UNITED STATES GEOLOGICAL SURVEY

Trace elements investigations report

TEI-211

THE GEOLOGICAL SURVEY'S WORK ON DEVELOPMENT OF PROSPECTING TOOLS, INSTRUMENTS, AND TECHNIQUES

By
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This preliminary report is released without editorial and technical review for conformity with official standards and nomenclature, to make the information available to interested organizations and to stimulate the search for uranium deposits.

May 1952

Prepared by the Geological Survey for the
UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service, Oak Ridge, Tennessee

INSTRUMENTATION

AEC, Oak Ridge, Tenn.-W25338

UNITES STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

THE GEOLOGICAL SURVEY'S WORK ON DEVELOPMENT OF PROSPECTING TOOLS, INSTRUMENTS, AND TECHNIQUES*

Trace Elements Investigations Report 211

*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

THE GEOLOGICAL SURVEY'S WORK ON DEVELOPMENT OF PROSPECTING TOOLS, INSTRUMENTS, AND TECHNIQUES

By Frank W. Stead

(Read at the Information Meeting on Raw Materials Research, University of Arkansas, Fayetteville, Arkansas, November 30, 1951)

ABSTRACT

The standard geophysical methods of exploration do not provide any direct indication of radioactive materials, although they may be used in the determination of geologic structures favorable for the occurrence of ore. The principal emphasis, therefore, of the Geological Survey's geophysical work on the atomic energy program has been placed on the development of equipment and techniques for rapid field measurement of radioactivity, principally portable survey counters, carborne and airborne equipment, and gamma-ray logging equipment. Experimental electrical resistivity surveys aimed at outlying areas favorable to the occurrence of uranium deposits, however, have been carried out on the Colorado Plateau during the past two years.

Our past investigations in the field of geophysical exploration could be classed in large part as applied research. The understandable need for speed in the present seach for uranium has tended to retard the more fundamental and theoretical research needed for future progress. Particularly in gamma radiation, we have continually found that satisfactory prediction could not be made on the basis of existing theory, and we have been forced to mark time while new concepts were developed to explain apparently anomalous data. We hope in the future to reach a better balance between the two extremes of the research spectrum, the purely empirical or applied phase and the fundamental or basic phase.

INTRODUCTION

The radioactivity characteristic of uranium and thorium, of course, offers a unique means of detection and identification. The other physical properties of radioactive raw materials are not significantly different from those of the common ore materials to afford the opportunity for developing specialized methods of exploration. With the possible exception of thermal gradients caused by radioactive decay, the standard geophysical methods of exploration do not provide any direct indication of radioactive materials, although they may be used in the determination of geologic structures favorable for the occurrence of ore. For these reasons the principal emphasis has been placed on the development of equipment and techniques for rapid field measurement of radioactivity, principally portable survey counters, carborne and airborne equipment, and gamma-ray logging equipment.

The portable Geiger counter has been the principal field tool for the reconnaissance geologist, the mining engineer, and the prospector. Early models of the counter were characterized by considerable bulk and unreliable performance, and few were available from commercial sources. Such as were available, required as much time expended in determining whether the counter was behaving properly as was spent in actual measurement of outcrop activity. We owe our thanks to the health physicists in the atomic energy program for developing the portable counter to the light-weight, rugged, and reliable instrument that it now is. The development of radiation-detection equipment by the U. S. Geological Survey, on behalf of the U. S. Atomic Energy Commission, has consisted largely of modifying commercial instruments of good design to fit the particular needs of the reconnaissance geologist.

The technique of using the counter for prospecting and exploration evolved in the early years of the program and has not changed radically since 1946. Based on comparison between the chemical analyses of carefully sampled outcrops and the counting rate of the particular counter used, the interpretation of field measurements of radioactivity now is at the point where an experienced reconnaissance geologist can predict the equivalent uranium content of a rock outcrop within a few thousandths of a percent. It should be borne in mind, however, that a field measurement of radiation intensity reflects a heterogeneous source configuration whereas a laboratory measurement is made on essentially homogeneous distribution. It is the intelligent, on-the-spot, evaluation by the field geologist that permits a satisfactory interpretation of the field measurement --it is not a matter of extreme statistical accuracy of measurement demanding the ultimate in elaborate equipment.

