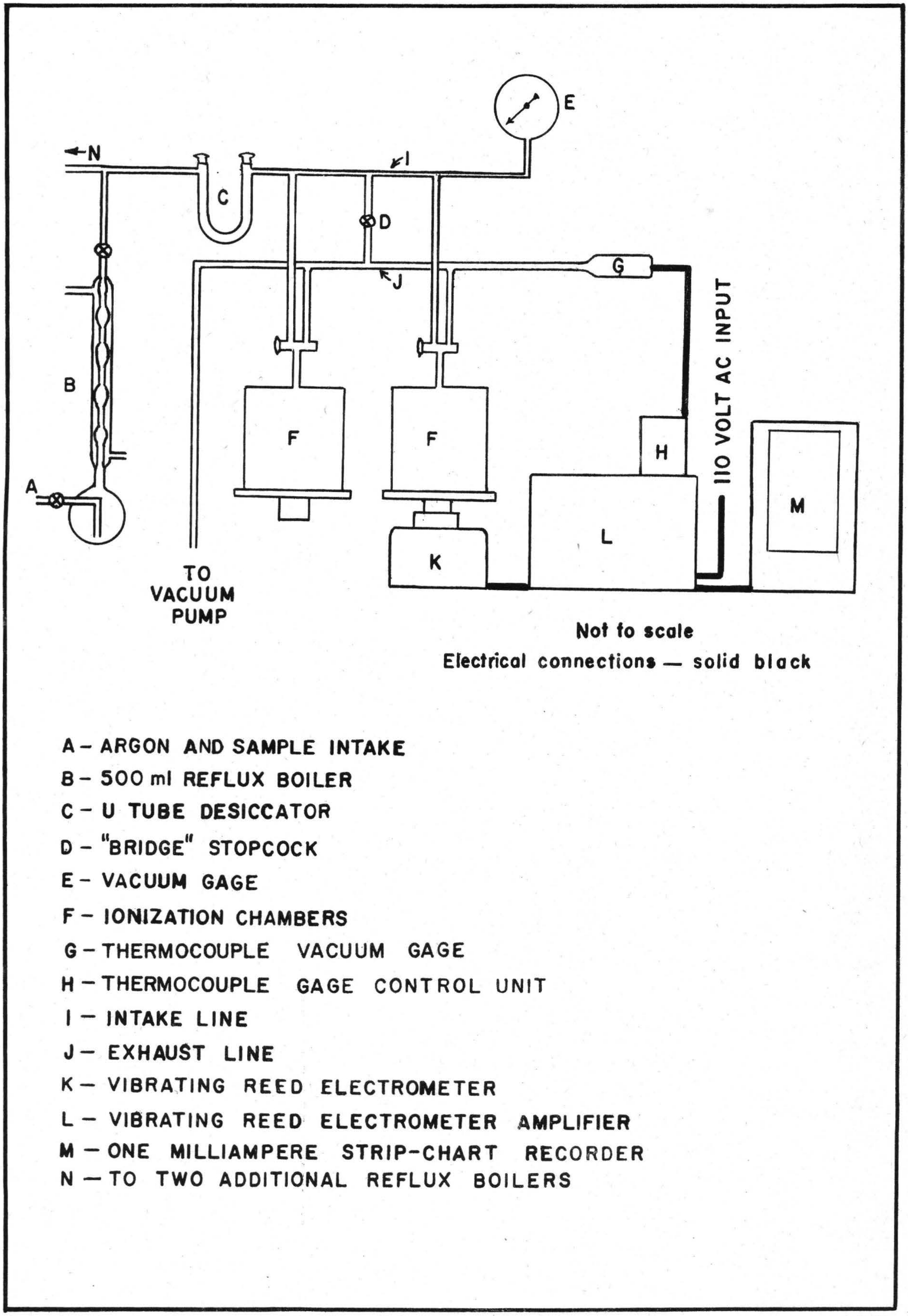

Figure 3- Diagrammatic sketch, of radon measuring apparatus

bridge is closed, it is possible to fill one chamber while evacuating the other.

The gas transfer system is made entirely of tygon tubing (3/1 inch x 1/4 inch) with glass joints and stopcocks. Tygon tubing has certain advantages over the conventional all-glass or copper tubing systems. It is cheap, and easy to construct and maintain. Changes in the system can be made easily. The cleaning of a contaminated glass or copper tubing system can be a tedious job; but if the tygon tubing becomes contaminated, it may be discarded and replaced by new tubing. Although the equipment was originally set up as a semipermanent installation in a laboratory, the tygon system was constructed with the idea that the equipment will eventually be installed as a mobile truck-mounted unit.

None of the tygon tubing-glass connections developed leaks during one year of almost daily use. A low vapor pressure silicone grease is used as a seal and lubricant in the connections. No organic greases or black rubber should be used because they tend to absorb radon.

A few limited experiments showed that no appreciable radon is lost in the tygon system by absorption or diffusion. Radon was allowed to expand freely from a full ionization chamber through about 20 feet of tygon tubing into an evacuated chamber. The radon was then measured in each chamber and generally there was less than one percent difference. R. D. Evans (personal communication) has investigated radon losses in black rubber, gum rubber, and tygon tubing. His results indicate that the loss of radon to gum rubber or tygon tubing in a breath-collecting system is negligible if the volume of the radon-air (radon-argon in this report) enclosed by the tubing at any time is small compared to the total volume collected.

Sampling techniques

Samples of waters were collected in glass tubes of approximately 300 ml. volume, with pressure-adapted stopcocks at each end (fig. 4). The tubes were first flushed with argon in the laboratory and then filled by gently applying suction with the mouth to one end of the tube with the other end immersed in the stream or spring. The difference in radon content found in water between filling sample tubes by suction or by using tubes evacuated in the laboratory was one or two percent and was considered negligible in this work. The water samples, after collection, were never again exposed to the atmosphere, as radon is rapidly flushed from any water sample that is allowed to mix with the atmosphere. It has been found that collecting a water sample in a bottle and measuring out a volume in a graduate and then pouring the measured volume into a reflux boiler, about 45 percent of the radon is dissipated to the atmosphere. Kuroda, Damon, and Hyde (1954) report the same phenomenon.

Field procedures

At the start of the first radon survey, stream samples were taken at widely spaced intervals, usually near prominent outcrops and changes in lithology. When a large amount of radon was found in the stream, samples were taken both upstream and downstream from that point. It soon became evident that the source of the radon could be established accurately, and that short sample intervals were necessary.

All samples were usually taken from the center of the stream at a depth of about one inch, and primarily in fast-flowing parts of the streams. All stagnant pools and beaver ponds were avoided.

