[redacted]C Category: HEALTH AND SAFETY

CEX-59.4.23

CIVIL EFFECTS STUDY

AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF PARTS OF OHIO AND INDIANA (ARMS-I)

Robert G. Bates

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AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF PARTS OF OHIO AND INDIANA (ARMS-I)

By

Robert G. Bates

Approved by: Director
U. S. Geological Survey

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U. S. Geological Survey
and
Division of Biology and Medicine, USAEC
June 1964

NOTICE

ABSTRACT

An airborne radioactivity survey was made of an area of 11,250 square miles in central and western Ohio and eastern Indiana. Parallel flight lines were flown in an east-west direction at an interval of one mile and an altitude of 500 ft above the ground. The survey was made by the U. S. Geological Survey for the U. S. Atomic Energy Commission as part of its nationwide program of airborne radioactivity surveys of nuclear installations. Reactors in the survey area are at West Jefferson, Dayton, Columbus, and Piqua, Ohio.

Approximately 90 percent of the survey area has been intensely glaciated and is covered by glacial deposits ranging from a few feet to several hundred feet in thickness. In the nonglaciated southeast corner of the survey area, exposures of bedrock are common. Outwash deposits cover the bottoms of the larger valleys and patches of loess mantle the valley sides and ridges.

Little geologic information was obtained from the radioactivity data. The interlobate area formed between the Miami and Scioto glacial lobes during late Wisconsin time is outlined by a radioactivity low. Two exposures of Ohio Shale north of Columbus, Ohio, are outlined by radioactivity highs.

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AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF PARTS OF OHIO AND INDIANA (ARMS-I)

1. INTRODUCTION

1.1 Location and Purpose of Survey

The survey area is in central and western Ohio and eastern Indiana and is a rectangle 150 miles long and 75 miles wide (Fig. 1). During the fall of 1960, the U. S. Geological Survey, on behalf of the Division of Biology and Medicine of the U. S. Atomic Energy Commission, made an airborne radioactivity survey of the area. This survey was part of the Aerial Radiological Measurement Surveys (ARMS-I) program, a program of airborne radioactivity surveys of all nuclear installations in the United States. Within the survey area reactors are located at the Battelle Memorial Institute, West Jefferson, Ohio; Wright-Patterson Air Force Base, Dayton, Ohio; Ohio State University, Columbus, Ohio; and at Piqua, Ohio. The first three reactors are operated under license from the Atomic Energy Commission. The Piqua Nuclear Power Facility is owned and operated by the Atomic Energy Commission through its Power Demonstration Reactor Program.

The purpose of the survey was to determine the natural radioactivity background of the rocks and soils. This information will serve as a reference to determine the amount and extent of any possible future increase in radioactivity level of the area by the nuclear facilities through normal operations or accidents that may occur. Another purpose of the survey was to determine the relation between the distribution of radioactivity and the areal geology.

1.2 Airborne Survey Procedure

The survey was made with scintillation-detection equipment installed in a twin-engine aircraft. Parallel east-west flight lines were flown at one-mile intervals. The plane maintained an approximate altitude of 500 ft above the ground and an air speed of 150 mph. County road maps were used for pilot guidance. The flight path of the aircraft was recorded by a gyrostabilized continuous-strip-film camera, and the distance of the aircraft from the ground was measured by a continuously recording radar altimeter. Fiducial markings (providing a common reference for the radioactivity and altimeter data and the camera film) were made with an electromechanical edge-mark system operated by the observer when the aircraft passed over recognizable features on the ground.

The gamma-ray flux at 2000 ft above the ground, which comes from cosmic radiation and to a much lesser extent from radionuclides in the air, except after nuclear tests, was measured twice each day during the survey. This quantity is called the cosmic background at 2000 ft. Theoretically, the cosmic background at 500 ft is nine-tenths that at 2000 ft, and the compensated data have had this nine-tenths of the cosmic component removed. The cosmic background measured during this survey ranged from 240 to 400 cps (counts per second) and averaged 320 cps.

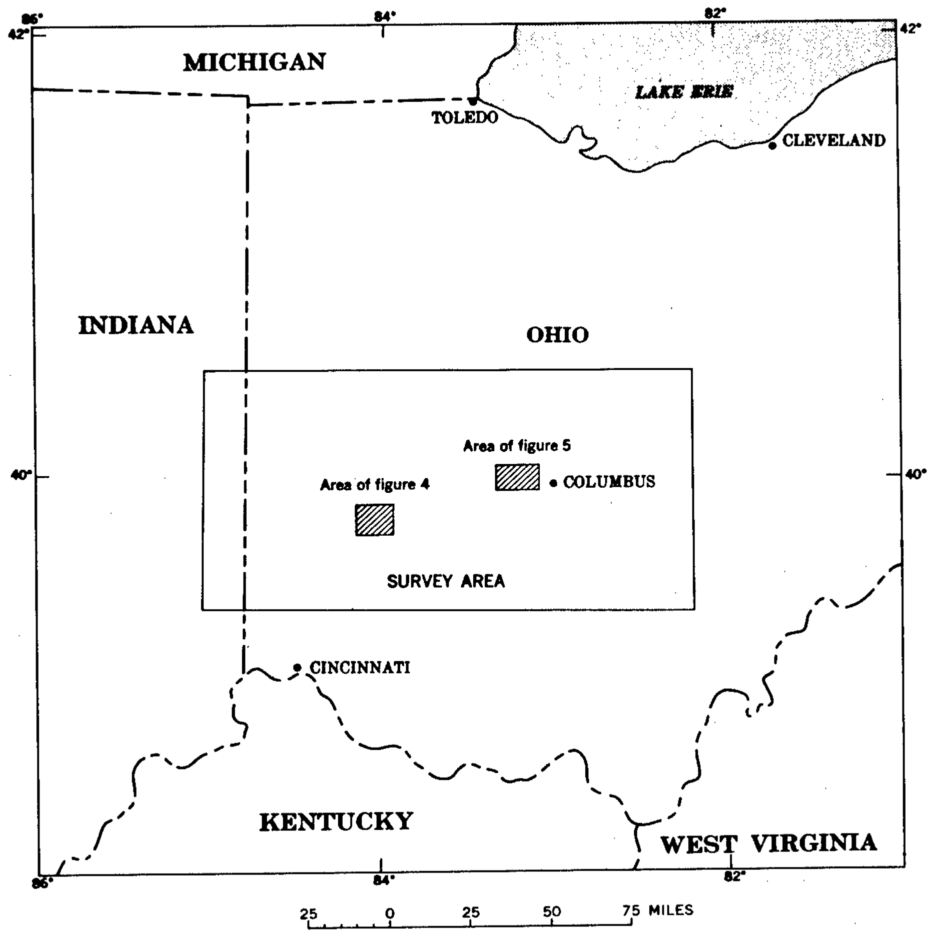


Fig. 1—Location of survey area, Ohio and Indiana.

1.3 Scintillation-Detection Equipment

The scintillation-detection equipment used by the Geological Survey was designed by the Health Physics Division of the Oak Ridge National Laboratory and has been described in detail by Davis and Reinhardt[1]. In describing the sensitivity of the equipment, they state (Ref. 1, p. 717): "With a microgram of radium at one foot from the crystals, the counting rate is roughly 2000 cps". Kermit Larsen[2] determined in 1958 that a count rate of about 77,000 cps would be recorded by the Geological Survey equipment 500 feet above an infinite area of fallout that produced a gamma-ray flux of 1 mr/hr, measured 3 ft above the ground. Davis and Reinhardt[3] experimentally determined the airborne count rates at 500 feet above Cs^{137} and Co^{60} semi-infinite plane sources. Each source had a gamma-ray flux of 1 mr/hr, measured 3 ft above the ground. The airborne count rates were 25,000 and 18,000 cps, respectively. This seeming discrepancy between the data of Larsen and that of Davis and Reinhardt may be due to the fact that Larsen's data was obtained over an infinite area of fallout which contained many isotopes with different gamma-ray energy levels, whereas Davis and Reinhardt obtained their data from a semi-infinite array of sources containing only one isotope at a time during the experiments.