PORTABLE EQUIPMENT

The varieties of portable survey meters, commonly called Geiger counters, used by the Geological Survey, are shown in figure 1. Most of them are standard health-physics meters with three ranges, normally 0.2, 2.0, and 20 mr/hr, and are modified to meet our particular field needs. As a general working principal, we have striven to achieve a maximum simplicity of equipment, coupled with ruggedness, reliability, and adequate resolution of measurement.

The portable scale-of-eight, an undesirably complex but reliable instrument, is used where a quantitative measurement is desired, particularly on samples selected for immediate guidance of further investigations in remote areas.

At the moment, about 500 portable survey meters are being used by the Survey in the search for radioactive materials. All meters are periodically calibrated in terms of milliroentgens per hour to allow intercomparison between measurements made on different types of materials with different types of meters.

Typical field equipment

The typical field equipment carried by parties in remote areas such as Alaska is shown in figure 2. Consideration has been given to maximum flexibility of use and to a minimum of weight. Such equipment is normally carried cross-country and transported by light planes.

One portable survey meter is used for all probes: the standard small beta-gamma probe, the standard 2-by 20-inch probe, the logging probe with 50 feet of cable for use in drill holes and mine shafts, and the bank of large tubes for carborne or airborne use. The total weight of this equipment is about 30 pounds.

A field party or reconnaissance geologist so equipped can undertake all types of radiometric examination such as cross-country traversing, detailed outcrop examination, carborne surveying, airborne surveying, and shallow bore-hole logging.

Portable assay equipment

The use of portable assay equipment, such as shown in figure 3, permits the field geologist to determine the equivalent uranium content of samples to within a few thousandths of a percent. The assay cup contains a thin-walled beta-gamma tube; either the portable survey meter or the portable scale-of-eight can be used as the indicating instrument.

The technique of measurement is simple and involves but three measurements: (a) the measurement of a standard sample containing a known amount of uranium in equilibrium, (b) the measurement of the unknown sample, and (c) the measurement of the background counting rate. The equivalent uranium content of the unknown is then determined by the ratio of the net counting rates for the unknown and standard samples.

CAR-TRAVERSE TECHNIQUE

Car-mounted radiation-detection equipment was first used in Wyoming in 1945. An installation, such as shown in figure 4, is semi-permanent but can be easily detached from the car. Two to six large Geiger tubes are used as the detector proper.

The car-traverse technique has several applications. Its most important use is in rapid reconnaissance of large areas at the rate of 200 or more miles per day. Other uses are: first, exploration in a wide area around known deposits, and second, traversing to and from localities under investigation. We have calibrated car-mounted equipment in terms of equivalent uranium by using carefully sampled roadside outcrops as standards and have demonstrated that differences of about two thousandths of a percent equivalent uranium in the roadside outcrops can be detected easily. Any abnormally radioactive outcrop noted in car-traversing can be immediately examined more carefully.

I might again emphasize that on-the-spot evaluation by the geologist is of permanent importance. A wide variation in the observed radiation intensity can occur due solely to the geometry of the measurement. A road cut in granite, for example, commonly causes a severalfold increase in the observed activity, which is an apparent rather than real increase reflecting a change in uranium content.

Jeep-mounted equipment

A recent installation of detection equipment in a jeep is shown in figure 5. The tubes are shock-mounted inside the body to overcome the effect of rapid temperature change. Here again, the portable survey meter is used, and simplicity of equipment consistent with the desired accuracy of measurement is emphasized. Consideration has been given to the use of other presently available equipment such as anti-coincidence and crystal counting systems; however, the complexity of such equipment in its present stage demands too much maintenance, calibration, and knowledge of electronics and thus tends to divert the reconnaissance geologist from the geologic aspects of his problem.

GAMMA-RAY LOGGING EQUIPMENT

A mobile gamma-ray logging unit engaged in logging a small diameter drill hole on the Colorado Plateau is shown in figure 6. Such units can log holes up to 2,000 feet in depth and have a logging capacity of 20,000 feet per month. To date, about 700,000 feet of drill hole have been logged on the Colorado Plateau.

