

CEX-59.4.14

CIVIL EFFECTS STUDY

AERORADIOACTIVITY SURVEY AND
AREAL GEOLOGY OF PARTS OF
EAST-CENTRAL NEW YORK AND
WEST-CENTRAL NEW ENGLAND
(ARMS-1)

Peter Popenoe

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

20050916 193

Issuance Date: October 1964

**CIVIL EFFECTS TEST OPERATIONS
U.S. ATOMIC ENERGY COMMISSION**

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

This report has been reproduced directly from the best available copy.

Printed in USA. Price \$1.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Va.

NOTICE

This report is published in the interest of providing information which may prove of value to the reader in his study of effects data derived principally from nuclear weapons tests and from experiments designed to duplicate various characteristics of nuclear weapons.

This document is based on information available at the time of preparation which may have subsequently been expanded and re-evaluated. Also, in preparing this report for publication, some classified material may have been removed. Users are cautioned to avoid interpretations and conclusions based on unknown or incomplete data.

AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF PARTS OF EAST-CENTRAL NEW YORK AND WEST-CENTRAL NEW ENGLAND (ARMS-I)

By
Peter Popenoe

Approved by: Director
U. S. Geological Survey

Approved by: L. J. DEAL, Chief
Civil Effects Branch

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

August 1962

ABSTRACT

An airborne gamma-radiation survey of Connecticut, Rhode Island, and parts of New York, Massachusetts, New Hampshire, and Vermont was made during the period from 1958 through 1960 by the U. S. Geological Survey in cooperation with the Division of Biology and Medicine, U. S. Atomic Energy Commission. Results of the survey indicate that a wide range of natural radioactivity exists and that the levels are closely related to the type of bedrock underlying glacial material, and subordinately to the glacial material. This report discusses the radioactivity and correlates the data with the areal geology of the northern portion of the area surveyed. The southern portion of the area is discussed in CEX-58.4.6¹.

The area was traversed with parallel flight lines flown 500 ft above the ground and spaced at 1-mile intervals. Continuous aeroradioactivity profiles were obtained with scintillation detection equipment installed in a twin-engine aircraft. A map of radioactivity units was prepared from the profiles.

Parts of four physiographic provinces are included in the survey area: the Appalachian Plateau province underlain by relatively flat-lying Paleozoic shale, sandstone, and limestone; the Valley and Ridge province underlain by weakly folded Paleozoic shale, sandstone, limestone, and dolomite; and the New England and Adirondack provinces, underlain chiefly by highly deformed Precambrian and Paleozoic schist, gneiss, and amphibolite. Bedrock in the survey area is mantled with unconsolidated glacial deposits that range in thickness from 0 to more than 200 ft.

Rocks of both sedimentary and igneous origin produced high and low levels of radioactivity. Three large areas containing rocks of moderate to high radioactivity are present: one is associated with clastic rocks of Devonian age in the Helderberg Plateau and foothills of the Catskill Mountains; another is associated with phyllite and slate of Cambrian and Ordovician age in the Taconic Mountains and foothills; and a third is associated with a broad belt of phyllite, micaceous quartzite, and intrusive igneous rock, chiefly of Devonian age, in New Hampshire and east-central Massachusetts. Low radioactivity is associated with a large massif of anorthosite in the Adirondack Mountains, large areas of the Precambrian complex of the Green and Adirondack Mountains, a broad belt of Cambrian, Ordovician, and Devonian schist, gneiss, and amphibolite in eastern Vermont; igneous rocks of the Oliverian Plutonic Series (Devonian?) in New Hampshire and Massachusetts, and glacial lacustrine deposits along the Hudson and Connecticut Rivers.

CONTENTS

	Page
ABSTRACT	5
1. INTRODUCTION	11
1.1 Location of Area	11
1.2 Purpose of Survey	11
1.3 Airborne Survey Procedure	13
1.4 Scintillation Detection Equipment	13
1.5 Theoretical Considerations	15
1.6 Compilation of Aeroradioactivity Data	17
2. GENERAL GEOLOGY	19
3. GENERAL DISTRIBUTION OF RADIOACTIVITY	25
4. GEOLOGY AND RELATED RADIOACTIVITY OF THE APPALACHIAN PLATEAU AND VALLEY AND RIDGE PROVINCES	28
5. GEOLOGY AND RELATED RADIOACTIVITY OF THE NEW ENGLAND AND ADIRONDACK PROVINCES	29
5.1 Adirondack Province	29
5.2 Western New England Highlands	30
5.2.1 Taconic Mountains	30
5.2.2 Green Mountains	31
5.2.3 Berkshire Highlands	32
5.2.4 Eastern Vermont and West-central Massachusetts	32
5.3 Triassic Rocks of Central Massachusetts	33

CONTENTS (Continued)

	Page
5.4 Eastern New England Highlands	34
6. SUMMARY	36
REFERENCES	37

ILLUSTRATIONS

FIGURES

1. Location of the Survey Area and Nuclear Facilities Within the Area	12
2. Diagram of Radioactivity Survey Equipment	14
3. Aeroradioactivity Profile in the Keene and Brattleboro Quadrangles, New Hampshire and Vermont, Showing Relationship to Bedrock Geology and Effects of Topography, Altitude, and Water	18
4a. Detailed Aeroradioactivity Map of Parts of the Keene and Brattleboro Quadrangles, New Hampshire and Vermont, Showing Radioactivity Units, Geology, and Flight Lines . .	20
4b. Aeroradioactivity Profiles along Flight Lines 178 through 191 Shown in Figure 4a	21
5. Physiographic Divisions of Parts of East-central New York and West-central New England	22
6. Geologic Sketch Map of Parts of East-central New York and West-central New England	23
7. Glacial Map of Parts of East-central New York and West-central New England	26

ILLUSTRATIONS (Continued)

	Page
8. Generalized Aeroradioactivity of Parts of East-central New York and West-central New England	27

PLATE

1. Aeroradioactivity of East-central New York and West- central New England	in pocket
--	-----------

TABLE

1. Approximate Amounts of Uranium, Thorium, and K^{40} in Common Rocks	17
---	----

AERORADIOACTIVITY SURVEY AND AREAL GEOLOGY OF PARTS OF EAST-CENTRAL NEW YORK AND WEST-CENTRAL NEW ENGLAND (ARMS-I)

1. INTRODUCTION

1.1 Location of Area

An aeroradioactivity survey of Connecticut, Rhode Island, central and western Massachusetts, eastern New York, and parts of southern Vermont and southwestern New Hampshire was made between Oct. 17, 1958, and Aug. 31, 1960, by the U. S. Geological Survey in cooperation with the Division of Biology and Medicine, U. S. Atomic Energy Commission, as part of the Aerial Radiological Measurement Surveys (ARMS-I) program. The surveyed area comprises about 28,000 square miles; however, only the northern part of the area is discussed in this report (Fig. 1). The southern part of the survey area is discussed in CEX-58.4.6¹.

1.2 Purpose of Survey

The survey is part of a nationwide program to obtain data on the existing gamma radioactivity for areas in and adjacent to nuclear facilities. These data provide information that can be used to detect any future variations in radioactivity which may result from nuclear testing, reactor or other Atomic Energy Commission operations, or radioactivity accidents.

The major nuclear facilities included within the surveyed area are: Brookhaven National Laboratory, Upton, N.Y.; Consolidated Edison Reactor, Indian Point, N. Y.; Knolls Atomic Power Laboratory, Schenectady, N. Y.; Submarine Intermediate Reactor (Mark A) West Milton, N. Y.; Combustion Engineering Facility, Windsor, Conn.; Electric Boat Works, Groton, Conn.; and Yankee Atomic Power Company, Rowe, Mass. (Fig. 1).

Information on radioactivity levels in the environs and outside the plant boundaries of Atomic Energy Commission and contractor installations are reported in special periodic reports from each installation. These reports are published in the U. S. Public Health

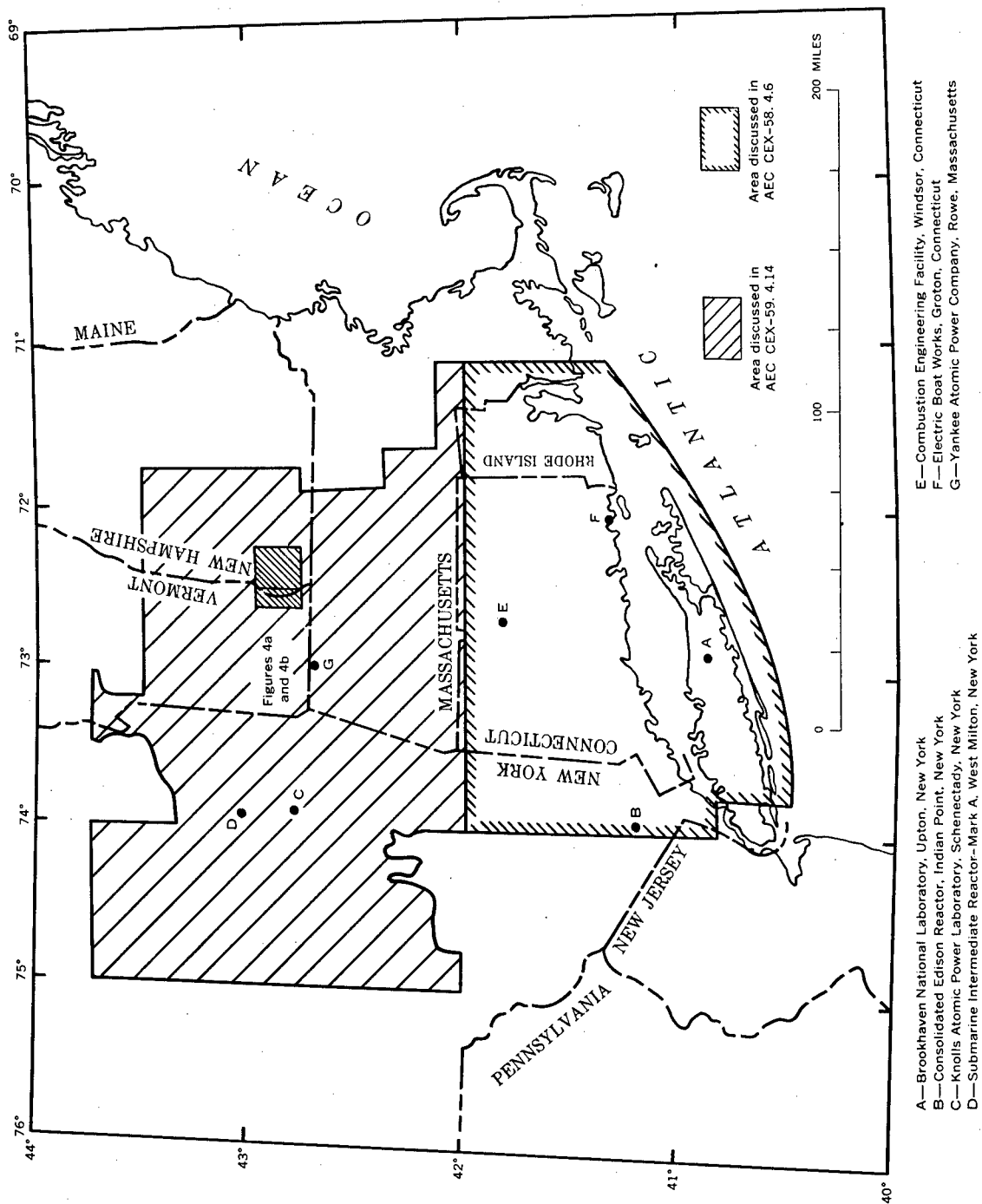


Fig. 1—Location of the survey area and nuclear facilities within the area.

Service series titled "RADIOLOGICAL HEALTH DATA", issued monthly and available from the Government Printing Office, Washington, D. C.

The entire area surveyed includes the overlapping areas within 50 miles of the Rowe, Schenectady, Windsor, and Brookhaven facilities. Parts of the area could not be flown because of the rugged topography. These are labeled "not surveyed" on the radioactivity map (Pl. 1).

1.3 Airborne Survey Procedure

Radioactivity data were obtained with scintillation detection equipment installed in a DC-3 type aircraft. East-west flight lines were flown at 1-mile intervals in the entire area except the part west of Albany, N. Y., where the lines were oriented north-south. The aircraft maintained an approximate altitude of 500 ft above the ground at an average air speed of 150 mph. Topographic maps were used for pilot guidance. The flight path of the aircraft was recorded by a gyro-stabilized continuous-strip-film camera, and the distance of the aircraft from the ground was measured by a continuously-recording radar altimeter. Fiducial markings which provide a common reference for the radioactivity and altimeter data and the strip film, were made with an electromechanical edgemark system operated by the flight observer when the aircraft passed over recognizable features on the ground².

1.4 Scintillation Detection Equipment

The gamma radiation detection equipment used by the Geological Survey was developed by the Health Physics Division of Oak Ridge National Laboratory and has been described in detail by Davis and Reinhardt³. Briefly, the detecting element consists of six thallium-activated sodium iodide crystals, 4 in. in diameter and 2 in. thick, each with a photomultiplier tube and connected in parallel. The signal from the detecting element is amplified and fed through a discriminator and pulse shaper that is set to accept only pulses originating from gamma radiation with energies greater than 50 thousand electron volts (kev). The signal is then fed to two rate meters. One rate meter feeds a circuit that records total radioactivity on a graphic milliammeter. The signal from the other rate meter is recorded by a circuit from which the cosmic background has been removed and which is approximately corrected for altitude variations from the nominal 500-ft surveying altitude by a signal from the radar altimeter servomechanism. The system described is illustrated by a diagram (Fig. 2).

The range of topographic roughness handled satisfactorily by the altitude compensator is approximately between 100 and 900 ft. The gamma absorption of a 1000-ft-thick air layer is great enough to make detection of all but the largest natural sources impractical⁴, therefore a large percentage of the measured signal when the aircraft is more than 900 ft above the ground is supplied by the altitude compensator. The compensator on the Geological Survey equipment was

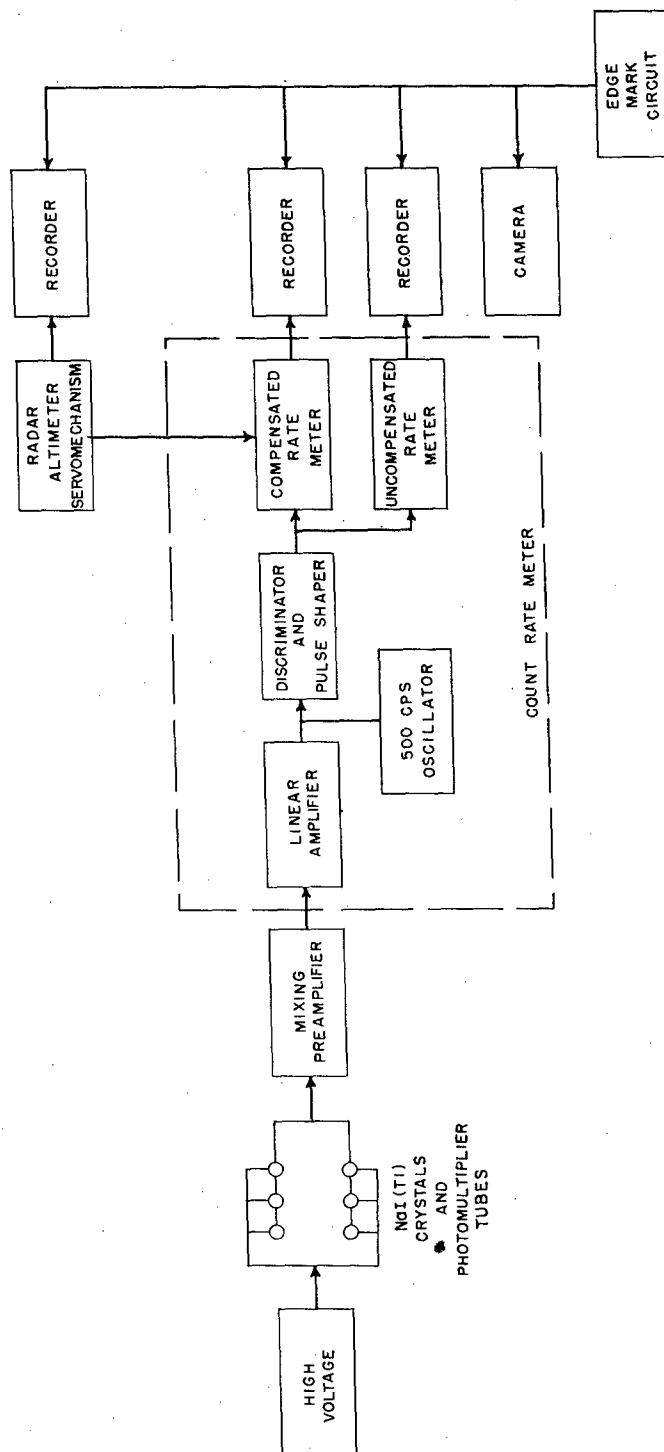


Fig. 2—Diagram of radioactivity survey equipment.

adequate in all areas but those having the most extreme topographic roughness. The limits of the compensator were exceeded in small areas of Green and Schoharie Counties, N. Y.

The gamma-ray flux at 2000 ft above the ground, which comes mainly from cosmic radiation and to a much lesser extent from radionuclides in the air, except after nuclear tests, is measured each day before surveying is started, and the assumed cosmic component is removed from the compensated circuit. A part of a regular flight line, called a test line, is flown at the beginning and end of each day's surveying. Through a comparison of these data, variations due to atmospheric and meteorological conditions and to equipment calibration may be obtained.

The effective area of response of the scintillation crystals at an altitude of 500 ft above the ground is a circle roughly 1000 ft in diameter, and the radioactivity recorded is an average of the radioactivity received within the area of response. Theoretical aspects of the area of response and other considerations are discussed by Sakakura⁵, Gregory⁶, and Moxham⁷.

Several times each day the rate meter is calibrated with a resonant reed controlled oscillator, and the scintillation detection equipment is calibrated with a Cs¹³⁷ source. A ground check of the crystals is made several times each week with a 10-microgram radium source.

The detection equipment is calibrated in counts per second (cps), which may be directly related to the average equivalent uranium content of the surface material. The sensitivity of the Geological Survey equipment has been expressed in many ways; Davis and Reinhardt (Ref. 3, p. 717) state "with a microgram of radium at one foot from the crystals, the counting rate is roughly 2,000 cps" and "when flying over a one gram radium source at 2,000 feet, an increase of 50 cps over background was noted". Davis and Reinhardt⁸ also state "The count rates at 500 ft equivalent to a ground reading of 1 micro-roentgen/hour for Cs¹³⁷ and Co⁶⁰ plane sources are 25 and 18 cps respectively". Theoretical aspects of sensitivity are also discussed by Sakakura (Ref. 5).

1.5 Theoretical Considerations

The principal sources of the gamma-ray flux at 500 ft above the ground are cosmic radiation, radionuclides in the air (mostly radon daughter products), and radionuclides in the surface layer of the ground. It is difficult to accurately determine the contribution of each component at any particular time during the survey day; however certain assumptions on theory and calibration procedure permit reasonable estimates to be made.

The cosmic background is measured at 2000 ft above the ground twice each day and the assumed cosmic component at 500 ft above the ground is removed from the altitude-compensated circuit. Variations in this component during the survey day are difficult to separate from the other components, but they are believed insignificant in normal surveying.

Many variables, such as moisture content of the soil, temperature, barometric pressure, and wind velocity, affect the

concentration of radionuclides in the air. It is not uncommon in cases of temperature inversion to have a ten-fold increase in radon concentration. The gamma effect from radon concentration has not been fully evaluated, but it is believed to be insignificant in normal surveying.

The radioactivity of synthetic particles (fallout, cooling effluent gases, etc.) in the atmosphere may cause sharp or broad radioactivity anomalies, but these conditions were not encountered during the survey of this area.

The ground component of radioactivity measured at 500 ft above the ground comes mainly from the upper few inches of surface material and originates from natural radionuclides and radioactive fission products of fallout. Although an increase in measured radioactivity believed to be caused by fallout was noted during the survey of the southern part of the area in Oct. 1958 (Ref. 1), all of the area discussed in this report was flown in 1959 and 1960 and does not appear to be greatly affected by the fallout. This may be a result of the cessation of nuclear testing prior to September 1961 and the rapid decay of the short-lived fission products⁹. Gustafson, Marinelli, and Brar¹⁰ concluded from a study of the radioactivity of soil at Lemont, Ill., that in the spring of 1957 the activity due to fallout was less than one-tenth of the total gamma activity of the soil. This conclusion is supported by the fact that less than 100 cps due to natural radioactivity and fallout was recorded over several large areas in the New England and New York portions of the project. Any fallout that may be present is assumed to be uniform over the area surveyed.

Of the naturally occurring radionuclides in the surface layer of the ground only members of the uranium and thorium decay series, and K^{40} are sufficiently abundant to affect the measured radioactivity. Trace amounts of these elements are found in all natural materials (Table 1). The concentration of these elements in the surficial material (glacial drift, soil, weathered rock, etc.) is determined by the original composition of the parent rock from which the surficial material was derived, and changes brought about by geologic and soil forming processes.

An important consideration in any study of the radioactivity of surficial material is whether the material is derived from the bedrock beneath it or whether it is derived from rock entirely different from that on which it is resting. The fact that the surficial material in the New York-New England area consists chiefly of unconsolidated glacial drift has an important bearing on the radioactivity of the area. It will be demonstrated later that the glacial material bears a close relationship to the underlying bedrock.

TABLE 1 - - APPROXIMATE AMOUNTS OF URANIUM, THORIUM, AND K^{40} IN
COMMON ROCKS*

Common rocks	Uranium, ppm	Thorium, ppm	K^{40} , ppm
Ultramafic	0.001	0.004	0.005
Basaltic	1.0	4.0	0.99
Granodiorite	3.0	8.5	3.0
Granite	3.0	17.0	5.0
Syenite	3.0	13.0	5.7
Shale	3.7	12.0	3.2
Sandstone	0.45	1.7	1.3
Carbonate	2.2	1.7	0.32

* Adapted from Turekian and Wedepohl¹¹, assuming the isotopic abundance of K^{40} is 0.0119 percent of total potassium.