A diagram of the equipment is shown in Figure 2. The detecting element consists of six thallium-activated sodium iodide crystals,

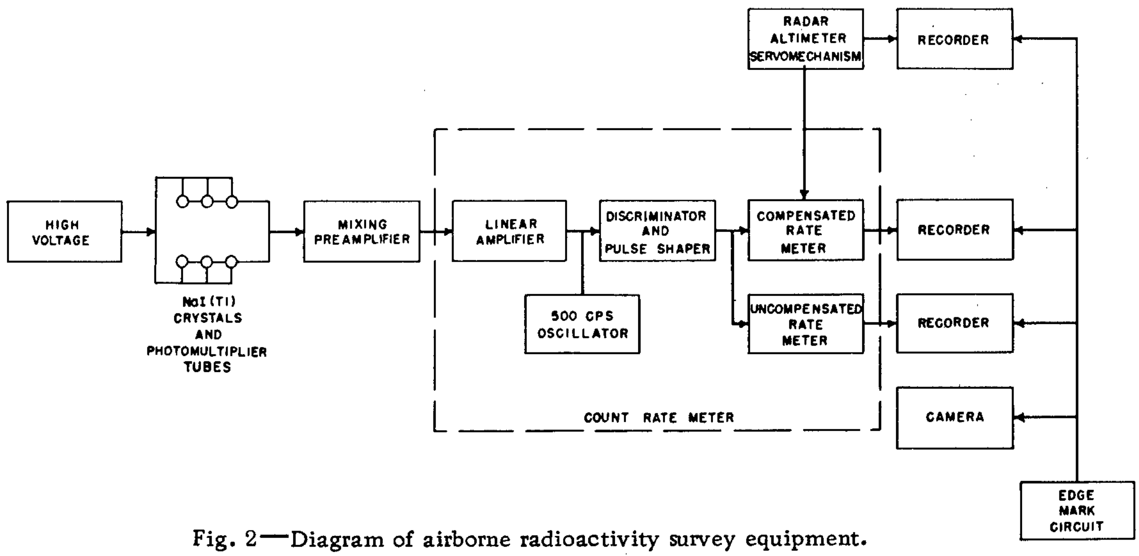


Fig. 2—Diagram of airborne radioactivity survey equipment.

4 in. in diameter and 2 in. thick, and six photomultiplier tubes connected in parallel. The signal from the detecting element is fed through amplification stages to a pulse-height discriminator, which is usually set to accept only pulses from gamma radiation with incident energies greater than 50 kev. The signal is then fed to two rate meters. One rate meter feeds a circuit that records total count on a graphic milliammeter. The signal from the other rate meter is recorded by a circuit from which the cosmic background has been removed. This circuit includes a variable resistance regulated by the radar altimeter servomechanism which compensates the radioactivity data for deviations from the 500 ft surveying altitude. Tests run to determine the area or cone of response of the detection equipment at an altitude of 500 ft indicate that 85 percent of the measured gamma radioactivity comes from a circular area on the ground with a radius of 500 ft.

1.4 Compilation of Aeroradioactivity Data

Flight-line and check-point locations from the strip film exposed during the survey were plotted on compilation base maps at a scale of 1 in. equals 1 mile (1:63,360). The altitude-compensated radioactivity profiles for each flight line were examined and points of change or breaks in radioactivity level were selected. These points of change in radioactivity level along the flight line were plotted on the base map.

Corresponding changes on adjacent lines were connected to form radioactivity units; the units were assigned values, in counts per second, reflecting the range of fluctuations in radioactivity level within the unit. The compilation base maps were reduced to a scale of 1 in. equals about 4 miles (1:250,000), and the data were transferred to maps of the Army Map Service 1:250,000-scale topographic map series. The final map thus produced (Pl. 1) shows radioactivity levels and points of change in level and sufficient culture and drainage features for orientation in the field. This map has also been published by the Geological Survey[4].

1.5 Theoretical Considerations

From the standpoint of airborne radioactivity surveys, only three naturally occurring radioactive elements or isotopes and their daughter products are important. They are uranium, thorium, and K^{40}. Only those radionuclides that decay by gamma-ray emission can be detected and measured with scintillation equipment used in airborne surveys.

Sakakura[5] has developed equations that relate airborne radioactivity data, semiquantitatively, to the radioactivity of the ground surface underlying the aircraft.

Radioactivity measured at the surveying altitude of 500 ft above the ground has three components:

1. Gamma-ray activity from radionuclides in and on the ground.
2. Gamma-ray activity from radionuclides in the air.
3. Cosmic-ray component.

The activity from radionuclides in air, such as radon, cannot always be separated from the activity of the radionuclides on the ground. The radon content of the air is variable. Minimum values occur on windy days with high barometric pressure or very wet ground conditions. These radon values can increase by a factor of 10 under conditions of low barometric pressure and strong temperature inversion.

The ground component comes from the surface and the upper few inches of the ground and consists of gamma rays from natural radionuclides and fission products in fallout. The distribution of fallout, if present in the survey area, is assumed to be uniform and small in amount. This conclusion is supported by the fact that the minimum radioactivity recorded over parts of the area due to naturally occurring radionuclides and any fallout present was 150 to 250 cps.

2. GENERAL GEOLOGY

Most of the survey area lies within the glaciated prrtions of Ohio and Indiana (Fig. 3) where glacial deposits as much as several hundred feet thick cover the bedrock. Exposures of bedrock are rare in the western and central parts of the area. A few exposures occur on the low hills of the area, but more occur in the banks and beds of streams. In the eastern part of the area exposures of bedrock are more plentiful, particularly in escarpments of the Appalachian Plateaus province.

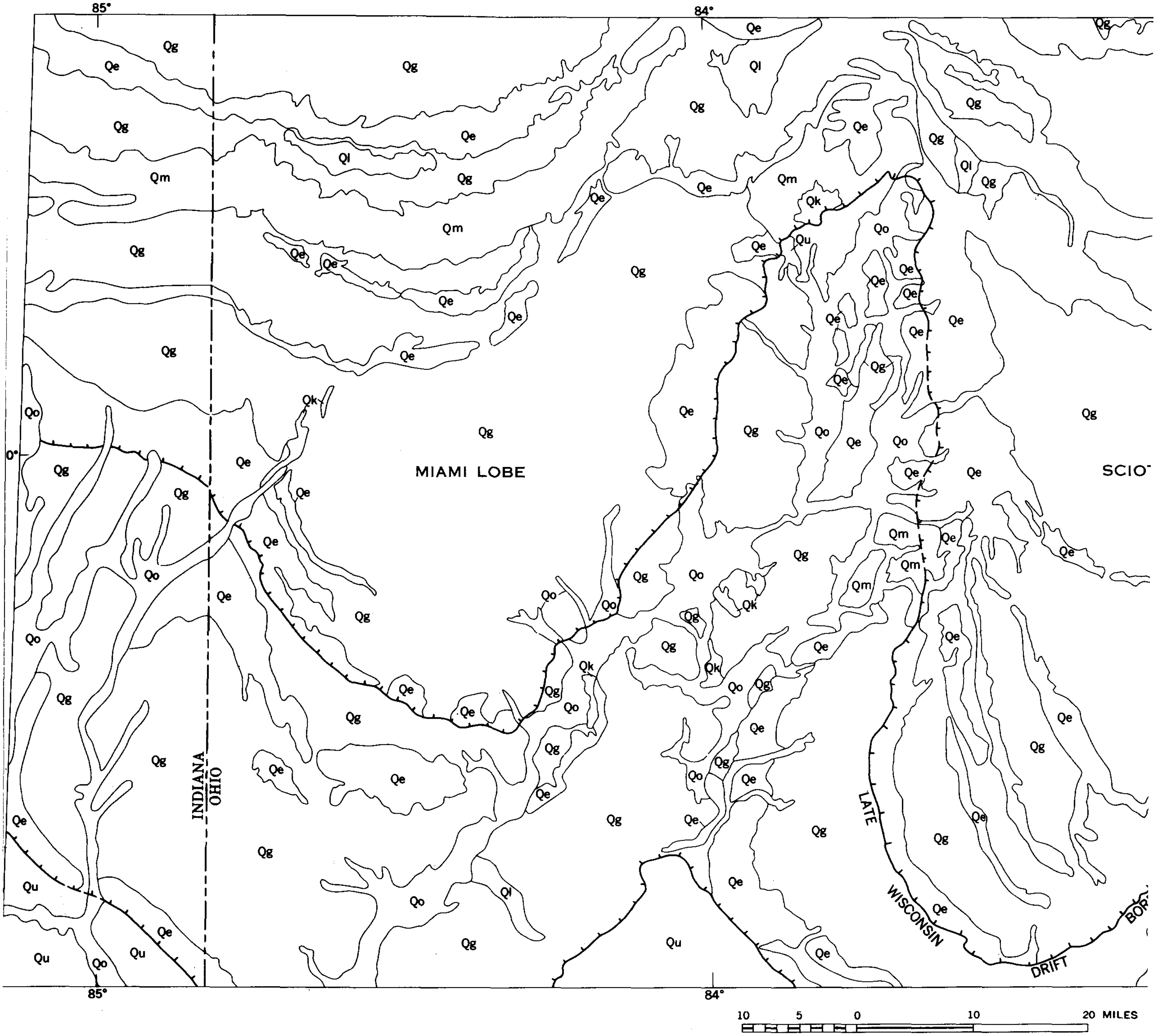
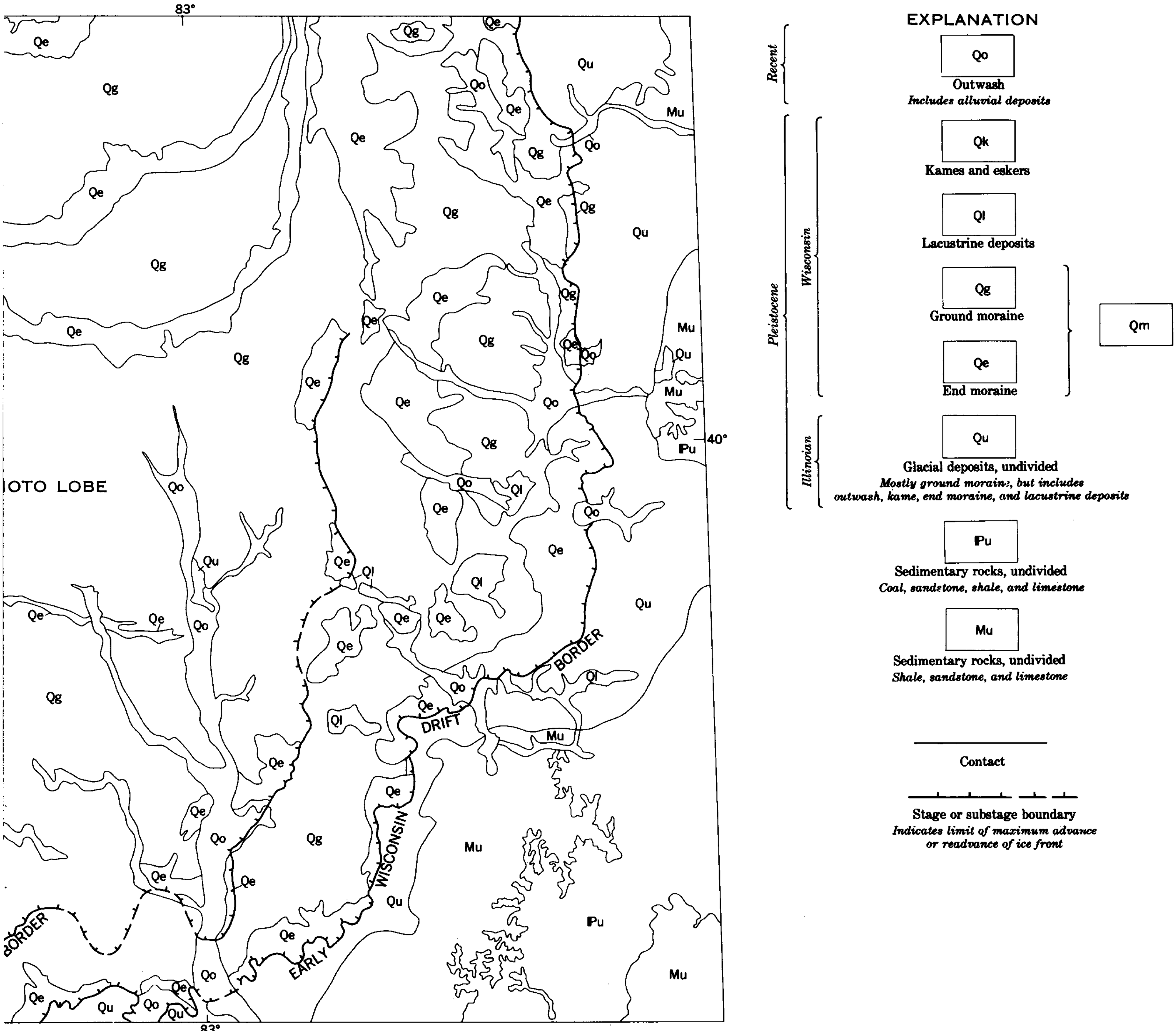