The technique of the gamma-ray logging is by no means new and for many years has been used successfully in the petroleum industry for the stratigraphic correlation of subsurface formations. As used in the petroleum industry, however, the measurements of the radiation intensity of the formations logged are essentially qualitative. Attempts by commercial companies to establish a calibration of the gamma-ray logs in terms of equivalent uranium content have been unsuccessful, largely because they lack the intensive data, basic theory, and facilities required for the undertaking.

The objective in our development of gamma-ray logging has been to calibrate the gamma-ray log in terms of equivalent uranium content, leading ultimately to the determination of the thickness and grade of carnotite ores penetrated by drill holes.

Calibration of gamma-ray logs

The mounting of the amplifier and strip-chart recorder is shown in figure 7. The calibration of the gamma-ray logs obtained with this equipment has proceeded along two lines of attack: first, by logging simulated drill holes containing known configurations and grades of uranium ore, and second, by measuring under controlled conditions the radiation intensity in cylindrical cavities. The first line of attack has provided a wealth of empirical data on which the present calibration of gamma-ray logs is based. The second line of attack, carried out in cooperation with the Bureau of Standards and the Oak Ridge National Laboratory, has investigated the probable effect of variations in the electronic density of the source-bearing medium and of variations in the diameter of the cylindrical cavity.

Although the present calibration of gamma-ray logs is characterized by a high degree of empiricism and is not entirely satisfactory from either the theoretical or practical viewpoint, we can determine the thickness and grade of carnotite ores with reasonable accuracy. By comparison with the chemical analyses of drill-core samples, the interpretation of the gamma-ray logs yields data that agree closely in the thickness of the ore zone but are high by a factor of 1.5 in the grade of the ore.

AIRBORNE RADIOACTIVITY SURVEYING

Our objective in the development of airborne radioactivity surveying has been to establish a prospecting technique that could cover large areas in a short time at a low cost per square mile. The Geological Survey has had extensive experience, gained from its development of the technique of aeromagnetic surveying, that permitted determining with accuracy the position of an airborne measurement in respect to the ground. The Oak Ridge National Laboratory has played the major role in the development of the instrumentation and also of the basic theory of absorption and scattering of gamma radiation by air.

Using the Douglas DC-3 shown in figure 8, at a nominal 500-foot flight level and at $\frac{1}{4}$-mile spacing of flight lines, it is possible to survey approximately 30 square miles in one hour. Radioactivity anomalies detected in an area cannot be interpreted in terms of either actual size or radioactive content of the particular locality. The existence of anomalies does suggest a greater probability of occurrence of uranium and thorium deposits. Where anomalies are noted, they serve to outline areas preferentially for more detailed ground examination. The lack of anomalies does not eliminate an area from further consideration where for sound geologic reasons the area seems of promise.

Installation of equipment

The installation of equipment in the plane is diagrammatically shown in figure 9. The technique of airborne surveying requires that all chart records be keyed together by consecutively numbered edge marks. Any airborne measurement can then be accurately located in respect to the ground by cross-reference to the continuous-strip photograph and the radar altimeter record.

Our present procedure is to make a combined aeromagnetic and radioactivity survey. Not only is economy of operation obtained, as the Geological Survey normally flies about 45,000 traverse miles per year as aeromagnetic projects, but the simultaneous recording of radioactivity and magnetic data has disclosed some results of interest. In two areas, one in New Mexico and the other in California, we have noted sharp negative magnetic anomalies associated with radioactivity anomalies. Of further interest, we were recently informed that the Canadian Geological Survey has noted also a sharp negative magnetic anomaly associated with a radioactivity anomaly over a pitchblende deposit. This unusual association warrants further investigation.

Scintillation-detection equipment

The components of the scintillation-detection equipment are best conveyed by a block diagram (fig. 10). Here, in contrast to the simplicity and flexibility achieved in portable field equipment, we have been forced by the requirement for maxiumum resolution of measurement to develop highly complex and specialized equipment.

The crystals are 2-inch long by 4-inch diameter sodium iodide thallium activated. Each crystal counts at the rate of 500 counts per second at ground level and 300 counts per second at 500 feet above the ground. A photomultiplier tube, pre-amplifier, and linear amplifier form the amplification phase of the system.

