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NEW ENGLAND SEISMOTECTONIC STUDY ACTIVITIES DURING FISCAL YEAR 1977

P. J. Barosh, Coordinator

Weston Observatory, Boston College

Prepared for
U. S. Nuclear Regulatory Commission

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NEW ENGLAND SEISMOTECTONIC STUDY ACTIVITIES DURING FISCAL YEAR 1977

P. J. Barosh, Coordinator

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SUMMARY

The New England Seismotectonic Study is a program of investigations designed to better understand the manifestations and causes of seismicity in New England and adjacent areas, in order to assess the seismic hazard and its variation within the region. The study, which officially began July 1, 1976, is a cooperative effort with several universities and State and Federal Geological Surveys and is principally funded by the U.S. Nuclear Regulatory Commission. The first year's program directly involved six investigators from Boston College, Bowdoin College, the University of Kentucky, the State Geological Surveys of New York and Connecticut, and also personnel of the U.S. Geological Survey.

The initial effort is aimed at: 1) the compilation and analysis of the available pertinent information on seismicity, geology and geophysics in the region, 2) the acquisition of new information by investigating previously well defined problems, and 3) the development and organization of a comprehensive program that in five years, will provide an overall assessment of the seismic hazard of the region.

The program will intergrate seismological, geophysical, geological and remote-sensing studies to complement the program of the Northeastern U.S. Seismic Network. The program is designed to provide: 1) regional information needed to acquire a general understanding of seismicity and its relations with geologic and geophysical features and to delineate seismotectonic provinces, and 2) more detailed data in the areas of higher seismicity to attempt to reveal specific relations of seismicity with geology

and to identify active features. Both regional and detailed studies will be used to evaluate the various hypotheses proposed to explain the causes of earthquakes in the region.

The Study is coordinated with, and complementary to the cooperative program of the Northeastern U.S. Seismic Network, funded by both the U.S. Nuclear Regulatory Commission and the U.S. Geological Survey. The network has the responsibility of maintaining seismograph stations and monitoring earthquakes in the region. Other complementary projects in the region include the studies on the Clarendon-Linden fault zone, present day vertical uplift of the Adirondack Mountains, the compilation and study of brittle structures of New York by the New York Geological Survey and the seismic array investigations in New York by the Lamont Doherty Observatory. Contributing investigations by the U.S. Geological Survey include structural geologic studies in eastern Connecticut and eastern Massachusetts, engineering geologic studies near Penobscot Bay, Maine, and coastal marine geophysical surveys.

Results thus far document the importance of faulting in the region and demonstrate the effectiveness of remote-sensing, magnetic-lineament and gravity-lineament analyses to reveal faults in the region. The present data also indicate that the more information available on earthquake location and faults in an area, the closer the spatial relation of earthquakes with faults. Report manuscripts (which are now being processed) of studies partially funded by the U.S. Nuclear Regulatory Commission include: "The preliminary bedrock geology of the Boston 2-degree sheet," "Bibliography of Seismology of the Northeastern United States," "Bedrock geology of the Cape Ann area, Massachusetts", "Preliminary Bouguer gravity map of onshore-offshore northeastern United States and Southeastern Canada", "Bedrock geology of the Worcester Region, Massachusetts", "Regional bedrock geology of the Moodus area, Connecticut", "Bedrock geology of the eastern half of the Portland 2-degree sheet", and "Interpretation of aeromagnetic data in southwest Connecticut and evidence for faulting along the Northern Fall Line". Some results have already been presented at several conferences and many others will be presented in a symposium entitled "Seismicity and Crustal Studies in the Northeastern United States". chaired by P. J. Barosh and E. F. Chiburis at the Northeastern Section of the Geological Society of America meeting in March, 1978, at Boston, Massachusetts.

Proposals for fiscal 1978 were accepted for 29 projects to begin July 1, 1977. These involve 25 investigators and over 20 assistants, and require 17 subcontracts.

The program includes studies of remote sensing, gravity, magnetics, fracture analysis, reanalysis and cataloging of instrumental data on earthquakes, and both detailed and reconnaissance geologic mapping. The State Geological Surveys of New York, Connecticut and Maine, the U.S. Geological Survey and personnel from Bowdoin and Boston Colleges, the Universities of Rhode Island, Massachusetts, Kentucky and Delaware and the Rensselaer Polytechnic Institute are participating.

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NEW ENGLAND SEISMOTECTONIC STUDY,

ACTIVITIES DURING FISCAL YEAR 1977

(JULY 1, 1976 - JUNE 30, 1977)

Patrick J. Barosh, Coordinator

INTRODUCTION

The intelligent selection of nuclear power plant sites giving due consideration to the seismic hazard and the designation of appropriate gravity acceleration values for construction standards, requires a far more sophisticated understanding of the structure and tectonics of the region and their relationship to the seismicity than is presently available. The current practice of selecting a site without this information, followed by an extensive investigation of the region, is a slow and costly procedure, especially when faults are discovered near the site during such investigation.

The values of gravity acceleration chosen for construction standards for nuclear power plants are selected on the basis of the estimated earthquake intensity to be expected. When information is insufficient to judge the earthquake hazard, the values may be set too low for adequate safety or too high, and raise construction costs tremendously. The seismicity in New England varies greatly from place to place (Boston Edison, 1976, Hadley and Devine 1974) (Figures 1 and 2) and a scientifically based means must be found to determine the appropriate values for different locations within the region. A thorough study of the structure, tectonics, and seismicity of the region and their mutual relationships is required to obtain the needed information. The level of seismic