Fig. 3—Generalized geologic map of Ce



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Geology modified from Bownocker[9], Goldthwait and others[11], and Wayne[12]

Central Ohio and East-central Indiana.

2

3

EXPLANATION

Qo
Outwash
Includes alluvial deposits

Qk
Kames and eskers

Ql
Lacustrine deposits

Qg
Ground moraine

Qe
End moraine

Qm

Qu
Glacial deposits, undivided
Mostly ground moraine, but includes outwash, kame, end moraine, and lacustrine deposits

Wisconsin (Qk, Ql, Qg, Qe); Illinoian (Qu); Qg and Qe = Qm

QUATERNARY (Qo through Qu)

IPu
Sedimentary rocks, undivided
Coal, sandstone, shale, and limestone

PENNSYL-VANIAN

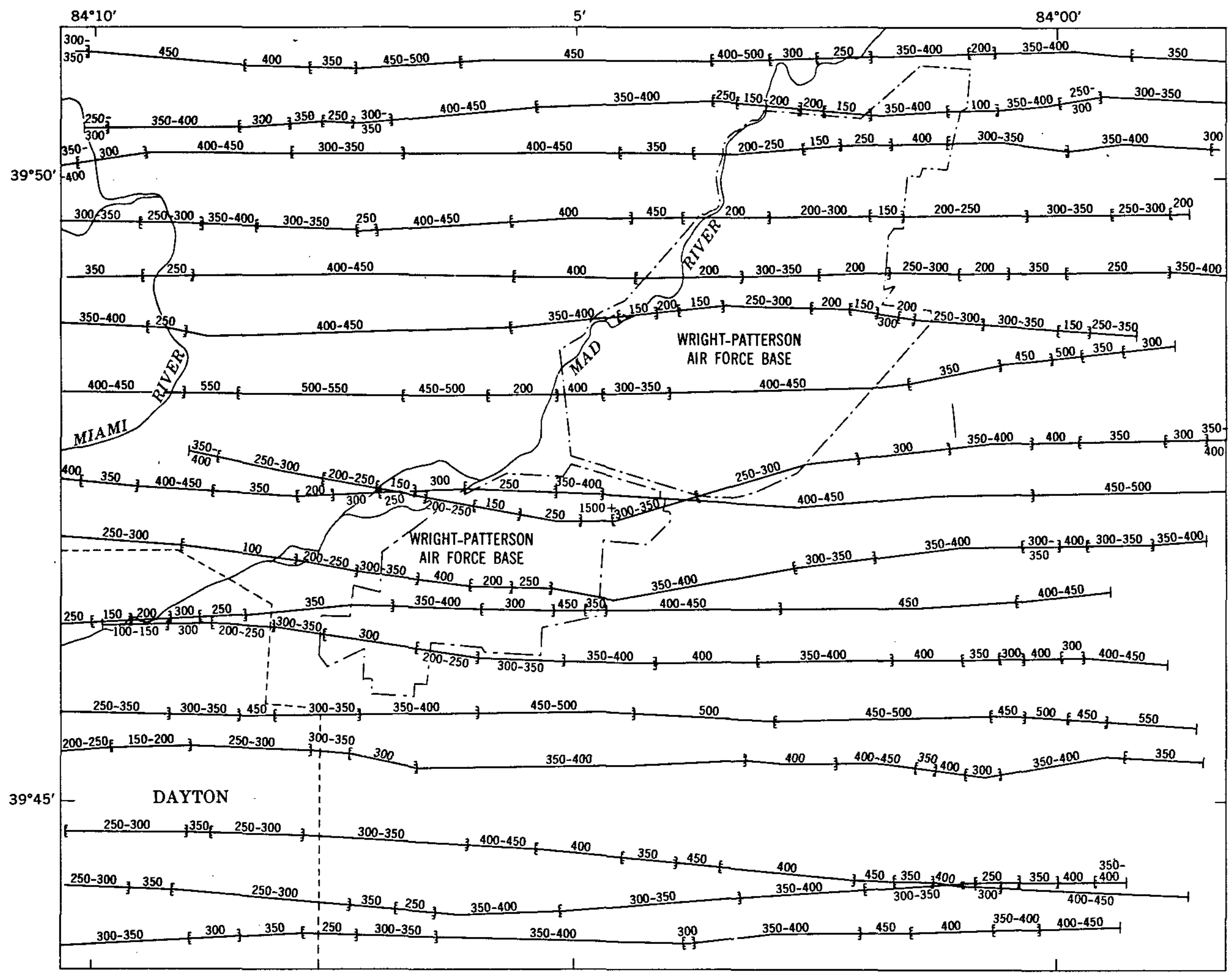
Mu
Sedimentary rocks, undivided
Shale, sandstone, and limestone

MISSIS-SIPPIAN

CARBONIFEROUS (IPu and Mu)

Contact

Stage or substage boundary
Indicates limit of maximum advance or readvance of ice front



250 300-350 350-400
Radioactivity levels and points of change along flight line
Radioactivity values are in counts per second. Hachures point toward lower radioactivity levels

Base from U.S. Geological Survey topographic quadrangles: Bellbrook, Dayton North, Dayton South, Fairborn, Xenia, and Yellow Springs

1 ½ 0 1 MILE

Radioactivity survey flown September and October, 1960

Fig. 4—Aeroradioactivity survey, Wright-Patterson Nuclear Facility, Dayton, Ohio.