The dual-channel counting-rate computer is a new development and is essentially similar to a scaling circuit. By coupling the dual-channel computer to an automatic timer, the incoming signal is measured over a one-second period and is recorded in the following one-second period;

the two channels alternately measure and record the radiation intensity.

The automatic correction of the radiation intensity for variation in distance from the source was developed to overcome the limitation placed on airborne radioactivity surveying by the fluctuating distance of the plane above the ground. The radar altimeter output was utilized to modify the output of the counting-rate computer in accordance with the recently established variation of radiation with distance from the source. With such automatic correction, the distance of the plane from the ground can range from 250 to 1,000 feet without impairing the value of the radiation measurement.

Scintillation counting system

The scintillation counting system is shown in the immediate foreground of figure 11; the control panel for the airborne magnetometer is in the right background.

In our airborne development, one significant advance stands out. It was early noted that empirical measurements of radiation intensity from known sources did not accord with the intensity predicted on the basis of classical theory. Based on studies by the Oak Ridge National Laboratory of the scattering of gamma radiation and on numerous measurements over large natural and artificial sources, a build-up factor for scattered radiation over primary radiation has been established. This build-up factor is proportional to the height 'h' above the ground for a point source in the region of interest--that is, between 300 and 1,800 feet above the ground. Allowing for a build-up factor, the attentuation of radiation with height follows the law e^{-uh}/h for a point source and e^{-uh} for a broad source. Because of these relationships, satisfactory measurements of the radiation intensity from ground sources can be made at much greater distances above the ground than were first considered feasible on the basis of classical theory.

RECONNAISSANCE WITH CARBORNE AND AIRBORNE EQUIPMENT

The areas covered to date by airborne and carborne radioactivity surveys are outlined on figure 12. Thus far, we have flown 35,000 traverse miles with the airborne equipment and have scanned about 40,000 miles of road with carborne equipment. Last month we located the first valid occurrence of radioactive materials as the result of an airborne radioactivity survey. This discovery of carnotite in the Wasatch formation of central Wyoming shows that the technique and equipment can be applied successfully to the search for new deposits.

CURRENT AND FUTURE INVESTIGATIONS

We have reviewed briefly the development of equipment and techniques for the field measurement of radioactivity. I shall outline now the nature of current and future investigations. In part, I am speaking on behalf of the Oak Ridge National Laboratory, our principal collaborator in radiation investigations. Any errors either in theory or in presentation of data are mine and are not attributable to the Laboratory.

Radiation absorption and scattering

The Oak Ridge National Laboratory is at present investigating the spectral energy distribution of gamma radiation in our simulated drill holes at Grand Junction, Colo., using a 1½-inch diameter by 2-inch long sodium iodide crystal housed in a 2-inch diameter logging probe. Although the investigation was planned largely to add to our overall understanding of gamma radiation, it was also aimed at determining whether spectral-energy measurements might enable the identification of uranium ores at a greater distance from a drill hole than is possible using the Geiger counter. The empirical data, as usual, are not entirely consistent with theoretical prediction. With increasing distance from the source, the relative amount of softer radiation increases markedly over hard radiation. The need for further investigation is clearly indicated, and spectral-energy studies will be continued.

The Oak Ridge National Laboratory also plans to investigate the natural neutron flux in the simulated drill holes at Grand Junction. As a practical exploration method, natural neutron logging does not appear at all promising. Based on existing pile theory, we have calculated that the thermal neutron flux from 0.4 percent uranium ore is about 0.003 $n/cm^2/sec$; using a 1-inch by 6-inch B^{10} counter, the calculated counting rate would be about 0.7 n/min. The half-thickness for thermal neutrons in sandstone containing one percent vanadium and four tenths of a percent uranium would be about 12 cm. Neither the calculated magnitude of the neutron flux nor the penetration of neutrons through rock seems favorable for natural neutron logging.