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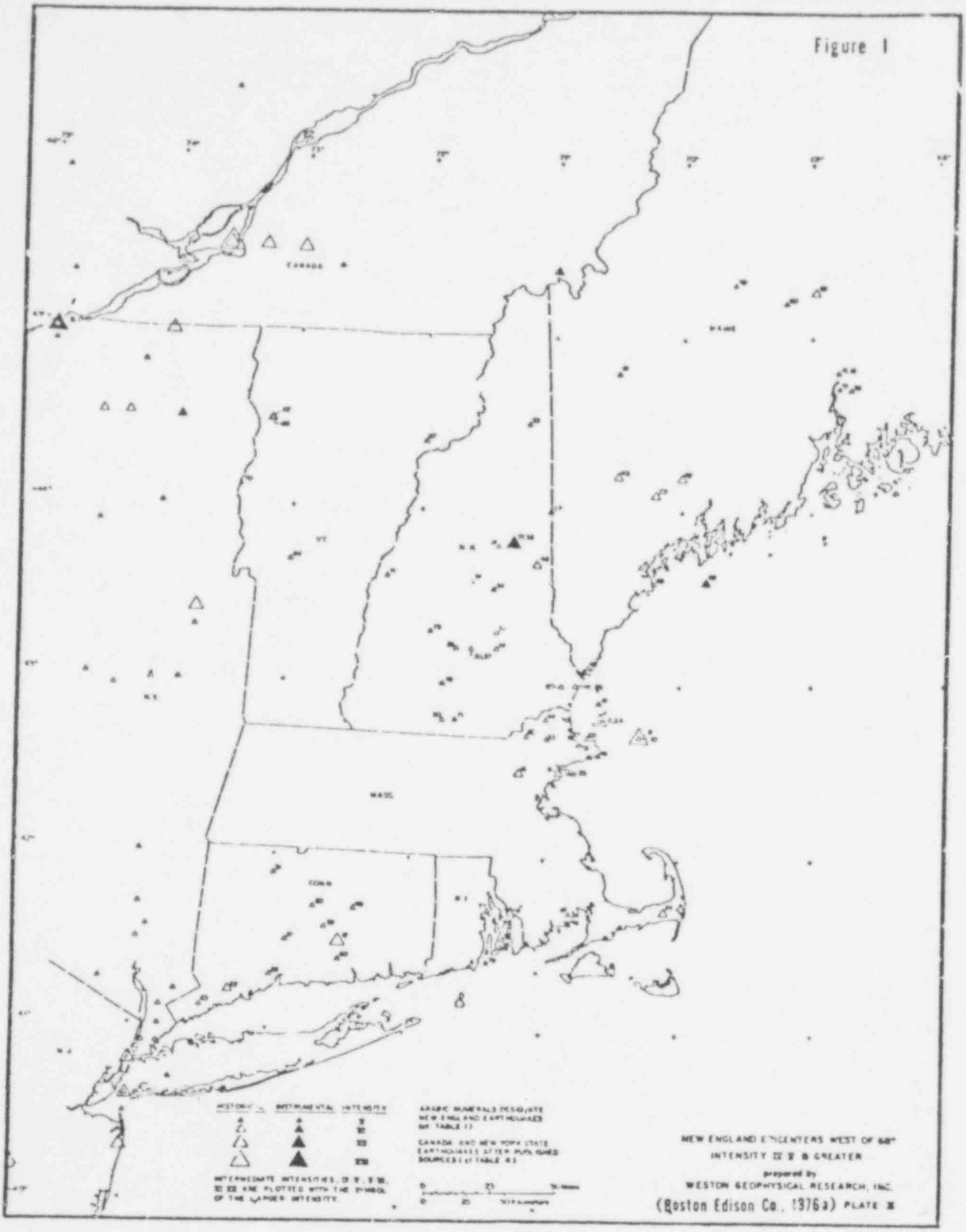

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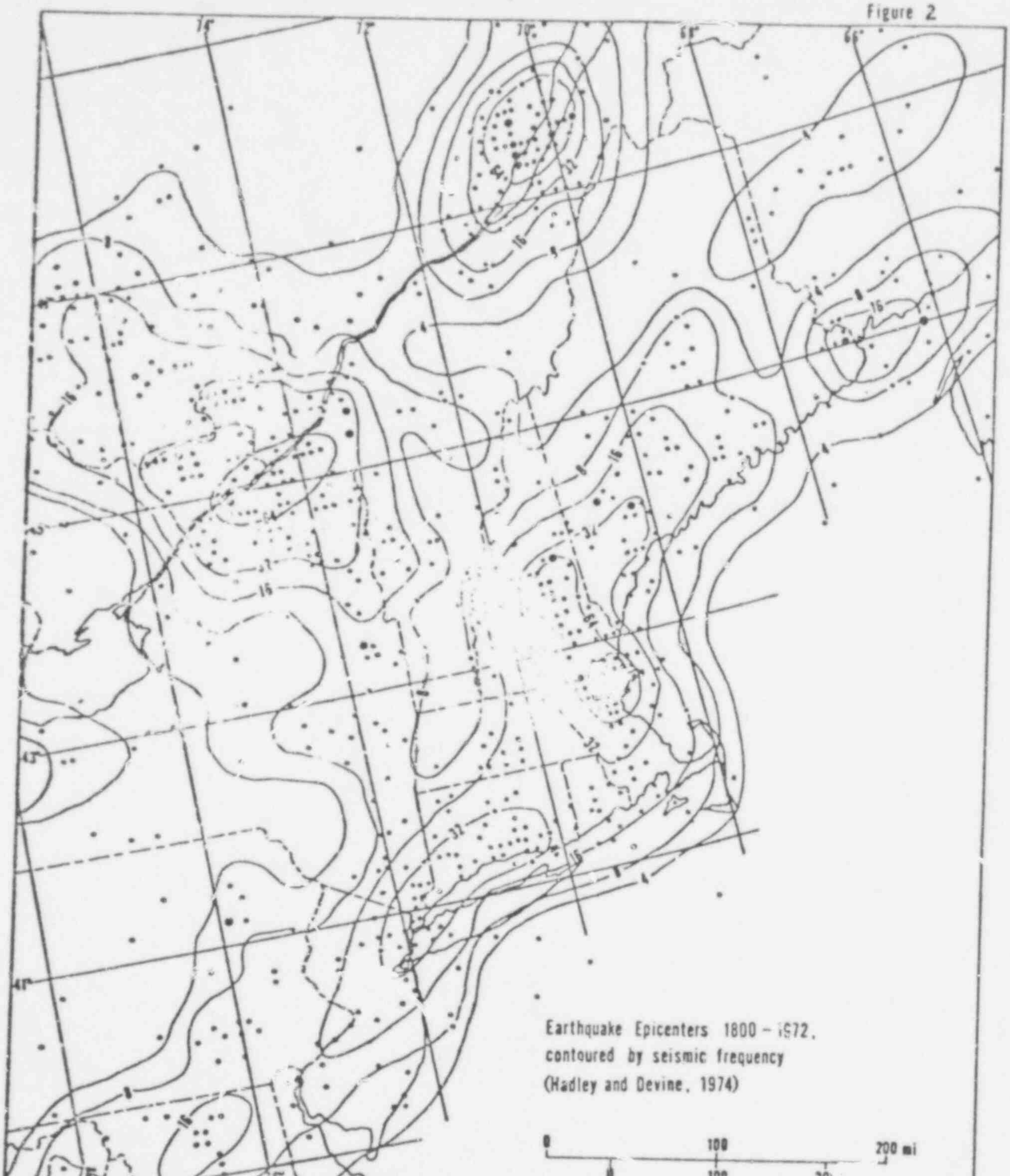
Figure 2



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activity appears to have varied in the past 300 years (Shakal and Toksoz, 1977, but the locations of the most active areas appear to have remained about the same (Figure 1, 2, and 3).

New England is not in the most seismically active belt in the United States, but seismic activity has been recorded in the region since the first English settlers; and before that, one locality, Moodus, Connecticut, was sacred to the Indians due to the numerous earthquakes there. The 1755 earthquake, estimated at about intensity VIII, off Cape Ann is the largest recorded seismic event in the region (Figure 1), and largely because of it, the Coast and Geodetic Survey placed the Boston region in the highest seismic risk category.

Early U.S. Geological Survey workers recognized the highly faulted nature of the region, but most workers in the region concentrated on mineralogic and related studies, and little was done to unravel the fault structure. Hobbs, in the early 1900's, recognized the probable regional extent of the faulting, based on lineament studies (Hobbs, 1904). He also suggested a relationship between these regional faults and seismicity, especially at fault intersections.

Extensive faulting in the region has been slowly revealed, mainly through quadrangle mapping by the U.S. Geological Survey and through mapping tunnels and expressway roadcuts. Recently, geophysical and remote-sensing data has revealed even more faults and possible faults both onshore and offshore. The more detailed structural and tectonic framework shows an improved fit with the epicentral maps of the region and suggests fu... work would lead to a much greater understanding of the regional seismicity and earthquake mechanisms.