1.6 Compilation of Aeroradioactivity Data

Flight lines were plotted from the strip film onto base maps at a scale of 1 in. equals 1 mile (1:62,500). The altitude-compensated radioactivity profiles were compared with topographic maps of the same areas and all radioactivity lows attributable to lakes, ponds, rivers, or swamps were marked as such on the profiles (Fig. 3). This step was necessary because the glacial terrain is responsible for the numerous poorly drained areas in which lakes and swamp abound. These water bodies limit the source area by shielding the ground component, thus producing many lows on the radioactivity profiles. The amplitudes of the lows are proportional to the areal extent of the water within the area of response of the scintillation crystals. To reproduce all these lows on the aeroradioactivity map would greatly complicate it with numerous undesirable readings.

Adjacent aeroradioactivity profiles were then reexamined and significant changes or breaks in the level of radioactivity were correlated from line to line (Figs. 4a and 4b). The changes were plotted on overlays of the base maps and connected by solid or dashed lines depending on the degree of correlation. As would be expected



in a glaciated area many of the radioactivity boundaries are gradational, whereas others stand out quite sharply. The solid lines denote relatively distinct changes in radioactivity level, and the dashed lines denote relatively minor or subtle changes. After the records obtained over these specific areas had been scanned, the areas between the lines of change were assigned general ranges of radioactivity level.

The overlays were then photographically reduced and the data plotted on sheets of the Army Map Service, Corps of Engineers 1:250,000-scale, topographic map series. The final 1:250,000 map was thus derived (Pl. 1). This map is also published in the Geological Survey Geophysical Investigations Map Series¹².

2. GENERAL GEOLOGY

A detailed description of the geology is beyond the purpose and scope of this report, however, a general knowledge of the regional geology is necessary to better interpret the radioactivity pattern.

Parts of four physiographic provinces are included in the area (Fig. 5); the Appalachian Plateau province underlain by relatively flat lying Paleozoic shale, sandstone, limestone and dolomite; the Valley and Ridge province underlain by weakly folded Paleozoic shale, dolomite, limestone, and sandstone; and the New England and Adirondack provinces underlain chiefly by Precambrian and Paleozoic complexes of highly deformed schist, gneiss, and amphibolite of sedimentary and igneous origin.

Fig. 6 is a geologic sketch map compiled from published maps and descriptive literature. The geology of much of the area is currently being restudied and there is much unpublished or only informally published data that contradict existing maps. Only recently have geologists working in the region begun to have a good understanding of the complex metamorphic geology. The nature of many of the formations is poorly understood and discrepancies in origin, boundaries, names, and ages of many of the formations exist from state to state, or area to area. Some of the difficulty in bedrock mapping is caused by the mantle of glacial drift, but the major difficulties are the complex structure, high degree of metamorphism, deformation, igneous intrusion, and heterogenous lithology of the units. Many of the metasedimentary schists and gneisses have been intruded to such a degree that the rocks must be mapped as mixtures. In addition, reliable guide fossils on which age determinations may be based are very scarce in New England.

Most of the geologic data for Vermont are based on the new Centennial Geologic Map of Vermont by Doll, et. al.¹³. In New Hampshire the State Geological Map by Billings¹⁴ is the major source of data. For Massachusetts detailed quadrangle maps were used where available, but most of the geology is based on the Preliminary Geologic Map by Emerson¹⁵ published nearly a half century ago. For New York various data were used, primarily the Geologic Map of the Southern Taconics¹⁶, geologic quadrangle maps, ground-water resources maps, and the 1901 Geologic Map of New York by Merrill¹⁷.

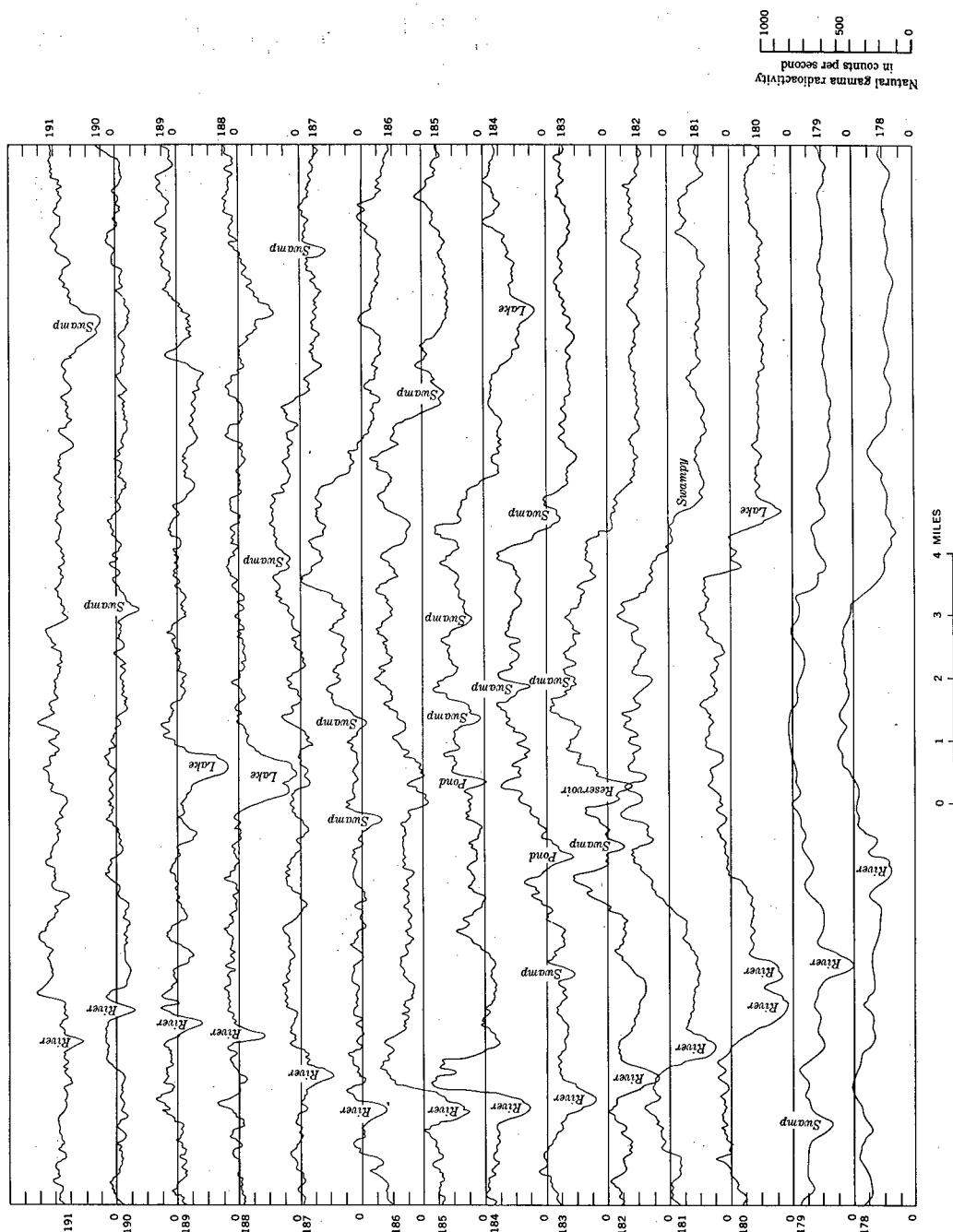


Fig. 4b—Aeroradioactivity profiles along flight lines 178 through 191 shown in Fig. 4a.

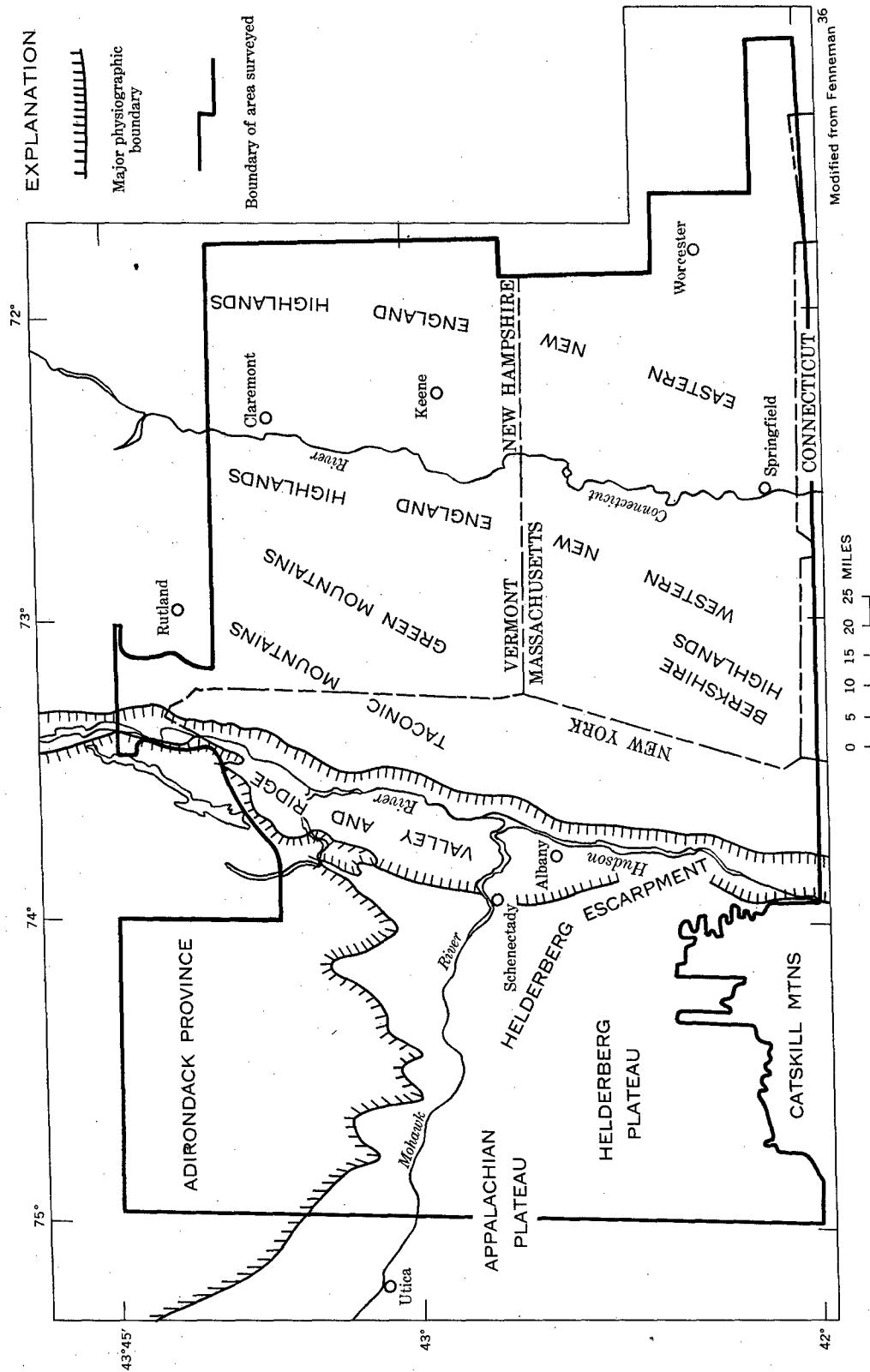
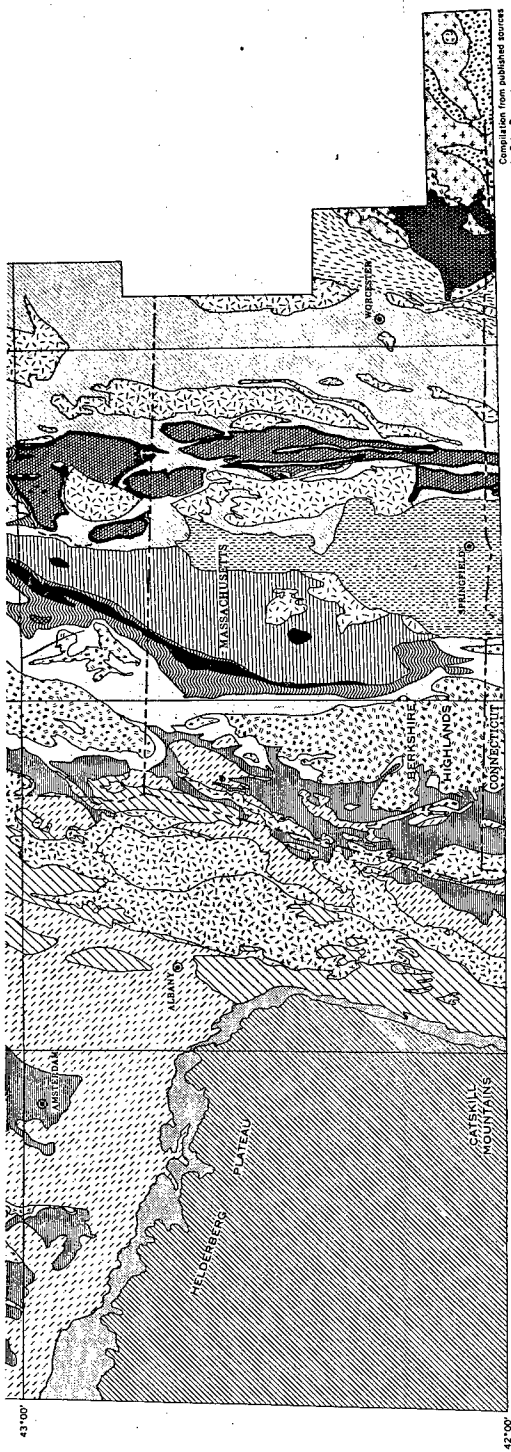


Fig. 5— Physiographic divisions of parts of east-central New York and west-central New England.



Compilation from published sources
by Peter Rogness

0 5 10 15 20 MILES

EXPLANATION

Upper Permian or Lower or Middle Triassic Arkose, conglomerate sandstone, and shale <i>Includes some basaltic rocks</i> Intrusive igneous stocks chiefly syenite, gabbro, diorite, and granite <i>Chiefly White Mountain Plutonic Volcanic Series</i> Conglomerate, arkose, sandstone, and shale Schist, phyllite, and quartzite Granite, quartz monzonite, quartz diorite, binary granite, and gabbro <i>New Hampshire Plutonic Series, and rocks not yet assigned to series but probably New Hampshire Plutonic Series</i>	PERMIAN OR TRIASSIC Granodiorite, quartz diorite, quartz monzonite, and granite <i>Olivertown Plutonic Series</i> Granodiorite, granite, syenite <i>Milford Granite, and rocks of the Dedham-Salem pluton*</i> Sandstone, shale, graywacke, and conglomerate Phyllite, micaceous quartzite, interbedded volcanic rock, or higher grade metamorphic equivalents <i>Chiefly Littleton Formation, but includes other Paleozoic rocks</i> Quartzite and micaceous crystalline limestone, quartz-muscovite-phyllite or schist, micaceous quartzite, calcareous mica schist <i>Chiefly Waits River (Silurian and Devonian) and Gile Mountain (Devonian) Formations</i>	SILURIAN AND DEVONIAN Limestone, and interbedded shale Dry Hill Granite Gneiss, Williamsburg Granodiorite, Dana Diorite, Belcherown Tonalite <i>Not yet assigned to a plutonic series</i> Ultramafic rocks <i>Dunite, peridotite, serpentinite, and talc-carbonate rocks</i> Quartzite, granulite, schist, and phyllite Biotite gneiss, hornblende gneiss, and amphibolite <i>Chiefly metamorphosed volcanic rocks</i>	PRECAMBRIAN Shale and sandstone Shale, slate, and phyllite <i>Taconic sequence</i> Shale, phyllite, schist, graywacke <i>Taconic sequence</i> Limestone, dolomite, and marble Carbonaceous and noncarbonaceous schist, phyllite, quartzite, amphibolite, and gneiss Shale, slate, phyllite, and graywacke, with minor amounts of sandstone and limestone <i>Taconic sequence</i> Sandstone and conglomerate Basement complex of highly metamorphosed rocks of sedimentary and igneous origin Northbridge Granite Gneiss Anorthosite
---	---	---	---

*Dating by total lead ratio in zircon indicates that rocks mapped as Dedham granodiorite have two ages, 260 MY and 350 MY 38.

Unconsolidated glacial drift covers perhaps 98 percent of the surface of the New York-New England area (Fig. 7) and outcrops exist only where bedrock projects through the glacial cover. Till, or boulder clay, an unsorted deposit, blankets most of the area. Several large lacustrine deposits of sorted silt, clay, and sand are present in the Hudson and Connecticut River valleys. Goldthwait¹⁸ estimates the average thickness of the glacial deposits in New Hampshire to be 37 ft. Although accurate information as to depths of glacial material is lacking for much of the area, generally the most extensive deposits are located in the valleys, and the deposits are thin over the upland areas or steep slopes. Composition of the deposits is extremely variable but is generally relatable to the nearby bedrock which usually supplied the dominant material in the deposit. Thus deposits over shale are generally argillaceous, while those over areas of crystalline rock are general arenaceous.

3. GENERAL DISTRIBUTION OF RADIOACTIVITY

A summary of the radioactivity measured in the survey is shown in Fig. 8. Radioactivity levels ranged from less than 100 cps (counts per second) to 1150 cps, the average being about 500 cps.

The radioactivity map (Pl. 1) of the area demonstrates that the great majority of the glacial drift mantling the bedrock bears a close relationship to the underlying bedrock, except where its depth is too great, as in areas of lacustrine deposits, or along the contacts between formations where material from one formation is intermingling with that of another. Radioactivity boundaries are in most cases gradational owing to this intermingling of materials. It is surprising that bedrock radioactivity boundaries can be seen at all, but Nelson and Narten¹⁹ found in a radioactivity study of Maine that "the radioactivity of the glacial materials is about the same magnitude as that of the rocks in the areas where they are found. It would thus seem that glacial debris from the eroded rocks of Maine has not been transported great distances". On the aeroradioactivity map many of the bedrock units may be traced for miles by their characteristic level regardless of the glacial cover.

Both sedimentary and igneous rocks show relatively high and low radioactivity levels. In the Appalachian Plateau province the radioactivity of the carbonate rocks generally range from 300 to 500 cps whereas the shale and sandstone generally range from 350 to 700 cps. The shale, phyllite, graywacke and limestone underlying the foothills of the Taconic Mountains generally range from 300 to 750 cps, but levels as high as 1050 cps are associated with the shale and phyllite underlying the Taconic Mountains. The New England and Adirondack provinces contain sedimentary and igneous rocks of varied radioactivity ranging from less than 100 to 1150 cps. Exceptionally low radioactivity (100 to 400 cps) is associated with the schist and gneiss of the Green Mountains and eastern Vermont, the igneous rocks of the Oliverian Plutonic Series of New Hampshire and eastern Massachusetts, and a large massif of anorthosite and areas of complex rock in the Adirondack Mountains of New York. Moderate to high

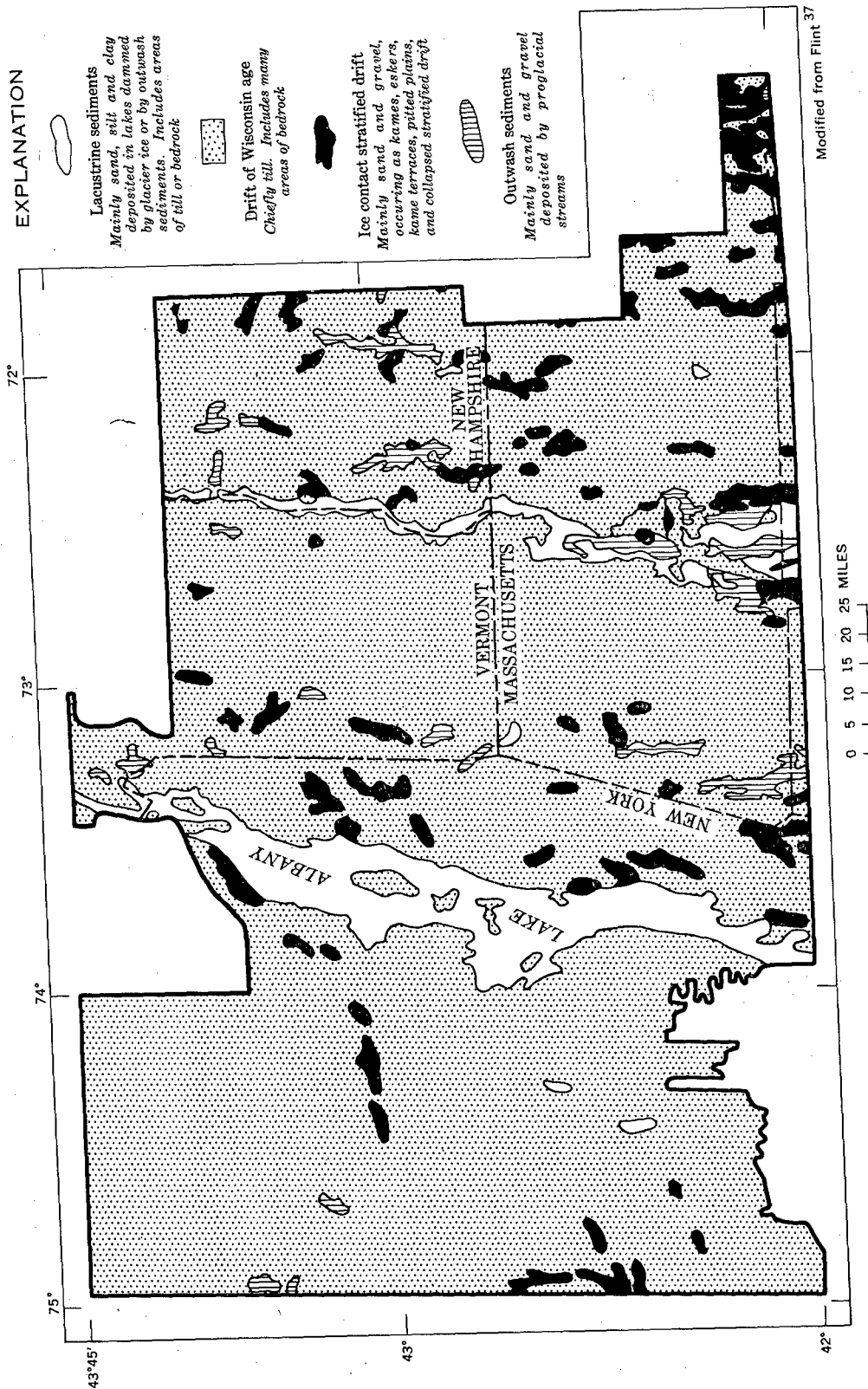


Fig. 7 — Glacial map of parts of east-central New York and west-central New England.