Neutron measurements, however, offer possible application in exploration for raw materials. Neutron measurements combined with gamma measurements might serve as a simple field technique of distinguishing uranium from thorium; they might also serve to determine equilibrium conditions in uranium ores; again, they might indicate the presence and amount of vanadium, an element with a relatively high capture cross-section for neutrons.

In our calibration of gamma-ray well logs, we obtained the full cooperation of the potash industry. Drill holes for which complete cores of potash salts were available were logged both with commercial gamma and neutron equipment and with Geological Survey equipment. By complete analysis of the potash salts, we were able to calibrate the gamma-ray logs in terms of potassium equivalent. Somewhat to our surprise, by analysis of the gamma and neutron data, we could not only determine the grade and thickness of the potash salts but could also distinguish the anhydrous from the hydrous salts, a matter of considerable interest to industry. I now understand that the potash industry is sufficiently impressed with these results to contract with commercial concerns for further development of instrumentation and technique for potash exploration.

We are also much interested in obtaining further basic data on the physical and chemical behavior of radon. Mr. Faul will discuss this aspect of our program tomorrow morning.

The thermal gradient in rocks due to the energy release from radioactive materials may be useful in exploration. Temperature anomalies will be small and extremely sensitive, and precise equipment will be required. Such equipment, capable of measuring temperature to within 0.02 C and temperature variations as small as 0.01 C has already been developed by the Geological Survey. We plan to make temperature measurements on a purely experimental basis to determine if temperature anomalies are related in any manner to mineralized areas or to favorable ground, by virtue perhaps of anomalous conditions of thermal conductivity, porosity, permeability, alteration, or other effects.

Electrical resistivity surveys

Experimental electrical resistivity surveys aimed at outlining areas favorable to the occurrence of uranium deposits have been carried out on the Colorado Plateau during the past two years. Interpretation of results has proved difficult because of the variable nature of the Morrison formation and of the small resistivity anomalies associated with the ore-bearing sandstone; nevertheless, these surveys show promise in guiding exploration drilling for ore deposits lying at shallow to intermediate depths.

Interpretation of resistivity data over deposits 500-600 feet beneath the surface has been unsuccessful for the most part, because the highly conductive upper members of the Morrison short out and mask the effects of lithologic changes at greater depths. It is therefore planned to increase the electrical energy applied to the ground by several orders of magnitude by using a $7\frac{1}{2}$ KVA power source, in the hope that changes in the deeper beds may be indicated with greater certainty.

In addition, experimental electrical surveys will be made using inhole-surface configurations of electrodes in the expectation that greater resolving power will be obtained when one electrode is placed near favorable ground in a drill hole and the others are arranged on the surface.

Electrical and thermal logging of drill holes are also planned during the coming field season. Electrical logs are required to give detailed information on the relationships among resistivity and lithology and thus permit more authoritative interpretation of resistivity measurements made in advance of drilling.

High-precision natural potential surveys of the surface will likewise be made on an experimental basis. Several such surveys show that small natural potential anomalies exist, in some areas at least, over mineralized ground, although their cause is not known. It is nevertheless apparent that if this relationship is general or widespread, natural potential surveys would have important uses in exploration on the Colorado Plateau.