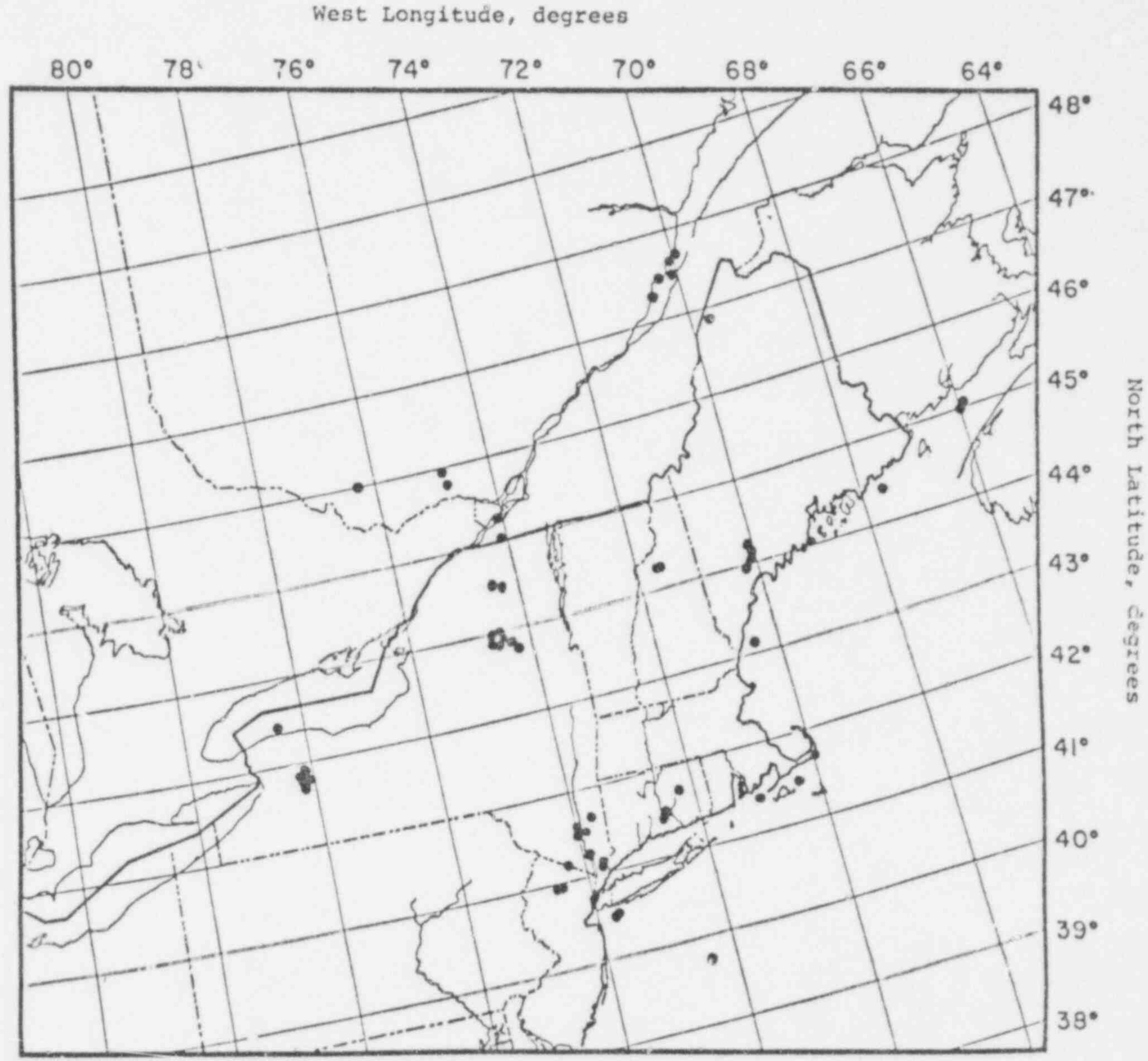

Figure 3. Earthquake epicenters during the period October 1975 - September 1976.
(Northeastern U.S. Seismic Network Bulletin No.4. 1976)

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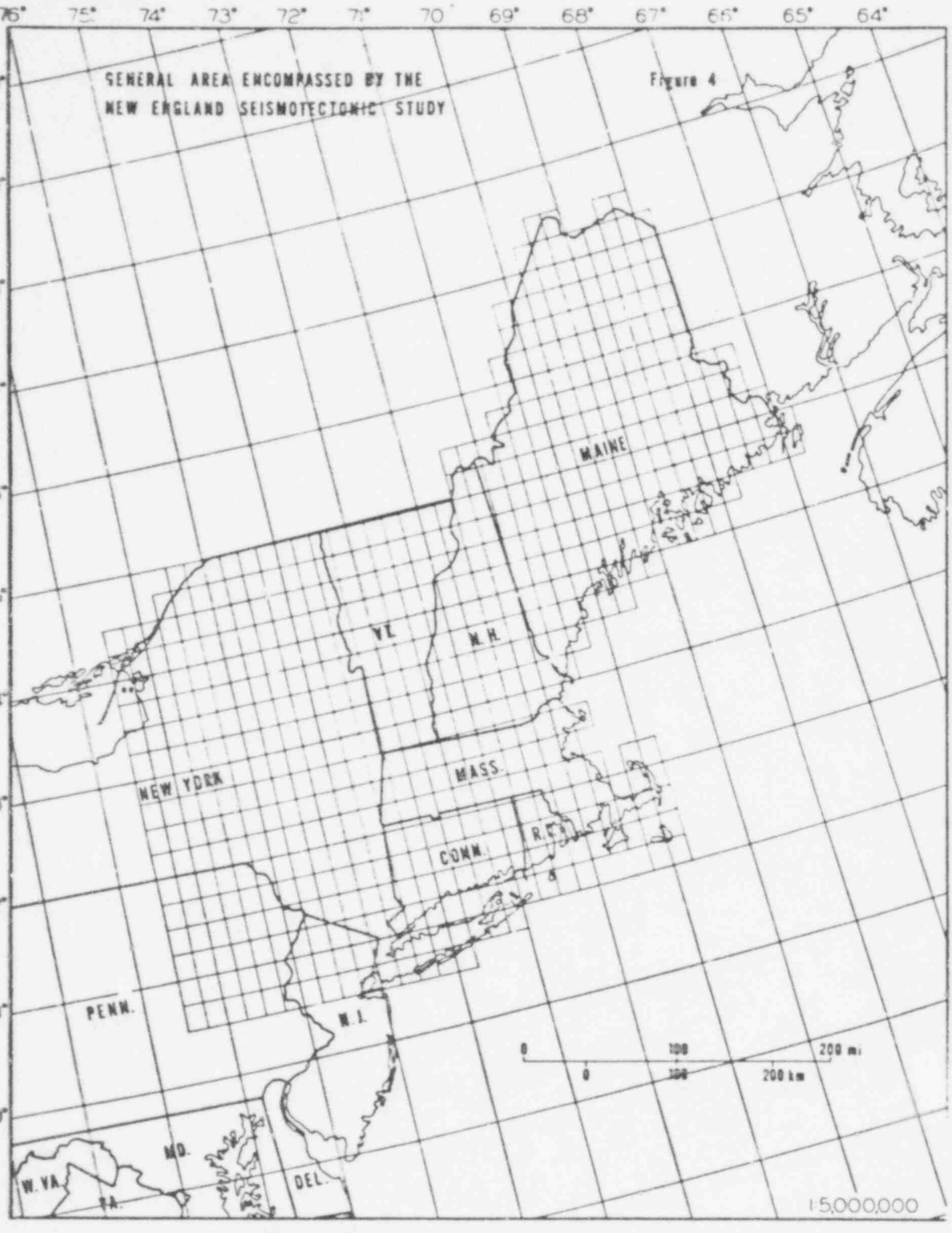
At present, most of the mapped faults have been compiled for New York and southern New England (Isachsen, 1977; Barosh, Pease, Schnabel, Bell, and Peper, 1977) and a very preliminary compilation has been made for all the New England region (Barosh; 1976). Evidence for Post-glacial faulting in the region have been summarized (Woodworth 1907, Oliver, Johnson, and Dorman, 1970). Interpretation of the aeromagnetic data has been done in a general way for all of southern New England with more detailed studies at some places. Landsat and Skylab analysis has been done for New York (Isachsen, 1977; and Isachsen, et. al., 1974) and SLAR lineaments have been drawn for southern New England (Banks, 1974). Several very small-scale tectonic maps (Rodgers, 1970), containing little fault data, cover the region, but the generalized small-scale map of Hadley and Devine (1974) is the only seismotectonic map available. Much of what has been done is in the general nature of preliminary work and should be refined. In addition a great deal of geophysical, remote-sensing, and geologic data is presently available for analysis and synthesis.