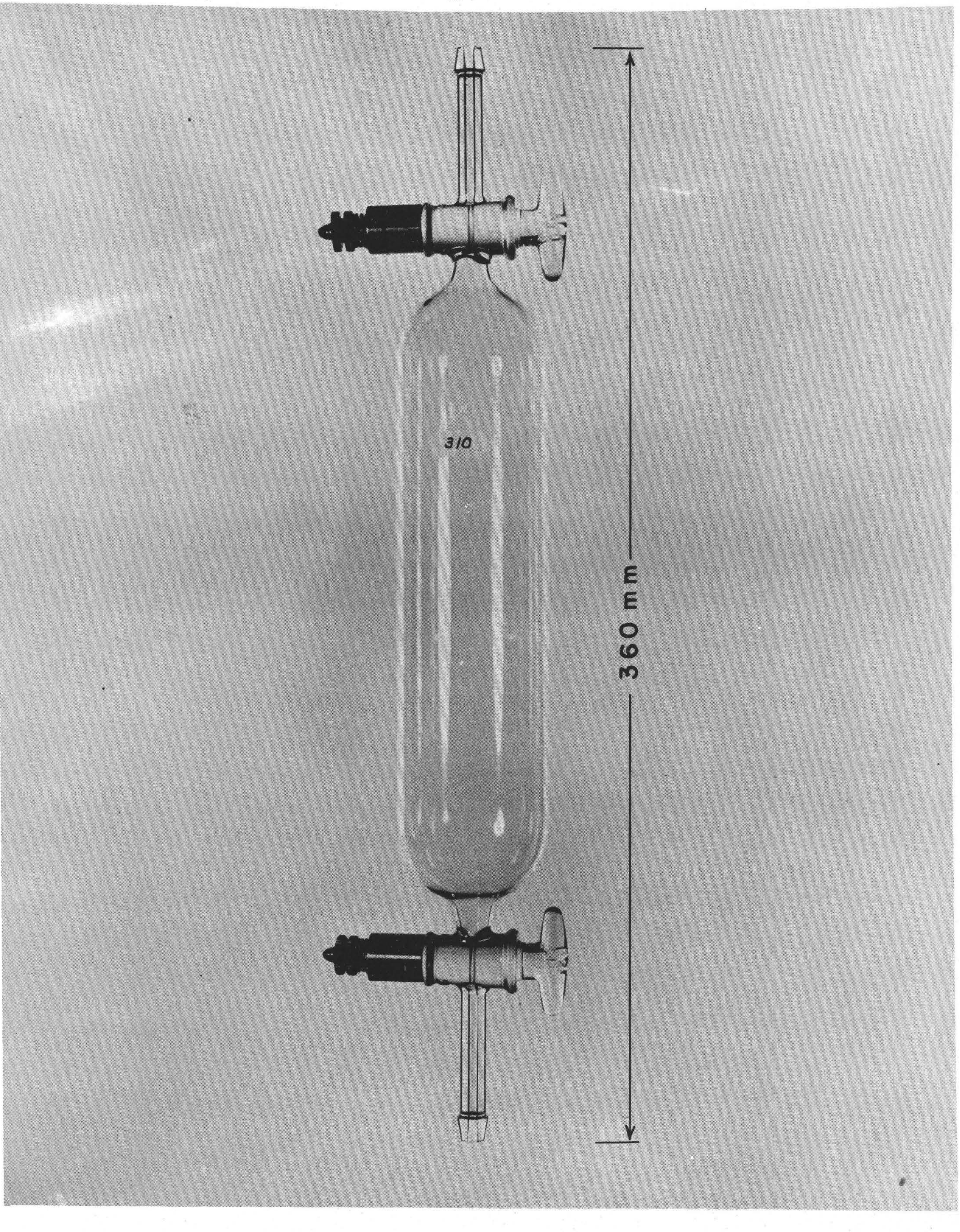

Fig. 4 Sampling tube (310 ml volume)

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The samples were returned to the laboratory for radon determination, usually within three days.

RADON DISTRIBUTION IN SURFACE WATERS DRAINING PARTS OF THE WASATCH MOUNTAINS

Purpose and scope of the investigation

In the spring of 1953 a few preliminary radon determinations were made in several streams that drain the Wasatch Mountains near Salt Lake City, Utah. These samples showed sufficient range in radon content to warrant further investigation. The investigation was postponed until the summer of 1953, when the streams reached a stable condition and were not affected by melting snow. At that time another series of preliminary radon measurements, taken periodically over an interval of one week, at several places, generally showed little variation in the radon content found at each place. Therefore it seemed reasonable to assume that significant interpretations were possible concerning the distribution of radon in stream waters.

The distribution of radon in stream waters and related springs, and the relation of the distribution to both geologic and non-geologic conditions was then investigated in several drainage areas (fig. 5) of the Wasatch Mountains adjacent to Salt Lake City, Utah. The results were then applied to a definite ground-and surface-water problem in a part of the lower Weber River drainage area near Ogden, Utah.

Geologic setting

The Wasatch Mountains extend from Nepi, in central Utah, northward into Idaho. Their western face forms part of the eastern limit of the

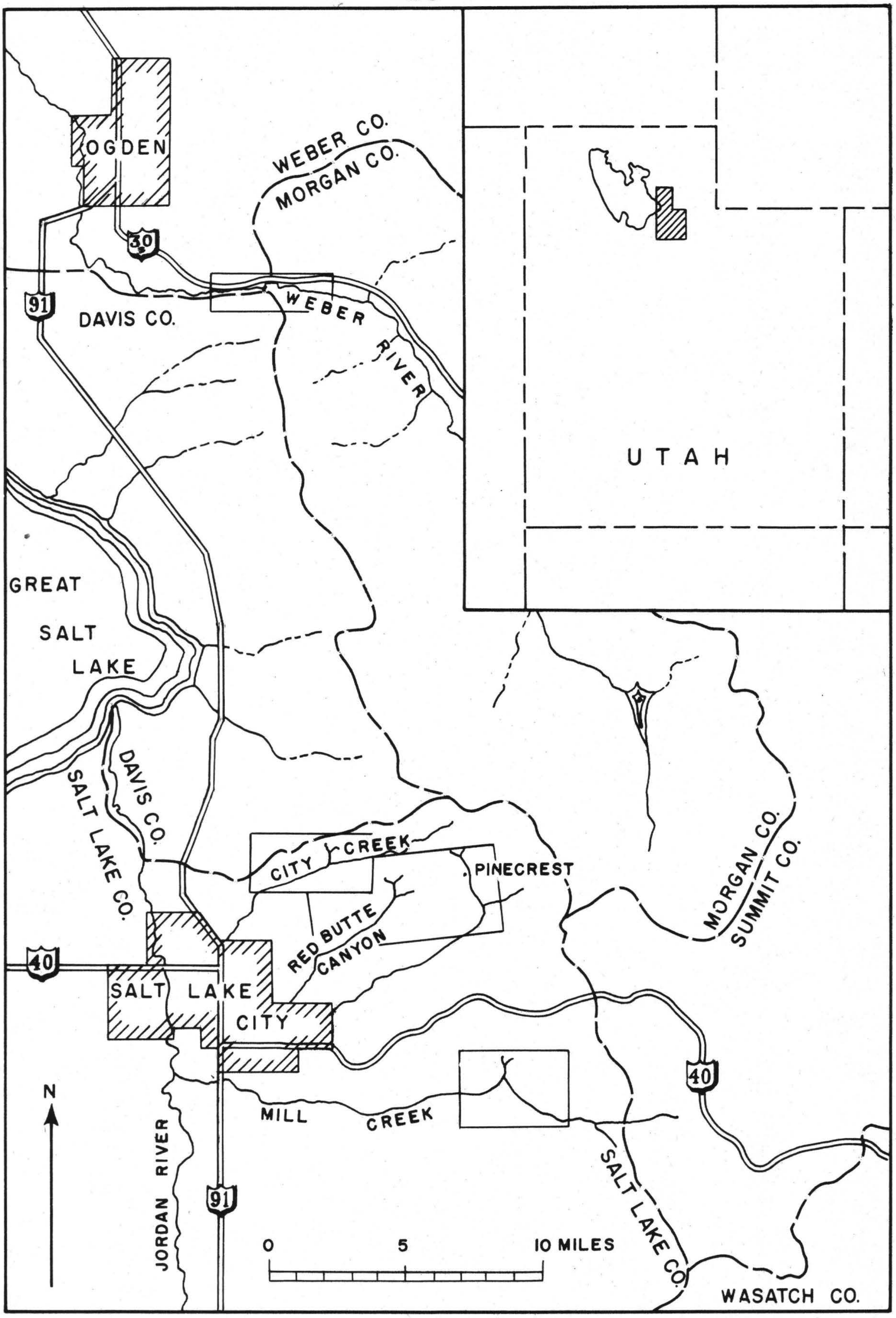

Figure 5 - Index map of area near Salt Lake City showing where radon surveys were made.

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Basin and Range province. Salt Lake City is in the northeast part of Jordan Valley near the steep front of the central Wasatch Mountains.

The area adjacent to Salt Lake City, which includes Red Butte Canyon, City Creek, and Mill Creek, has a relief of 2,500 to 5,000 feet above the floor of the valley.

Near Salt Lake City, the major structural element of the Wasatch Mountains is a broad eastward-trending syncline, which is modified by smaller folds along its trough. The syncline is flanked on the south by the Cottonwood uplift and on the north by the northern Utah uplift. The sedimentary rocks range in age from Precambrian to early Tertiary.

The sedimentary rocks in the Red Butte Canyon and Pinecrest area range in age from Pennsylvanian to Tertiary (fig. 6). The oldest formation is the Weber quartzite of Pennsylvanian age with an estimated thickness of 1,200 feet. Apparently conformably overlying the Weber quartzite is the Park City formation, of Permian age. Granger (1953) measured a thickness of 974 feet of Park City formation at the head of Red Butte Canyon. For the most part, the Park City formation is made up of limestone with a thick, somewhat phosphatic, shale member in the middle of the formation.

Approximately 3,600 feet of Triassic sedimentary rocks overlie the Park City formation, and include the Woodside red shale, the Thaynes marine limestone and shale, and the Ankareh red shale, siltstone, and sandstone. The Thaynes formation, which is of particular interest in the present investigation, has a thickness of 1,931 feet (Granger, 1953) and consists primarily of shales, sandy and shaly limestones, and one or more beds of gray limestone, which form prominent ridges.