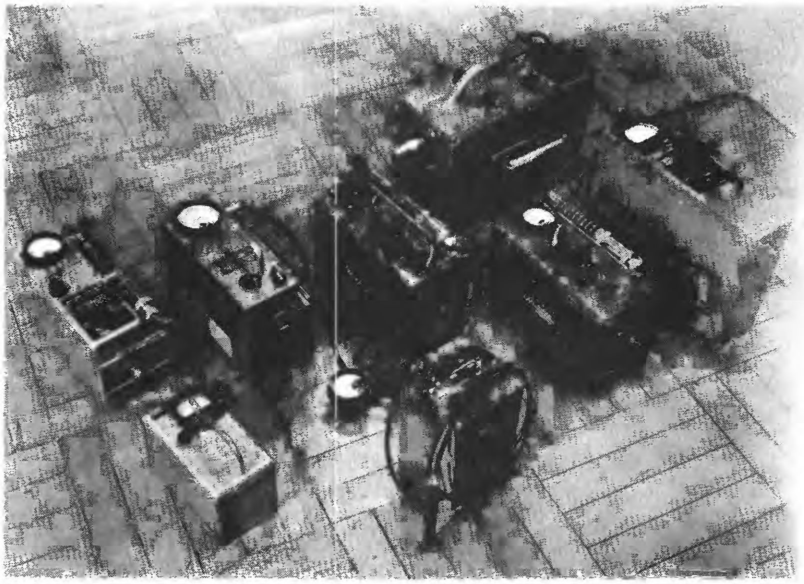

Figure 1.—Portable survey meters

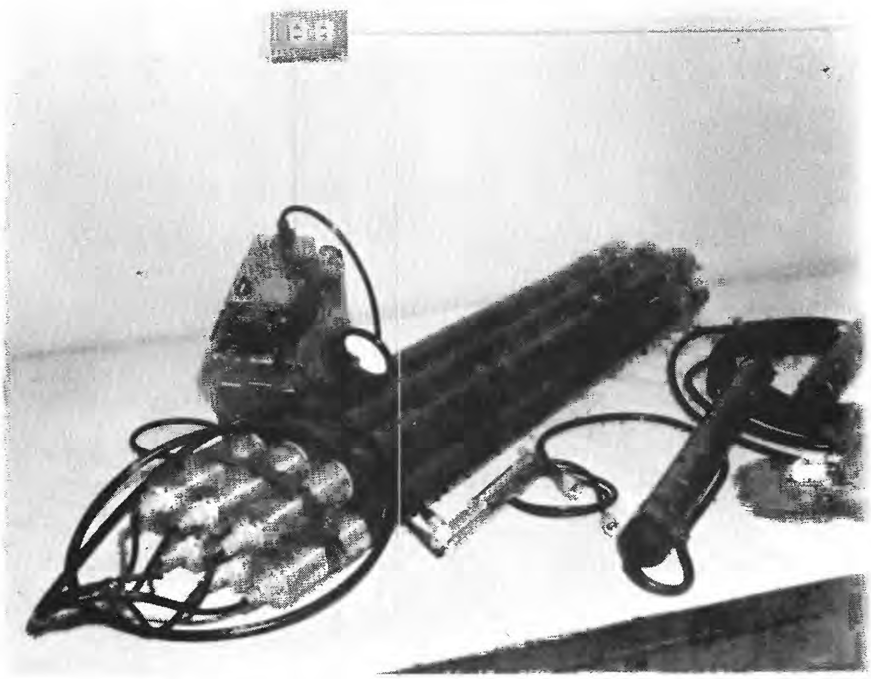

Figure 2.—Typical field equipment

Figure 3.—Portable assay equipment

Figure 4.—Carborne equipment externally mounted

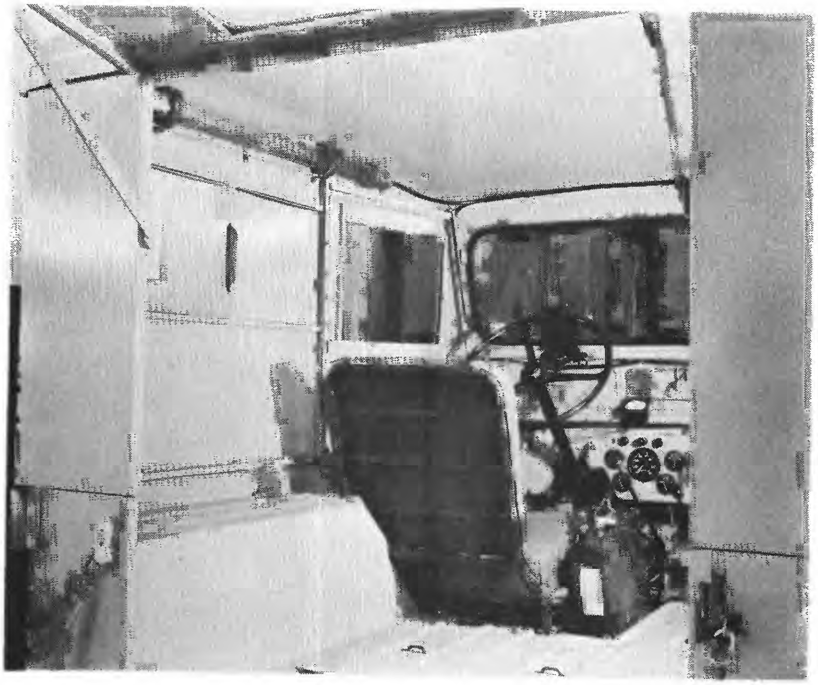

Figure 5.—Carborne equipment internally mounted

Figure 6.—Gamma-ray logging unit