SCOPE, PLANS AND GOALS OF THE STUDY

The New England Seismotectonic Study covers the area of the New England States, eastern New York, and Pennsylvania, northern New Jersey, the offshore areas and adjacent parts of Canada (Figure 4). In the discussion below, the reference to the New England region implies this broader area. New England is not a separate geologic entity, but is part of an orogenic belt, including the Maritime Provinces and it is necessary to include them for an understanding of the tectonics and seismicity. Also, a great deal of geology in adjacent Canada bears directly on Maine geology; the



GENERAL AREA ENCOMPASSED BY THE
NEW ENGLAND SEISMOTECTONIC STUDY
Figure 4
76°
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
64°
50°
49°
48°
47°
46°
45°
44°
43°
42°
41°
40°
MAINE
VT.
N.H.
MASS.
NEW YORK
CONN.
R.I.
PENN.
N.J.
MD.
W. VA.
VA.
DEL.
0
100
200 mi
0
100
200 km
1:5,000,000

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Canadian area is less metamorphosed, so some aspects of geology are more clearly seen there, thus contributing to an important understanding of Maine geology to the south. The offshore structure and tectonics in this region is essentially a continuation of that on land (Ballard and Uchupi, 1975) and needs to be included in any regional study.

The objective of the Study is a more definitive understanding of the distribution and sources of the seismicity of the region. Specific goals for the region are the delineation of (1) faults and fault zones, (2) the age of faulting and evidence of recent faulting, (3) geophysical and remote-sensing lineaments and their interpretation, (4 tectonic provinces, (5) seismotectonic features, (6) possible earthquake mechanisms, and (7) seismotectonic provinces.

The Study is planned as a series of specific projects that will be integrated to obtain the desired goals. The projects fill present gaps in the information, both by obtaining new data and by the compilation and analysis of present data. A tremendous amount of published and unpublished data is presently available for analysis. Southern New England and New York have some of the best geophysical coverage in the country (Figure 5), in addition to having good remote-sensing data. These have been analysed only in part and little has been done with the more limited data of northern New England. Most of southern New England has been covered by 1:24,000 geologic quadrangle mapping, that, although of uneven quality, forms a great reservoir of geologic data to draw upon in revealing structures. Many lineaments in southern New England, when

Figure 5. Aeromagnetic Map of Southern New England (Zietz, Gilbert, and Kirby, 1972)

plotted on the geologic maps, were found to lie along dislocations in the b.s.c geologic data and apparently represent faults (Figure 6).

Initial projects include tion of presently available data on faults, aeromagnetics ity, and epicenters for the region into a useful format .th for evaluation and for analysis with other data. The evaluation of the present data at the start of the Study will result in several preliminary reports on seismicity, geologic st cture, and tectonics that will serve as a backgr for further work and make the information available for general use.

The Study cooperates closely with and complements the program of the Northeastern U.S. Seismic Network (Figure 7) of recording earthquakes in the region and draws upon the resources of the Weston Observatory of Boston College. Special projects in seismology, such as compilation of earthquake catalogs and use of arrays of portable seismometers, are planned as part of the Study to augment these sources of earthquake data.

Most projects are designed to provide information bearing on (1) faulting across the region, and (2) faulting in areas of relatively higher seismicity. Information on regional faulting is necessary to understand the regional tectonics and to begin to distinguish faults by age. At present, the region is shown to vary from highly faulted areas to broad areas with no faults. This distribution of faulting appears to reflect areas where experienced personnel have done detailed mapping versus areas

Figure 6-- Faults, aeromagnetic lineaments and selected geologic units in southwest Connecticut and adjacent New York. Heavy lines mapped faults, dashed where described, but not plotted (Fisher, Isachsen and Rickard, 1970; Prucha, Scotford and Sneider, 1968; Hall, 1968; Rodgers, Cameron, Gates and Ross, 1956. J. Clarke, written communication. Fine lines, 100 gamma total intensity contours from Zietz, Gilbert and Kirby, (1972). Heavy dot-dashed lines, aeromagnetic lineaments; Stippled pattern, areas of carbonate rock and quartzite; Ruled pattern, areas of Triassic-Jurassic rock (TR-J), dashed where roughly approximate (Fisher, Isachsen, and Rickard, 1970; Rodgers, Cameron, Gates and Ross, 1956.