The Triassic sediments are overlain by approximately 4,700 feet of Jurassic sandstones, argillaceous limestones, and red siltstones.

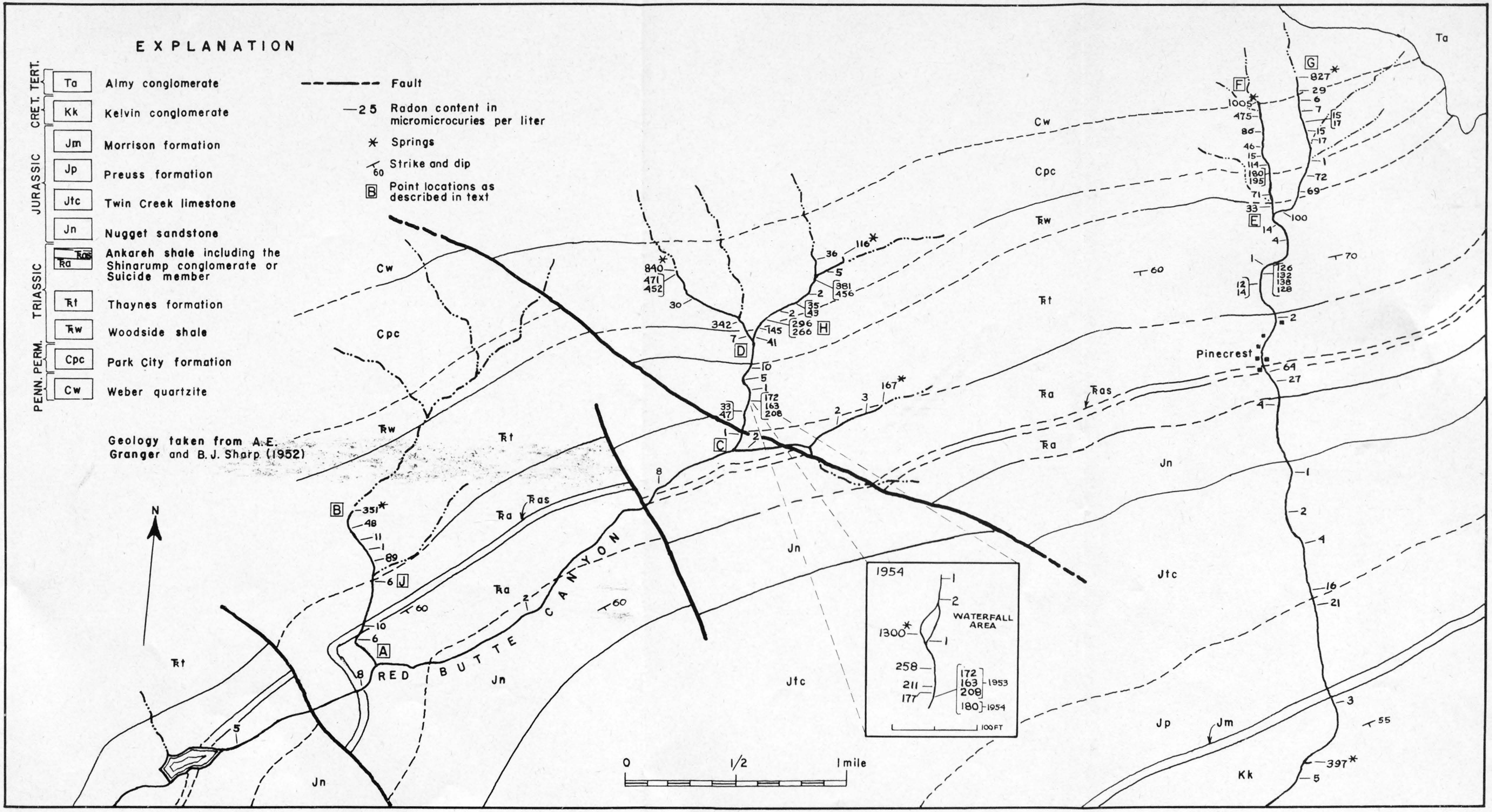

Figure 6 – GEOLOGIC MAP OF RED BUTTE CANYON AND PINECREST AREA SHOWING RADON DISTRIBUTION IN STREAMS AND SPRINGS

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The Kelvin conglomerate and red siltstones of Cretaceous age overlies the Jurassic strata with apparent conformity and is about 1,500 feet thick.

Unconformably overlapping the older rocks in the northern part of the area is the Almy conglomerate, of Tertiary age.

The lithology in the Mill Creek area (fig. 7) is similar to that of the Red Butte Canyon and Pinecrest area. The lower half of the Thaynes formation includes three rather thick limestone ridge-forming strata.

In the City Creek area there is a sequence of vertically dipping Paleozoic sediments (fig. 8) that represents an entirely different section than the Red Butte Canyon area and the Mill Creek area. Here the Paleozoic strata are unconformably overlain by Tertiary conglomerates and volcanic rocks.

Drainage

The streams in the Red Butte Canyon and Pinecrest area are small, with steep gradients. The flow at Points A, C, and E (fig. 6) is probably about one cubic foot per second. The average stream gradients, which were approximated from topographic maps, are: B to A -- about 300 feet per mile; D to C, and including the headwaters -- about 850 feet per mile, and from either F or G to Pinecrest -- about 800 feet per mile.

The average gradient of Mill Creek (fig. 7) between A and C is about 300 feet per mile. About 3 miles downstream from point C, the streamflow was approximately 12 cubic feet per second. Because of water diversion, the streamflow between A and B, perhaps 8 or 10 cubic feet per second, is probably twice the flow between B and C.