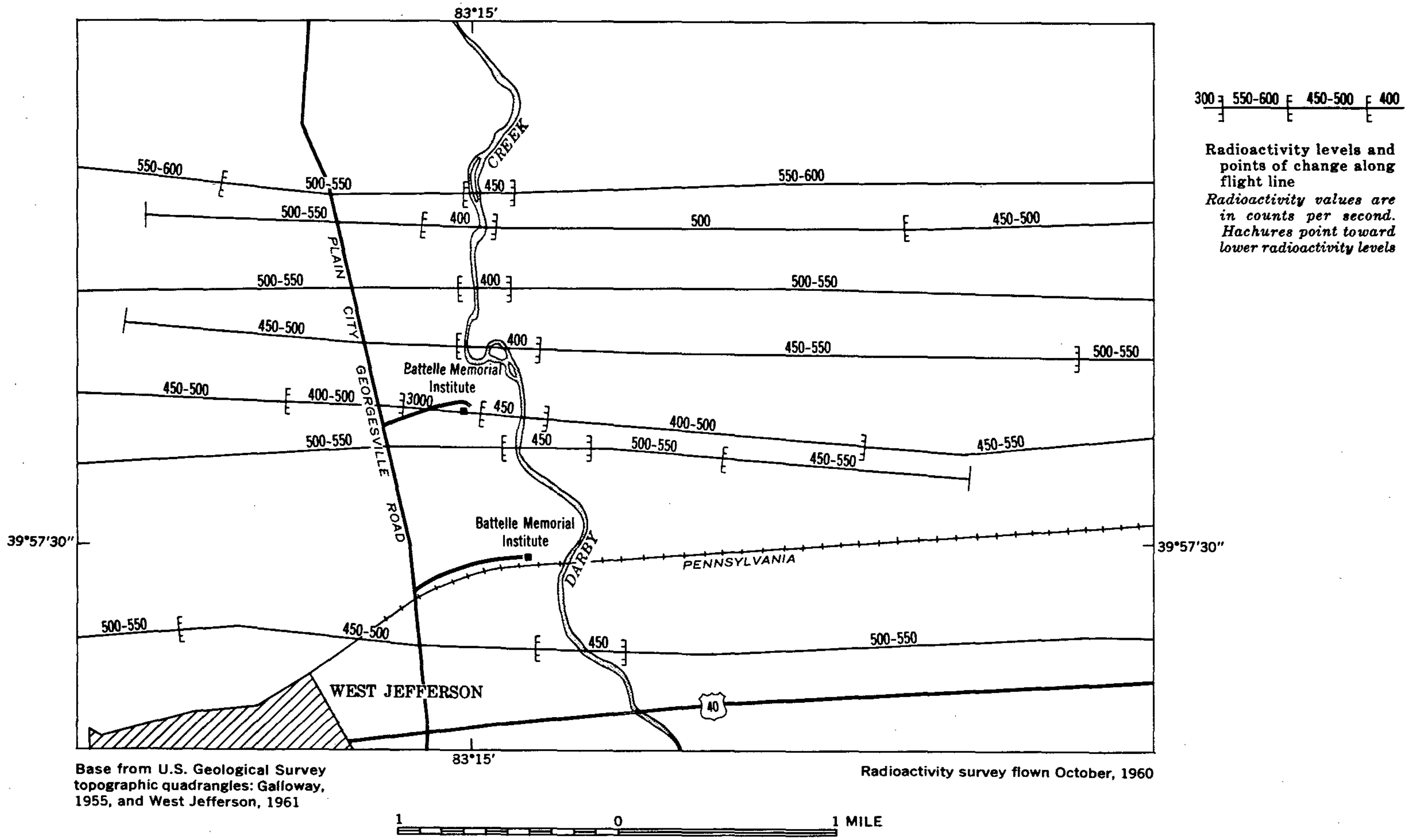


Fig. 5—Aeroradioactivity survey, Battelle Memorial Institute, West Jefferson, Ohio.

Most of the glacial deposits are of Wisconsin age. However, an intermittent narrow band of glacial deposits of Illinoian age is present along the eastern and southern borders of the younger deposits of Wisconsin age.

Arcuate end moraines mark points of maximum advance of the fluctuating ice sheet. Behind each end moraine are ground moraine deposits, overlain in places by lake deposits. Outwash deposits are present along the streams and rivers, being most extensive along the Scioto, Mad, and Miami Rivers.

Most of the glacial material was derived from local bedrock. Pebble counts[6,7] of till and terrace deposits show that 85 to 90 percent of the pebbles are limestone, dolomite, sandstone, and shale from nearby bedrock sources. The remainder are pebbles of plutonic rocks carried by the ice from source areas in Canada.

The southeast corner of the survey area lies within the nonglaciated portion of Ohio. This area is a maturely dissected region characterized by narrow valleys and steep hillsides[8]. The larger valleys are partly filled by glacial outwash, and thin intermittent patches of loess are present on the uplands.

Rocks exposed in this area range in age from Devonian through Pennsylvanian[9]. They consist of shale and sandstone with the addition of some limestone and coal in the Pennsylvanian rocks.

The only rock unit that has any identifiable expression in the radioactivity data is the Ohio Shale of Devonian age. The Ohio Shale is a black carbonaceous shale, massive to thin-bedded, which includes zones of pyrite and "iron-stone" concretions. It is lithologically similar to, and the age equivalent of, the Chattanooga Shale of Tennessee, Kentucky, and Alabama. The Ohio Shale is exposed only in a few places in the nonglaciated portion of the survey area, generally in the beds of streams. The basal part of the formation is exposed on the sides of valleys of streams in the area north of Columbus.

3. DISTRIBUTION OF AERORADIOACTIVITY

3.1 Survey Area

The natural gamma-radioactivity level within the survey area ranged from a low of 0 cps over Indian Lake and Lake Saint Mary along the northern edge of the survey area to a high of 1000 cps around Dublin, 10 miles northwest of Columbus. However, the radioactivity level throughout most of the survey area is remarkably uniform, 80 to 85 percent of the area has a radioactivity level ranging between 400 and 600 cps.

3.2 Reactor Sites

The distribution of natural and facility-induced gamma radioactivity within the Wright-Patterson Air Force Base and Battelle Memorial Institute areas is shown in Figures 4 and 5, respectively. Within these areas supplemental flight lines were flown to obtain a flight-line spacing of one-half mile. Natural gamma radioactivity levels in the Wright-Patterson area ranged from 150 to 550 cps and averaged about 350 to 400 cps. Natural gamma radioactivity levels of the area around the Battelle Memorial Institute ranged from 400 to 600 cps and averaged about 500 to 550 cps. Radioactivity values higher than 600 cps within these site areas result from normal atomic energy operations.

Information on radioactivity levels in the environs and outside the plant boundaries is reported from selected Atomic Energy Commission and contractor installations. This information is reviewed and abstracted for inclusion in the U. S. Public Health Service series of reports entitled "Radiological Health Data". They are issued monthly and can be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington, D.C. 20402.

4. AERORADIOACTIVITY DATA AND AREAL GEOLOGY

Little geologic information was obtained from the radioactivity data. This is probably due to the fact that the glacial deposits are mixtures of material derived almost wholly from local bedrock sources which, with the exception of the Ohio Shale, have similar radioactivity levels. In the nonglaciated portions of the survey area, outwash covers the bottoms of the larger valleys and patches of loess are present on the slopes and ridge tops.

Just to the west of the center of the map (Pl. 1) is a large area with a lower radioactivity level, 200 to 500 cps. This area extends from the southern boundary of the survey area almost to the northern boundary. This area corresponds very closely with the interlobate area formed between the Miami and Scioto glacial lobes during late Wisconsin time (Pl. 1 and Fig. 3). The lower radioactivity level probably is caused, in part, by the extensive glacial outwash deposits which blanket the interlobate area. It may also be due to the greater depth of leaching of the interlobate till deposits that are older than the surrounding till of the Miami and Scioto lobes.

Linear radioactivity lows, ranging from 100 to 500 cps, occur along some rivers within the area. These low readings are caused, in part, by the water within the stream channel and in part, by deposits of well-washed sand and gravel along the course of the streams.

Only two correlations of radioactivity data with bedrock exposures were noted. They are the linear radioactivity highs (500 to 800 cps) along the Olentangy River and Alum Creek, north of Columbus. There the basal part of the Ohio Shale is exposed along the sides of the stream valleys. The correlative of the Ohio Shale, the Chattanooga Shale, has been intensively studied in eastern Tennessee. There, the uranium content of the basal unit ranges from 0.0024 to 0.0052 percent, and the uranium content of the whole formation ranges from 0.0011 to 0.0086 percent[10]. The radioactivity data indicate that the Ohio Shale has about the average uranium content for marine black shales but less than that of the Chattanooga Shale.

5. SUMMARY

Little geologic information was obtained from the radioactivity data. The majority of the survey area has been glaciated and almost all of the area is covered by deposits of till, outwash, or loess.

The interlobate area formed between the Miami and Scioto glacial lobes during late Wisconsin time is defined by a radioactivity low. Two radioactivity highs along Alum Creek and the Olentangy River north of Columbus outline areas where the basal part of the Ohio Shale is exposed on the sides of the stream valleys.