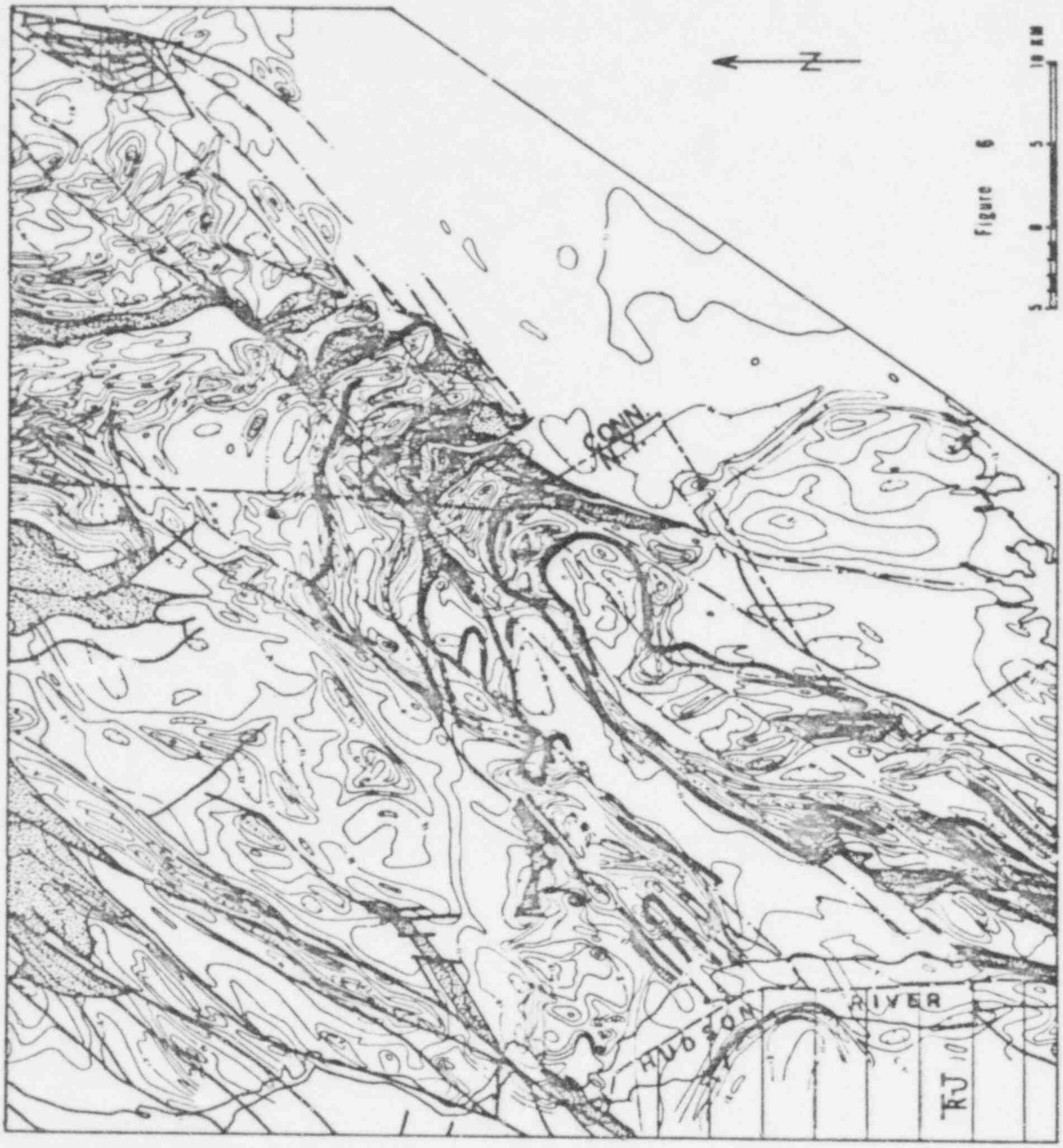

Figure 6

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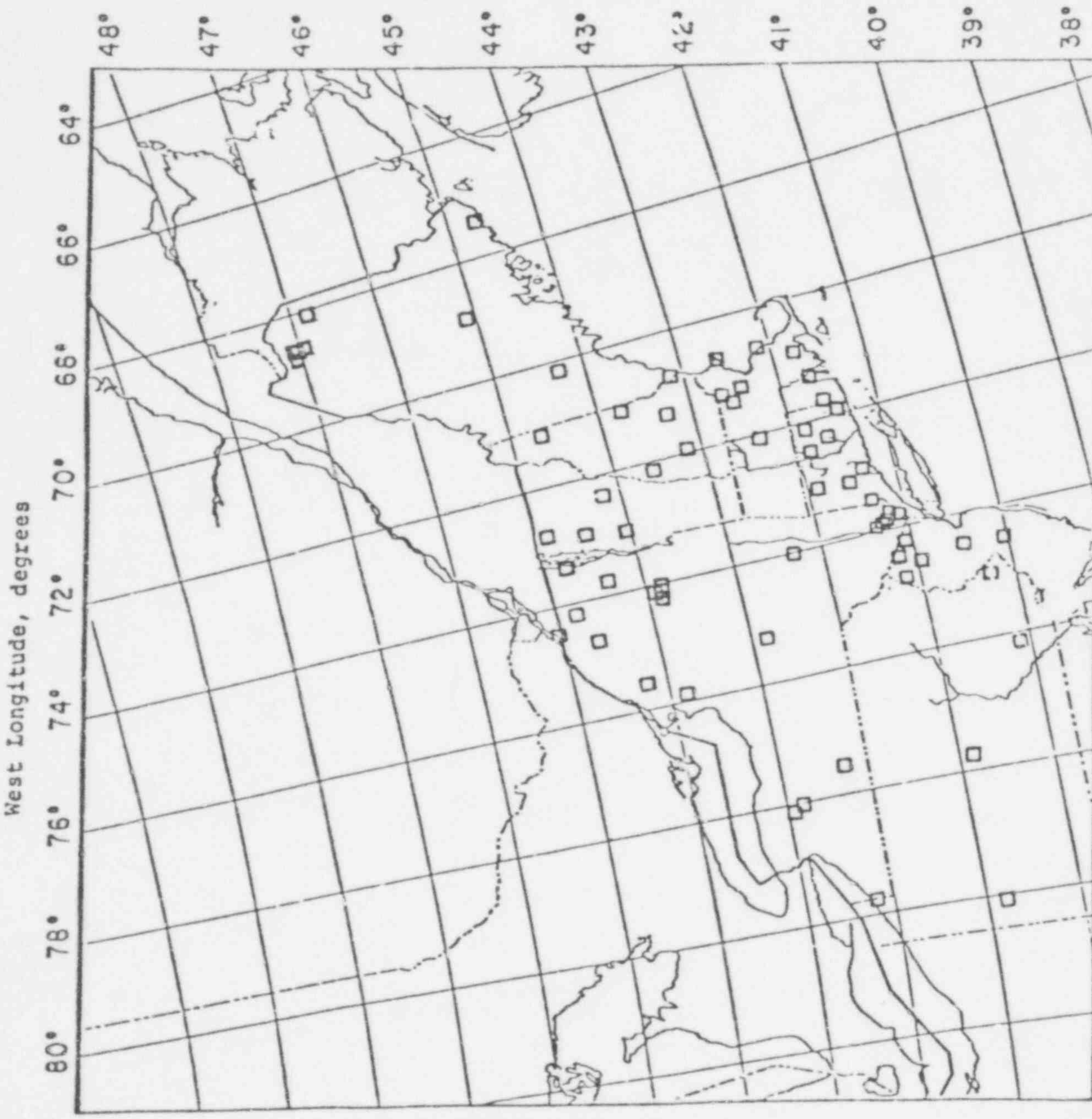
North Latitude, degrees Figure 7