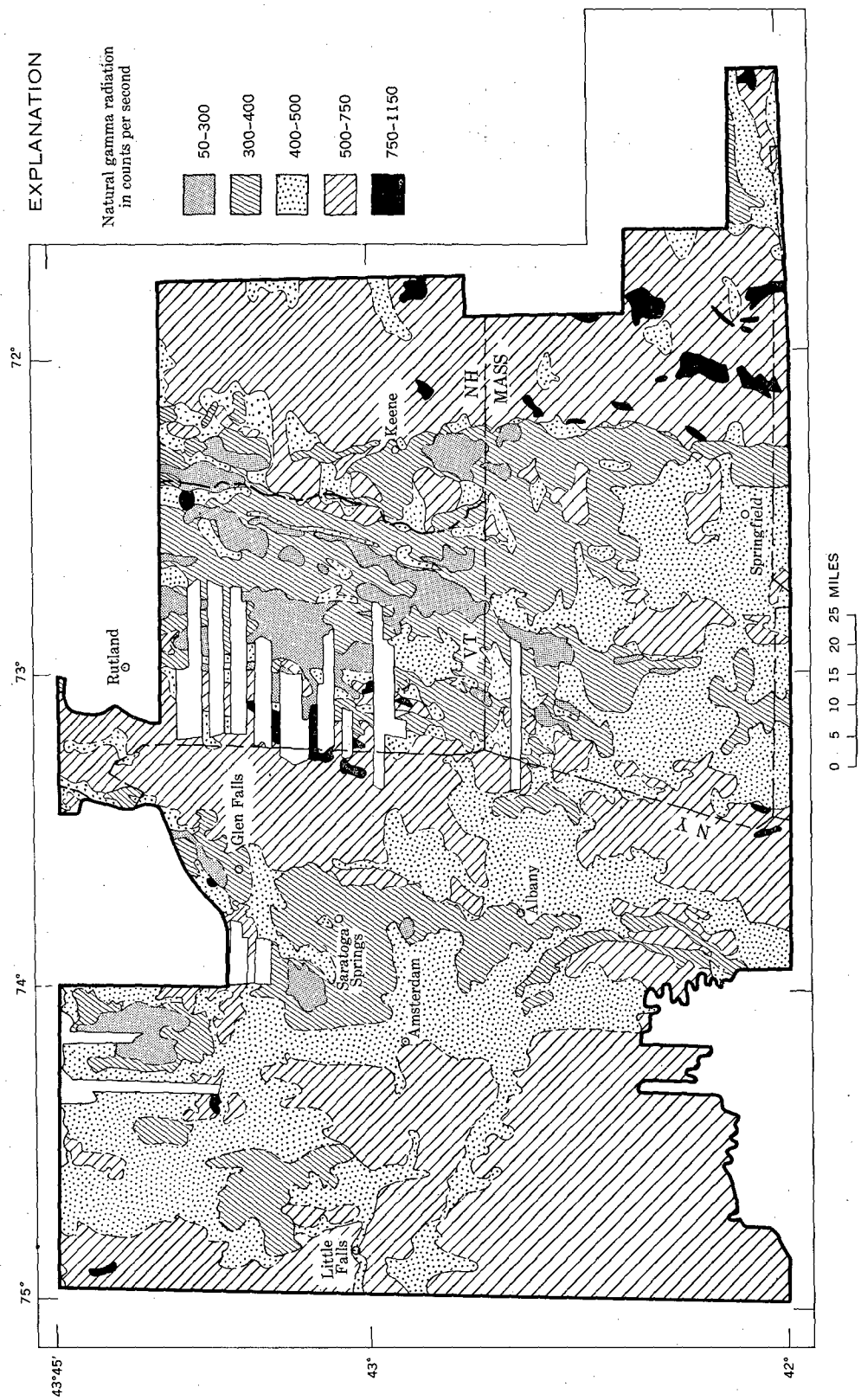


Fig. 8—Generalized aeroradioactivity parts of east-central New York and west-central New England.

radioactivity (400 to 1150 cps) is associated with a broad belt of igneous and metasedimentary rocks in New Hampshire and eastern Massachusetts, the Ascutney Mountain stock in Vermont, and locally in the Adirondack Mountains.

Glacial lacustrine deposits in the vicinity of Albany, N. Y., and scattered along the Connecticut River in Massachusetts generally have low associated radioactivity (200 to 400 cps). In many areas recent river or stream alluvium differs in radioactivity from the bedrock.

Several radioactivity highs were measured at or near Springfield, Mass. (1050 cps) and Schenectady, N. Y. (900 and 1000 cps). These measurements (Pl. 1) have no obvious geologic explanation and are believed not due to natural effects.

4. GEOLOGY AND RELATED RADIOACTIVITY OF THE APPALACHIAN PLATEAU AND VALLEY AND RIDGE PROVINCES

The sedimentary rocks of the Appalachian Plateau and Valley and Ridge provinces within the survey area range in age from Late Cambrian to Late Devonian. The rocks are relatively flat lying in the Appalachian Plateau, and become weakly folded and metamorphosed in the Valley and Ridge province before they disappear under the rocks of the Taconic thrust sheets.

The Upper Cambrian section resting unconformably on Precambrian rocks and cropping out at the margins of the Adirondack Mountains, consists of sandstone and conglomerate overlain by several formations of dolomite. A great thickness of massive gray Ordovician limestone overlies the Cambrian section. The Mohawk River valley is underlain by Ordovician black bituminous shale and gray calcareous shale with interbedded sandstone and limestone. Resistant Silurian and Lower Devonian limestone with lesser amounts of sandstone and thin bedded shale uphold the Helderberg escarpment, a prominent topographic feature to the south of the Mohawk River valley. Middle Devonian rocks, which are exposed at the surface in the Helderberg Plateau, consist predominantly of black bituminous shale in the west, grading eastward to bluish-gray sandy shale.

The Upper Devonian section exposed in the Catskill Mountains and foothills, is characterized by arkosic sandstone, siltstone, graywacke, some conglomerate, and greenish to reddish clay. The Upper Devonian generally consists of marine shale near its base and grades upward to continental red beds.

Radioactivity levels range from 200 to 1050 cps. The level of the Cambrian and Lower Ordovician carbonate section generally ranges from 300 to 500 cps, but in many areas that section is not separable by radioactivity from the Ordovician shale sequence. The radioactivity of the Ordovician shale exposed along the Mohawk Valley ranges from 300 to 750 cps. Generally the shale is higher in radioactivity (500 to 650 cps) in the western part of the area, and lower (350 to 500 cps) west of Schenectady, N. Y., where the section contains abundant sandstone.

The resistant Silurian and Lower Devonian limestone sequence along the Helderberg escarpment forms what is perhaps the best

exposure of bedrock in the project area. The carbonate sequence is marked by a distinct radioactivity low (generally 300 to 500 cps).

Radioactivity of the Middle Devonian marine shale exposed on the Helderberg Plateau generally is from 400 to 600 cps in level, but several large areas in Schoharie and Otsego Counties, N.Y., average 500 to 700 cps. The Upper Devonian Catskill red beds generally range from 450 to 600 cps in level.

Locally, in Green and Schoharie Counties, radioactivity levels range from 700 to 1050 cps in steep-sided valleys. Comparison of the radioactivity profiles and altimeter records over these areas indicate that these anomalous values are due to overcompensation by the altitude-compensated circuit in the Geological Survey equipment, rather than to natural radioactivity.

Analyses of the Paleozoic rocks of the Hudson and Mohawk valleys by Narten and McKeown²⁰ indicate that "In the Paleozoic rocks the average radioactivity of the most strongly radioactive rocks is 0.003 percent equivalent uranium".

In the Hudson River valley low radioactivity levels averaging 250 to 400 cps are associated with lacustrine sand, gravel, and clay deposited in the glacial Lake Albany (Fig. 7). A significant radioactivity break occurs along a north-south line in the center of the lake deposits. It is interesting that northeast of Saratoga Springs, N. Y., where the change in level is particularly pronounced, the break occurs near the location of a fault mapped by Cushing and Ruedemann²¹. On the east side of the fault the Snake Hill Formation, a unit lithologically similar to the rocks of the Taconic sequence is present, and on the west side the Canajoharie Shale, a black shale, is present. The Snake Hill Formation is now thought to be a facies of the Canajoharie Shale. The fault shown by Cushing and Ruedemann corresponds closely to the place where the cleaved rocks merge into uncleaved rocks²². It seems that the change in level is not due to a difference in the bedrock, but may be due to a difference in source area for the lake sediments, those on the west derived from the Precambrian Adirondack region, and those on the east derived from the Taconic Mountains.

5. GEOLOGY AND RELATED RADIOACTIVITY OF THE NEW ENGLAND AND ADIRONDACK PROVINCES

5.1 Adirondack Province

The Adirondack Mountains of New York are underlain by a complex of Precambrian metasedimentary and meta-igneous rocks. The metasedimentary rocks, known as the Grenville Series, are dominantly marble, quartzite, amphibolite, and biotitic, garnetiferous, and sillimanitic gneiss. These rocks are moderately to highly deformed, and injected with anorthosite, gabbro, diorite, syenite, and a granitic complex, which have interacted with the metasediments to produce hybrid rocks and skarns. Paragneisses were injected lit-par-lit with magma and partially granitized by magmatic fluids which permeated the rocks. Some granites are not separable from granitized sediment or migmatite²³.

Radioactivity levels of the Precambrian rocks are generally below 500 cps, except near the western boundary of the project where they are slightly higher (up to 700 cps). A large massif of anorthosite exposed mainly in the Thirteenth Lake quadrangle²⁴ in northwestern Warren County, N. Y., is exceptionally low in level (150 to 350 cps). Large areas of rocks of anomalously low radioactivity are also found at the intersection of Herkimer, Fulton, and Hamilton Counties, N. Y., where quartz-feldspar-garnet gneiss and mixed granite, syenite, and Grenville rocks are 200 to 400 cps in level; and at the southeastern extension of the Adirondack Precambrian complex in Saratoga County, N. Y., where Grenville rocks and syenite are 100 to 400 cps in level. High levels are scattered throughout the area, the highest just west of the anorthosite massif (1150 cps), and another sharp high of 1050 associated with a known uranium-rich pegmatite located just north of the Sacandaga Reservoir in Fulton County, N. Y. Investigations by Narten and McKeown (Ref. 20, p. 23) in the Adirondack Mountains indicate that "although there are many abnormally radioactive rocks and glacial materials, particularly near the contacts of igneous and metamorphic rocks, pegmatites are the only known sources of concentrations of radioactive elements".

5.2 Western New England Highlands

5.2.1 Taconic Mountains

Underlying the Taconic Mountains and the foothills to the west is a succession of Cambrian and Ordovician clastic rocks, primarily micaceous and quartz-silt shale, purple and green shale and slate, red slate, quartzite, graywacke, and interbedded black shale and limestone. Dikes of diabase, albite basalt, and tuffs are present in the Taconic clastics indicating eugeosynclinal deposition. These clastics have relatively great north-south extent, relatively small east-west extent, and are surrounded by and rest discordantly on contemporaneous miogeosynclinal carbonates and orthoquartzites²⁵. The Taconic rocks are bounded on the west by a fault, or zone of faults known as "Logan's Line", but the nature of the eastern boundary is in doubt, for the Taconic rocks rest against and are metamorphosed with similar Ordovician argillaceous rocks that obscure the character of the contact.

Many hypotheses have been proposed to explain the apparent anomalous position of the Taconic rocks. Those of the north are thought to be a number of klippen, which have been thrust into their present position from a source area to the east (Ref. 25, p. 326). The emplacement of the rocks of the southern Taconics is controversial in nature with several hypotheses proposed to explain their structure and lithology (Ref. 16).

The miogeosynclinal rocks bounding the eastern edge of the Taconic sequence are equivalent with and lithologically similar to the Cambrian and Ordovician sequence of the Hudson and Champlain Valleys. Resting on the Precambrian rocks of the Green Mountains and Berkshire Highlands are Lower Cambrian quartzites and conglomerates. Cambrian and Ordovician carbonate rocks that overlie

the clastic sequence are described as gray, pinkish, and brown dolomite, white to gray marble, and calcareous sandstone and quartzite (Ref. 13). At the top of the section are black carbonaceous and pyritic slate and phyllite which correspond to the Snake Hill Formation of the Champlain Valley (Ref. 22).

Radioactivity levels over the rocks of the Taconic sequence range from 300 to 1050 cps. The highest levels of radioactivity, averaging 500 to 800 cps, are associated with the variegated slate and phyllite underlying the Taconic Mountains along the New York-Vermont state line. Medium high levels of 450 to 700 cps are also associated with the shale and slate in the foothills of the Taconic Mountains in Washington County, N. Y. In Rensselaer and Columbia Counties, N. Y., medium low levels of 300 to 500 cps are associated with the Rensselaer Graywacke and the Cambrian clastic rocks of the Taconic sequence.

Radioactivity levels of the quartzite-carbonate sequence range from 100 to 950 cps, but generally are below 600 cps. In Vermont a large area of the sequence is exceptionally low (100 to 300 cps) in level. The level increases in Massachusetts to an average of 300 to 500 cps. In many localities the bedrock in the valleys is mantled with a thick blanket of talus, glacial drift, and alluvium, which is the source of the gamma radiation.

5.2.2 Green Mountains

The Green Mountains of Vermont within the surveyed area are underlain by a complex of Precambrian metasedimentary and meta-igneous rocks similar to those of the Adirondack Mountains. The metasedimentary rocks, known as the Mount Holly Complex, consist dominantly of biotitic, muscovitic, and chloritic gneiss, hornblende gneiss, quartz mica schist, calcite and dolomite marble, micaceous quartzite, and amphibolite.

The metasedimentary rocks are intruded by both mafic and felsic igneous rock. At the southern tip of the Green Mountains the Mount Holly Complex is intruded by the Stamford Granite Gneiss, a gray coarse-grained, porphyritic granite gneiss with megacrysts of perthitic microcline. Elsewhere intrusions of gneissic biotite granite, quartz monzonite, granodiorite, and "white gneiss" with quartz, microcline, albite, and biotite are present. A small stock, mainly nepheline syenite and pulaskite, intrudes the complex near Cuttingsville, Vt. 13, 26, 27.

East of the Green Mountains several large areas of Precambrian rocks crop out in the cores of dome and nappe structures. These rocks are largely banded gneisses of granodioritic or quartz dioritic composition with minor amounts of biotite amphibolite and a few lenses of schist and quartzite²⁸.

Radioactivity levels associated with the rocks of the Green Mountains are generally low. That of a large central area of the Mount Holly Complex is exceptionally low (100 to 300 cps) and most of the complex is generally below 500 cps. Locally, the Mount Holly Complex has zones of rock displaying higher radioactivity. Northeast of Bennington, Vt., several zones strike north-south, and have associated radioactivity varying from 100 to 1000 cps. The

Cuttingsville, Vt., stock has a small "high" of 700 cps associated with it. A large portion of the Green Mountains could not be flown because of the rugged topography, and it is possible that some of the radioactivity values recorded over the complex are incorrect because of the limitations of the altitude-compensated circuit of the scintillation equipment.

The Precambrian rocks exposed in the dome and nappe structures to the east of the Green Mountains are uniformly low in radioactivity (generally 150 to 400 cps and rarely more than 500 cps).

5.2.3 Berkshire Highlands

South of the Green Mountains a complex of Precambrian age gneiss and schist of sedimentary and igneous origin forms the core of the Berkshire Highlands. The metasedimentary sequence includes quartzite gneiss, actinolite-epidote gneiss, muscovite-biotite-epidote schist, biotite amphibolite, garnetiferous gneiss, quartzite, and marble. As in the Green Mountains to the north, the closely folded sedimentary rocks have been invaded and altered by mafic and felsic igneous magma, locally with considerable absorption of material. The common orthogneiss is a medium-to fine-grained, light-colored biotite-(or biotite-muscovite) microcline-oligoclase gneiss. Locally there are small areas of light-colored porphyritic granite^{15,29,30}.

Radioactivity levels over the Berkshire Highlands generally range from 300 to 500 cps. Higher levels are found locally but none of these exceed 800 cps.

5.2.4 Eastern Vermont and West-central Massachusetts

The remainder of the western New England Highlands is underlain chiefly by a broad belt of mica schist and quartzite, interstratified with green schist, amphibolite, and gneiss, all of Paleozoic age. The mica schist and quartzite are metamorphosed shale and sandstone and the green schist, amphibolite and gneiss are largely metamorphosed volcanic rock. Igneous rocks ranging in composition from serpentinized dunite to granite are intrusive into the metasedimentary and metavolcanic rocks. Several large granodiorite and quartz diorite intrusions are present in Massachusetts, and these are similar to the intrusive rocks of the Eastern Highlands.

On the geologic sketch map (Fig. 6), the Western Highlands has been divided into three metasedimentary units, based primarily on age; the Cambrian, the Ordovician (separated into two units, one chiefly of sedimentary origin and the other chiefly volcanic origin) and the Devonian. The Silurian section, which is of small areal extent, is included with the Devonian section.

The Cambrian section is characterized by schist, phyllite, and gneiss, with interbedded amphibolite, greenstone, quartzite and dolomite (Ref. 13). The radioactivity over the sequence generally ranges from 200 to 500 cps. Locally, particularly over Lower Cambrian schists, the level reaches 600 cps. Radioactivity of most of the Cambrian formations of Massachusetts is 300 to 500 cps in level.

The Ordovician rocks, particularly the volcanic rocks, are among the best defined by radioactivity lows on the map. The Barnard Volcanic Member of the Missisquoi Formation, mainly biotite gneiss, hornblende gneiss, and amphibolite (Ref. 13) shows a low of 100 to 300 cps that can be traced across Vermont to the vicinity of West Cummington, Mass. Similarly, a low occurs east of Ascutney Mountain, over volcanic members of the Partridge Formation, and around the margins of the Oliverian Plutonic Series of New Hampshire (Ammonoosuc Volcanics). Most metasedimentary rocks in the Ordovician section, consisting of quartzite, granulite, schist, and phyllite, are below 400 cps in radioactivity in Vermont and northern Massachusetts and below 500 cps in southern Massachusetts. Several ultramafic bodies intrude the Ordovician rocks. The largest ultramafic intrusion near East Dover, Vt., is represented by a low of 150 to 250 cps.

The Devonian metasedimentary formations of the Western Highlands have been grouped into two units on Fig. 6; the Littleton Formation, discussed later under the Eastern Highlands section, and the Gile Mountain and Waits River Formations. The Waits River Formation (which is Silurian and Devonian in age) is chiefly gray quartzose and micaceous marble interbedded with gray quartz-muscovite phyllite or schist. The Gile Mountain Formation is chiefly gray quartz-muscovite phyllite or schist interbedded and intergradational with gray micaceous quartzite, calcareous mica schist, and locally quartzose and micaceous marble (Ref. 13). Both formations have volcanic members. Radioactivity of the two formations is generally below 450 cps in level in Vermont and increases in level toward the southern part of the belt in Massachusetts, where it attains a level of 450 to 650 cps near Huntington, Mass. Several large igneous bodies occur within the Devonian belt, but these generally are not discernible by radioactivity measurements.

A consistent change in radioactivity level occurs between the Devonian rocks of the Western Highlands (Waits River, Gile Mountain Formations) and those of the Eastern Highlands (Littleton Formation, etc.). The break occurs just west of the Connecticut River and can be traced to where the formational boundaries disappear beneath the Triassic rocks of Massachusetts. The rocks of the Western Highlands area are generally low whereas those of the Eastern Highlands are noticeably higher in level.

The most highly radioactive rocks in the area occur at Ascutney Mountain in the northeastern part of the belt. Here a large stock containing comagmatic intrusions of gabbro, diorite, syenite, and granite has invaded the schist and gneiss³¹. The rocks are similar to, and classed with, the White Mountain Plutonic-Volcanic Series of New Hampshire. The granite at Ascutney Mountain has a radioactivity level of 1100 cps, the gabbro diorite has a low level of 200 to 300 cps.

5.3 Triassic Rocks of Central Massachusetts

In central Massachusetts continental clastic rocks of Triassic age consisting chiefly of unmetamorphosed arkose, sandstone, conglomerate and shale underlie the Connecticut River Valley and extend southward into Connecticut. Basaltic lava flows are inter-

bedded with the clastic rocks and crop out in a narrow belt in the west-central part of the area. The coarser clastics were deposited as alluvial fans by streams which dumped their load of gravelly wash into a structural trough; the finer clastics are largely lacustrine or palustrine deposits³². The beds strike north and dip toward the east.

The radioactivity level of the Triassic rocks is a fairly uniform 300 to 500 cps. Locally the radioactivity level reaches 600 cps, possibly owing to a different source area for the sedimentary or glacial material. The basaltic lava flows generally have a slightly lower level (250 to 400 cps), but in most areas they do not have sufficient areal extent for their effect to be noticeable. Glacial lacustrine deposits with low radioactivity (200 to 400 cps) are present along the Connecticut River (Fig. 7). The contact of the Triassic rocks with the surrounding Paleozoic rocks is not discernible by radioactivity except in the southwest corner of the area where the Paleozoic rocks are slightly higher in level.