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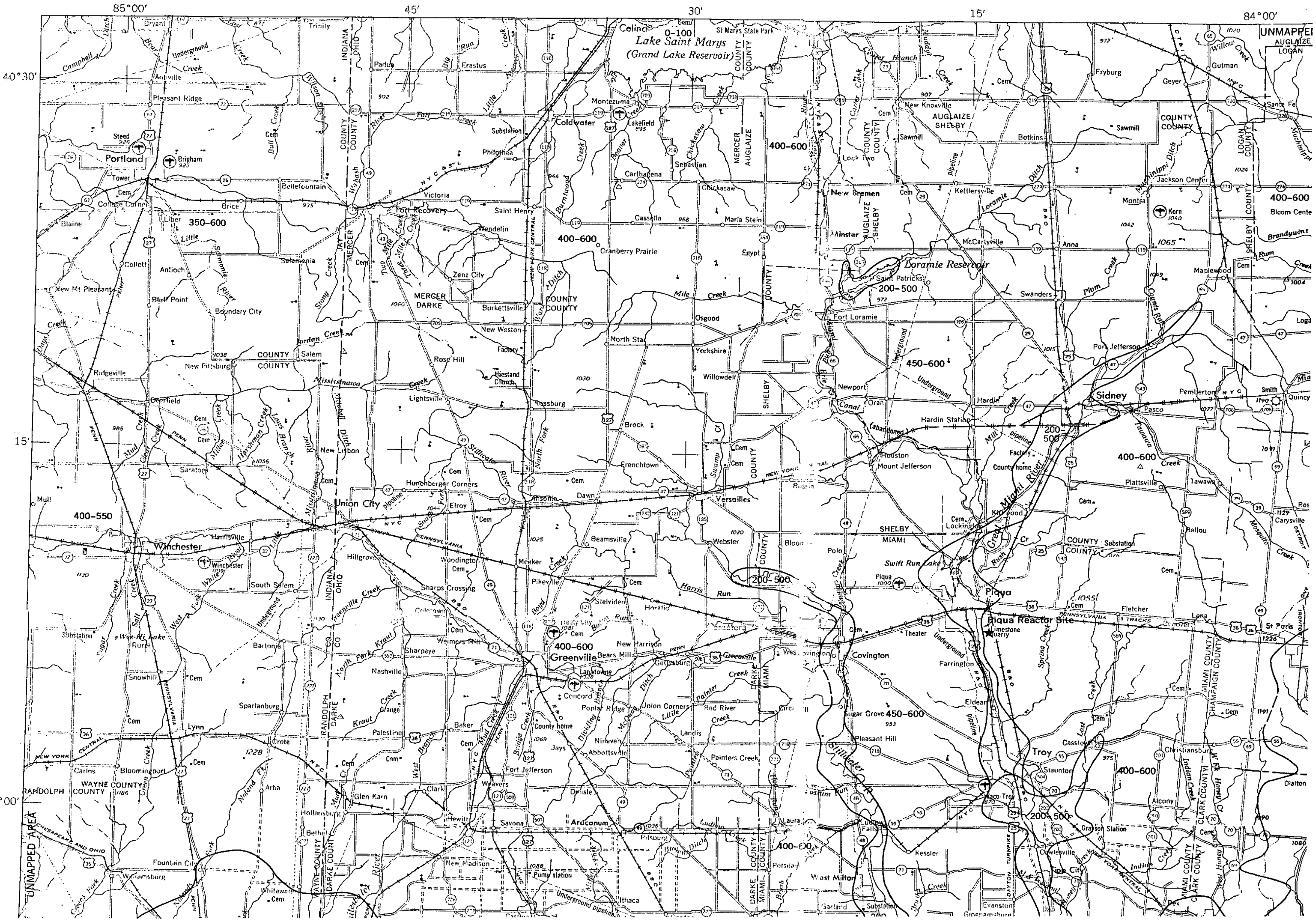
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY



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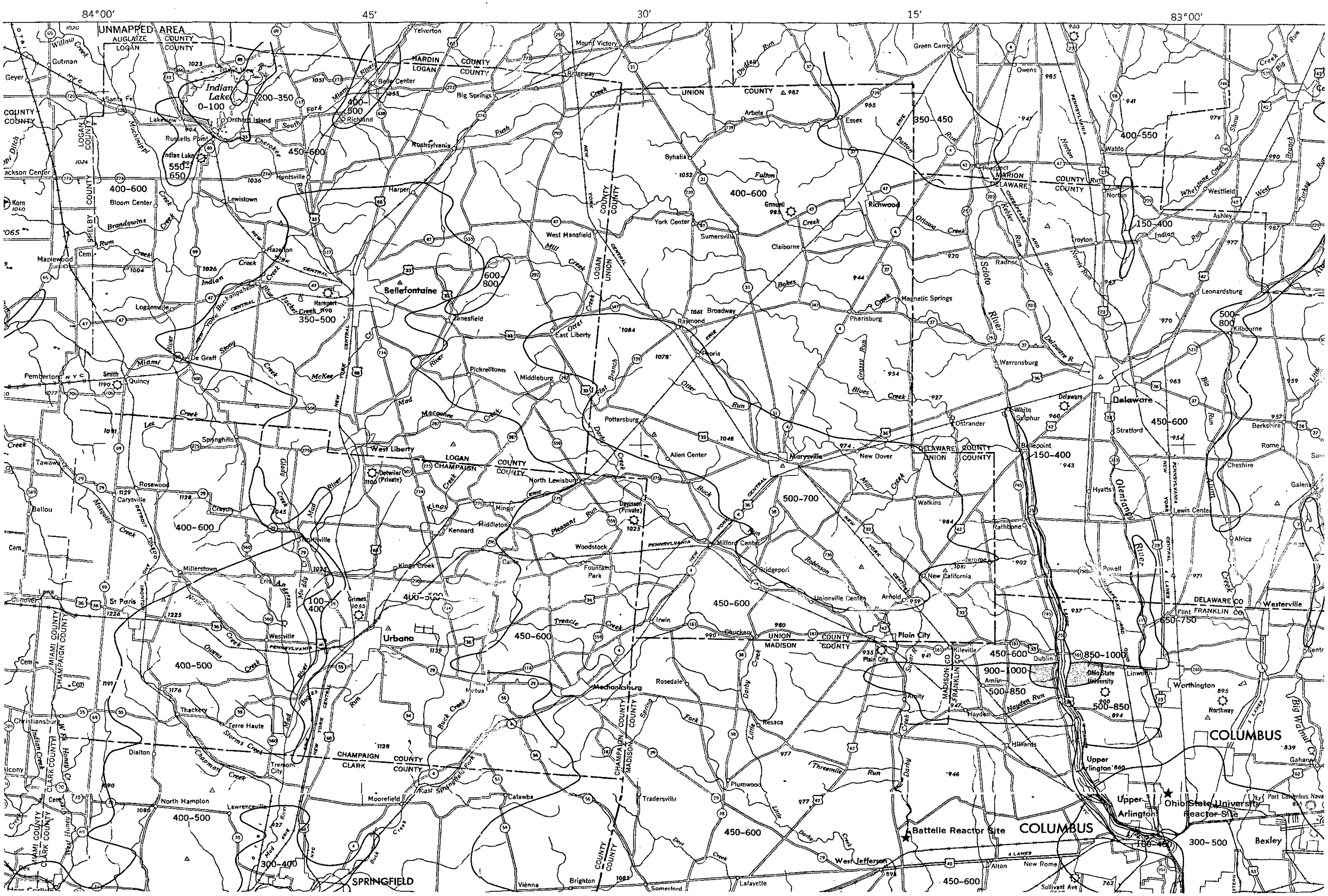
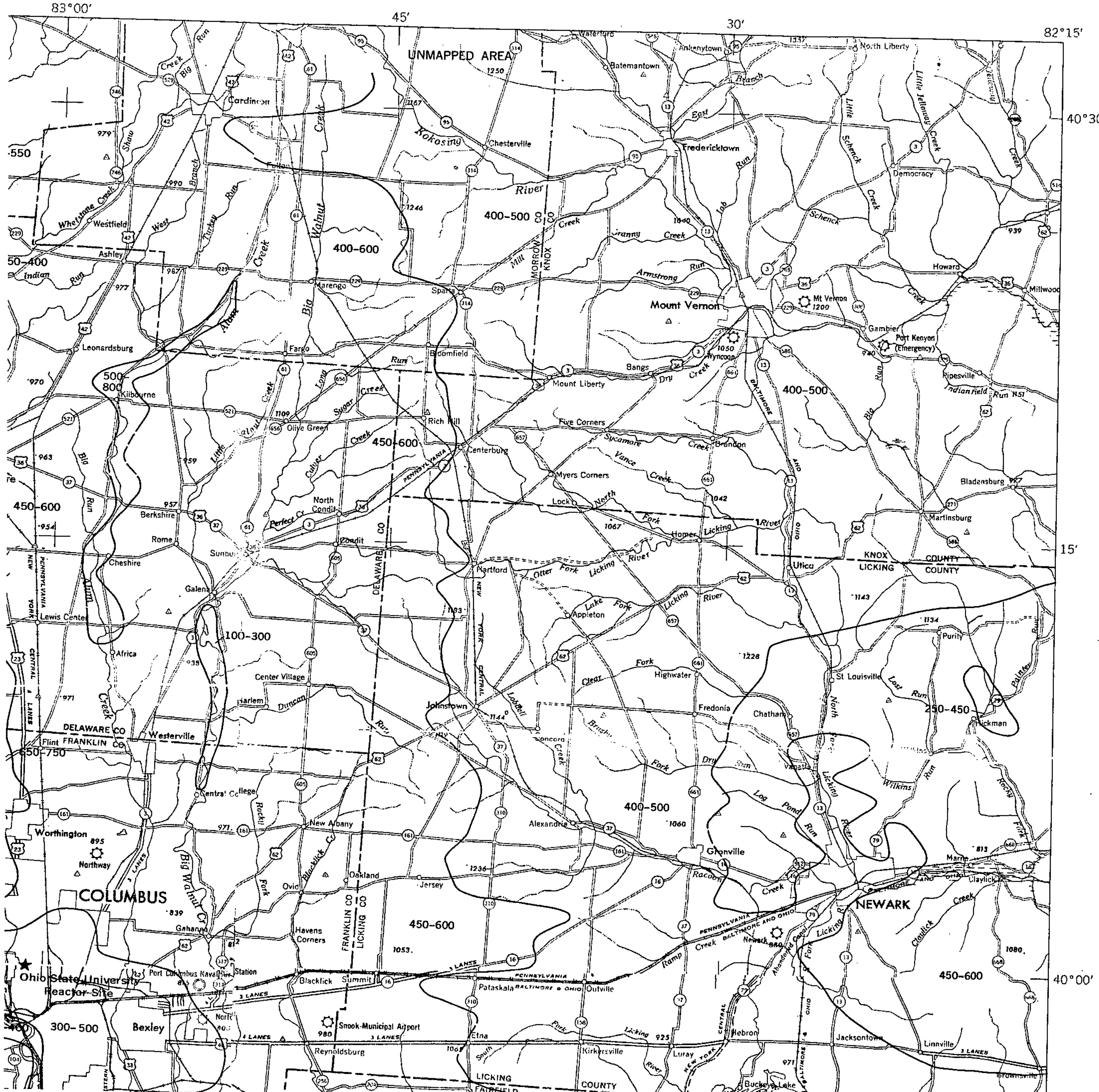