Northeastern U.S. Seismic Network
June 1977

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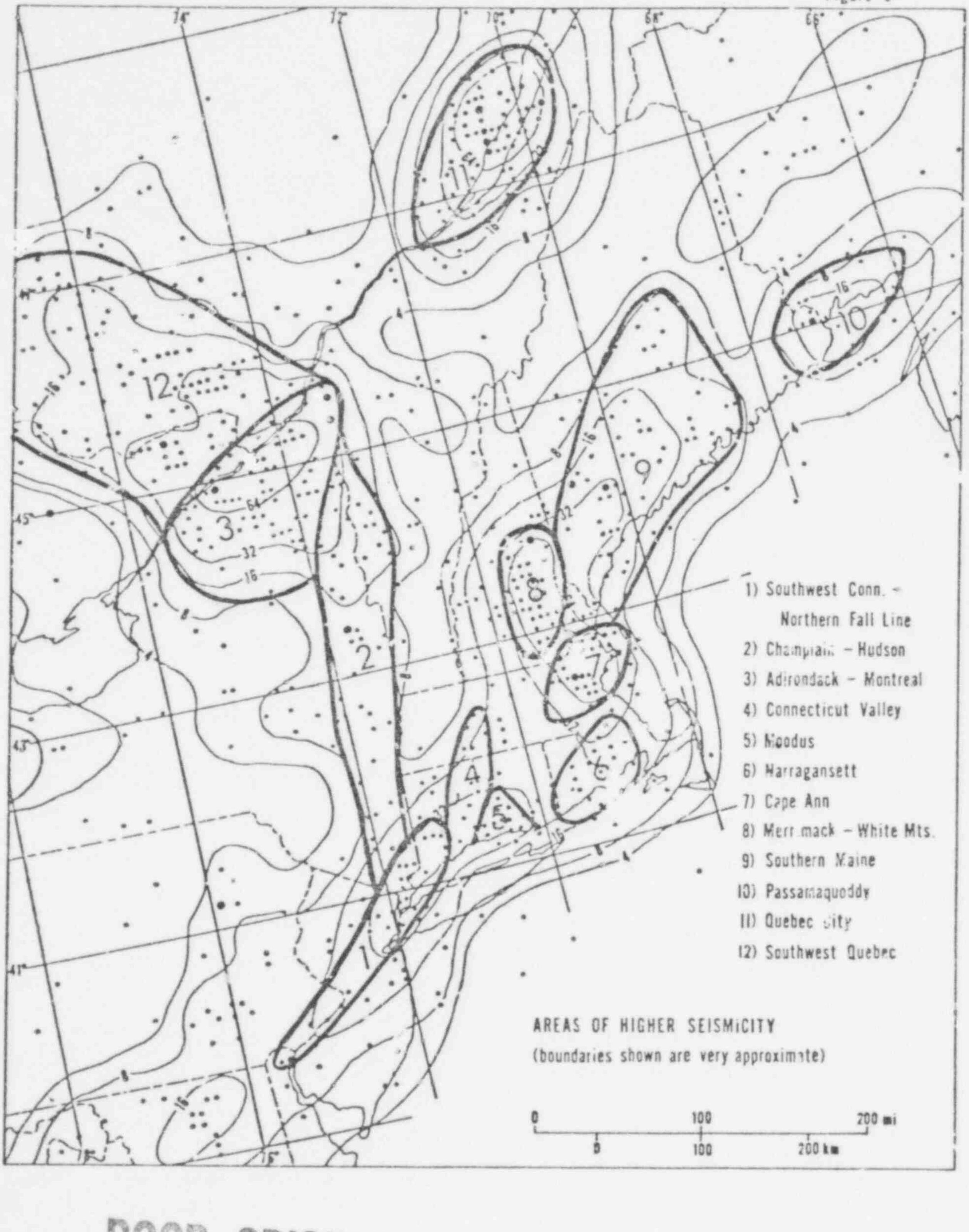
of reconnaissance mapping, and is not neccesarily a basic tectonic pattern. A much more uniform investigation of the region is necessary to understand the real fault density and brittle tectonics. A thorough geologic mapping program of the region is beyond the scope of the study, but selective mapping and field checking of geophysical and remote-sensing lineaments should provide most of the needed information.

A remarkably close match of the geology of well-mapped areas in southern New England with geophysical and remote-sensing data demonstrates the feasibility of integrating such data with the available geology to extend and interpret faulting (Isachsen et al, 1974; Barosh, 1976; Alvord, Bell, Pease and Barosh, 1976; Barosh, Pease, Schnabel, Bell, and Peper, 1974, revision 1977; Gay, 1972). Thus, a series of projects analyzing lineaments on Landsat and Skylab imagery, such as Isachsen (1977) did in New York, and on aeromagnetic maps will provide valuable information. Analyses of aeroradioactivity and gravity data is also being done where sufficient data is available. The lineaments are matched against compilations of the available geology for interpretation and are selectively field checked. This provides an efficient approach that obtains a great deal of structural data in a relatively short time across the geologically poorly known areas of northern New England.

The areas of higher seismicity (Figure 8) are recieving a more thorough treatment. The lineament analyses are being supplemented by aerial photo analysis, more detailed geophysical analysis where data is available, and more extensive field mapping for areas where important faults may be present or

Figure 8



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where very little structural data, is available. In critical areas, additional geophysical data is being acquired. Critical reviews of seismicity and of particular seismic events in these areas will be made where the data warrants it. It is in these areas that the greatest effort in dating faults and searching for active faults is being made. The presently available information on the seismically active areas shown on Figure 8 varies greatly and the types of studies needed for each area will necessarily vary also. Data on the adjacent seismically active areas in Canada are being compiled and reviewed for their importance in understanding the seismicity of the region, but no active field investigation of these areas, other than for reported recent faulting, is being done.

The problem of trying to date fault movement in the region is being worked on where possible. The problem is acerbated in that the fault pattern seen is apparently Paleozoic, parts of which have later been selectively reactivated. Thus, there is no distinct difference in pattern of faults of different ages (such as in the Great Basin of the Western U.S.) to aid in their dating. Faults are being distinguished by direct and indirect geologic relationships with sedimentary units, relationships with intrusive rocks and radioactive dating of material in the fault zones. Once the faults are better delineated and distinguished by age, a clearer picture will emerge between Paleozoic and post-Paleozoic tectonics. A special project is investigating all reported occurences of recent faulting. Also, faults that are in seismically active areas that may cut surficial deposits are being searched for.

The final principal products of the study will be:

1) A fault map of the New England region and adjacent parts of Canada showing ages of faulting;

2) A lineament map of the New England region;

3) A tectonic map of the New England region and adjacent parts of Canada;

4) A report on earthquake mechanisms in the New England region; and

5) A seismotectonic map of the New England region

<u>METHOD OF OPERATION</u>

Weston Observatory, Boston College, is the administrative and coordinating headquarters of the Study in addition to being the location of many investigations and much of the overall integration and analysis of the studies. The Study is conducted as a group of separate projects which has the advantage of keeping the study very flexible; projects can be expanded, added, or dropped, and new developments can easily be incorporated into the overall program. The Coordinator, P. J. Barosh, encourages participation, and integrates and expedites cooperative efforts of State and Federal agencies and University personnel to achieve the goals of the study. The proposals received are coordinated into a balanced comprehensive program. The financial arrangements of the entire study are handled by Boston College. The Coordinator, ablely assisted by John O'Toole of Administrative Research, Boston College, prepares subcontracts for the cooperating participants.

The Study also seeks the active cooperation of Canadian Provincial and Federal Geological Surveys and University personnel to obtain data necessary for an analysis of the tectonics and seismicity of the region.

The Study maintains an active exchange of information with the New Madrid and Nemaha Seismotectonic Studies groups on ideas, approaches and results.