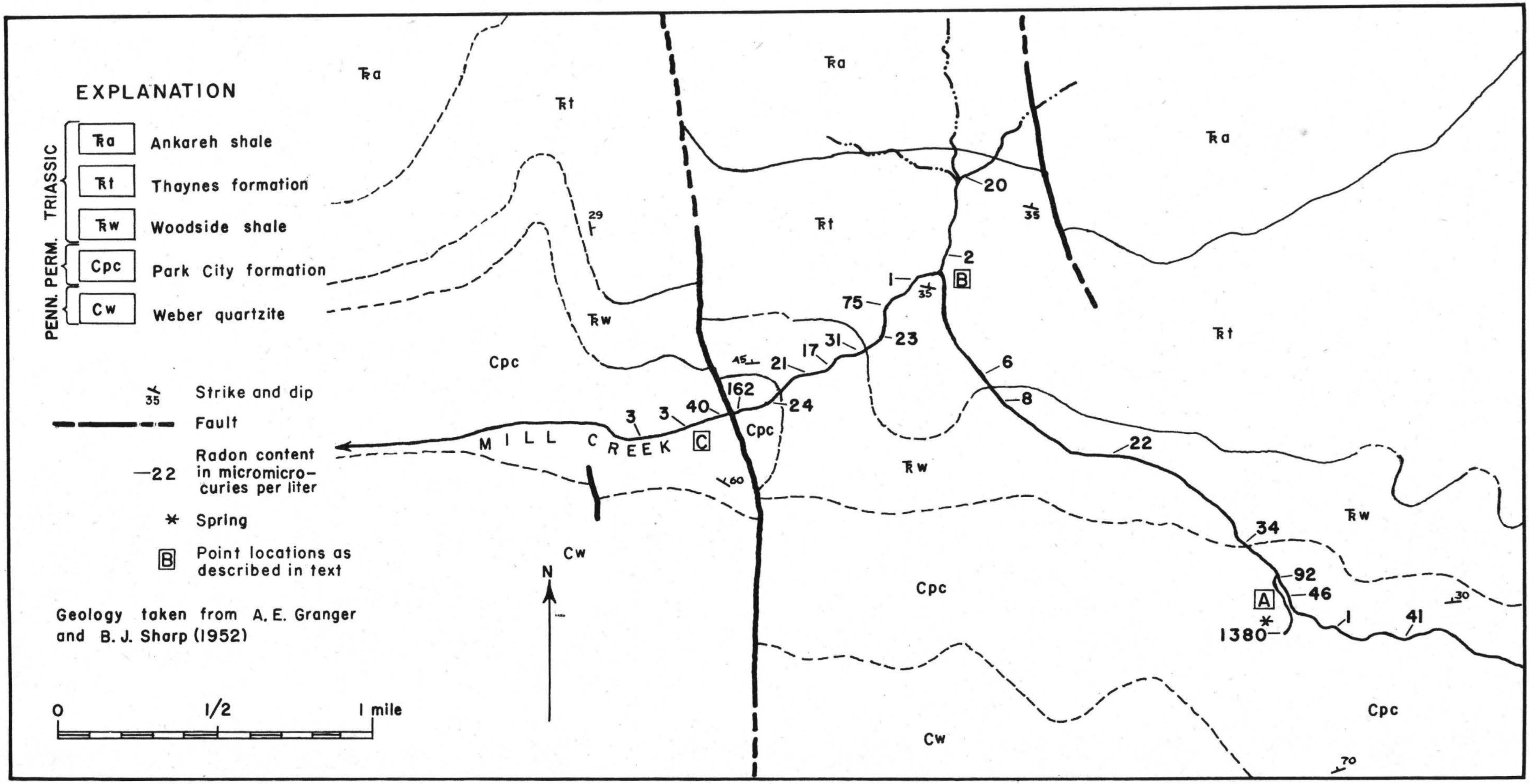

Figure 7 - GEOLOGIC MAP OF PART OF MILL CREEK AREA SHOWING RADON DISTRIBUTION IN STREAMS AND SPRINGS

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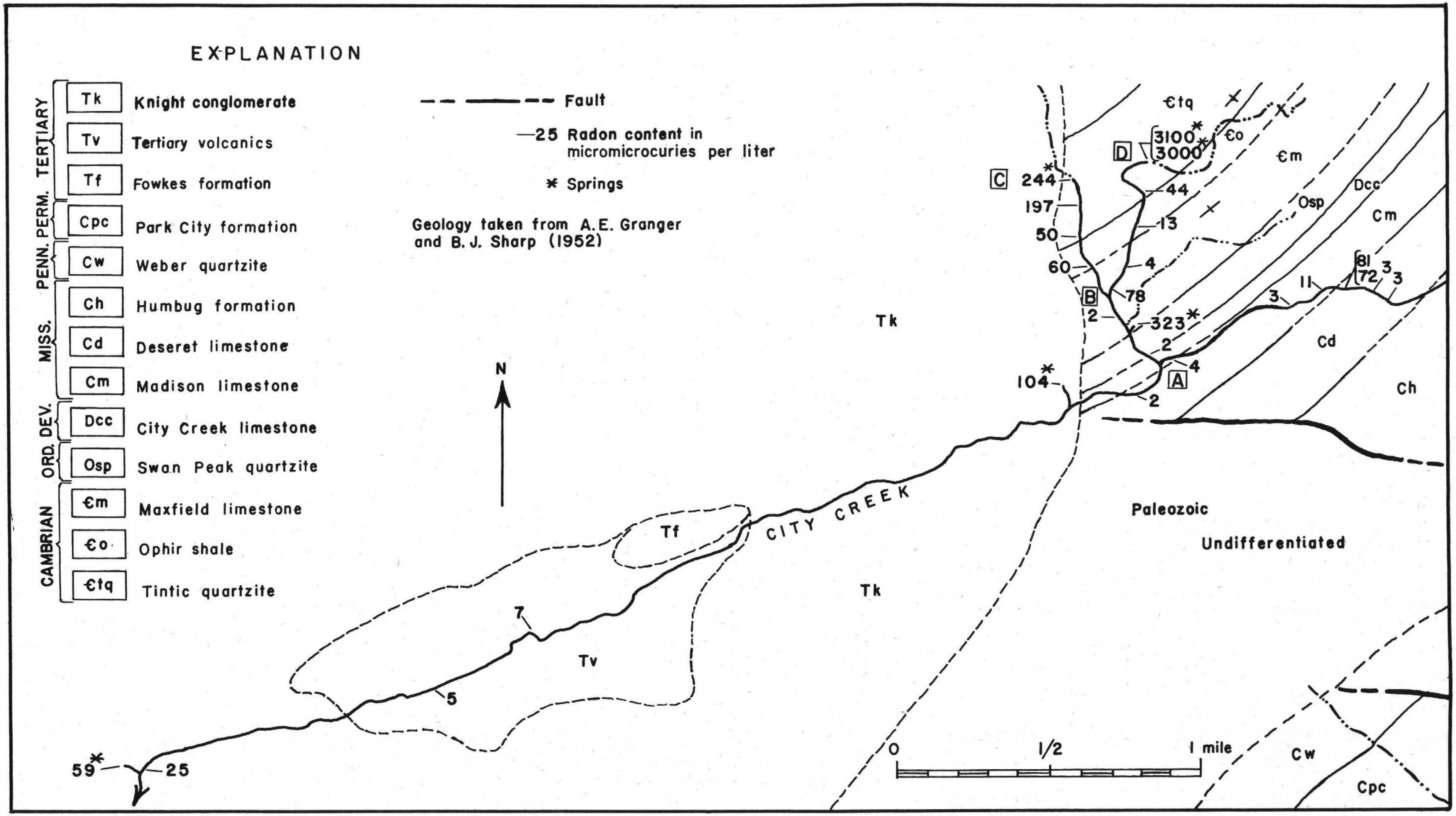

Figure 8 – GEOLOGIC MAP OF PART OF CITY CREEK AREA SHOWING RADON DISTRIBUTION IN STREAMS AND SPRINGS

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The average stream gradient on City Creek (fig. 8) between D and B is about 800 feet per mile. At point A the streamflow, based on measurements in 1950, is probably about two cubic feet per second in each fork.

Observations in Red Butte Canyon and Pinecrest areas

The radon contents of stream waters and springs in the area are shown on figure 6 in micromicrocuries per liter. All repeat samples at the same localities are shown in brackets.

The distribution of radon in the stream waters was found to follow a definite pattern. In each case relatively high radon contents are found in springs at the sources of the various streams. As the water moves downstream, the radon content decreases rapidly, in some places almost to zero within 500 feet. Farther downstream other zones of high radon concentrations are noted in the stream waters which also decrease rapidly as the water moves downstream.

This pattern of radon distribution in stream waters apparently depends upon the influx of radon-bearing ground water into the stream, and, in turn, upon the loss of radon from the stream water to the atmosphere. As air usually contains less than one micromicrocurie per liter, any radon exceeding one micromicrocurie per liter in the stream water is out of equilibrium with that in the atmosphere and will therefore decrease and approach equilibrium (fig. 1). After a large amount of radon has been introduced into the stream by ground water, it is quickly released to the atmosphere at a rate governed by the volume and gradient of the stream, and the nature of the stream channel. When radon content is plotted against distance of streamflow the loss of radon to the atmosphere is an exponential function with somewhat different slopes in different drainage areas (fig. 9).

The anomalously high radon concentrations indicate areas where large amounts of ground water relative to the stream volume are being added to the stream, although, in most places, no evidence of spring activity is apparent.

This ground-water source for the anomalous radon concentrations in stream waters is postulated for the following reasons:

1. The springs in the area generally contain more radon than the stream waters and seem to be the logical source. A water-saturated sedimentary rock with a density of 2.5, a 10 percent porosity, uranium content of 1 ppm (3.3×10^{-13} grams of radium per gram of rock) and an emanating power of 10 percent can theoretically contribute 825 micromicrocuries of radon per liter to the enclosed ground water under static conditions. If ground water, under dynamic conditions, containing about 800 micromicrocuries of radon per liter enters and contributes 10 percent to the total volume of streamflow, the radon concentration in the stream water will increase by about 80 micromicrocuries per liter at the point of ground water entrance.

2. The decay constant for radon is 0.007551 per hour or 0.000126 per minute. This shows the fraction of radon per unit time that will build up from a radium source. Hence, it seems unlikely that the radium content of the rocks and detritus exposed in the stream channel itself will contribute much radon to the stream waters. The radon will be continuously and swiftly swept downstream and dissipated to the atmosphere, which precludes any build up or accumulation of radon in the stream water.