Figure 7.—Amplifier and recorder in gamma-ray logging unit

Figure 8.—Geological Survey Douglas DC-3

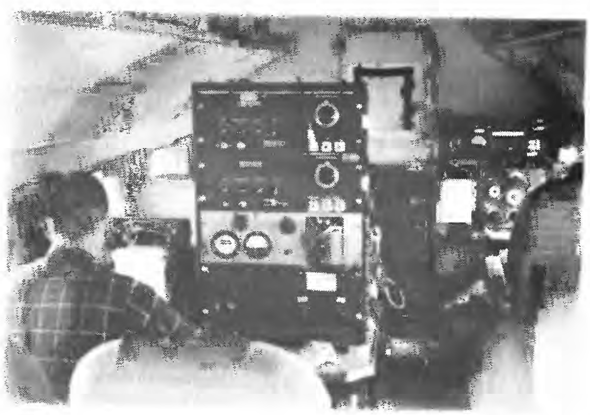

Figure 9.—Interior of Douglas DC-3 showing equipment

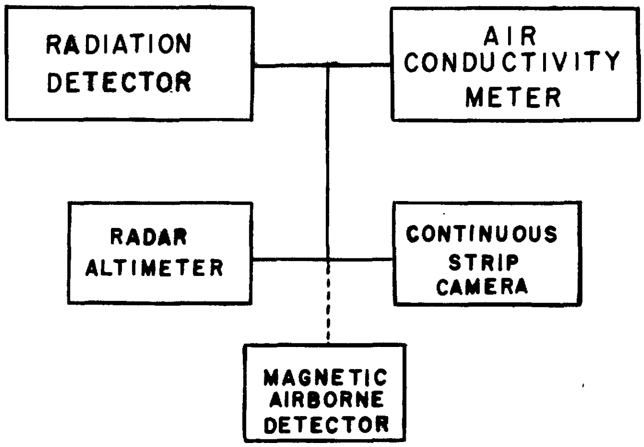

FIGURE 10. INSTALLATION OF EQUIPMENT FOR DETECTION OF RADIOACTIVITY

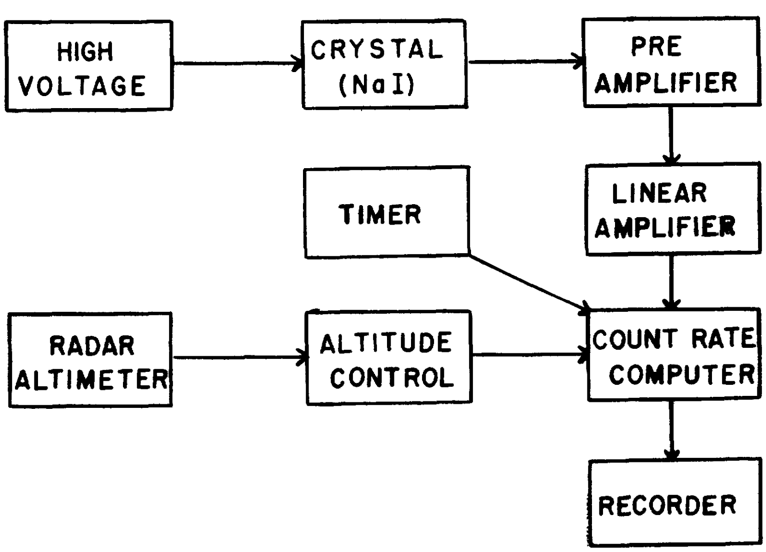

FIGURE 11. BLOCK DIAGRAM OF SCINTILLATION DETECTION EQUIPMENT