FIRST YEAR'S PROGRAM: JULY 1, 1976 - JUNE 30, 1977

The primary goals for the first year's program are: 1) compilation and analysis of the available pertinent information on seismicity, geology and geophysics in the region, 2) the acquisition of new information by investigating previously well-defined problems (Figure 9), and 3) the developmant and organization of a comprehensive program that in five years, will provide an overall assessment of the seismic hazard of the region.

The first year's program directly involved six investigators from Boston College, Bowdoin College, the University of Kentucky, the State Geological Surveys of New York and Connecticut, and also personnel of the U.S. Geological Survey.

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INDEX MAP FOR INVESTIGATIONS FOR 1977
Figure 9
1) New York, Lineament
2) Moodus region
3) Southwest Rhode Island
4) Boston 2° sheet
5) Cape Ann area
6) Portland and Bath 2° sheets
76° 75° 74° 73° 72° 71° 70° 69° 68° 67° 66° 65° 64°
50° 49° 48° 47° 45° 44° 43° 42° 41° 40°
1:5,000,000

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COORDINATING ACTIVITIES

The coordinator, Patrick J. Barosh, attended to the planning, organization and adminintration of the New England Seismotectonic Study. An office was established at the Weston Observatory of Boston College and a staff assembled. Subcontracts were prepared to initiate New York projects and the Portland 2-Degree Sheet, and financial arrangements were set up at Boston College for that part of the Study under the direction of the Connecticut Geological Survey. Office and field conferences were held with the participants during the year. An exchange of information was maintained with the New Madrid Seismotectonic Study, the Nemaha Uplift Study and the Northeastern U.S. Seismic Network by attendance at meetings and discussions.

An integrated program of seismological, geological, geophysical and remote-sensing studies was developed to achieve in five years the goals of the New England Seismotectonic Study. State and Federal agencies (State Geological Surveys; U.S. Geological Survey in Boston, Reston, Denver, Menlo Park and Woods Hole; and U.S. Corps of Engineers) and numerous university personnel were contacted to encourage participation, obtain information and coordinate existing programs. Individual participants and projects were identified and anticipated levels of participation were determined. Proposals for practical studies were integrated and scheduled.

Two meetings were held in Silver Springs, Maryland, with U.S. Nuclear Regulatory Commission personnel for presentation and discussion of the study prior to its initiation and one at Weston Observatory at the inauguration of the Study. Also, a discussion of the overall program, results to date and plans for the coming year were presented later in the year at two meetings in Silver Springs, Maryland.

Several conferences were attended during the year to present papers bearing on aspects of the study: "Interpretation of aeromagnetic data in southwest Connecticut, and evidence for faulting along the Northern Fall Line" with M. H. Pease, Jr. at the Second International Conference on the New Basement Tectonics; "Fault Tectonics of New England" at the Geological Society of America Annual Meeting; "Mesozoic faults in southern New England" at the U.S. Geological Survey, Reston; "The Penobscot Line; evidence for a major Lineament in Maine" with D. W. O'Leary at the International Geologic Correlation Program Project 143 Meeting and at the Northeastern Section Geological Society of America Meeting; "Relationship of seismicity to geology in the Northeastern United States" at the American Nuclear Society Annual Meeting; "Bedrock geology of the Boston 2-Degree Sheet" with M. H. Pease, Jr. as part of a symposium the coordinator organized with Elliott Thomas to present recent work in the region for the New England Section of the Association of Engineering Geologists, and also "Faults and related deformation in the Clinton-Newbury--Bloody Bluff fault complex of eastern Massachusetts" and "Stratigraphy of the Webster-Worcester region, Massachusetts" at the New England Intercollegiate Geological Conference. Abstracts and summaries are presented in Appendix A.

COMPILATION AND ANALYSIS

Presently available information pertaining to earthquakes and tectonics of the region has been compiled and analyzed to assemble the data in a useable form, look for any possible relationships with seismicity, determine the best lines of investigation, locate gaps in the data and prevent duplication. Seismological, geophysical, geological and remote-sensing data is being compiled as it becomes available, on a standard 1:1,000,000-scale base map of the region.

Much of the information is being synthesized in a report on seismicity and its presently known relations with geology and tectonics in the region--"Seismicity and tectonics in the Northeastern United States".

Compilations and studies being done and reports in progress include:

1) Bibliographic data on selected background. A "Bibliography on the seismology of the Northeastern United States" has been prepared.
2) All available published and unpublished information on faults in the region. The data has been compiled on 1:250,000-scale 2-degree sheets and will be placed on a single 1:1,000,000-scale map.
3) Gravity data of the region. This is presented as a "Preliminary gravity map onshore-offshore Northeast United States and Southeast Canada" by C. T. Hildreth 1:1,000,000-scale (Figure 10 and Table 1).

4) Presently available data on seismicity, its spacial distribution and relations with structural zones in the Northeastern United States.

5) All available data on the "Boston-Ottawa Seismic Zone".

6) A review of reported Holocene fault movements in the Northeastern United States. About a dozen locations from New York to New Brunswick, are described as having evidence for Holocene fault movement (offset striated bedrock, apparent subsurface offset and offset fill) are being evaluated.