3. Surveys with a scintillation counter showed no abnormally high radioactivity in the rocks along the stream channels. On the contrary,

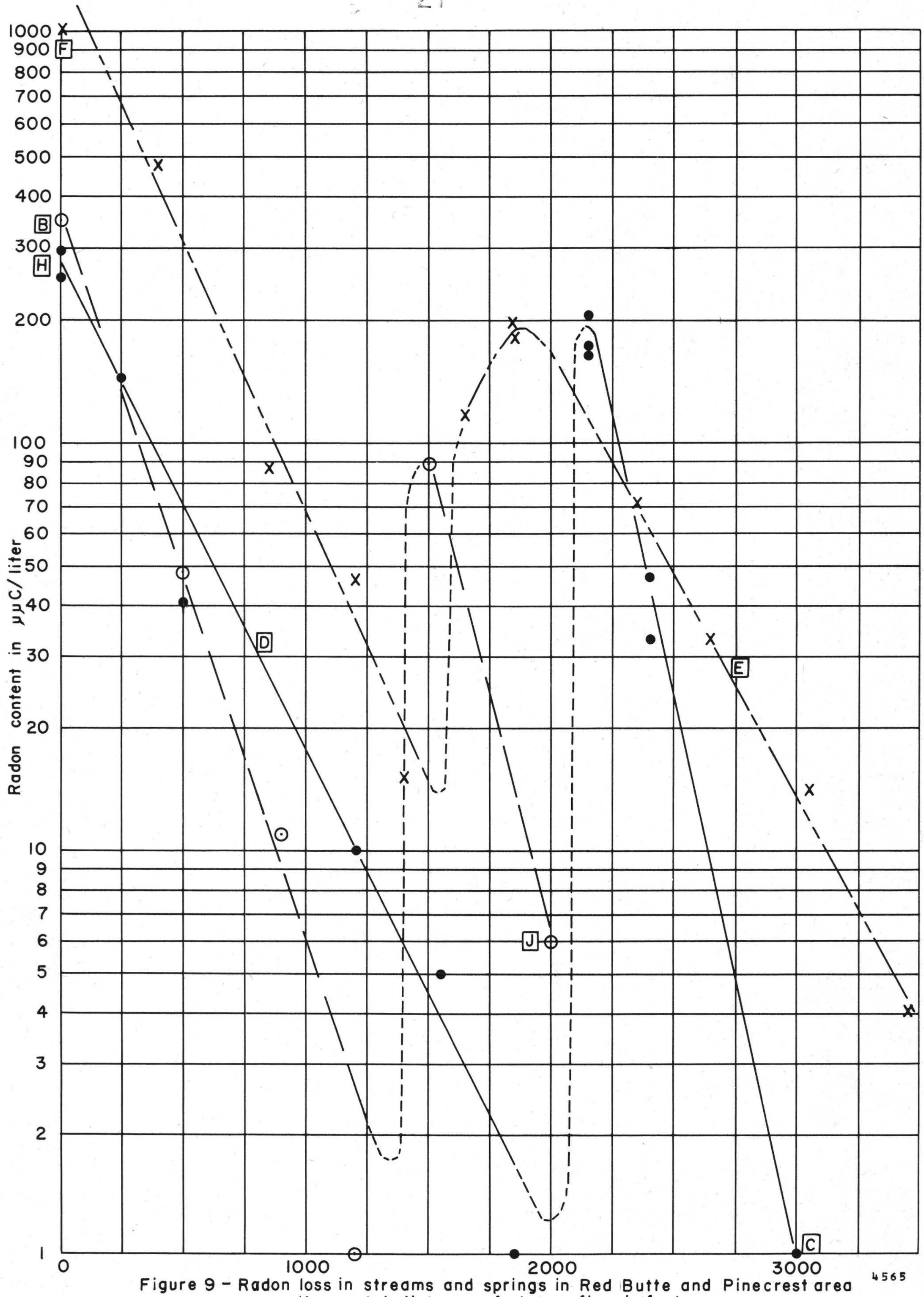

Figure 9 – Radon loss in streams and springs in Red Butte and Pinecrest area
Horizontal distance of stream flow-in feet

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the limestones in the area, with which most radon anomalies in the stream waters are related, show a normal, lower background than that of the adjacent shales. The radon anomalies in the streams cannot, therefore, be related to changes in the radium content in the stream channel debris or outcrops.

4. A definite relation has been found between some of the high radon content in stream waters and adjacent radon-bearing springs.

The areas of relatively large amounts of ground-water influx thus marked by radon anomalies can be related to rather definite stratigraphic horizons. The anomaly of 126 micromicrocuries per liter about 1/2 mile north of Pinecrest at a point where repeat samples were taken over a period of three months, is related to a thin (10 or 20 feet) prominent limestone ridge in the Thaynes formation that causes an abrupt change in stream gradient. The anomaly in the Thaynes in drainage DC (fig. 6) is similarly related to a thin limestone ridge. Although no prominent limestone ridge was noted in the Thaynes formation in drainage BA, there is an anomaly of 89 micromicrocuries per liter at a point of abrupt change in stream gradient, which suggests that the limestone is also present at the point of the anomaly in drainage BA. Another limestone ridge occurs near the base of the Thaynes formation north of Pinecrest, where an anomaly of 100 micromicrocuries per liter is found.

The upper limestone member of the Park City formation also acts as an aquifer, particularly near its contact with the Woodside shale. Radon anomalies are also associated with the Shinarump conglomerate or Suicide member of the Anareh shale, although they are generally small.

A somewhat perplexing difference in radon distribution exists between drainage FE and GE, which are parallel and only about 1,500 feet apart. Drainage FE contains a higher level of radon concentration than drainage GE, and there is a large radon anomaly near the Park City-Woodside contact in drainage FE; yet no anomaly was found in drainage GE. This marked difference may be due to the differences in the two stream channels. The channel of drainage FE is partly bedrock and partly soil derived from bedrock and with considerable vegetation. Whether the vegetation is supported by water from the stream or by spring water is not known, although there is presumably some influx of ground water into the stream to maintain the relatively high radon content.

Channel GE is full of cobbles and boulders of Weber quartzite and Almy conglomerate at least 15 feet thick near the Park City-Woodside contact. Increased turbulence probably contributes to the low radon concentrations. It is also possible that any ground water that enters the channel does so at depth, and then emerges to mix with the stream water in the area of the Woodside shale, where the layer of cobbles and boulders is thinner or absent.

In the summer of 1954 a more detailed study was made of the anomaly associated with a small limestone ridge in the Thaynes formation in drainage DC (see blowup on fig. 6). By sampling at very close intervals, the radon anomaly was pinpointed to within 50 feet of its source. The source was traced to a spring containing 1,300 micromicrocuries of radon per liter issuing from a limestone cavern under a waterfall. This spring had not been noticed during the 1953 survey. A spring flowing about 50 gallons per minute from the bottom of the stream channel and containing 550 micromicrocuries of radon per liter was found about 50 feet upstream from the radon anomaly in the Thaynes formation 1/2 mile north of Pinecrest. The entire streamflow had been diverted for domestic purposes and the stream channel upstream from the spring was completely dry.

Observations in the Mill Creek area

Large increases in radon content were found in the stream waters near limestones in the Thaynes and Park City formations. These limestones apparently act as aquifers in a manner similar to that found in the Red Butte Canyon and Pinecrest area. The spring at Point A (fig. 7) also acts as a source of radon in the stream water.

A plot of radon content versus distance of streamflow between A and C is shown in figure 10. This plot again shows that the rate of radon loss is an exponential function with respect to distance of stream-flow. The slope of curve between A and B is much flatter than those for drainages in the Red Butte Canyon and Pinecrest area (note the difference in the distance scale), probably owing to the greater stream volume and lower gradient in the Mill Creek area. The exponential function has a flatter slope between A and B than near point C. This is probably due to the smaller stream volume near point C. The slope of the function near point C is almost identical to those in the Red Butte Canyon and Pinecrest area.

As Mill Creek is a fairly wide stream, a series of samples were taken at point A at various positions in the stream to determine whether sampling position is a critical factor. The stream at point A is about 7 feet wide. The radon content, on the basis of this one experiment, varies only about 5 percent with respect to stream position. The results shown in figure 11 indicate that the radon content is a maximum in the center of the stream, and is apparently constant with depth.