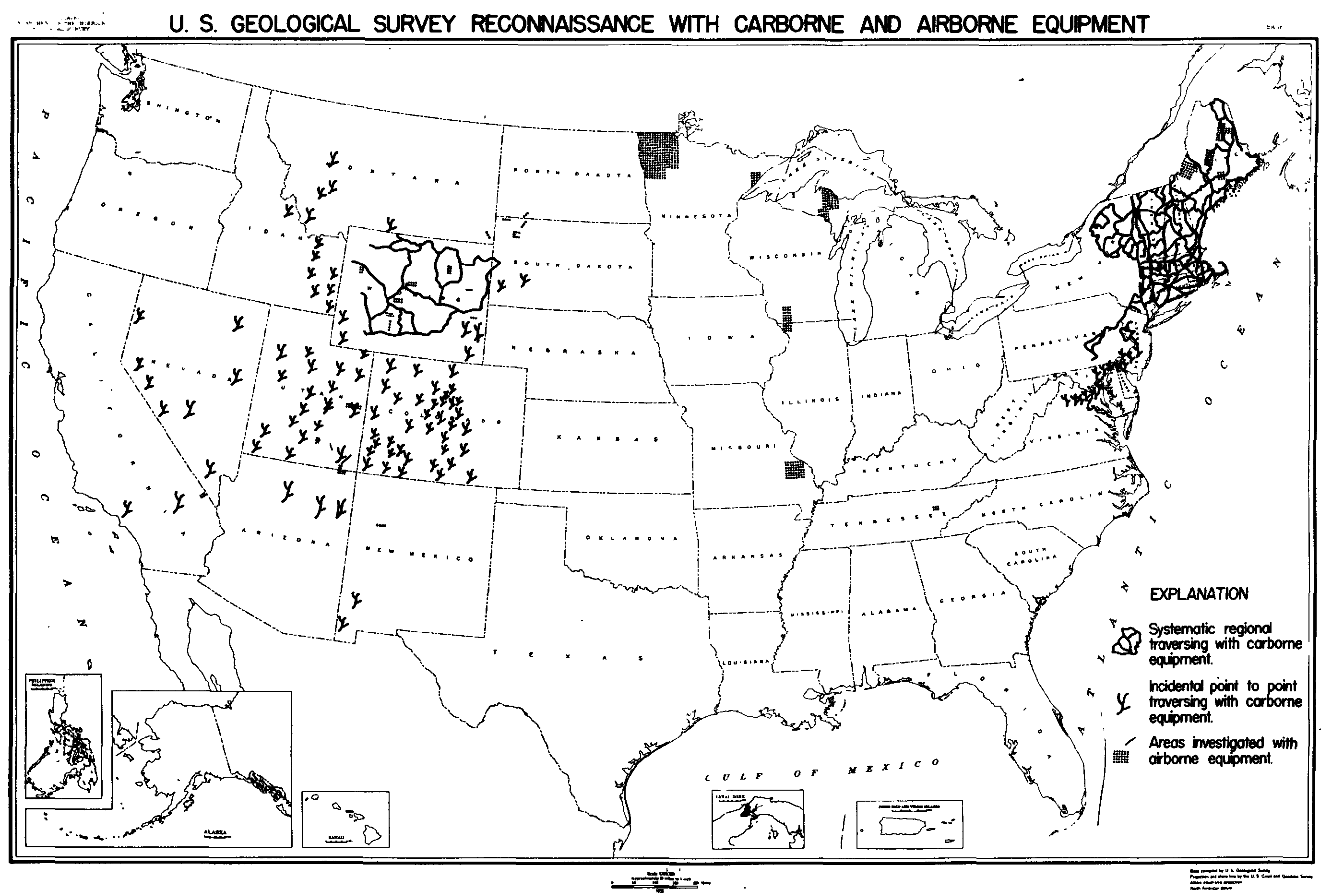
U. S. GEOLOGICAL SURVEY RECONNAISSANCE WITH CARBORNE AND AIRBORNE EQUIPMENT
EXPLANATION
Systematic regional traversing with carborne equipment.
Incidental point to point traversing with carborne equipment.
Areas investigated with airborne equipment.
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
ALASKA
HAWAII

Figure 12