84°00'
45'
30'
15'
83°00'
UNMAPPED AREA
Indian Lake
Bellefontaine
Urbana
Marysville
Delaware
Richwood
Plain City
SPRINGFIELD
COLUMBUS
Ohio State University Reactor Site
Battelle Reactor Site
Upper Arlington
Worthington
Westerville
Mechanicsburg
West Liberty
West Jefferson
Scioto River
Olentangy River
Mad River
LOGAN CHAMPAIGN COUNTY
UNION COUNTY
MADISON COUNTY
CHAMPAIGN CLARK COUNTY
DELAWARE CO FRANKLIN CO
0-100
200-350
400-600
450-600
550-650
350-500
600-800
500-700
400-500
300-400
150-400
350-450
400-550
300-500
850-1000
900-1000
500-850
100-400
650-750

3

GEOPHYSICAL INVESTIGATIONS
MAP GP-524



EXPLANATION

300-500

Radioactivity unit boundary

Solid where well defined, dashed where inferred. No boundary shown within radioactivity units where change in radioactivity level is gradational. Numbers indicate general range of radioactivity levels in counts per second

0-100	100-300	100-400
200- 500	350-600	450-700
450-800	500- 900	850-1000

Approximate range of radioactivity within radioactivity units

★ Location of reactor site

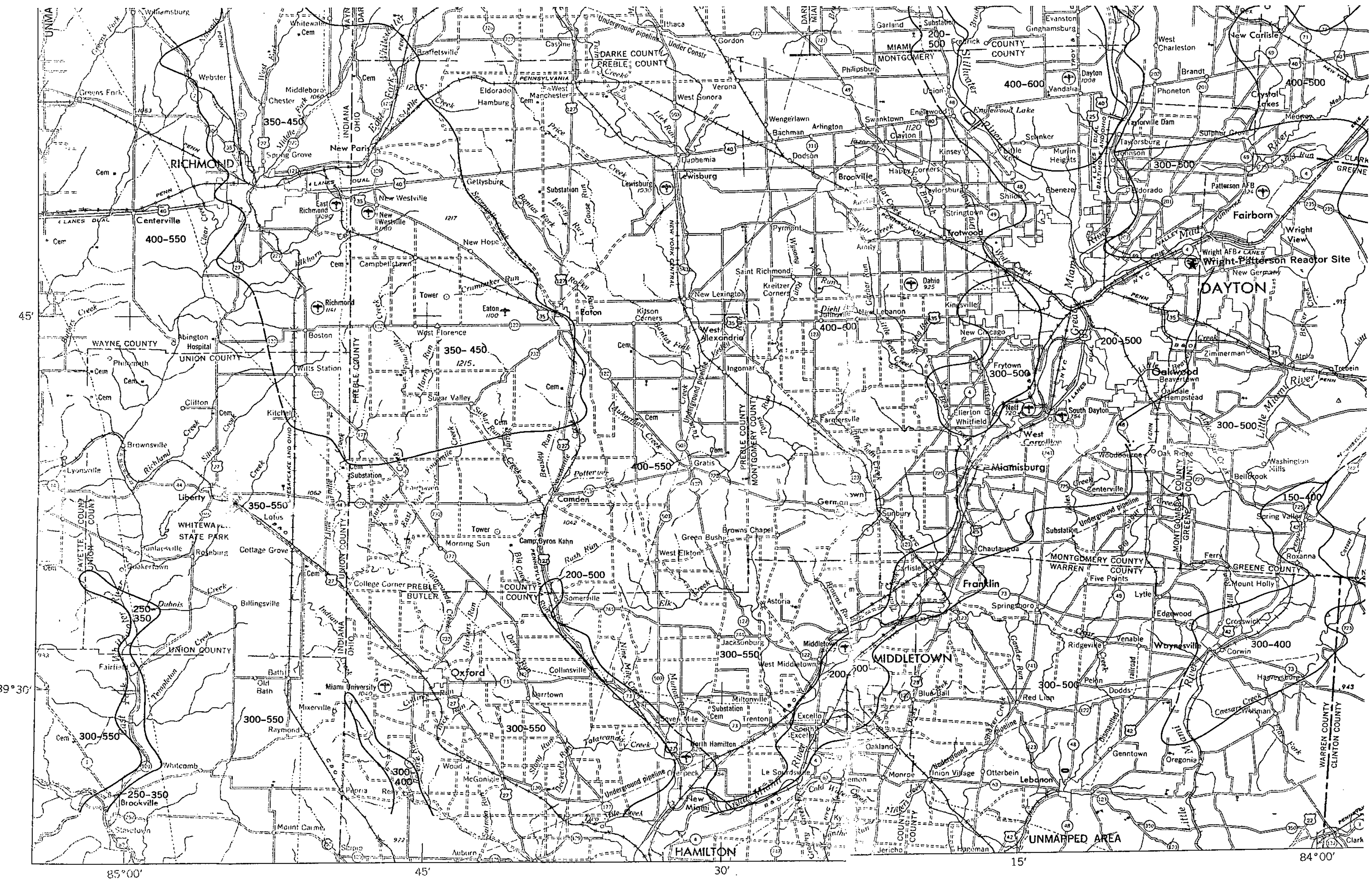
The survey was made with continuously recording scintillation detection equipment (Davis and Reinhardt, 1957) installed in a twin-engine aircraft. Parallel east-west flight lines spaced at one-mile intervals were flown at a nominal altitude of 500 feet above the ground. The flight path of the aircraft was recorded by a gyrostabilized continuous-strip-film camera. The radioactivity data were compensated for deviations from the 500-foot surveying altitude, and for the cosmic-ray component.

The effective area of response of the scintillation equipment at an altitude of 500 feet is that encompassed by a circle with a radius of 500 feet, and the radioactivity recorded is the average radioactivity of that area. The scintillation equipment records only pulses from gamma radiation with incident energies greater than 50 kev (thousand electron volts). A cesium-137 source is used during periodic calibrations to assure uniformity of equipment response.

The gamma-ray flux at 500 feet above the ground has three principal sources: cosmic radiation, radionuclides in the air (mostly radon daughter products), and radionuclides in the surficial layer of the ground. The cosmic component, called the cosmic background, is determined twice daily by calibration at 2,000 feet above the ground, and is automatically subtracted from the radioactivity data during recording. The cosmic background during this survey ranged from 240 to 400 cps (counts per second) and averaged 320 cps.