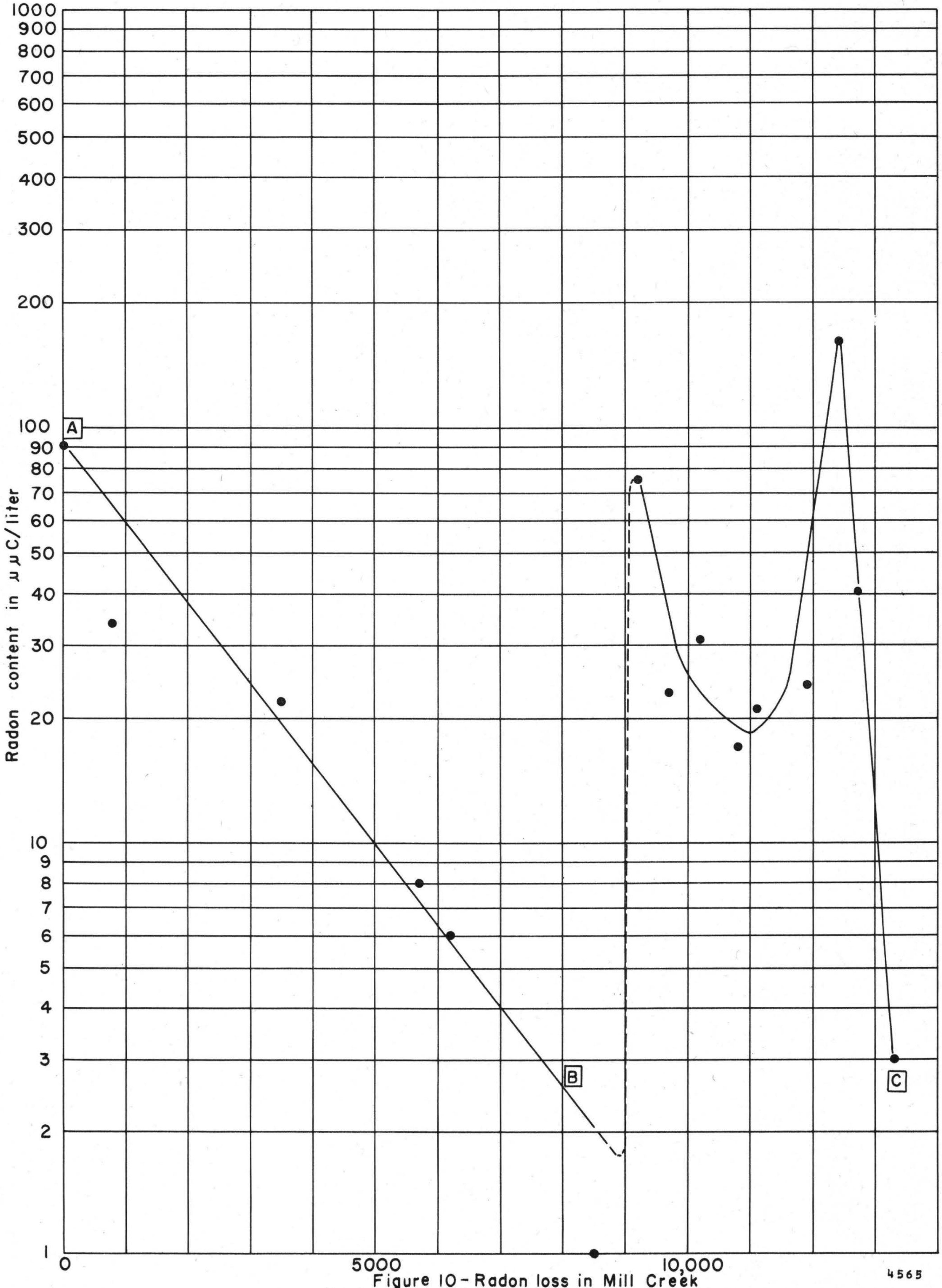

Figure 10 - Radon loss in Mill Creek
Horizontal distance of stream flow-in feet

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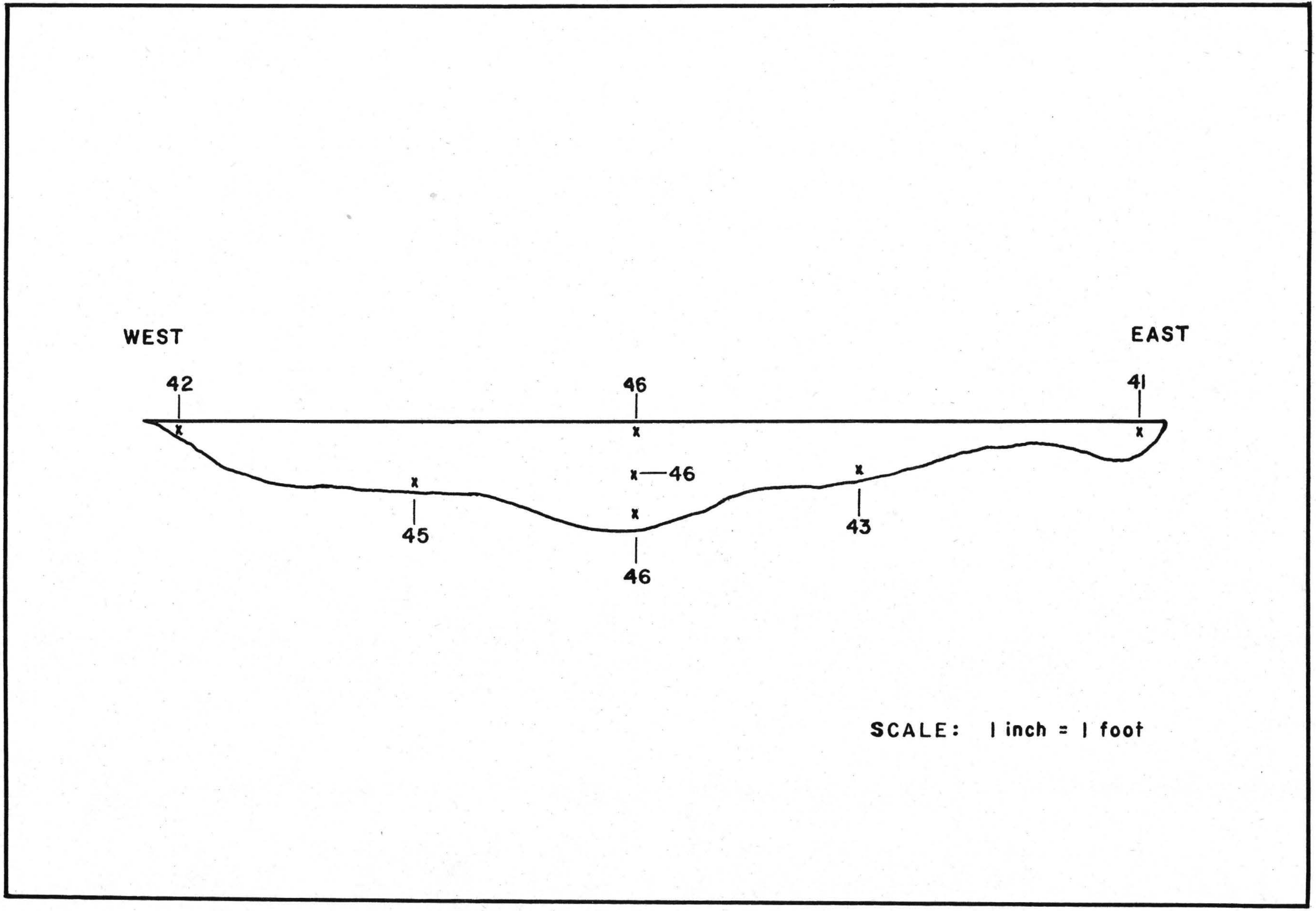

Figure 11 – Cross section of Mill Creek at point A showing radon distribution.

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Observations in the City Creek area

The results of the radon survey in the City Creek area are similar to those in the other two areas, although City Creek flows over an entirely different sequence of rocks than those exposed in the Red Butte and Mill Creek areas. Numerous small springs maintain a higher level of radon concentration along the fork CB than in fork DB.

Radium in streams and springs

Several radium determinations of stream- and spring-water samples show that the radon is almost completely unsupported by its parent radium in solution. The radium content in each sample is of the order of 1 micromicrocurie per liter. As this small amount approaches the limit of the sensitivity of the instrument, the radium content may be less. No uranium analyses of the samples were made.

APPLICATION TO A SURFACE-WATER PROBLEM IN WEBER RIVER DRAINAGE AREA

Radon determinations in stream waters and related springs were applied to a ground-water problem in a part of the lower Weber River drainage area, near Ogden, Utah (fig. 12).

The Weber River in this area flows due west through a steep-walled canyon in the northern Farmington Mountains. The Farmington Mountains, a division of the Wasatch Range, are characterized by a well-exposed Precambrian metamorphic terrain. Ten thrust plates, represented by diaphthorite zones of retrograde metamorphism, are exposed near the Weber River Canyon (Bell, 1952).