5.4 Eastern New England Highlands

East of the Connecticut River the bedrock of the New England Highlands is extremely complex. These rocks generally consist of phyllite, micaceous quartzite, and interstratified volcanic rocks, or their higher-grade metamorphic equivalents, which have been intruded by numerous types of igneous rocks (chiefly granite, quartz monzonite, quartz diorite, and granodiorite). The meta-sedimentary rocks are mainly of marine origin, originally arenaceous shales and argillaceous sands, mostly of Paleozoic age. At many places the sedimentary rocks are intricately intruded, both lit-par-lit and by granitization. All of the rocks have been regionally metamorphosed, chiefly to the sillimanite grade, and deformed (Ref. 14, p. 28).

On the basis of radioactivity the eastern New England Highlands within the project boundaries can be roughly divided into zones from west to east: a western zone of medium radioactivity, a zone of low radioactivity associated with the Oliverian Plutonic Series, a central zone of relatively high radioactivity, and an eastern zone of low to medium radioactivity.

The western zone of medium radioactivity is present mainly in Massachusetts and contains Devonian and older sedimentary rocks, and Paleozoic igneous rocks. On the geologic sketch map (Fig. 6), it includes the unit marked as Dry Hill Granite Gneiss, Williamsburg Granodiorite, Dana Diorite, and Belchertown Tonalite, and the surrounding metasedimentary rocks. The zone generally ranges from 300 to 600 cps. There is no difference in the radioactivity of the igneous or sedimentary rocks, and the belt is not distinguishable by radioactivity from the Triassic rocks to the west.

The second zone, of low radioactivity, is comprised of a discontinuous series of domes, collectively called the Bronson Hill anticline. These domes have cores of igneous intrusive rocks and are surrounded by metamorphosed Ordovician volcanic rocks. In New Hampshire, where the domes are extensively developed, the granite, quartz monzonite, and granodiorite that make up the domes have

collectively been assigned to the Oliverian Plutonic Series because of their lithologic similarity and structural position. The boundaries of the various rock types within the domes cannot be precisely located because they are transitional into one another. The rocks of the series are generally pink, medium- to coarse-grained, characteristically foliated, and commonly found near the top of the Ammonoosuc Formation, a series of Ordovician metavolcanic rocks. Most of the rocks of the series are older than or contemporaneous with deformation (Ref. 14, p. 52).

The volcanic rocks surrounding the domes are of two principal kinds: dark-green chlorite and chlorite epidote schist, and buff to white soda rhyolite that is massive to schistose. Some dark slate and impure gray quartzite are mixed with the volcanic rocks. The bedding, as well as the fragmental texture, indicates that most of the metavolcanic rocks are of phyroclastic rather than flow origin. These volcanic rocks are similar to, and have been correlated with the Ordovician volcanic rocks of the Western Highlands, which include the Barnard Member of the Missisquoi Formation, and volcanic members of the Partridge Formation (Ref. 13).

The granite, quartz monzonite, granodiorite, and the volcanic rock surrounding the domes have strikingly low radioactivity. Most of the Oliverian plutonic rocks are characteristically low in radioactivity (generally 150 to 400 cps) and can easily be traced across the project area by this associated low radioactivity. The exception is at one locality in the Sunapee quadrangle, near the north edge of the area, where the quartz diorite and quartz monzonite in the Croydon dome ranges from 500 to 700 cps with a small high of 900 cps. Where the individual rock types are mapped separately on geologic quadrangle maps, there appears to be a slight difference in the associated radioactivity. The quartz diorite, where mapped separately, generally ranges from 150 to 350 cps, and the quartz monzonite, granodiorite, and surrounding volcanic rocks generally range from 300 to 400 cps (Fig. 4a).

The central area of the Eastern Highlands contains as a whole the highest levels of radioactivity in the northern New England project area. The bedrock is generally metamorphosed shale and sandstone of Devonian age (mainly Littleton Formation), into which have been intruded many igneous bodies. Some gneiss, schist, quartzite, and igneous rocks of Carboniferous and Precambrian age are present in the eastern part of the zone. Most of the central area is metamorphosed to andalusite or sillimanite grade. Many of the metasedimentary rocks are highly migmatized and metasomatized, and some of the igneous rocks contain inclusions of metasedimentary rock.

Billings¹⁴ has classed the Devonian(?) igneous rocks that intrude the central zone in New Hampshire into the New Hampshire Plutonic Series, and rocks unassigned to series, but probably New Hampshire Plutonic Series. The dominant rock types are quartz monzonite, granodiorite, granite, biotite gneiss, and quartz diorite.

The average radioactivity of the central belt of rocks in New Hampshire is 400 to 700 cps. A large intrusion of quartz monzonite in the southwestern part of the state (500 to 700 cps) stands out in sharp contrast to the surrounding rocks of lower radioactivity (Fig. 4). Elsewhere there appears to be little difference in radio-

activity between the igneous and sedimentary rocks. Local high readings are found throughout the state over both igneous and sedimentary rocks. Several of the highest readings (up to 950 cps) occurred over Mount Monadnock, N. H., which is underlain by sedimentary rocks, and over and around a body of quartz diorite near Lyndeboro, N. H.

To the south in Massachusetts the average radioactivity of the central zone increases to 550 to 750 cps. The Paxton Quartz Schist of Massachusetts is slightly lower with an average level of 400 to 600 cps. Levels of 900 cps are present over rocks of both igneous and sedimentary origin. In the southeastern corner of the zone the Northbridge Granite Gneiss, a gneissoid porphyritic microcline-biotite granite of Precambrian age, ranges in radioactivity from 400 to 1000 cps. This rock is generally higher near its western margin and lower along its eastern margin. The radioactive zoning may be due to magmatic segregation, but it is possible that detailed geologic mapping will show several distinct rock types within the unit.

Johnson³³ and McKeown³⁴ have studied the central zone of high radioactivity in Massachusetts and New Hampshire and have concluded that "The radioactivity of the rocks of the central New England province is considered to be due mainly to thorium, as uranium analyses to date have not shown more than 0.001 percent uranium" (Ref. 34, p. 24).

Although the southeastern extension of the project just touches a zone of low to medium radioactivity, the rock types present are characteristic of a broad area in eastern Massachusetts and in Rhode Island. Two major bodies of igneous rock are present in the survey area; the Dedham Granodiorite, and the Milford Granite. The Dedham Granodiorite is typically a pale pink, coarse-grained biotitic granodiorite composed essentially of microcline, plagioclase, quartz, and biotite altered to chlorite. The Milford Granite is typically coarse-grained, alkalic pink granite containing biotite as its dark constituent and rounded blue quartz¹⁵.

Radioactivity levels over these plutonic rocks are generally low. Over the greater portion of the Milford Granite the level is a uniform 300 to 400 cps. The southern end of the Milford Granite and the greater portion of the Dedham Granodiorite range from 350 to 600 cps. A stock of porphyritic riebeckite granite which has relatively high radioactivity (850 to 950 cps) intrudes the Dedham Granodiorite at the tip of the southeastern project extension.

Clastic rocks of Pennsylvanian age are exposed in the extreme southeastern corner of the project area. These rocks consist of slightly metamorphosed conglomerate, arkose, sandstone, and shale of nonmarine origin. Radioactivity levels range from 350 to 500 cps.

6. SUMMARY

The natural gamma radioactivity in the project area ranges from less than 100 cps to 1150 cps, averaging about 500 cps. Comparison with geologic maps indicates that the level of radioactivity is closely related to the type of bedrock underlying soil or glacial

deposits and subordinately related to the glacial deposits. The association of radioactivity level with bedrock type is locally so good that some geologic units may be traced for miles by their characteristic level.

Rocks of both sedimentary and igneous origin produced high and low levels of radioactivity. Three large areas containing rocks of moderate to high radioactivity are present: one associated with clastic rocks of Devonian age in the Helderberg Plateau and foothills of the Catskill Mountains; another associated with phyllite and slate of Cambrian and Ordovician age in the Taconic Mountains and foothills; and the third associated with a broad belt of phyllite, micaceous quartzite, volcanic material and intrusive igneous rock, chiefly of Devonian age, in New Hampshire and east-central Massachusetts. Low radioactivity is associated with a massif of anorthosite in the Adirondack Mountains, a large part of the Precambrian complex of the Green and Adirondack Mountains, the Cambrian, Ordovician, and Devonian sedimentary sequence of eastern Vermont, the igneous rocks of the Oliverian Plutonic Series and surrounding volcanic rocks, and glacial lacustrine deposits along the Hudson and Connecticut Rivers.

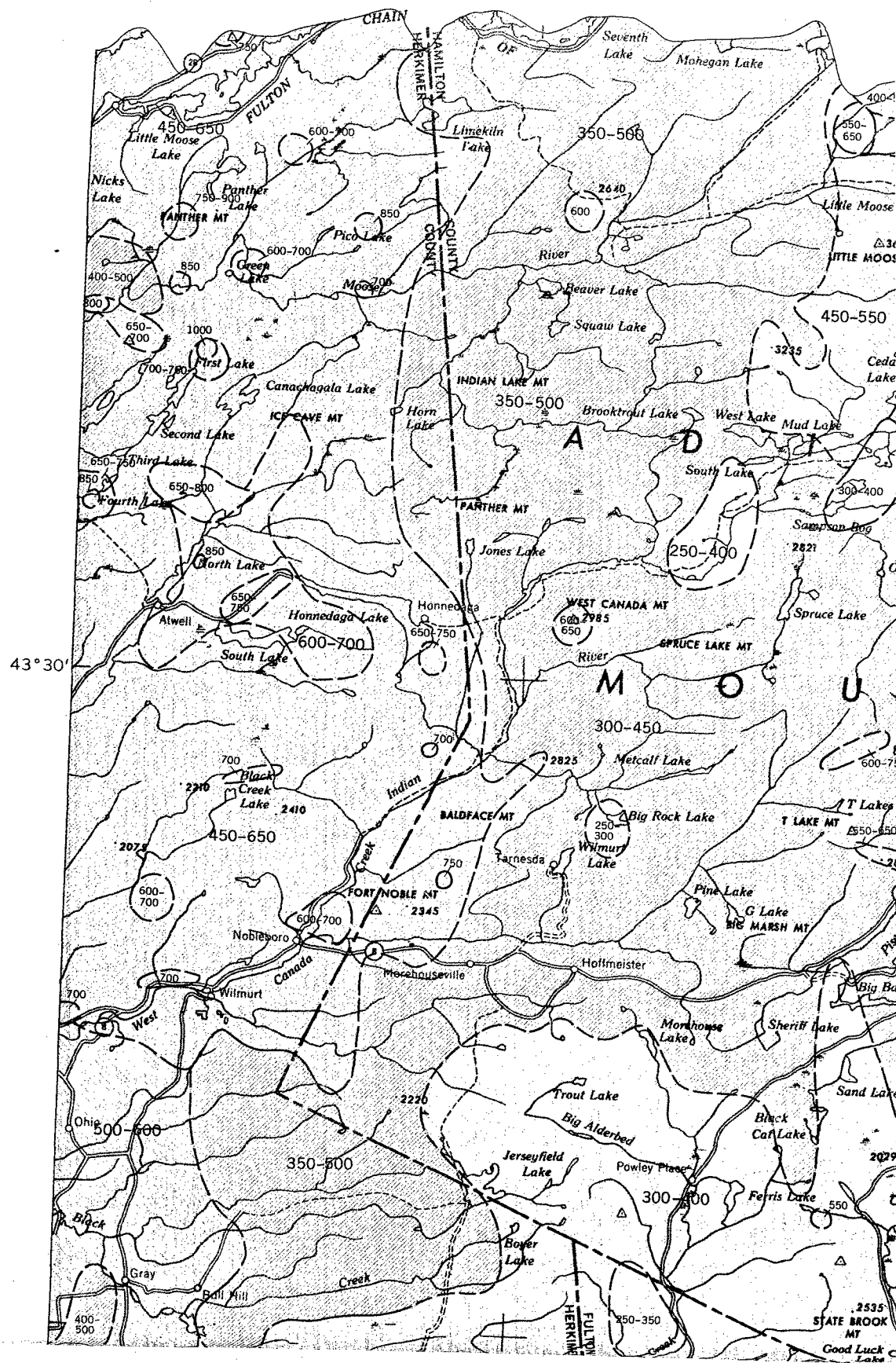
REFERENCES

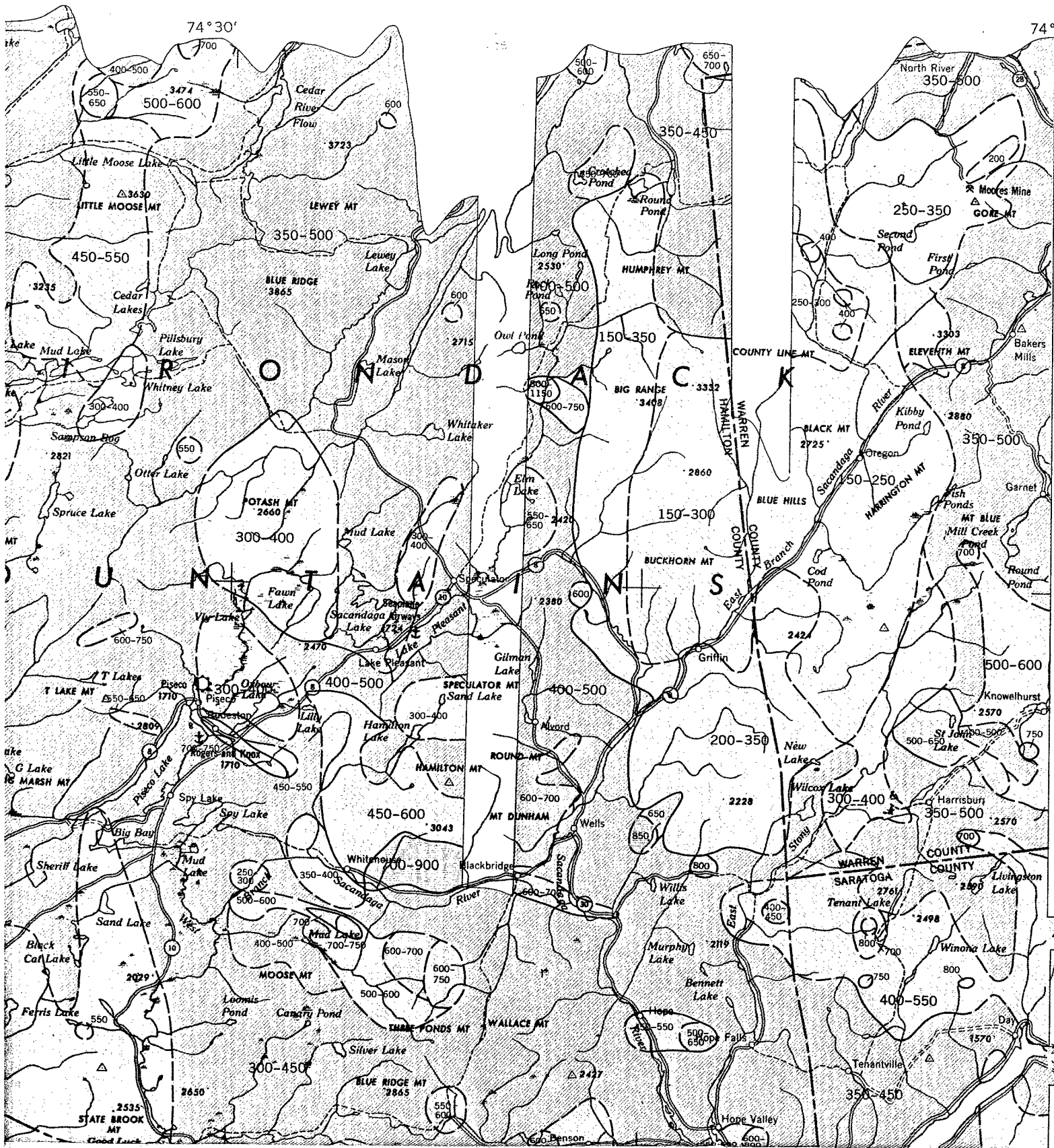
1. Peter Popenoe, Aeroradioactivity Survey and Areal Geology of Parts of Southern New York and Southern New England (ARMS-I), U. S. Atomic Energy Comm. Report CEX-58.4.6 (in preparation).
2. Fred Keller, Jr., J. R. Balsley, Jr., and W. J. Dempsey, Field Operations and Compilation Procedure Incidental to the Preparation of Isomagnetic Maps, Photogram. Eng., 13: 644-647 (1957).
3. F. J. Davis and P. W. Reinhardt, Instrumentation in Aircraft for Radiation Measurements, Nuclear Sci. and Eng., 2 (6): 713-727 (1957).
4. Henry Faul, Nuclear Geology, John Wiley and Sons, New York, 414 pp. (1954).
5. A. Y. Sakakura, Scattered Gamma Rays from Thick Uranium Sources, U. S. Geol. Survey, Bull. No. 1052-A, 50 pp. (1957).
6. A. F. Gregory, Geological Interpretation of Aeroradiometric Data, Canada Geol. Survey, Bull. No. 66, 29 pp. (1960).
7. R. M. Moxham, Airborne Radioactivity Surveys in Geologic Exploration, Geophysics, 25 (2): 408-432 (1960).
8. F. J. Davis and P. W. Reinhardt, Radiation Measurements over Simulated Plane Sources, Health Physics, 8: 233-243 (1962).
9. J. Vennart, Increases in Local Background Due to Nuclear Bomb Fallout, Nature, 185 (4715): 722-724 (1960).
10. P. F. Gustafson, L. D. Marinelli, and S. S. Brar, Natural and Fission-produced Gamma-ray Emitting Radioactivity in Soil, Science, 127 (3308): 1240-1242 (1958).
11. K. K. Turekian and K. H. Wedepohl, Distribution of the Elements in Some Major Units of the Earth's Crust, Geol. Soc. America, Bull. No. 72 (2): 175-192 (1961).