The component due to radionuclides in the air at 500 feet is difficult to evaluate. It is affected by meteorological conditions, and a tenfold change in radon concentration is not

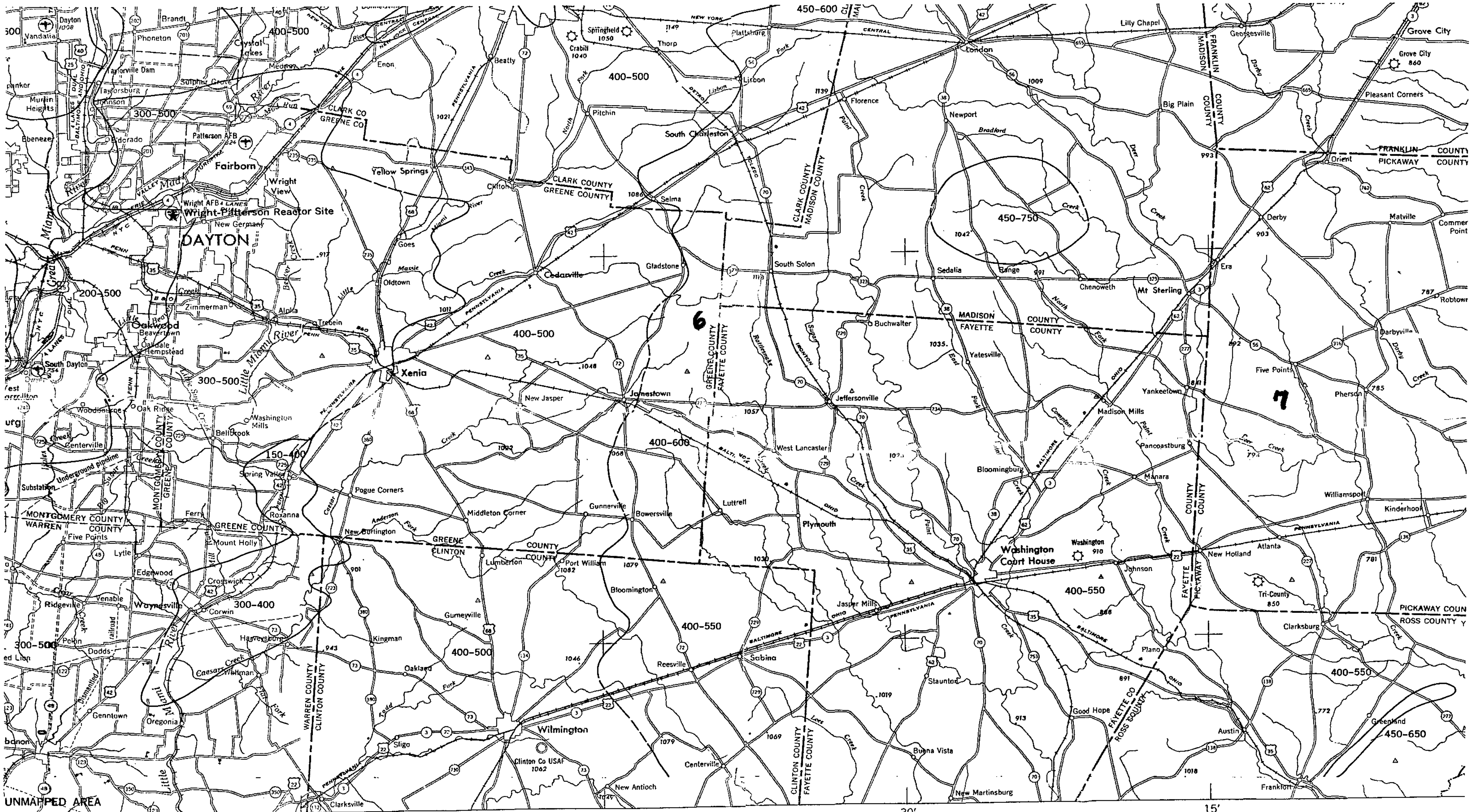
4



Base from Army Map Service 1:250,000 series: Cincinnati, 1953; Columbus, 1940; Marion, 1944; and Muncie, 1953

PLATE 1—NATURAL GAMMA AE

5



NATURAL GAMMA AERORADIOACTIVITY MAP OF CENTRAL OHIO AND EAST-CENTRAL

By

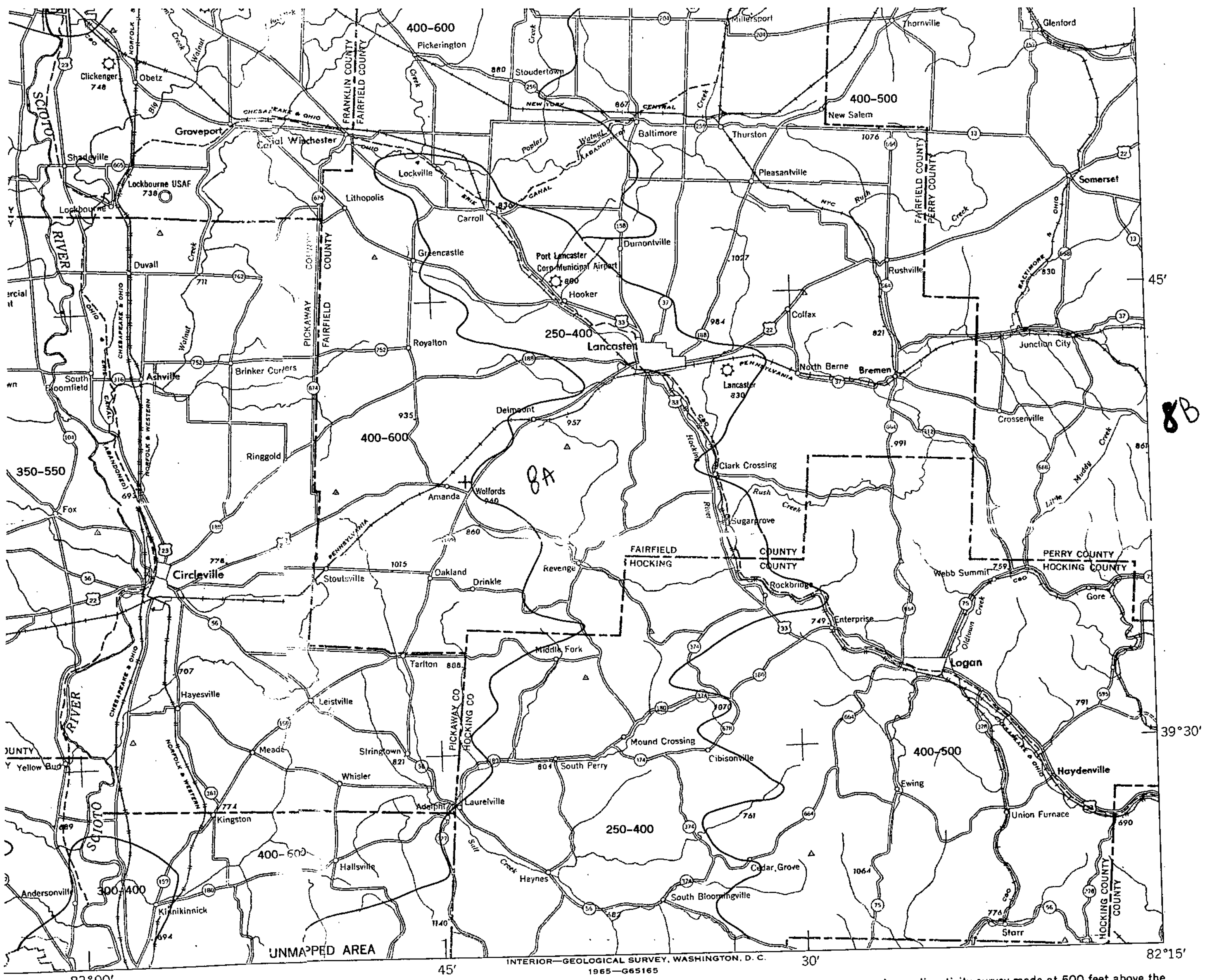
Robert G. Bates

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

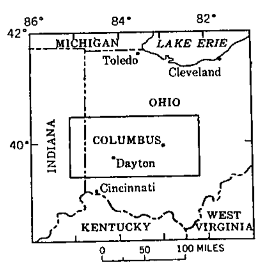
5 0 5 10 15 20 25 KILOMETERS

6



Aeroradioactivity survey made at 500 feet above the ground under the direction of P. W. Philbin, 1960

INDIANA



8A

8B

nent may be considered to be fairly uniform on a given day in a particular area, and will not mask the differences in radioactivity levels that reflect changes in the ground component.

The ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radionuclides, principally members of the uranium and thorium radioactive decay series and potassium-40, and fallout of radioactive nuclear fission products. The amount of fallout, if present in the survey area, must be small because of the overall low radioactivity level. Lacking any control information, the distribution of fallout is assumed to be uniform.

Typically, aeroradioactivity data from glaciated regions give little information on the areal distribution of underlying bedrock units. The present survey is a good example of this. Only two correlations of aeroradioactivity data with bedrock geology were noted in this area. They are the linear radioactivity highs (500 to 800 cps) along the Olentangy River and Alum Creek, north of Columbus. There the basal part of the Ohio Shale is exposed along the sides of the stream valleys. The correlative of the Ohio Shale, the Chattanooga Shale, has been intensively studied in eastern Tennessee (Brown, 1956). There, the uranium content of the basal unit ranges from 0.0024 to 0.0052 percent, and the uranium content of the whole formation ranges from 0.0011 to 0.0086 percent. The radioactivity data indicate that the Ohio Shale has about the average uranium content for marine black shales but less than that of the Chattanooga Shale.

A large area having a lower radioactivity level (200 to 500 cps) is immediately west of the center of the mapped area and extends from the southern boundary of the survey area almost to the northern boundary. This area, from Miamisburg northward, closely coincides with the interlobate area formed between the Miami and Scioto glacial lobes during late Wisconsin time. The lower radioactivity level probably is due, in part, to the large areas of sand and gravel deposited as outwash from the two glacial lobes.