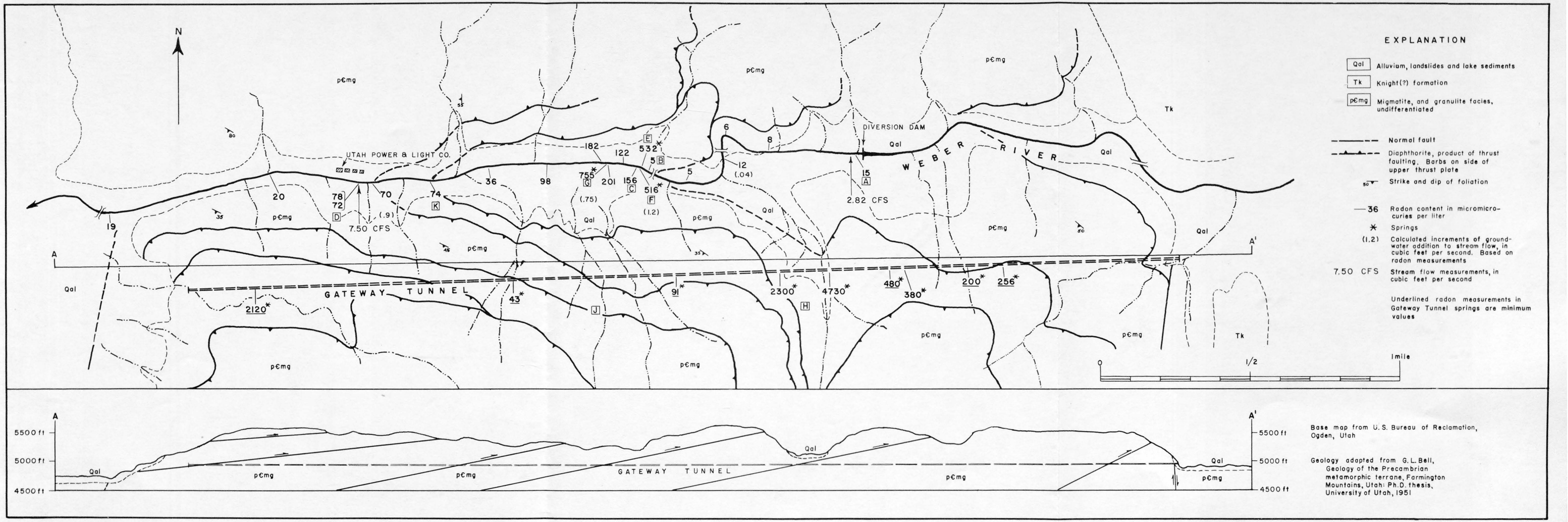

Figure 12—GEOLOGIC MAP AND CROSS SECTION OF PART OF THE LOWER WEBER RIVER AREA SHOWING RADON DISTRIBUTION IN STREAM AND SPRING WATERS

Measurements by John Feth of the Geological Survey show the flow of the Weber River increases from 2.82 cubic feet per second at point A to 7.50 cubic feet per second at point D, a distance of 1 1/2 miles (fig. 12). The only visible additions to the streamflow from springs at points E, F, and G, amounted to about 20 gallons per minute (about 1/20 cubic feet per second). The stream gradient is about 100 feet per mile.

The problem was to determine whether the increase in stream volume was due to a continual influx of ground water along the stream course between A and D or whether it was mostly confined to the limited area of visible seeps, at points E, F, and G. An attempt was also made to determine if the increase in stream volume was due to the influx of bedrock or bank storage ground water. It was impractical to gage the stream flow between A and D because of the abundance of large boulders in the stream channel.

The radon contents of stream waters and springs were determined in the Weber Canyon area (fig. 12). Radon contents of the major springs in the Gateway Tunnel, U. S. Bureau of Reclamation project, were also determined. The radon determinations in the tunnel, which are underlined on the map, were collected from galvanized troughs or drips from the back, and are considered to be low by at least 50 percent, and possibly more, due to the loss of radon to the air.

No abnormal radioactivity was detected by a scintillation counter traverse through the tunnel except in a small area 1,000 feet from the east portal. A sample was collected by John Powers, U. S. Geological Survey, who made the scintillation counter traverse. The sample, which was taken from a pod-like mass of pegmatitic material, contained 0.003 percent equivalent uranium.

Quality-of-water measurements were made on three spring and four stream samples, at points A through G, by Ignace Sekula, U. S. Geological Survey. These measurements were made partly to aid in ground- and surface-water studies in Ogden, Utah, area, and partly to determine if any relationships can be established between quality-of-water and radon measurements. The results of the quality tests are listed in table 1. There is no apparent direct relationship between quality-of-water and the radon content.

Table 1.--Quality of water data, Weber River, Feb. 15, 1954[*]

Sample Location	Temp. °F	pH	HCO_3 ppm	SO_4 ppm	Cl ppm	Hardness as $CaCO_3$-ppm	Noncarbonate hardness-ppm	Specific conductance micromhos	Radon content μμc/l
Stream samples									
A	39	8.1	280	32	26	257	27	554	15
B	35	8.3	277	32	26	256	29	549	5
C	42	8.0	256	32	22	234	24	512	156
D	42	8.2	218	28	20	200	21	446	78
Spring samples									
E	47	7.6	243	32	19	220	21	482	532
F	46	7.8	248	32	18	222	19	487	516
G	45	7.7	228	28	19	210	23	465	755

[*]Analysis by Ignace Sekula
U. S. Geological Survey

A clear relation was found between the distribution of high radon concentrations in the Weber River and the radon-bearing springs at E, F, and G. The distribution pattern is similar to that found in the streams in the Wasatch Mountains near Salt Lake City, Utah. When radon is plotted against distance of streamflow (fig. 13), the loss of radon again is an exponential function of distance.

On the basis that other high radon concentrations in the stream waters are related to springs, it is believed that ground water contributes a small amount to the streamflow below the railroad bridge in the S-shaped part of the stream and a larger amount in a zone between D and K. The large addition of ground water in the zone between D and K is supported further by the quality of water analyses (table 1). The total hardness and specific conductance measurements show that the solids content of the stream at point D is less than the solids content upstream at points A, B, and C, and also less than the solids content of the springs at E, F, and G. If it is assumed that the stream is not precipitating part of its solid content, then an addition of better-quality water occurs between G and D.

The area of springs at E, F, and G, as well as at D and K, which are the other areas of large ground-water influx, show a marked relation to the surface expression of thrust plates in the canyon. If bank storage is the controlling factor in the movement of ground water in this area, the entrance of ground water into the stream, and hence the radon anomalies in the stream, would probably occur in the areas where a large amount of alluvial material is present.

An attempt was made to use the radon measurements of stream and spring-waters to calculate the increments of increase of stream volume between points A and D, where intermediary stream gaging was impractical