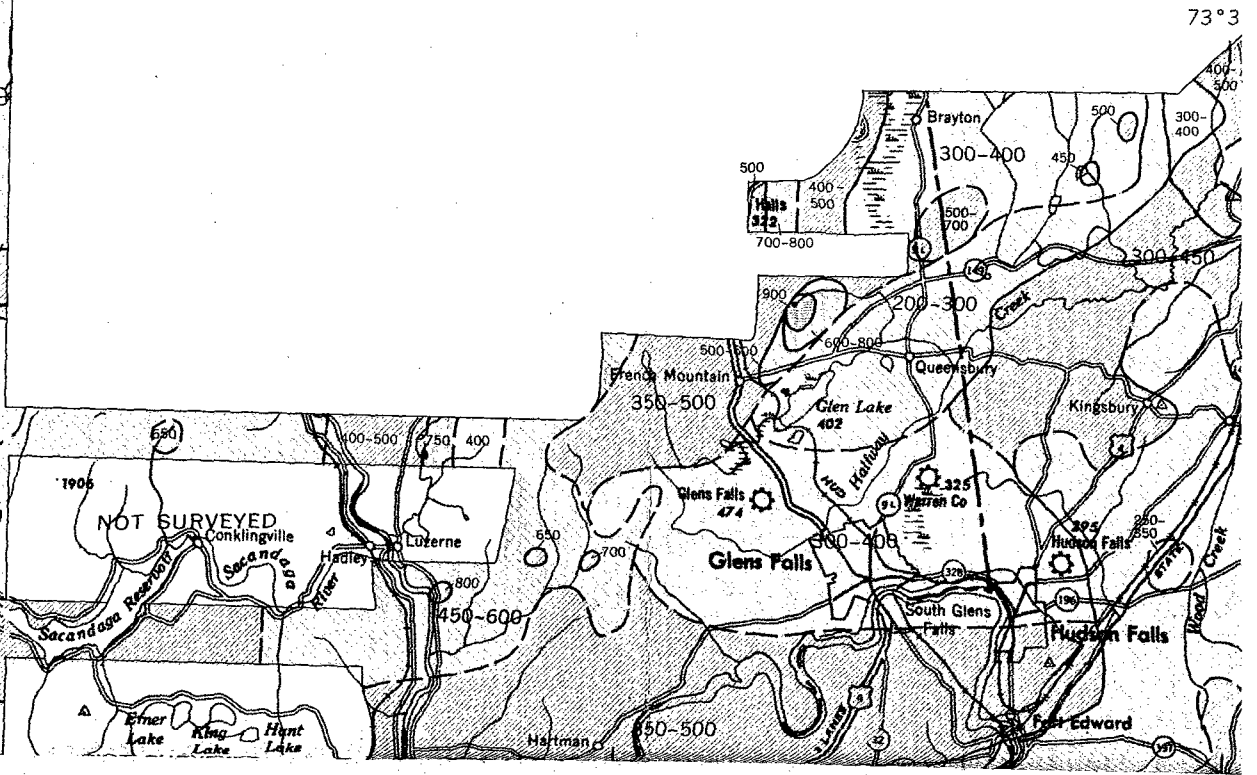
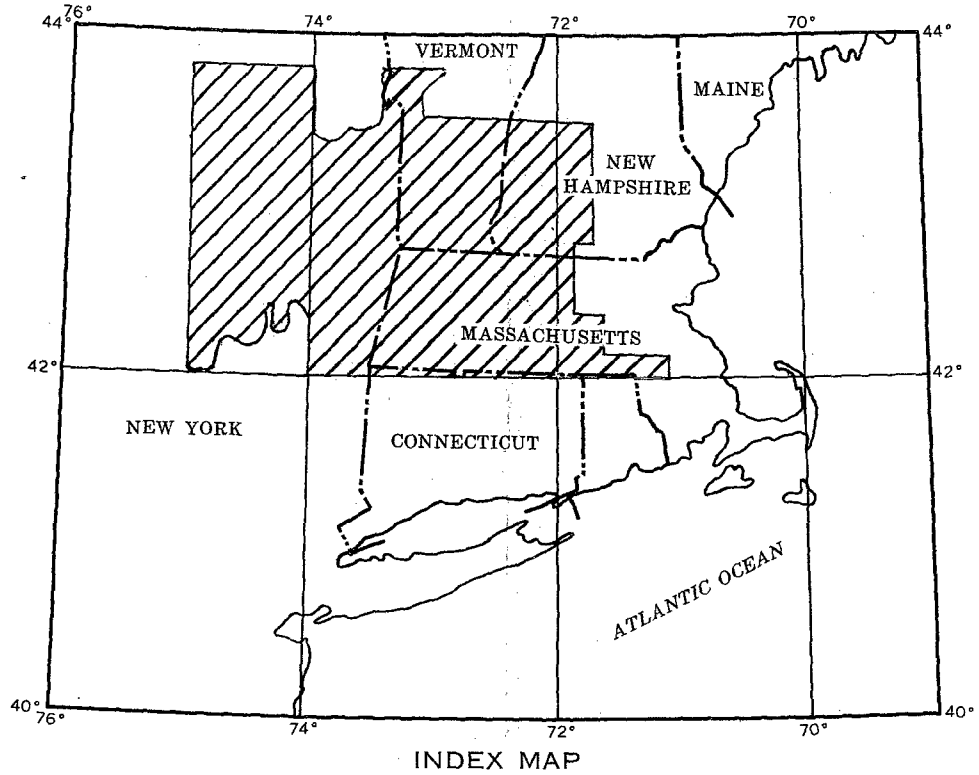
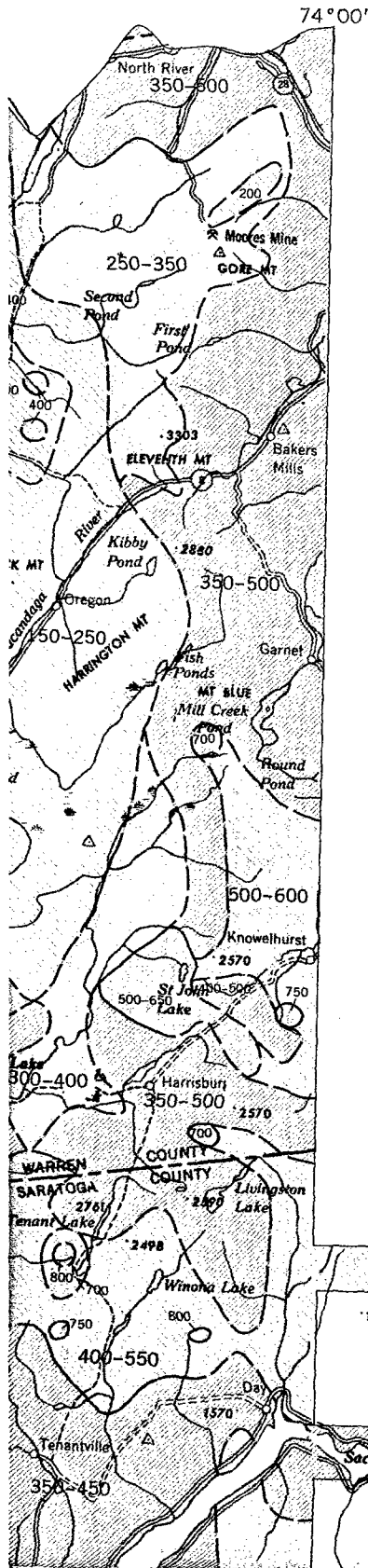
12. Peter Popenoe, Aeroradioactivity of Parts of East-central New York and West-central New England, U. S. Geol. Survey Geophys. Inv. Map GP-358 (1964).
13. C. G. Doll, W. M. Cady, J. B. Thompson, Jr., and M. P. Billings, Centennial Geologic Map of Vermont, Vermont Geol. Survey (1961).
14. M. P. Billings, The Geology of New Hampshire, Part 2-Bedrock Geology, New Hampshire State Plan. and Devel. Comm., 200 pp. (1956).
15. B. K. Emerson, Geology of Massachusetts and Rhode Island, U. S. Geol. Survey, Bull. No. 597, 289 pp., map 1:250,000 (1917).
16. D. W. Fisher, Stratigraphy and Structure in the Southern Taconics (Rensselaer and Columbia Counties, New York), N. Y. State Geol. Assoc. 33rd Ann. Meeting, Guidebook to Field Trips, Sec. D, p. 1-22 (1961).
17. F. J. H. Merrill, Geologic Map of New York, New York State Museum, in 12 parts (1901).
18. J. W. Goldthwait, Lawrence Goldthwait, and R. P. Goldthwait, The Geology of New Hampshire, Part 1-Surficial Geology, New Hampshire State Plan. and Devel. Comm., 83 pp. (1951).
19. J. M. Nelson and P. F. Narten, Reconnaissance of Radioactive Rocks in Maine, U. S. Geol. Survey TEI-68, 43 pp., Report prepared for U. S. Atomic Energy Comm. (1951).
20. P. F. Narten and F. A. McKeown, Reconnaissance of the Radioactive rocks of the Hudson Valley and Adirondack Mountains, New York, U. S. Geol. Survey TEI-70, 54 pp., Report prepared for U. S. Atomic Energy Comm. (1952).
21. H. P. Cushing and Rudolph Ruedemann, Geology of Saratoga Springs and Vicinity, New York State Museum, Bull. No. 169, 170 pp. (1914).
22. E-an Zen, U. S. Geol. Survey, written communication (1962).
23. A. J. E. Engle and C. G. Engle, Grenville Series in the Northwest Adirondack Mountains, New York, Geol. Soc. America, Bull. No. 64 (9): 1013-1097 (1953).
24. M. H. Krieger, Geology of the Thirteenth Lake Quadrangle, New York, New York State Museum, Bull. No. 308, 124 pp. (1937).
25. E-an Zen, Stratigraphy and Structure at the North End of the Taconic Range in West-central Vermont, Geol. Soc. America, Bull. No. 72 (2): 293-338 (1961).
26. W. F. Brace, The Geology of the Rutland Area, Vermont, Vermont Geol. Survey, Bull. No. 6, 120 pp. (1953).
27. J. A. MacFadyen, Jr., The Geology of the Bennington Area, Vermont, Vermont Geol. Survey, Bull. No. 7, 71 pp. (1956).
28. M. P. Billings, J. B. Thompson, Jr., and John Rodgers, Geology of the Appalachian Highlands of East-central New York, Southern Vermont, and Southern New Hampshire, Geol. Soc. America, 65th Ann. Meeting, Guidebook for Field Trips in New England, p. 14-31 (1952).
29. John Rodgers, R. M. Gates, and J. L. Rosenfeld, Explanatory Text for the Preliminary Geological Map of Connecticut, Connecticut State Geol. and Nat. Hist. Survey, Bull. No. 84, 64 pp. (1959).
30. Norman Herz, Bedrock Geology of the Cheshire Quadrangle, Massachusetts, U. S. Geol. Survey, Map GQ-108 (1958).

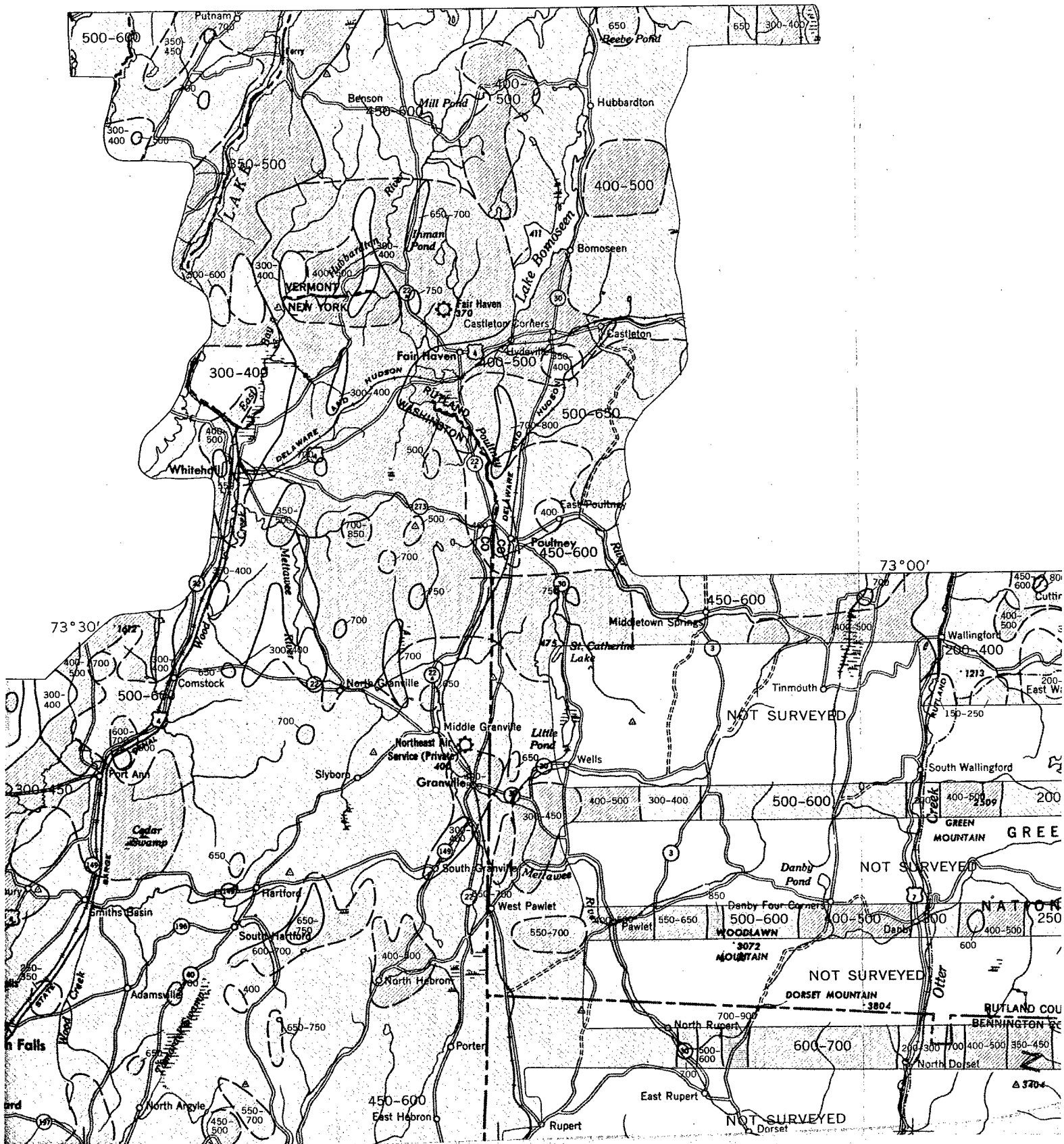
31. R. W. Chapman and C. A. Chapman, Cauldron Subsidence at Ascutney Mountain, Vermont, Geol. Soc. America, Bull. No. 51 (2): 191-212 (1940).
32. P. D. Krynine, Petrology, Stratigraphy and Origin of the Triassic Sedimentary Rocks of Connecticut, Connecticut State Geol. and Nat. Hist. Survey, Bull. No. 73, 239 pp. (1950).
33. D. H. Johnson, Reconnaissance of Radioactive Rocks of Massachusetts, U. S. Geol. Survey TEI-69, 16 pp., Report prepared for U. S. Atomic Energy Comm. (1951).
34. F. A. McKeown, Reconnaissance of Radioactive Rocks of Vermont, New Hampshire, Connecticut, Rhode Island, and Southeastern New York, U. S. Geol. Survey TEI-67, 46 pp., Report prepared for U. S. Atomic Energy Comm. (1951).
35. G. E. Moore, Jr., The Structure and Metamorphism of the Kenne-Battleboro Area, New Hampshire and Vermont, Geol. Soc. America, Bull. No. 60 (10): 1613-1669 (1949).
36. N. M. Fenneman, Physical Divisions of the United States, U. S. Geol. Survey Map, scale 1:7,000,000 (1946).
37. R. F. Flint (chr.), Glacial Map of the United States East of the Rocky Mountains, Geol. Soc. America (1959).
38. G. R. Webber, P. M. Hurley, and H. W. Fairbain, Relative Ages of Eastern Massachusetts Granites by Total Lead Ratios in Zircon, Amer. Jour. Sci., 254 (9): 574-583 (1956).

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY



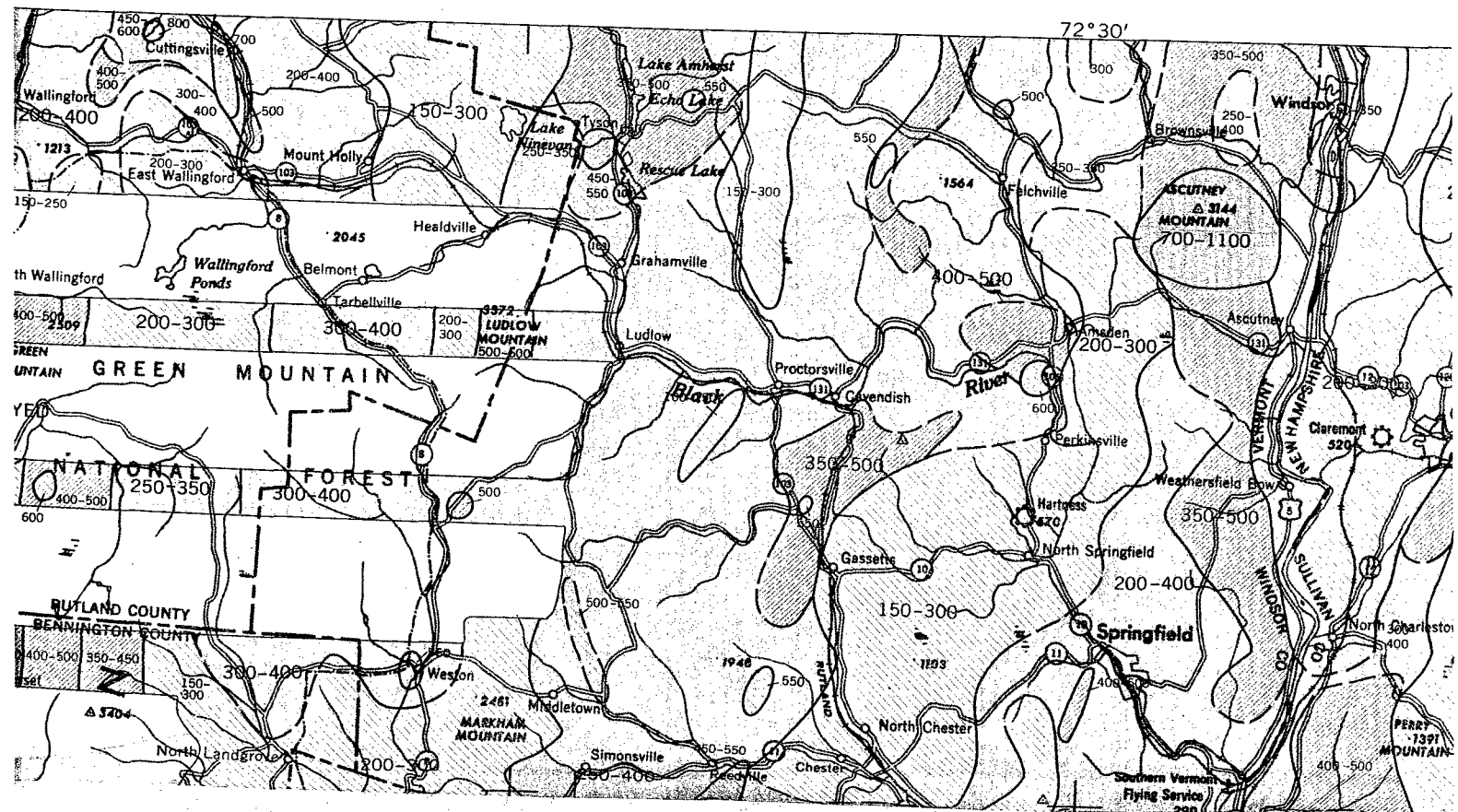




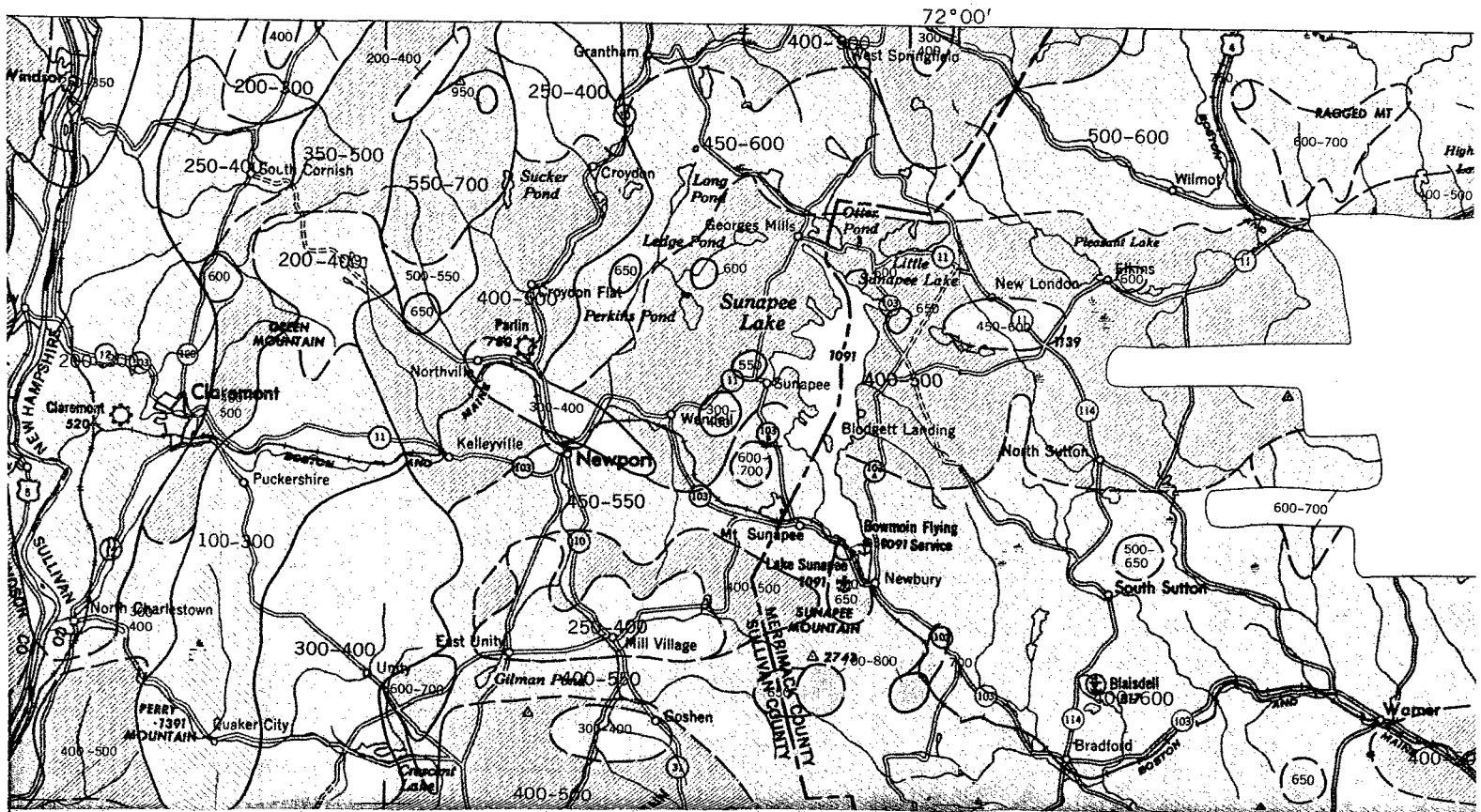


WITH
MEDICINE
MISSION

5

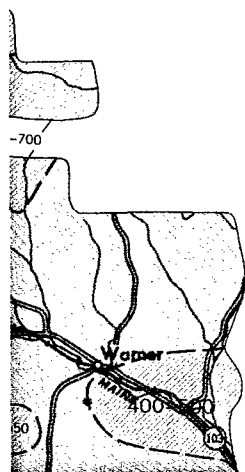
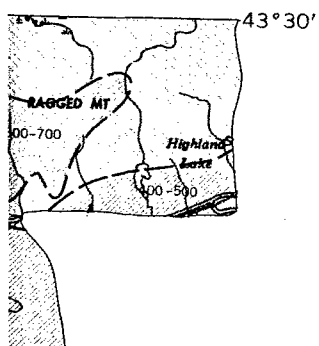