There is no obvious geologic explanation for the radioactivity high (500 to 1000 cps) south of Dublin, about 10 miles northwest of Columbus

Detailed information on the aeroradioactivity survey of this area is contained in another report (Bates, in preparation).

Bates, R. G., in preparation, Aeroradioactivity survey and areal geology of parts of Ohio and Indiana (ARMS-I): U.S. Atomic Energy Comm. Rept. CEX-59.4.23.

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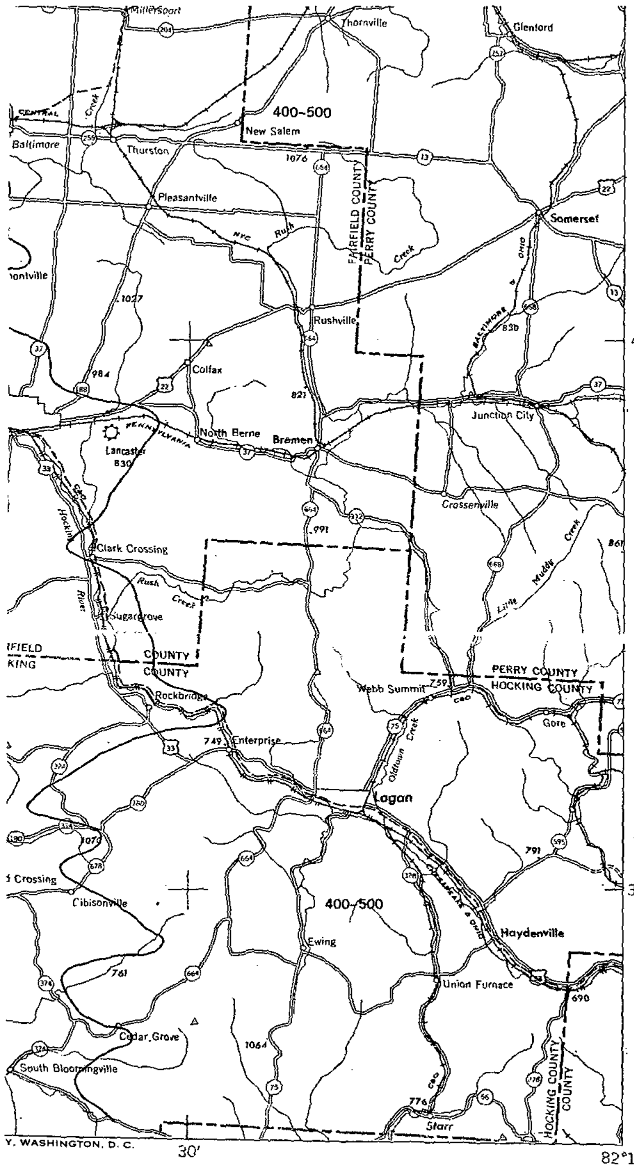
Map obtainable from U. S. Geological Survey, Washington, D. C. 20242, price 50 cents

7



Aeroradioactivity survey made at 500 feet above the ground under the direction of P. W. Philbin, 1960

8B

... inversion conditions are avoided, the air component may be considered to be fairly uniform on a given day in a particular area, and will not mask the differences in radioactivity levels that reflect changes in the ground component.

The ground component comes from approximately the upper few inches of the ground. It consists of gamma rays from natural radionuclides, principally members of the uranium and thorium radioactive decay series and potassium-40, and fallout of radioactive nuclear fission products. The amount of fallout, if present in the survey area, must be small because of the overall low radioactivity level. Lacking any control information, the distribution of fallout is assumed to be uniform.

Typically, aeroradioactivity data from glaciated regions give little information on the areal distribution of underlying bedrock units. The present survey is a good example of this. Only two correlations of aeroradioactivity data with bedrock geology were noted in this area. They are the linear radioactivity highs (500 to 800 cps) along the Olentangy River and Alum Creek, north of Columbus. There the basal part of the Ohio Shale is exposed along the sides of the stream valleys. The correlative of the Ohio Shale, the Chattanooga Shale, has been intensively studied in eastern Tennessee (Brown, 1956). There, the uranium content of the basal unit ranges from 0.0024 to 0.0052 percent, and the uranium content of the whole formation ranges from 0.0011 to 0.0086 percent. The radioactivity data indicate that the Ohio Shale has about the average uranium content for marine black shales but less than that of the Chattanooga Shale.

A large area having a lower radioactivity level (200 to 500 cps) is immediately west of the center of the mapped area and extends from the southern boundary of the survey area almost to the northern boundary. This area, from Miamisburg northward, closely coincides with the interlobate area formed between the Miami and Scioto glacial lobes during late Wisconsin time. The lower radioactivity level probably is due, in part, to the large areas of sand and gravel deposited as outwash from the two glacial lobes.

There is no obvious geologic explanation for the radioactivity high (500 to 1000 cps) south of Dublin, about 10 miles northwest of Columbus

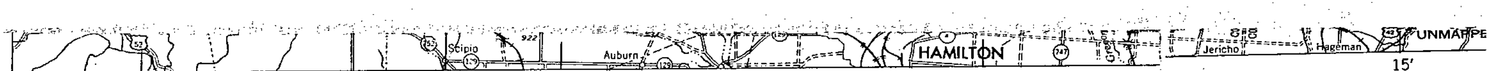
Detailed information on the aeroradioactivity survey of this area is contained in another report (Bates, in preparation).

Bates, R. G., in preparation, Aeroradioactivity survey and areal geology of parts of Ohio and Indiana (ARMS-I): U.S. Atomic Energy Comm. Rept. CEX-59.4.23.

Brown, Andrew, 1956, Uranium in the Chattanooga Shale of eastern Tennessee *in* Page, L. R., Stocking, H. E. and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on peaceful uses of atomic energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 457-462.

Davis, F. J. and Reinhardt, P. W., 1957, Instrumentation in aircraft for radiation measurements: Nuclear Sci. and Eng., v. 2, no. 6, p. 713-727.

Map obtainable from U. S. Geological Survey



Base from Army Map Service 1:250,000 series: Cincinnati, 1953; Columbus, 1940; Marion, 1944; and Muncie, 1953

PLATE 1—NAT

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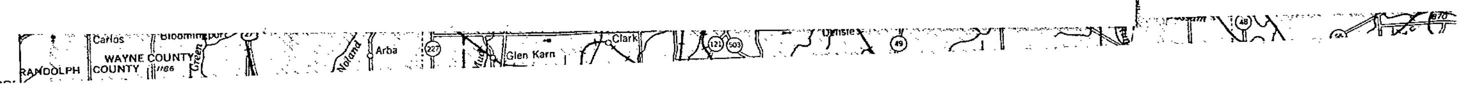
MAGNETIC NORTH DEVIATES FROM 0°30′E TO 2°45′W WITHIN MAP AREA



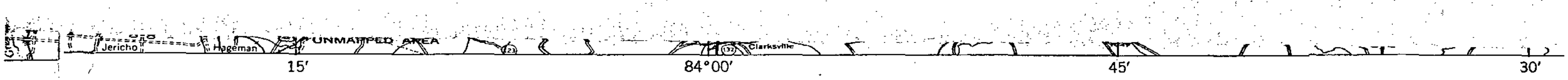


PLATE 1—NATURAL GAMMA AERORADIOACTIVITY MAP OF CENT

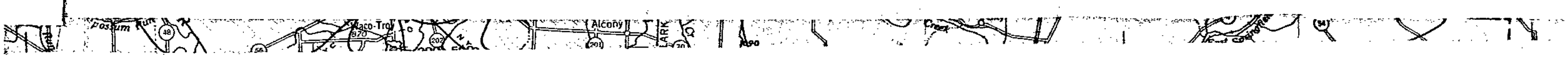
By
Robert G. Bates

SCALE 1:250 000

5 0 5 10 15

5 0 5 10 15 20

1965



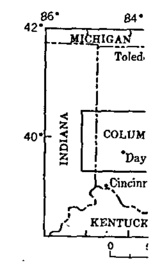
P OF CENTRAL OHIO AND EAST-CENTRAL INDIANA

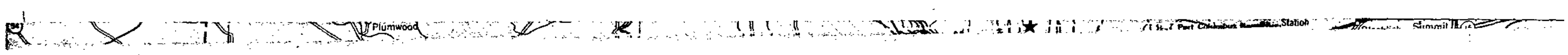
Bates

50 000

15 20 25 MILES

15 20 25 KILOMETERS





10

45′ 30′ 82°15′

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.
1965—G65165

Aeroradioactivity survey made at 500 feet above the ground under the direction of P. W. Philbin, 1960

INDEX MAP SHOWING AREA SURVEYED

energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 457-462.

Davis, F. J. and Reinhardt, P. W., 1957, Instrumentation in aircraft for radiation measurements: Nuclear Sci. and Eng., v. 2, no. 6, p. 713-727.

Map obtainable from U. S. Geological Survey, Washington, D. C. 20242, price 50 cents