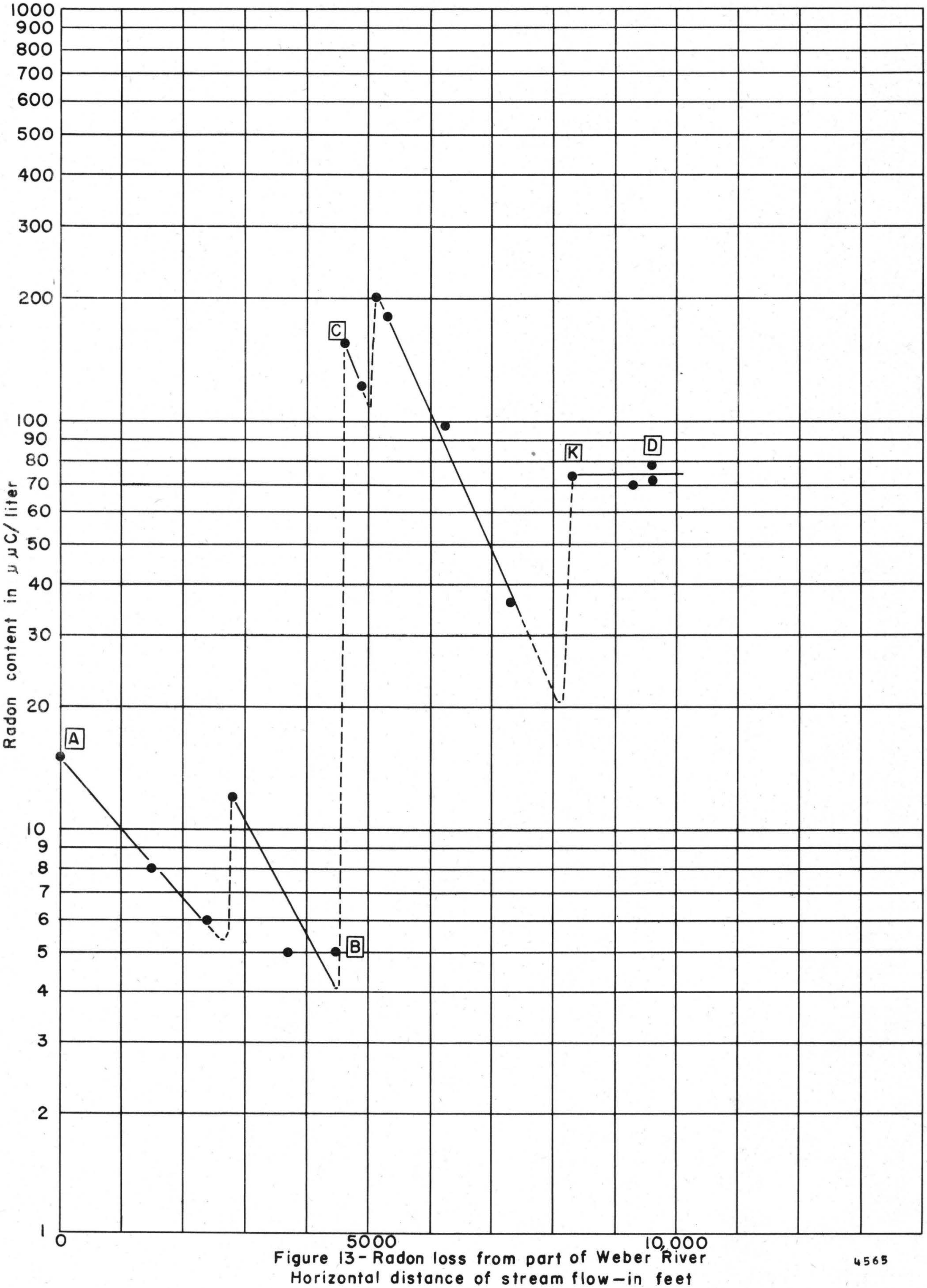

Figure 13- Radon loss from part of Weber River

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because of the abundance of large boulders in the channel.

The following assumptions were made in the calculations:

1. The stream does not lose or gain in volume between the points of radon anomalies; that is, the streamflow at B is 2.82 + .04 cubic feet per second. Similarly, the streamflow at point K is assumed to be 2.82 + 0.4 + 1.2 + .75 cubic feet per second.

2. Radon contents of the springs are representative of all ground water entering the stream at the particular point.

3. Complete mixing of radon occurs in the stream waters.

4. The rate of radon loss in the stream is constant. For instance, at a point just upstream from K, the stream is assumed to contain about 20 micromicrocuries per liter, based on the exponential rate of radon dissipation between G and K (fig. 7).

5. In the area DK, the radon content of the ground water entering the stream is assumed to be 600 micromicrocuries per liter, based on the average radon content of known springs at E, F, and G.

The results of the calculations, which are believed to be reasonable estimates, are shown on figure 12 at points F, G, the zone between D and K, and the small radon anomaly in the S-shaped part of the stream. At point F, for instance, the amount of influx of ground water, containing approximately 500 micromicrocuries per liter, was determined to be 1.2 cubic feet per second, in order to raise the radon concentration in the stream from 5 (at point B) to 156 (at point C) micromicrocuries per liter. The calculations thus account for about 65 percent of the stream flow increase between A and D.

In summary, the bulk of the ground water which enters and increases the flow of the Weber River can be considered bedrock rather than bank storage ground water. The movement of ground water in the area is apparently controlled by the diapthorite thrust plates. On the basis of radon concentrations in the stream waters and related springs, calculations were made which accounted for about 65 percent of the total increase in streamflow between points A and D.

SUMMARY OF CONCLUSIONS

Radon concentrations in stream waters can be used to determine areas where relatively large amounts of radon-bearing ground water enter small turbulent streams. These areas of influent ground water are marked by abrupt increases in the radon content of the stream waters and can be determined accurately, provided short intervals of sample spacing are used. The high radon concentration in the stream water is then rapidly dissipated to the atmosphere as an exponential function, of various slopes, with respect to distance of streamflow. The rate of radon dissipation is dependent upon the radon distribution ratio, the rate and volume of streamflow, the gradient of the stream, and the nature of the stream channel.

In the Wasatch Mountains adjacent to Salt Lake City, Utah, the high radon concentration in stream waters can generally be related to definite stratigraphic horizons in several drainage areas. Thus, lithologic units which act as the primary aquifers can be determined.

The technique of locating areas of ground-water influx into streams by radon determinations was applied to a definite ground- and surface-water problem in a part of the lower Weber River area. The problem was to determine the points of streamflow increase and whether this was due to the addition of bedrock or bank-storage ground water. Conventional methods, such as stream gaging, were not practical in this area. The increase in stream flow was found to occur primarily in three areas apparently associated with thrust faults. Calculations, based on radon concentrations in stream waters and adjoining springs, were made to determine the amount of ground water entering the Weber River at each zone of increase.

The radon content of both stream and spring waters was found to be almost completely out of equilibrium with its parent radium.

The results of the present investigation on the distribution of radon in streams and related springs should have potential applications to ground-water studies.

LITERATURE CITED

Arndt, R. H., and Kuroda, P. K., 1953, Radioactivity of rivers and lakes in parts of Garland and Hot Springs Counties, Arkansas: Econ. Geology, v. 48, no. 7, p. 551-567.

Bell, G. L., 1952, Geology of the central Wasatch Mountains, Utah: Utah Geol. Soc. Guidebook, 8th Ann. Field Conf., p. 38-51.

Clark, R. W., and Botset, H. G., 1932, Correlation between radon and heavy mineral content of soils: Am. Assoc. Petroleum Geologists Bull., v. 16, p. 1349-56.

Faul, Henry, Gott, G. B., Manger, G. E., Mytton, J. W., and Sakakura, A. Y., 1954, Radon and helium in natural gas: Internat. Geol. Cong., 19th sess., Algiers, Comptes rendus, Sec. 9, p. 339-348.

Granger, A. E., 1953, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U. S. Geol. Survey Circ. 296.

______________, and Sharp, B. J., 1952, Geology of the central Wasatch Mountains, Utah: Utah Geol. Soc. Guidebook, 8th Ann. Field Conf., p. 1-37.

Hevesy, G., and Paneth, F., 1926, A manual of radioactivity: London, Oxford Univ. Press.

Jennings, W. A., and Russ, S., 1948, Radon: Its technique and use: London, Middlesex Hosp. Press.

Kofler, M., 1913, Loslichkeit der Ra-Emanation in Wasserigensalzlosungen: Akad. Wiss. Wien Sitzungsber, Math-Naturw. Kl.. Abt. IIa, Band 122, p. 1473-1479.

Kovach, E. M., 1944, An experimental study of the radon-content of soil-gas: Am. Geophys. Union Trans., p. 563-571.

___________, 1945, Meteorological influences upon the radon content of soil-gas: Am. Geophys. Union Trans., v. 26, no. 2, p. 241-248.

_____________, 1946, Diurnal variations of the radon-content of soil-gas: Terrest. Magnetism and Atmos. Electricity, v. 11, no. 1, p. 45-56.

Kuroda, P. K., Damon, P. E., and Hyde, H. I., 1954, Radioactivity of the spring waters of Hot Springs National Park and vicinity in Arkansas: Am. Jour. Sci., v. 252, no. 2, p. 76-86.

Miholic, S., 1952, Radioactivity of waters issuing from sedimentary rocks: Econ. Geology, v. 47, no. 5, p. 543-547.

Norinder, H., Metnieks, A., and Siksna, R., 1953, Radon content of the air in the soil at Uppsala: Arkiv Geofysik, Band 1, Hafte 5-6, p. 571-579.

Pierce, A. P., Mytton, J. W., and Gott G. B., 1956, Radioactive elements and their daughter products in the Texas Panhandle and other oil and gas fields in the United States: U. S. Geol. Survey Prof. Paper 300, p. 527-532.

Schlundt, H., and Moore, R. B., 1909, Radioactivity of the thermal waters of Yellowstone National Park: U. S. Geol. Survey Bull. 395.

Wahl, A. C., and Bonner, N. A., 1951, Radioactivity applied to chemistry: New York, John Wiley and Sons, Inc.