6



7

AI
GEOPHYS

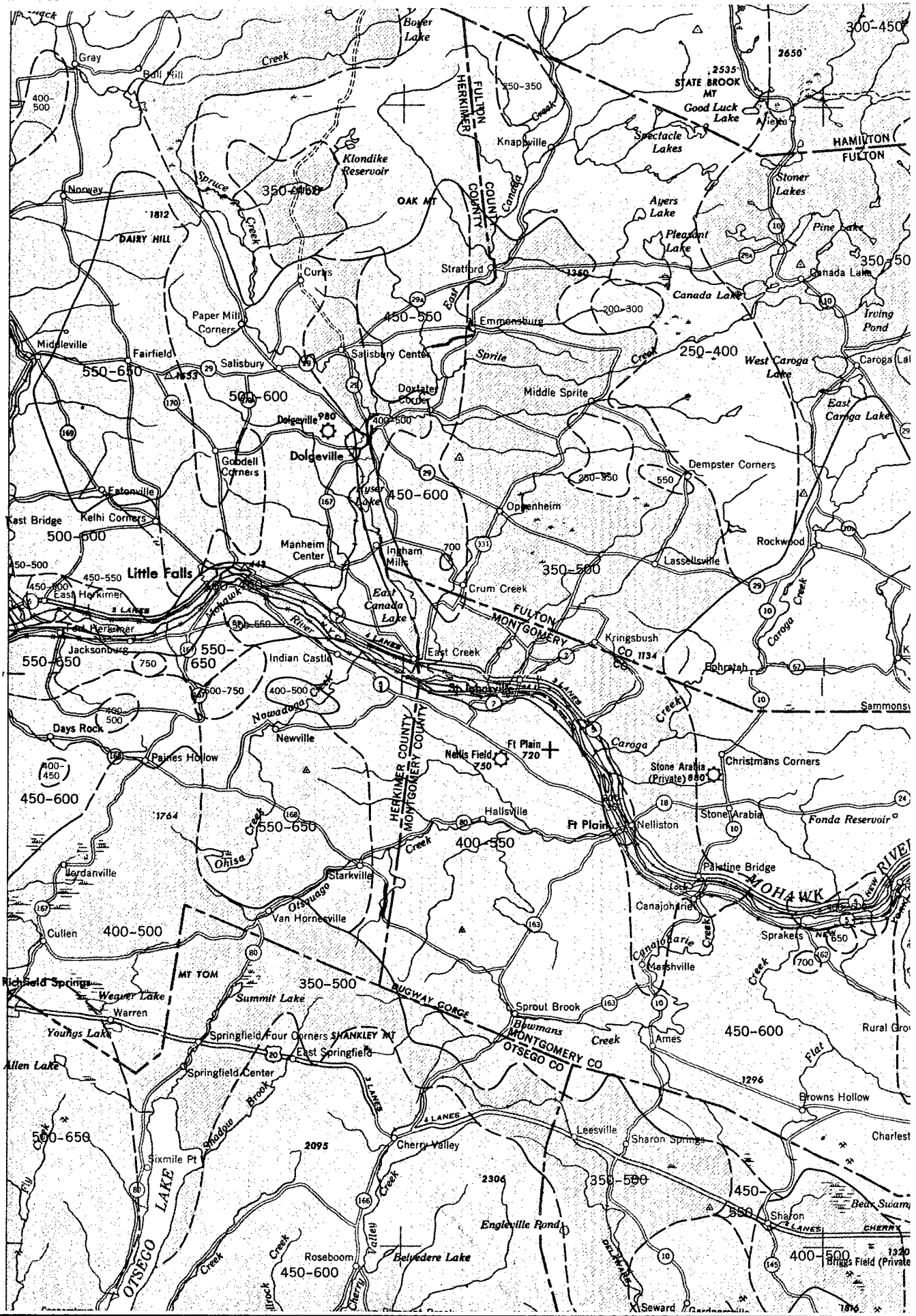


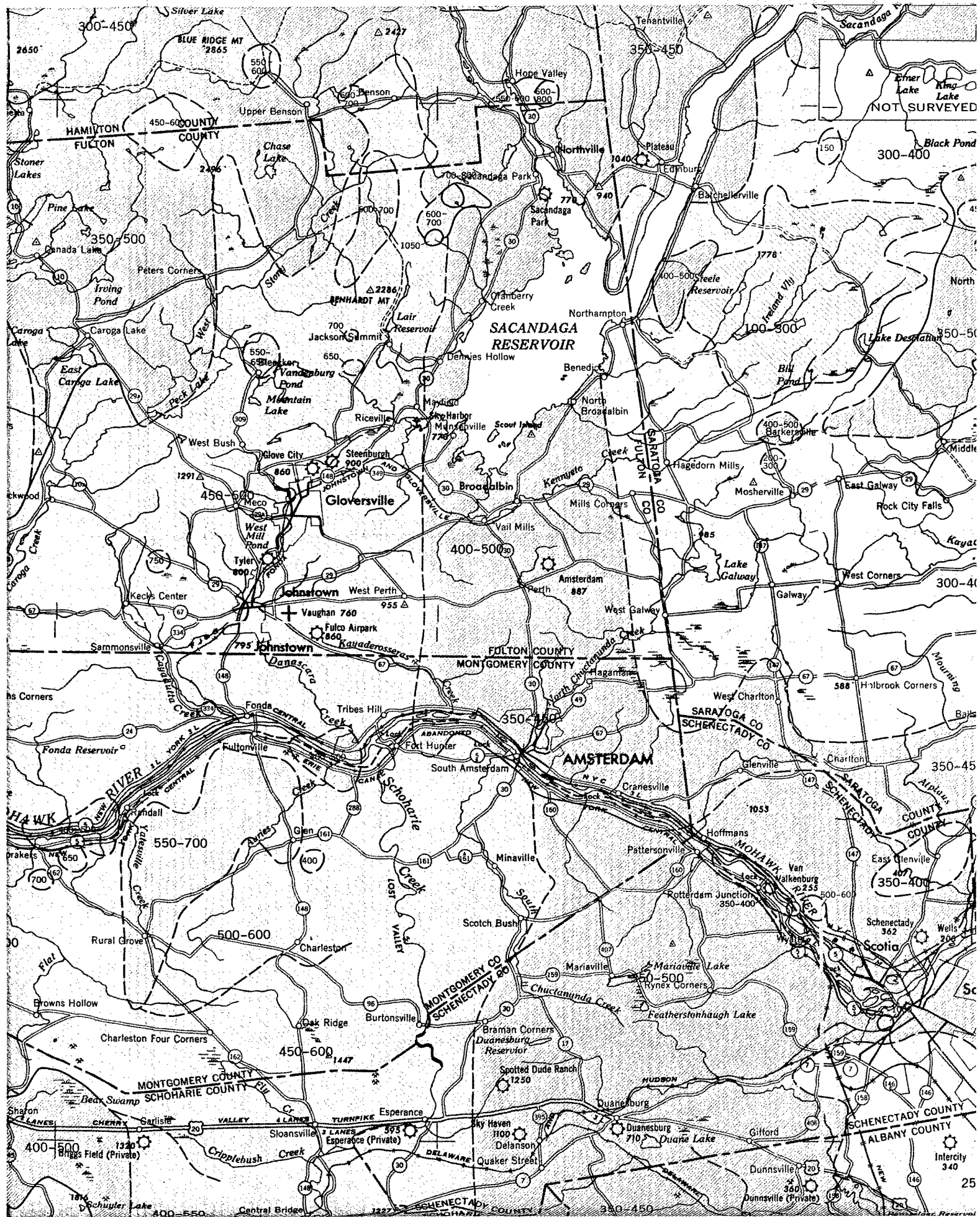
AEC-CEX-59.4.14
GEOPHYSICAL INVESTIGATIONS
MAP GP-358

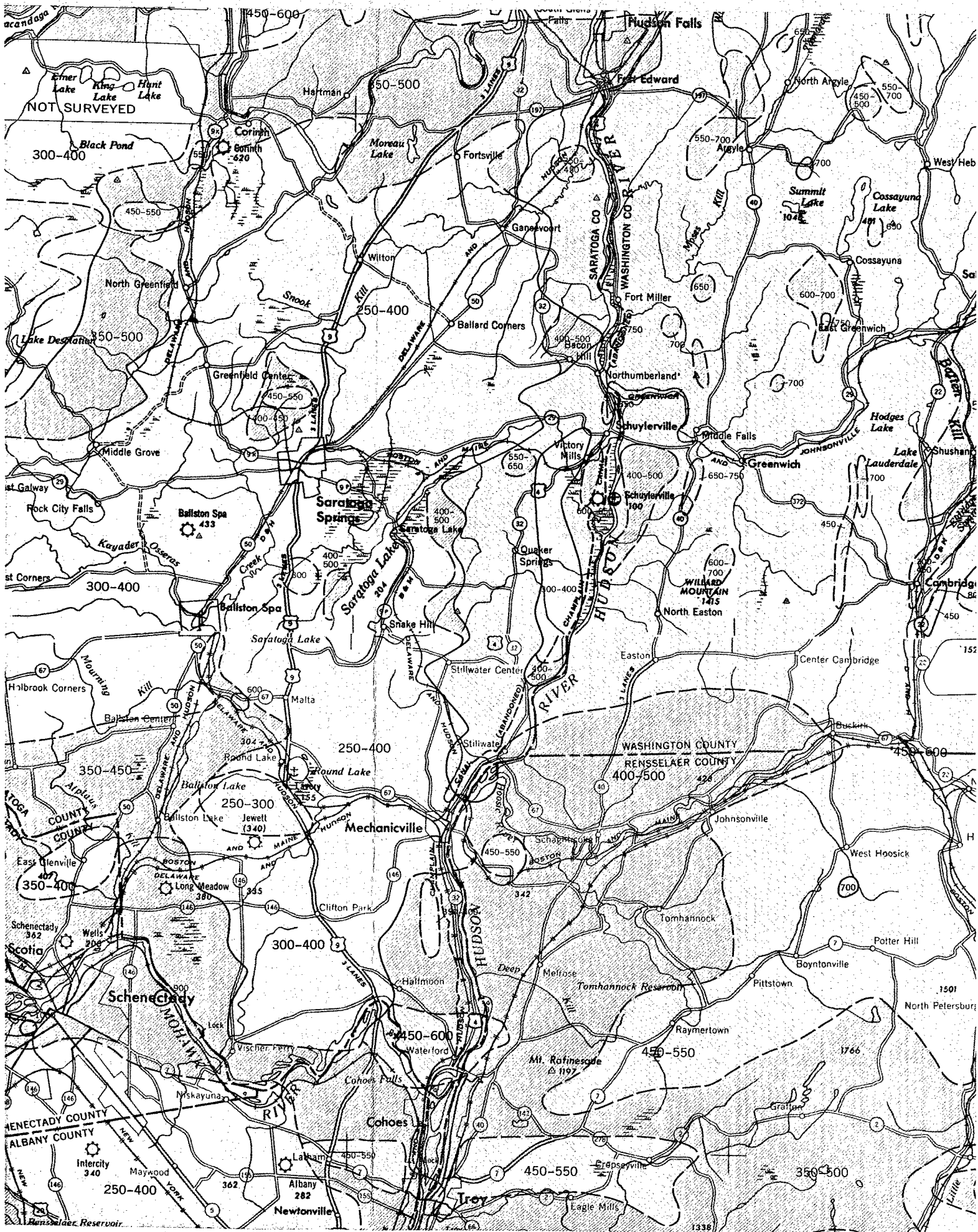
8

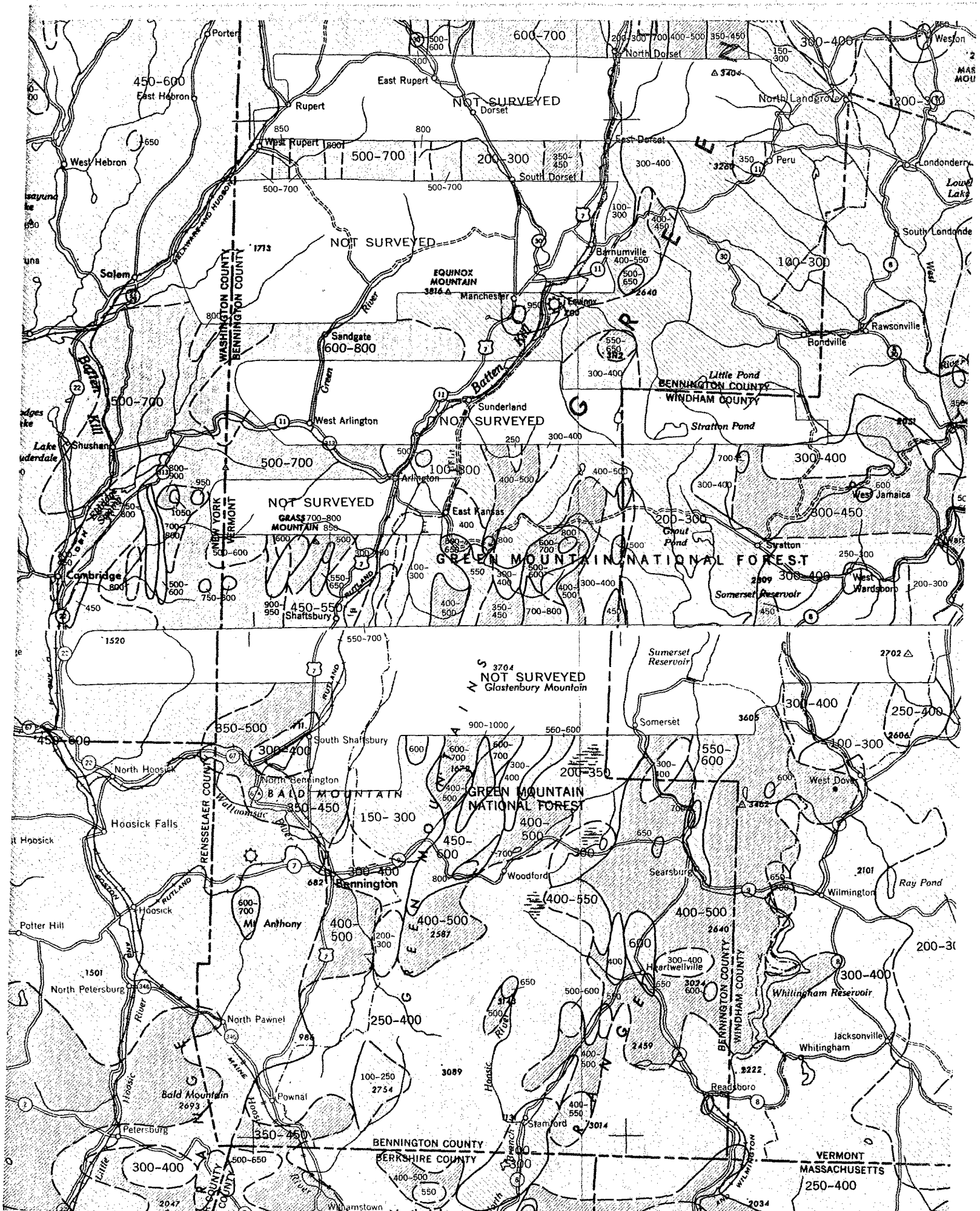
43°00'

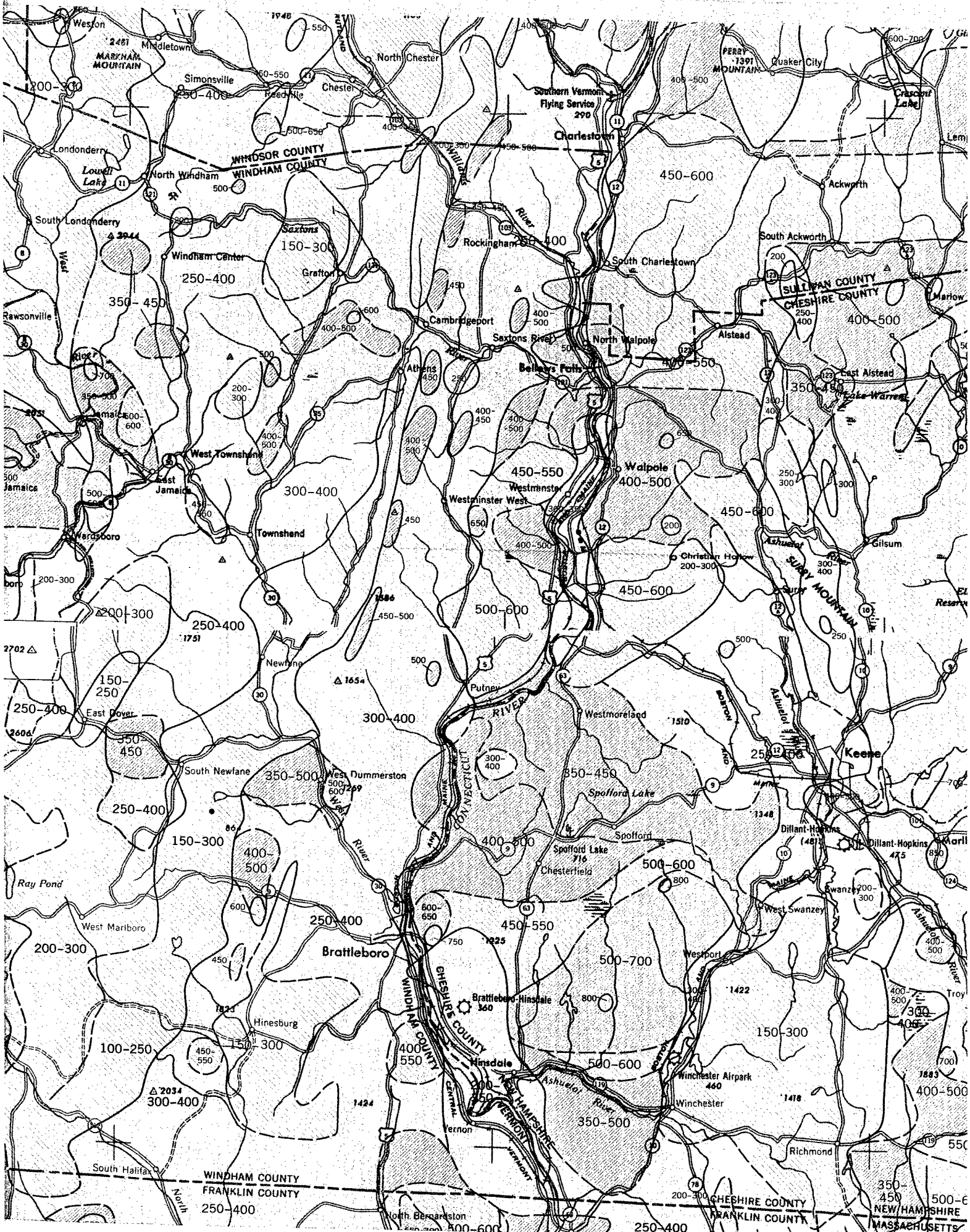
9

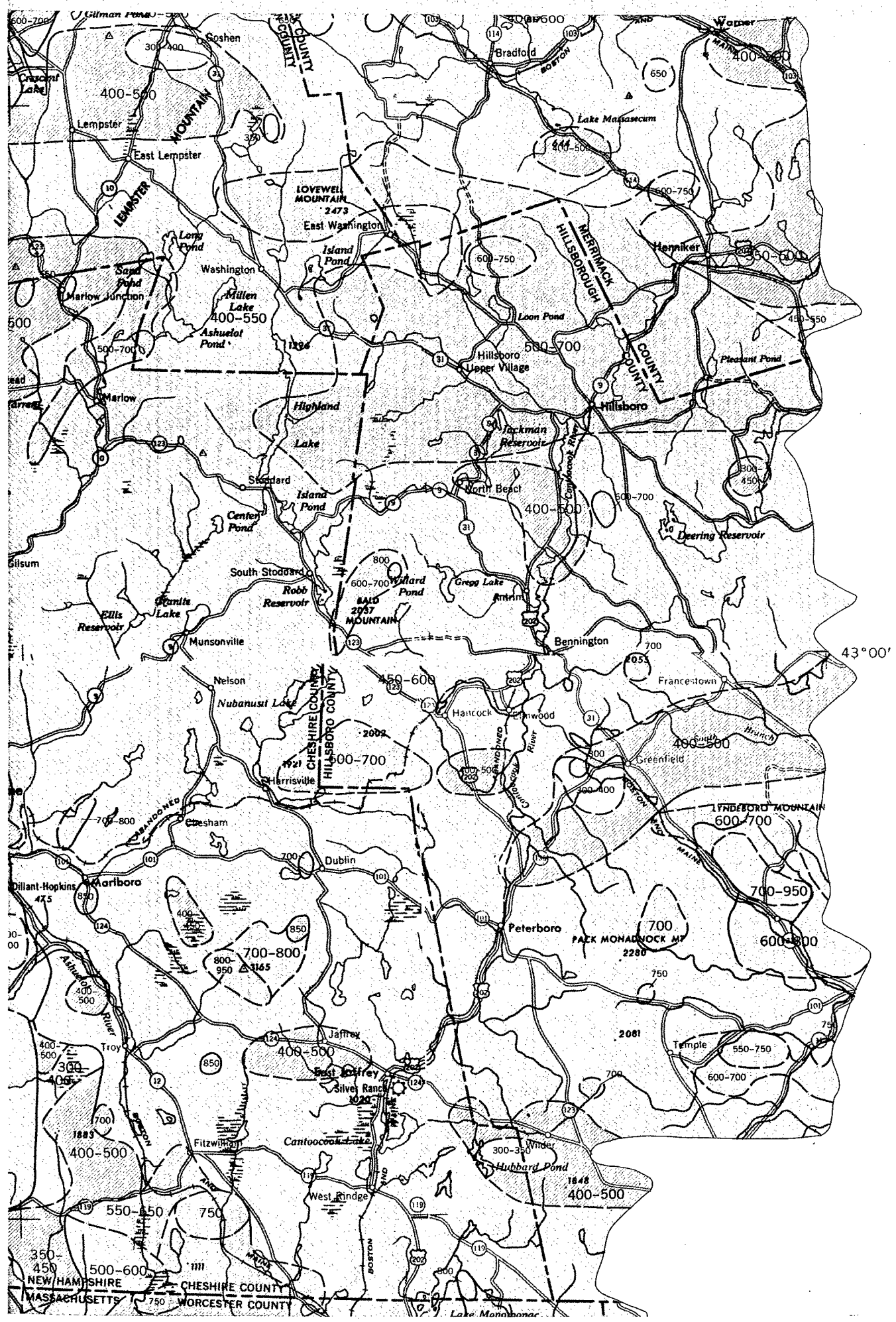










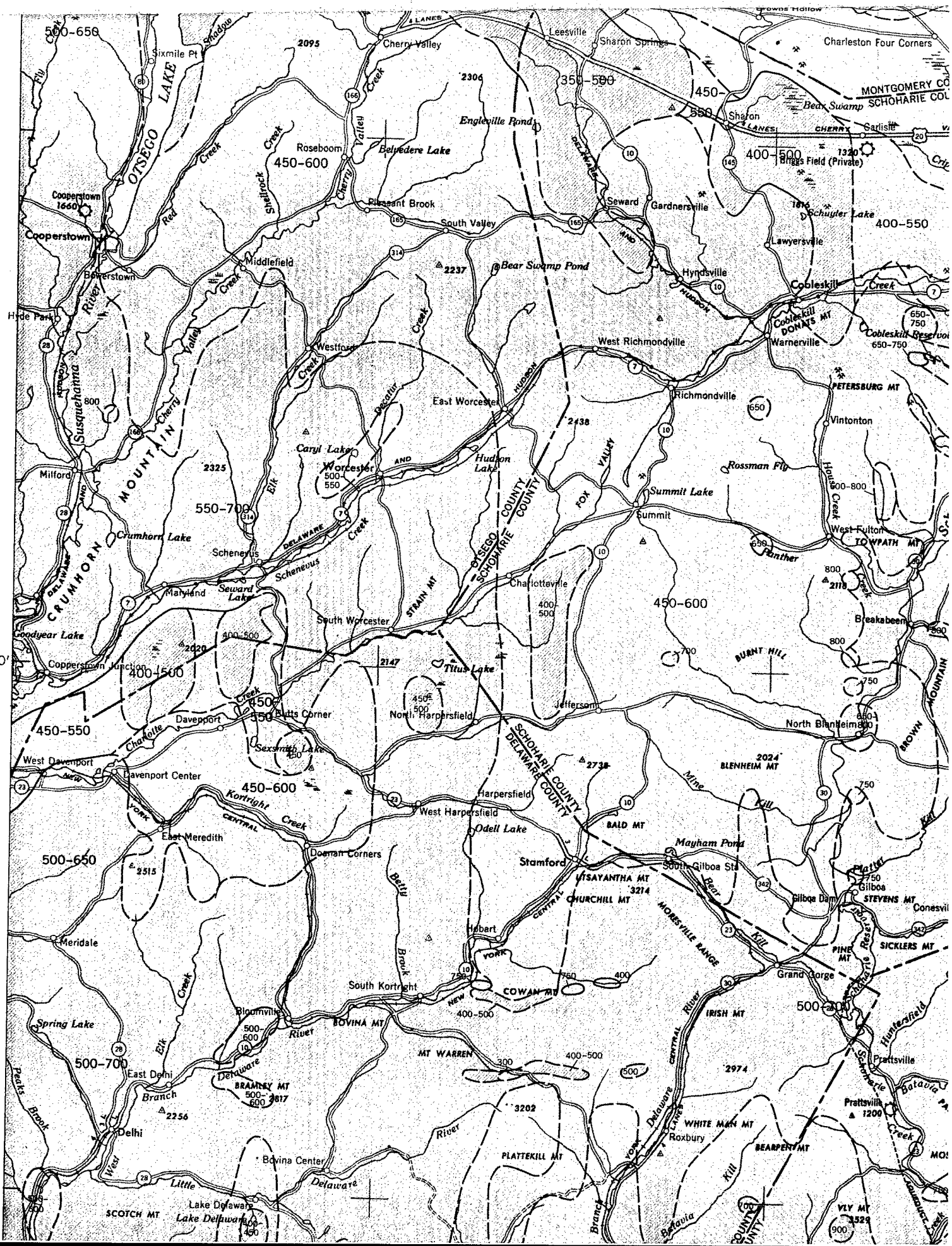


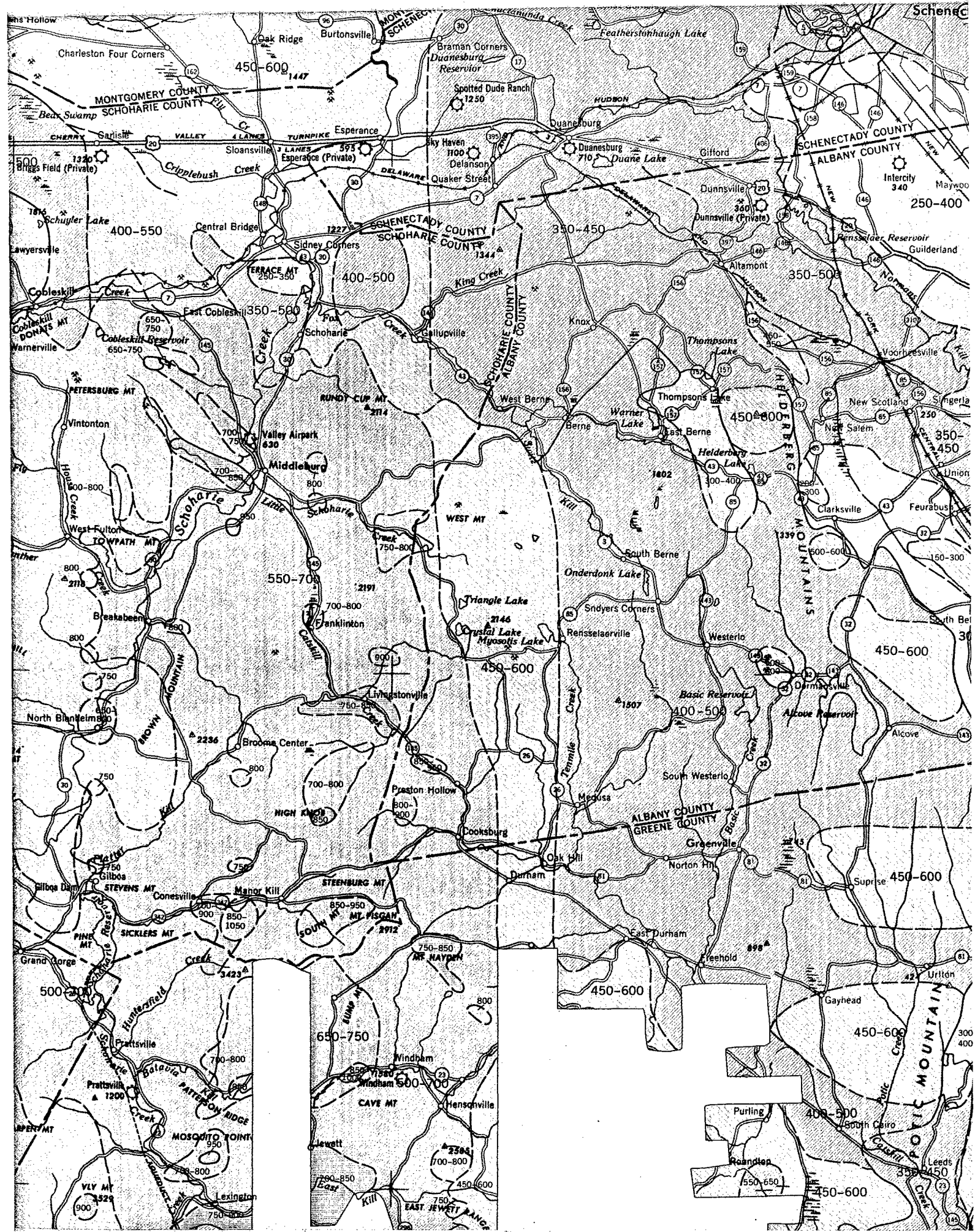
43°00'

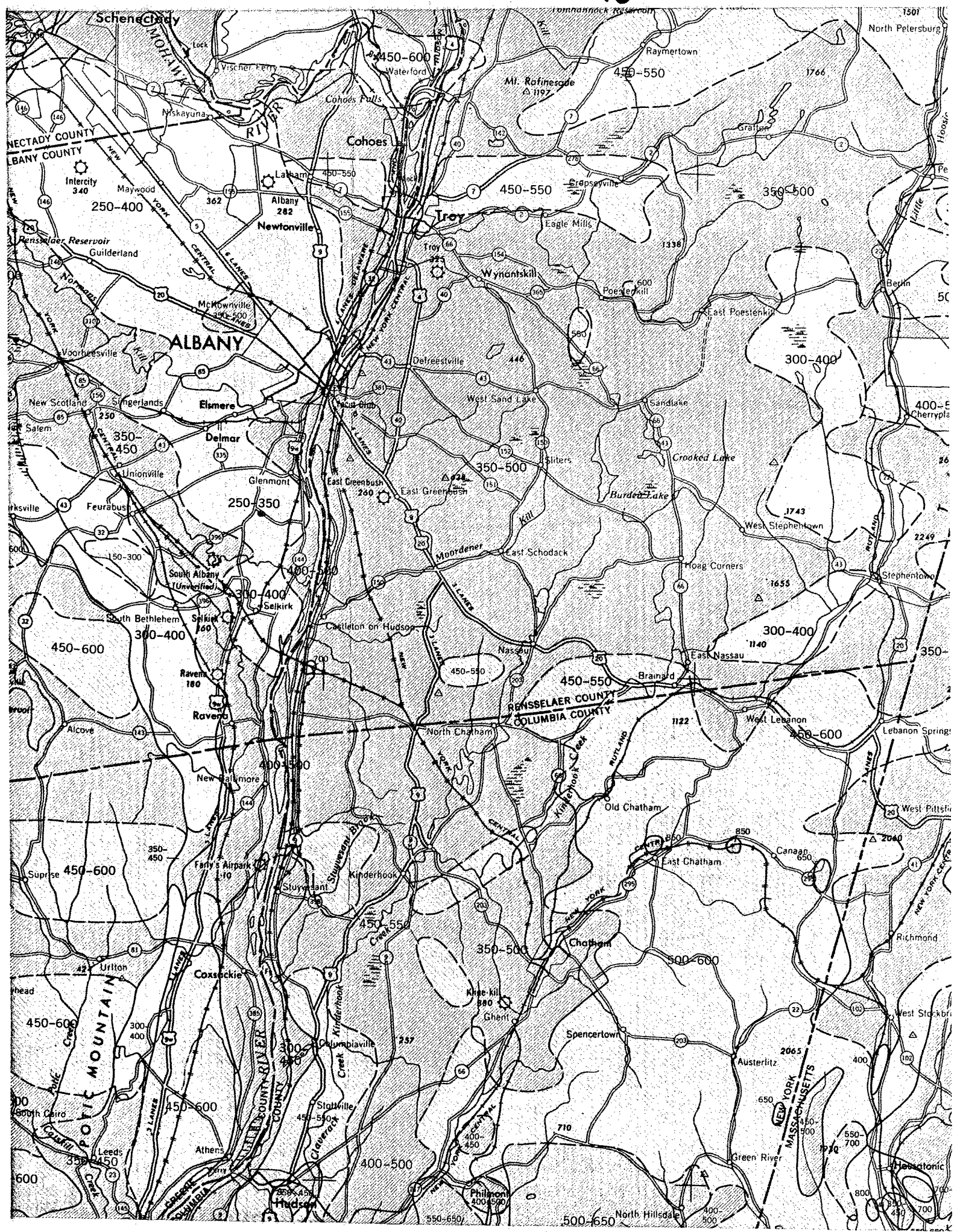
The radioactivity data was obtained with scintillation detection equipment (Davis and Reinhardt, 1957) installed in a twin-engine aircraft. Parallel flight traverses were oriented east-west except in the area west of Albany, N. Y., where they were oriented north-south, and flown at one-mile intervals at a nominal elevation of 500 feet above the ground. The radioactivity data were compensated for deviations from the surveying elevation, and for the cosmic-ray component. The flight path of the aircraft was recorded by a gyro-stabilized continuous-strip-film camera.

extreme temperature inversion. However, if 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 affect the discrimination of the radioactivity levels that reflect changes in the ground component.

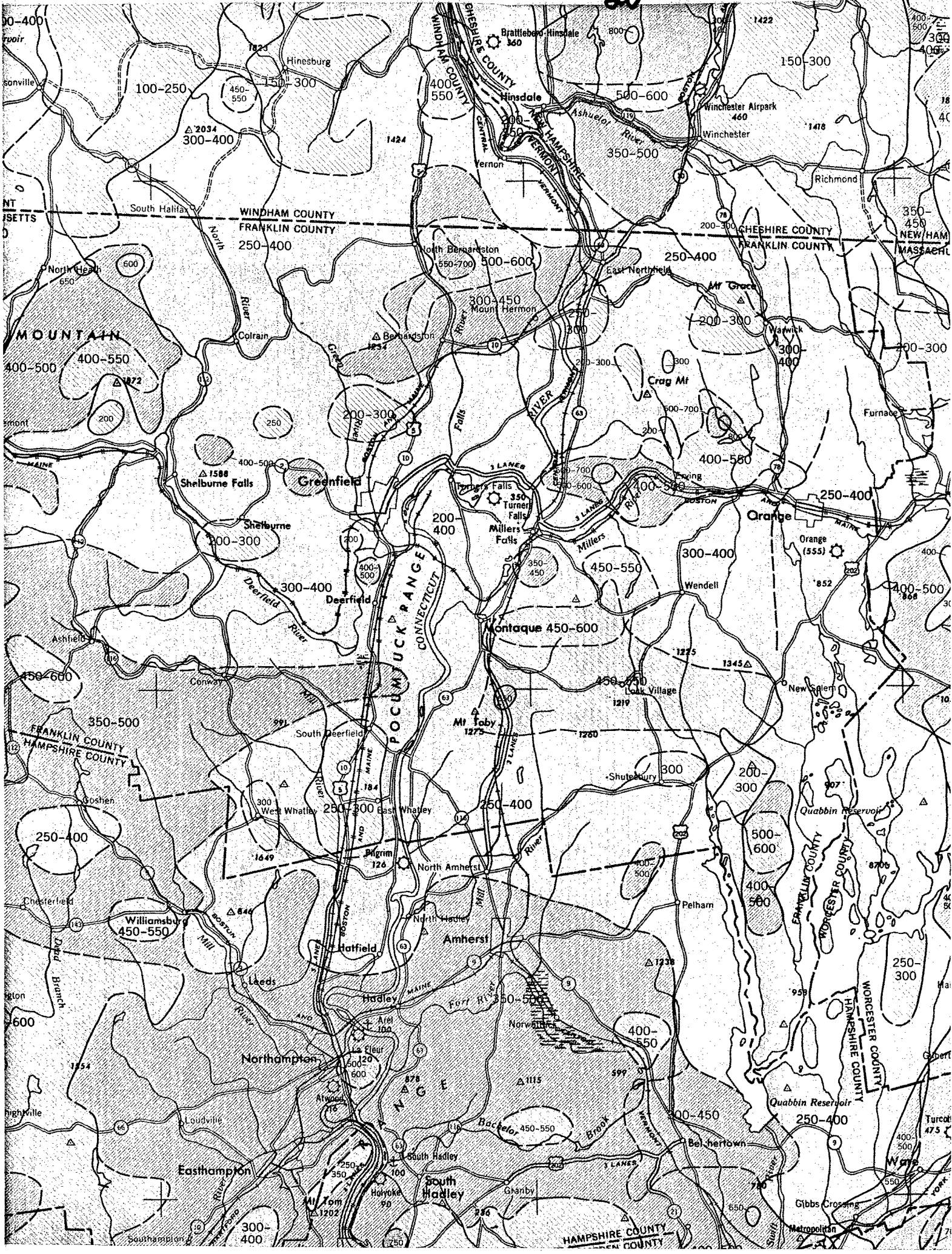
The ground component comes from the upper few inches of the ground. It consists of gamma rays from natural radionuclides, principally members of the uranium and thorium radioactive decay series and potassium 40, and fallout from radioactive nuclear fission.

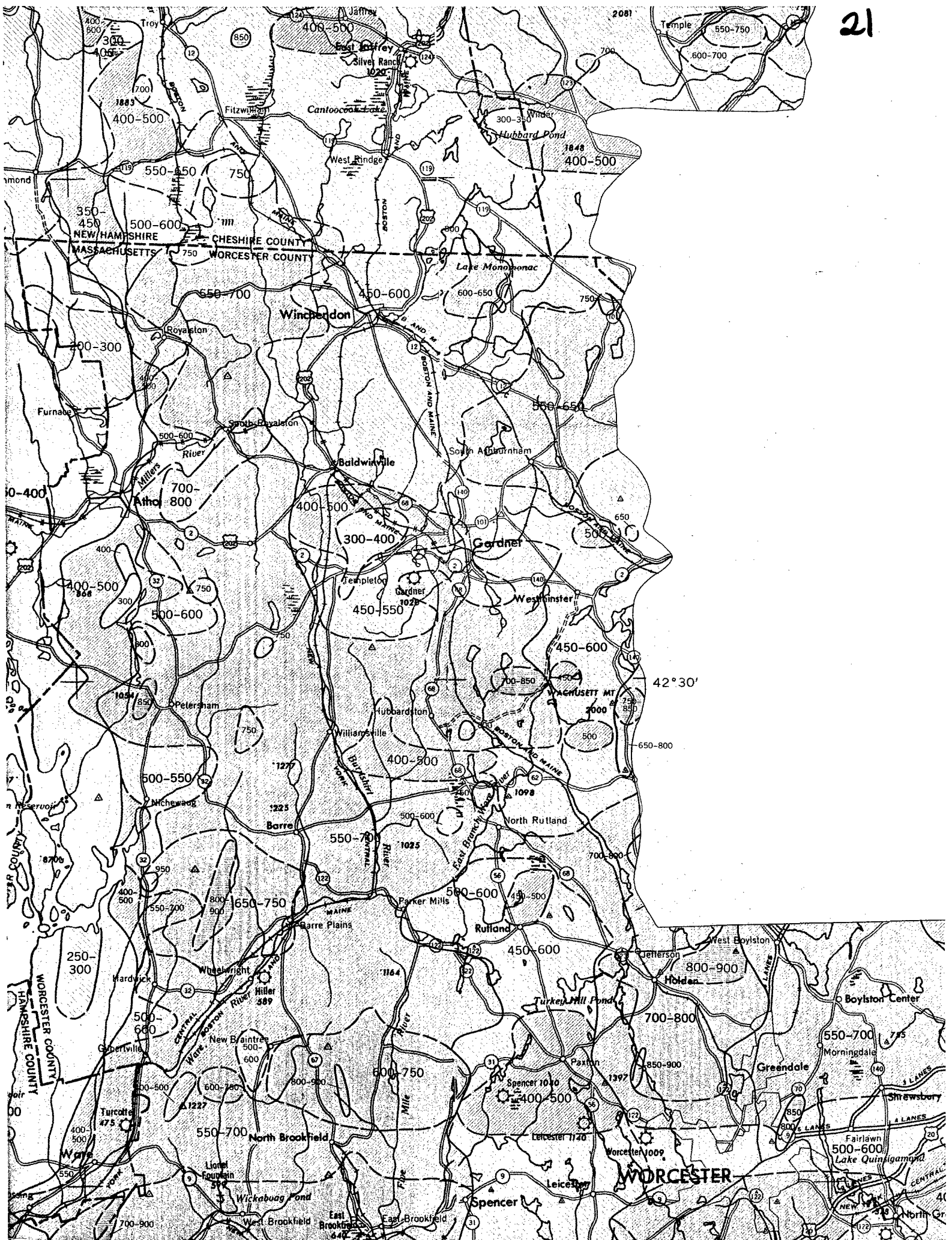












The radioactivity data was obtained with scintillation detection equipment (Davis and Reinhardt, 1957) installed in a twin-engine aircraft. Parallel flight traverses were oriented east-west except in the area west of Albany, N. Y., where they were oriented north-south, and flown at one-mile intervals at a nominal elevation of 500 feet above the ground. The radioactivity data were compensated for deviations from the surveying elevation, and for the cosmic-ray component. The flight path of the aircraft was recorded by a gyro-stabilized continuous-strip-film camera.

The effective area of response of the scintillation equipment at an elevation of 500 feet is a circle approximately 1,000 feet in diameter, and the radioactivity recorded is an average of the radioactivity received from within the area. The scintillation equipment accepts only pulses originating from gamma radiation with 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 radiation 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 is determined twice daily by calibrations at 2,000 feet above the ground and is removed from the radioactivity data.

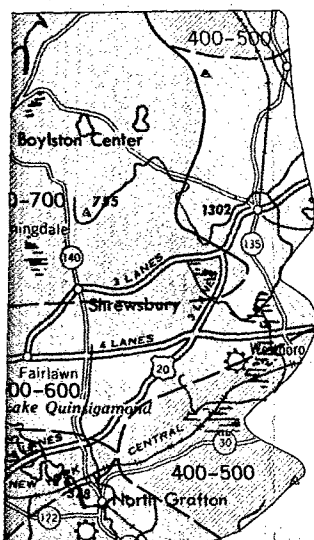
The component due to radionuclides in the air at 500 feet above the ground is difficult to evaluate. It is affected by meteorological conditions, and a tenfold change in radon concentrations is not unusual under conditions of

extreme temperature inversion. However, if 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 affect the discrimination of the radioactivity levels that reflect changes in the ground component.

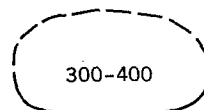
The ground component comes from the upper few inches of the ground. It consists of gamma rays from natural radionuclides, principally members of the uranium and thorium radioactive decay series and potassium-40, and fallout from radioactive nuclear fission products. Locally the amount of fallout must be small as the lowest total radiation measured over several areas in New York and New England was less than 100 counts per second in areas not affected by absorption of gamma energy by water. The distribution of fallout in the area surveyed is assumed to be uniform.

In compiling the radioactivity data, all radioactivity lows attributable to bodies of water were deleted to facilitate the reading of the map. The aeroradioactivity profiles were examined and significant changes or breaks in level were correlated from profile to profile. The changes were then plotted on overlays of the base maps and connected by solid or dashed lines depending on the degree of correlation. The areas between the lines of change were assigned general ranges of radioactivity level by scanning the records obtained over these specific areas.

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.



EXPLANATION



Radioactivity boundary

*Solid where well defined, dashed where transitional or not well defined.
Numbers indicate general range of radioactivity levels in counts per second*



900-1150

750-900

650-800

550-700

extreme temperature inversion. However, if 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 affect the discrimination of the radioactivity levels that reflect changes in the ground component.

The ground component comes from 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 from radioactive nuclear fission products. Locally the amount of fallout must be small as the lowest total radiation measured over several areas in New York and New England was less than 100 counts per second in areas not affected by absorption of gamma energy by water. The distribution of fallout in the area surveyed is assumed to be uniform.

In compiling the radioactivity data, all radioactivity lows attributable to bodies of water were deleted to facilitate the reading of the map. The aeroradioactivity profiles were examined and significant changes or breaks in level were correlated from profile to profile. The changes were then plotted on overlays of the base maps and connected by solid or dashed lines depending on the degree of correlation. The areas between the lines of change were assigned general ranges of radioactivity level by scanning the records obtained over these specific areas.

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.

EXPLANATION

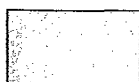
300-400

Radioactivity boundary

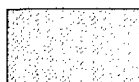
d, dashed where transitional or not well defined.
neral range of radioactivity levels in counts per



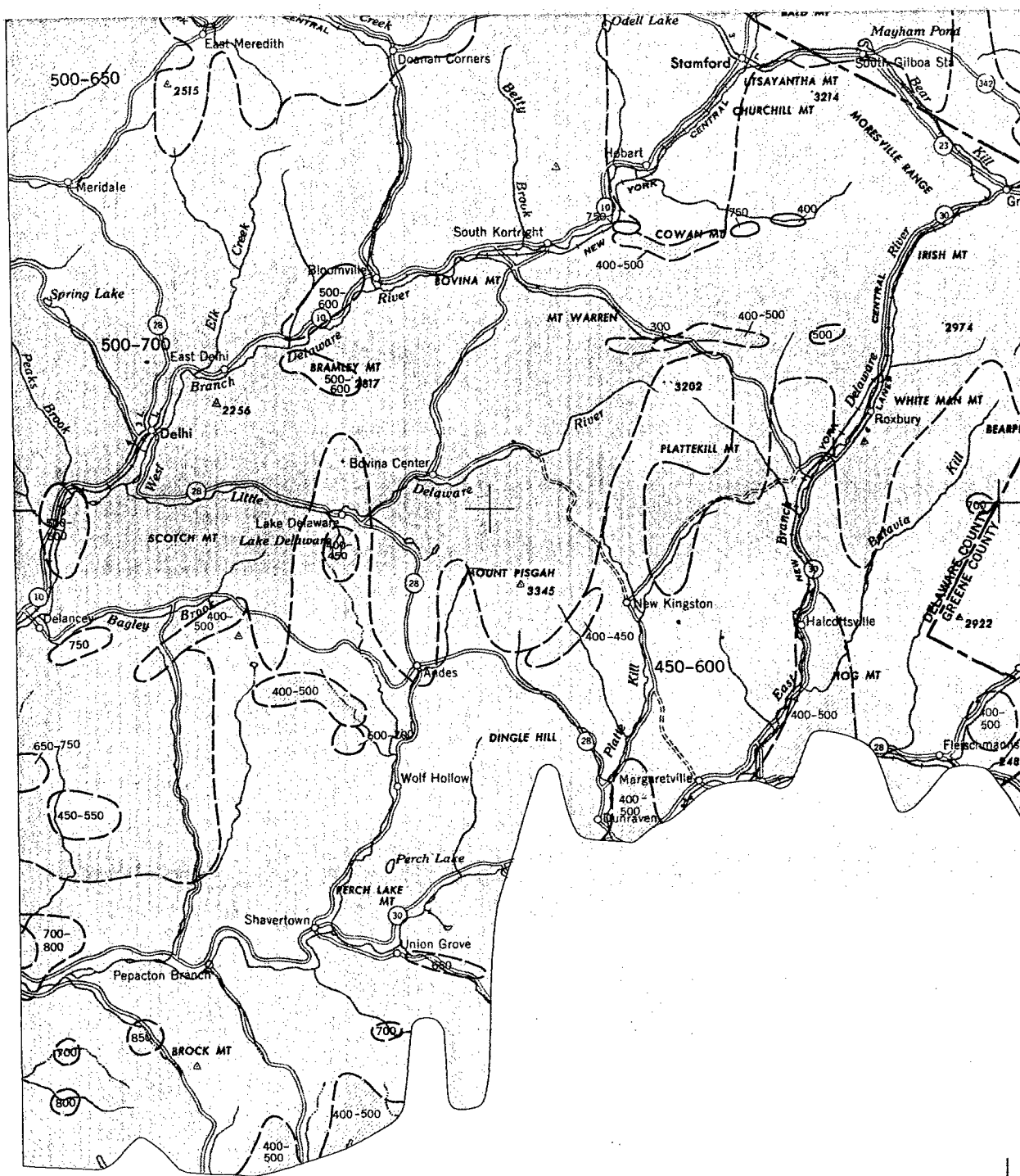
JO



650-800



550-700

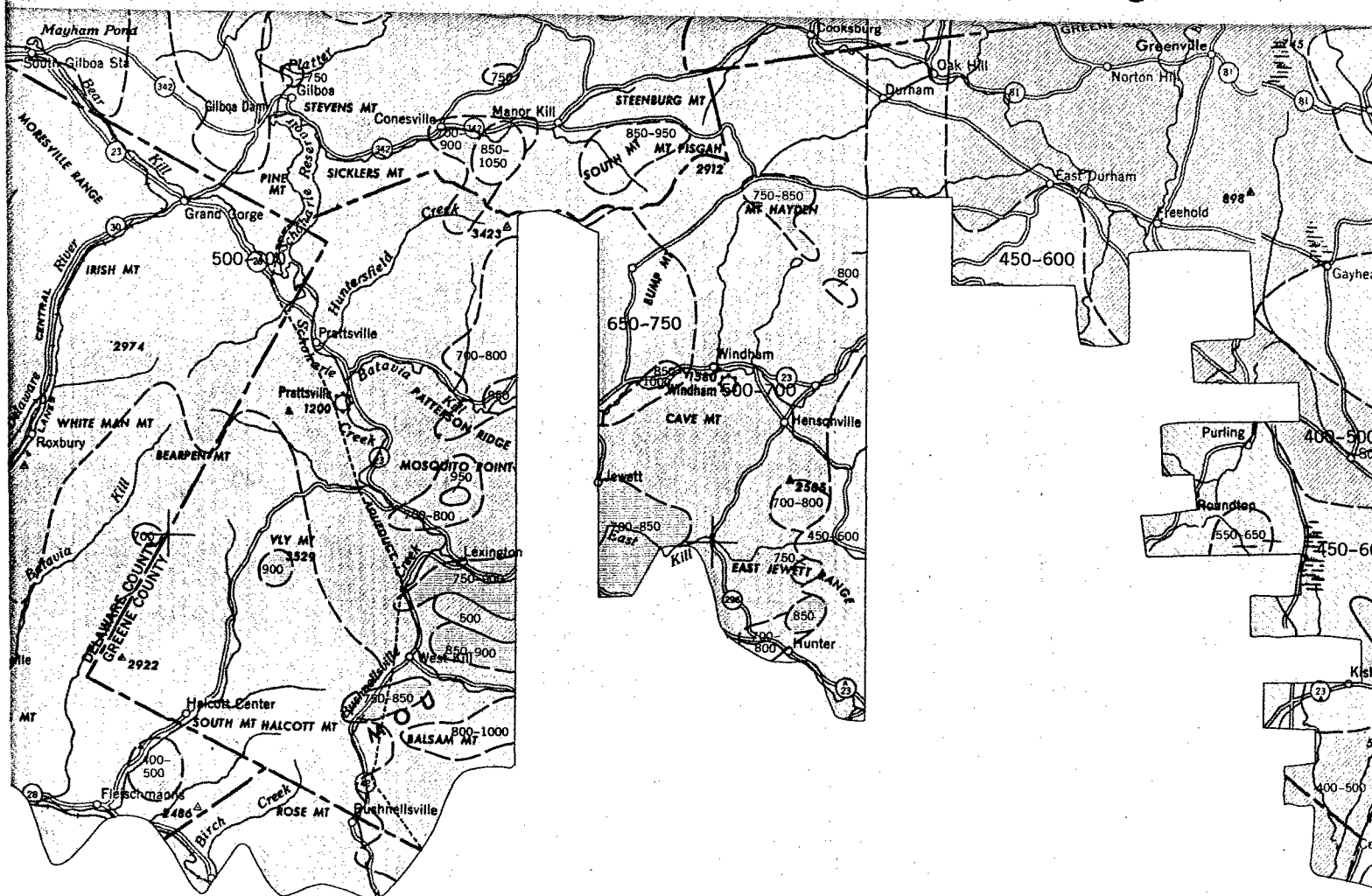


42°00'

74°3'

Base from U.S. Geological Survey 250,000 series quadrangles: Utica, 1944; Bing-hamton, 1944; Glen Falls, 1944; Albany, 1947; Portland, 1942; and Boston, 1947

GEOPHYSICAL INVESTIGATIONS
MAP GP-358
AEC-CEX-59.4.14



74°30'

74°00'

N

MAGNETIC NORTH DEVIATES
FROM 11°45'W TO 17°30'W
WITHIN MAP AREA

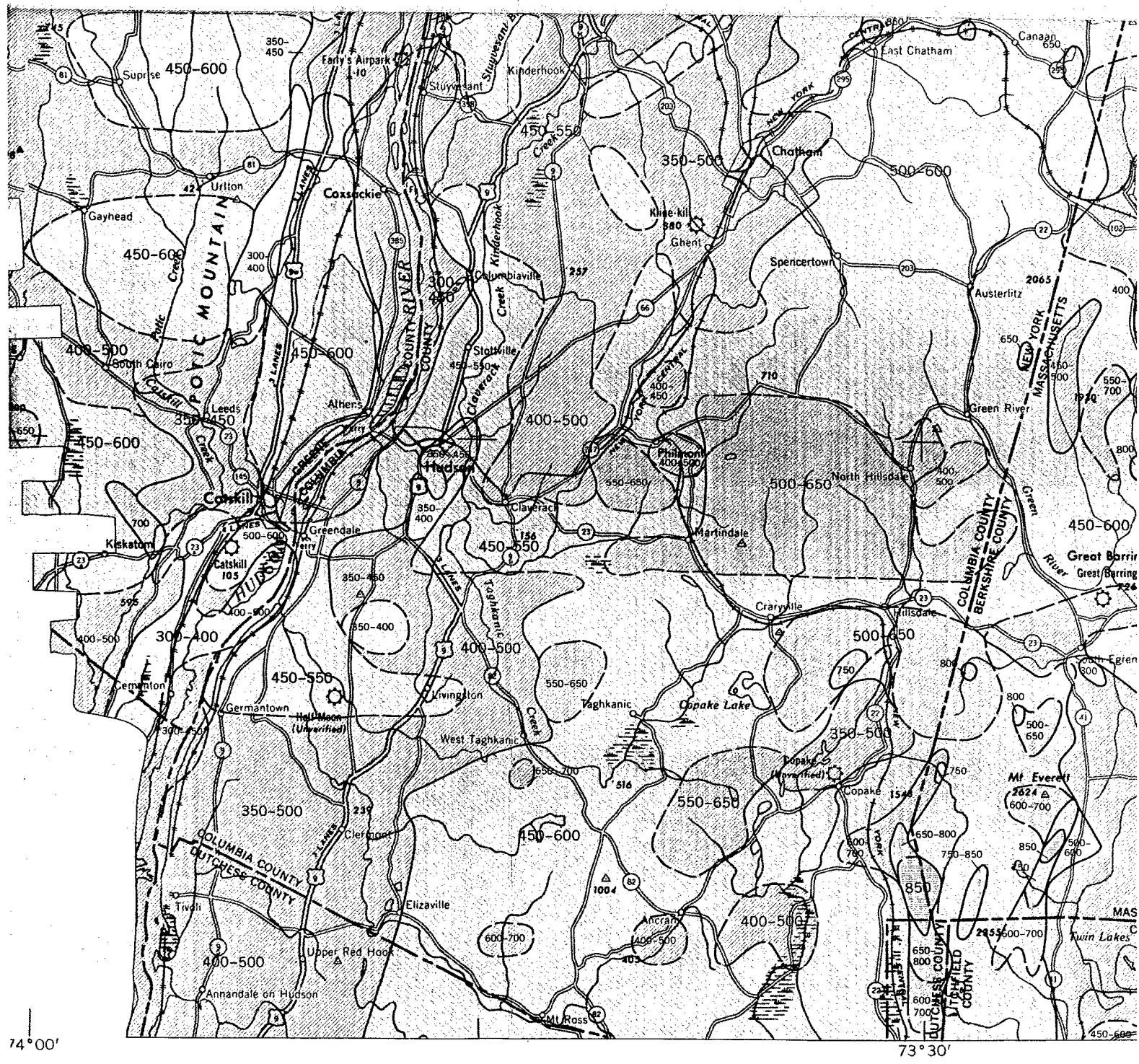


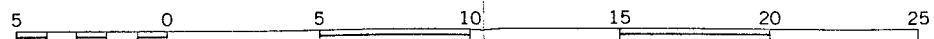
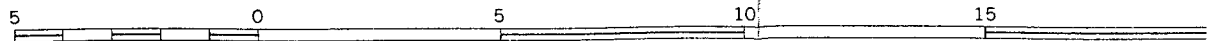
PLATE 1 AERORADIOACTIVITY C



MAP OF PARTS OF EAST-CENTRAL NEW YORK

By
Peter Popenoe

SCALE 1:250 000



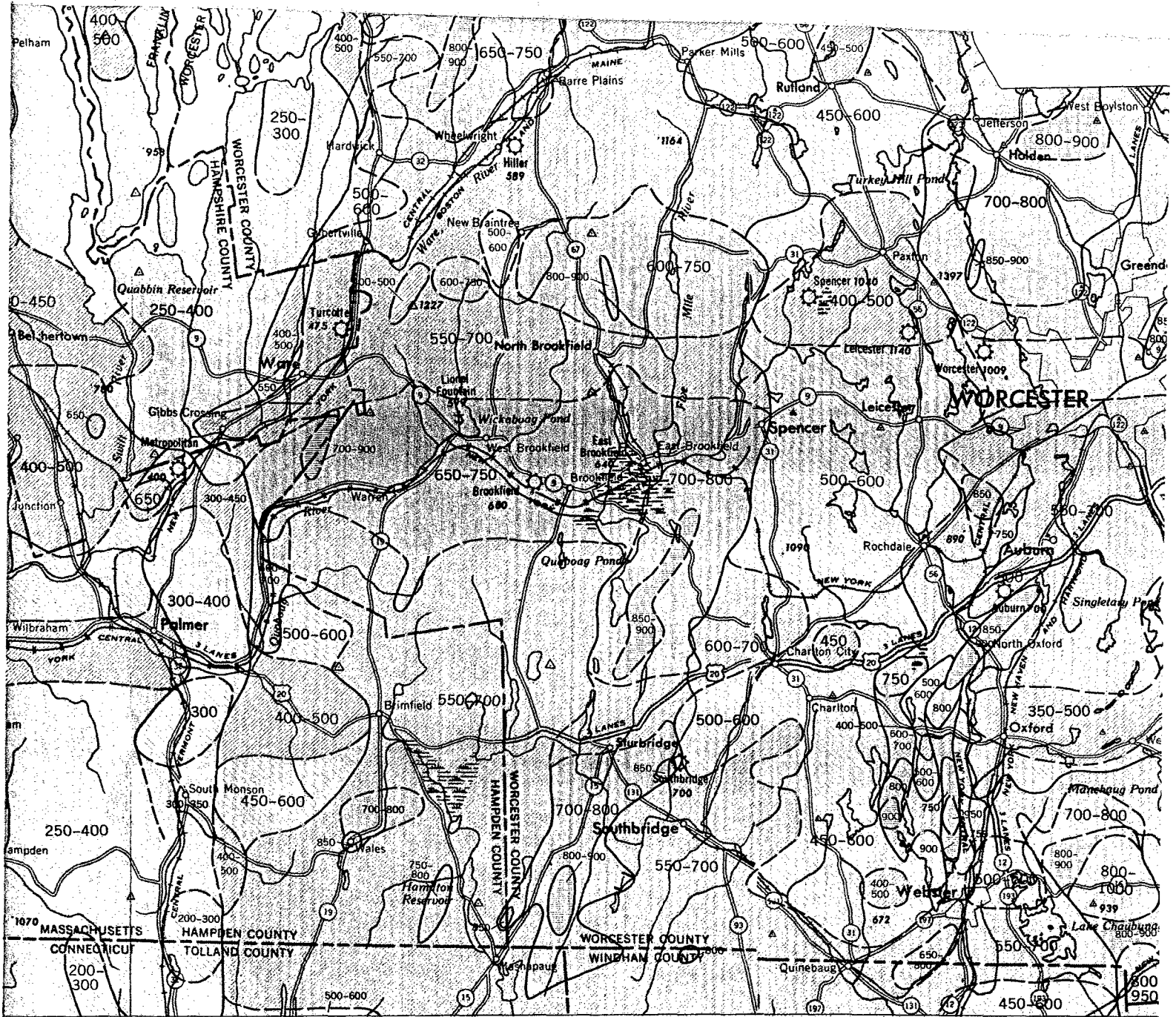
1964



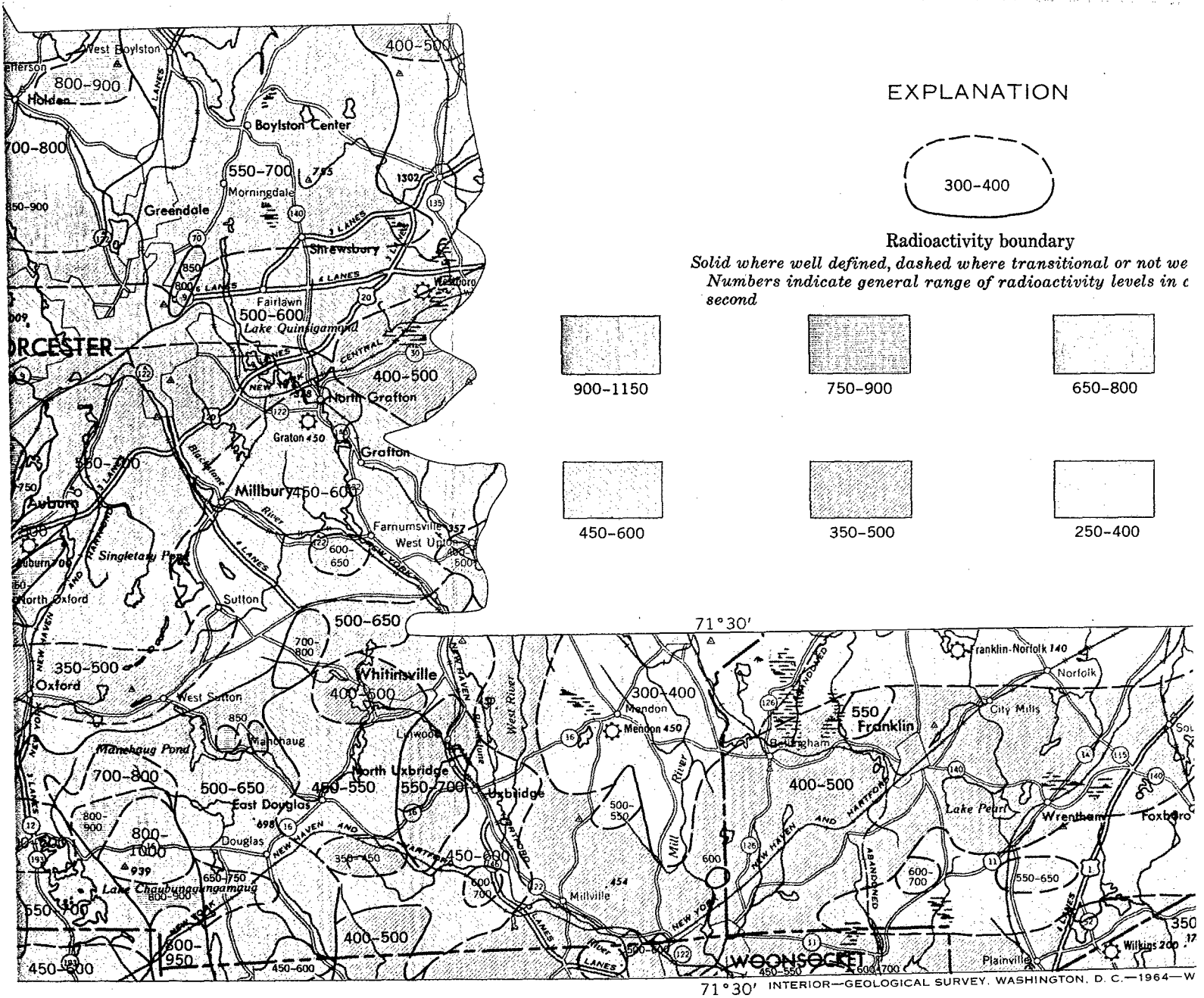
72°30'

NEW YORK AND WEST-CENTRAL NEW ENGLAND





W ENGLAND



71° 30' INTERIOR-GEOLOGICAL SURVEY, WASHINGTON, D. C.—1964—W

Aeror
 above
 of P. f

Map obtainable from U.S. Geol
 pric

EXPLANATION


 300-400

Radioactivity boundary

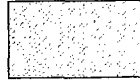
here well defined, dashed where transitional or not well defined.
 bers indicate general range of radioactivity levels in counts per
 d



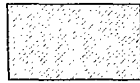
750-900



650-800



550-700



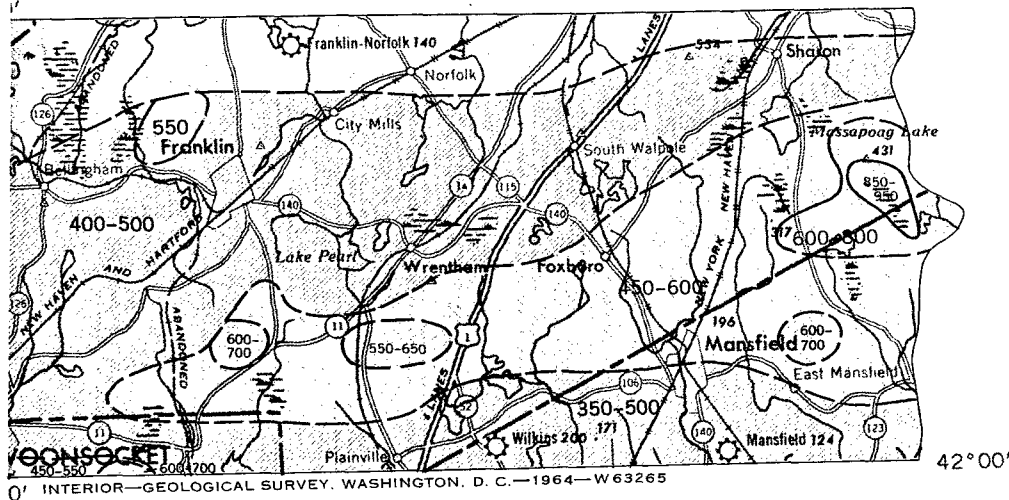
350-500



250-400



50-300



Aeroradioactivity survey made at 500 feet
 above the ground under the direction
 of P. Popenoe and others, 1958-60