7) Regional geologic map, 1:1,000,000 scale

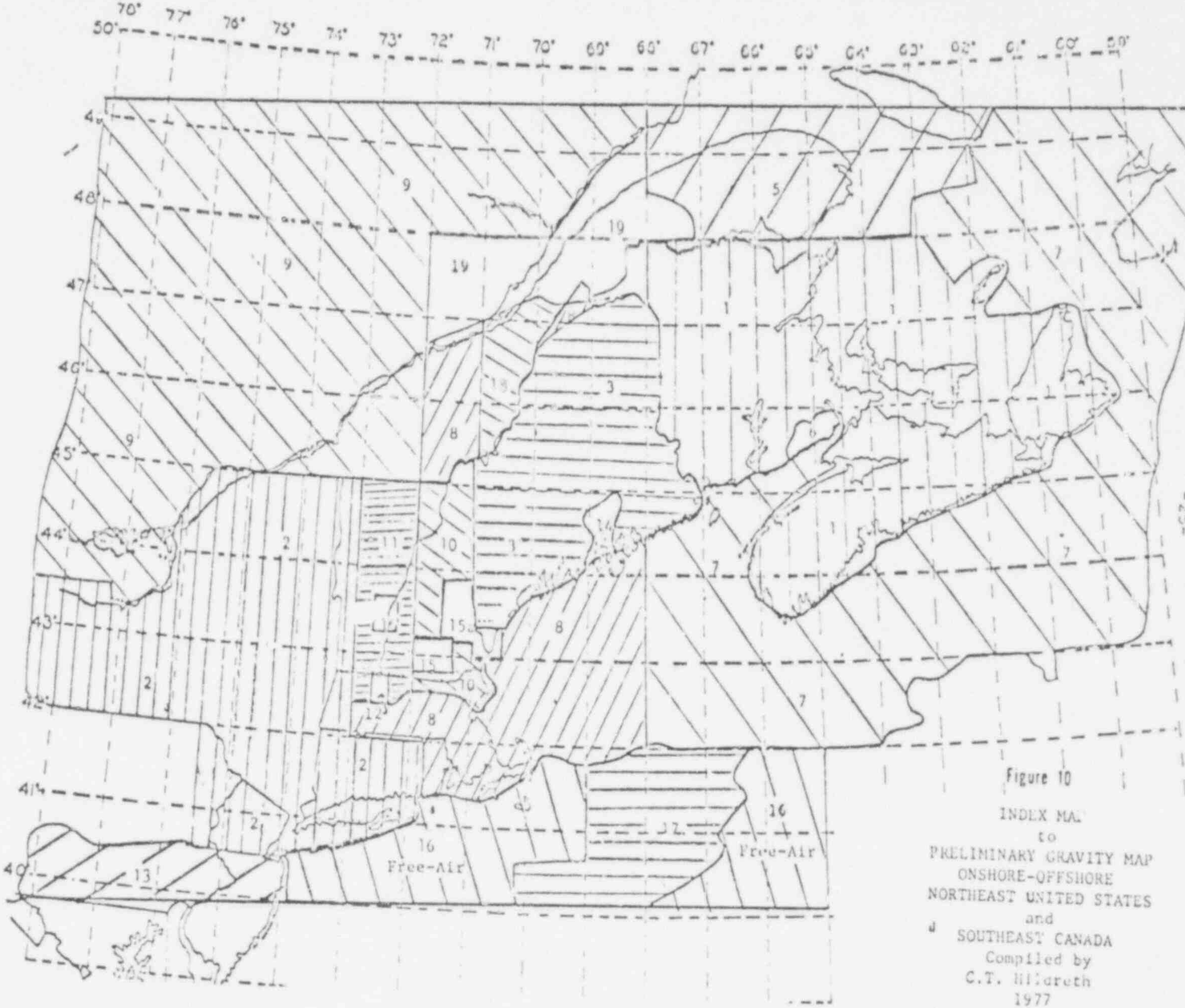

Figure 10

INDEX MAP
to
PRELIMINARY GRAVITY MAP
ONSHORE-OFFSHORE
NORTHEAST UNITED STATES
and
SOUTHEAST CANADA
Compiled by
C.T. Hildreth
1977

TABLE 1

PRELIMINARY GRAVITY MAP, ONSHORE-OFFSHORE NORTHEAST
UNITED STATES & SOUTHEAST CANADA

SOURCE REFERENCES

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FIELD INVESTIGAITON

FAULT AND STRESS STUDIES IN NEW YORK

Several studies have been undertaken in New York under the able direction of Yngvar W. Isachsen of the New York Geological Survey. The purpose of these studies is the recognition of faults, Holocene fault movement and criteria to determine paleostress analysis.

LANDSAT LINEAMENT INVESTIGATION

1) Remote sensing lineaments have been analyzed and plotted for New York. The results of this work, recently published with U.S. Nuclear Regulatory Commission support (Isachsen 1977), showed a number of lineaments that did not coincide with any recognized geologic feature. A selected number of these were investigated in the field and several previously unmapped faults were found.

BRITTLE STRUCTURES INVESTIGATION

1) When literature compilation of joint data for the State showed large areas in seismically active parts of western New York and the Adirondacks to lack such information, reconnaissance joint mapping was begun in 1975, and continued in 1976. A summary of the orientation of the joint data was recently published (Isachsen, 1977). Also mapped, where present, were slickenslides, stepped surfaces, coatings, and fillings, as evidence of rejuvenated movements. Numerous, previously unmapped faults were also found during this study.

DEVELOPMENT OF FAULT-RECOGNITION CRITERIA FOR USE WHERE CENTRAL PORTIONS OF FAULT ZONES ARE BURIED BENEATH ALLUVIUM.

1) Literature search for well-exposed faults to study;

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faults which involve basement rocks only, basement and cover rocks, and cover rocks only.

2) Study and measurements of several such faults, resulting in the development of zone analysis of faults: briefly, zones range from gouge through several kinds of breccia to scattered patches of anomalous fracturing in normally jointed rock, to megascopically unaffected rock.

DEVELOPMENT AND TESTING OF METHODS FOR DETERMININC POSSIBLE HOLOCENE FAULTING SUCH AS MAY HAVE ACCOMPANIED ADIRONDACK DOMING AND SEISMIC ACTIVITY

1) Made a very preliminary map analysis of Adirondack drainage - shows a surprising perserverance. perhaps even a dominance, of radial consequent drainage over subsequent drainage off the Adirondack dome. This suggests a very young age for the development of the dome and the unroofing of updomed Paleozoic strata.

2) Measured temperatures of several of the springs at Saratoga to see if there had been any change in temperature during the past half century, possibly associated with the current rapid rate of Adirondack doming. Result, no change.

3) Literature search and plotting on 15' quadrangle maps the locations of glacially-polished rock surfaces in the Adirondack region. These surfaces serve as 10,000-12,000 year old "reference planes" which can be studied for evidences of Holocene strike-slip or dip-slip movement on pre-existing joint planes of over 270 joints measured at 55 glacially-polished outcrops, 14 show offsets which range from .3mm to 3mm, and occur as much as 35m from blasted rock faces. The cause

of displacement cannot yet be assigned unambiguously to either tectonic causes or to ice wedging along possible hidden sheeting joints.

4) Geophysical study of unconsolidated sediments in Lake George graben-horst basin. This was done in cooperation with Richard Wold of U.S. Geological Survey at Woods Hole. The Study completed 110km of bathymetric seismic reflection and magnetic profiling of Lake George and discovered evidence for several possible faults, including growth faults, with displacements up to 24m.

PALEOSTRESS ANALYSIS - SEARCH FOR CRITERIA.

1) Successful search for vertical planes of stylolites in sub-horizontal Paleozoic strata as guides to paleostress systems.

2) Initiation of dike study, literature and field, as dateable guides to paleostress systems.

GEOLOGIC STRUCTURE AND LINEAMENTS IN THE REGION AROUND MOODUS, CONNECTICUT

An investigation is being made of selected lineaments and possible Jurassic or younger faulting in the region of the Moodus, Connecticut, earthquakes under the direction of Sidney S. Quarrier of the Connecticut Geological Survey. The Moodus area is one of the best located active seismic areas in New England. The center of seismic activity in the Moodus area lies at the junction of northeast-trending topographic lineaments, extending from the southeast border fault of the Juro-Triassic sedimentary rocks of the Connecticut Valley, and northwest-trending lineaments extending along the lower Connecticut River (Figures 8 and 11). The geology, as presently mapped, changes in crossing a zone along the Lower Connecticut River, but no significant faults are known (Figure 11). A change in the aeromagnetic map pattern also occurs along the river.

An investigation is being made of the regional geologic structure and the nature of the lineaments. The area chosen for study covers twelve 7 1/2 minute quadrangles; eight of which are published or open-filed (Figure 12). The first year's work will be completed work on the Branford, Guilford, and Haddam Quadrangles, and Open-File maps of these quadrangles are available at the Connecticut Geological Survey. At a future date the Haddam map and report will be published as part of the Connecticut Survey's Quadrangle Report series. With the addition of geologic data from the eastern part of the Durham Quadrangle from J. deBoer, a published or Open-File bedrock map will be available for each

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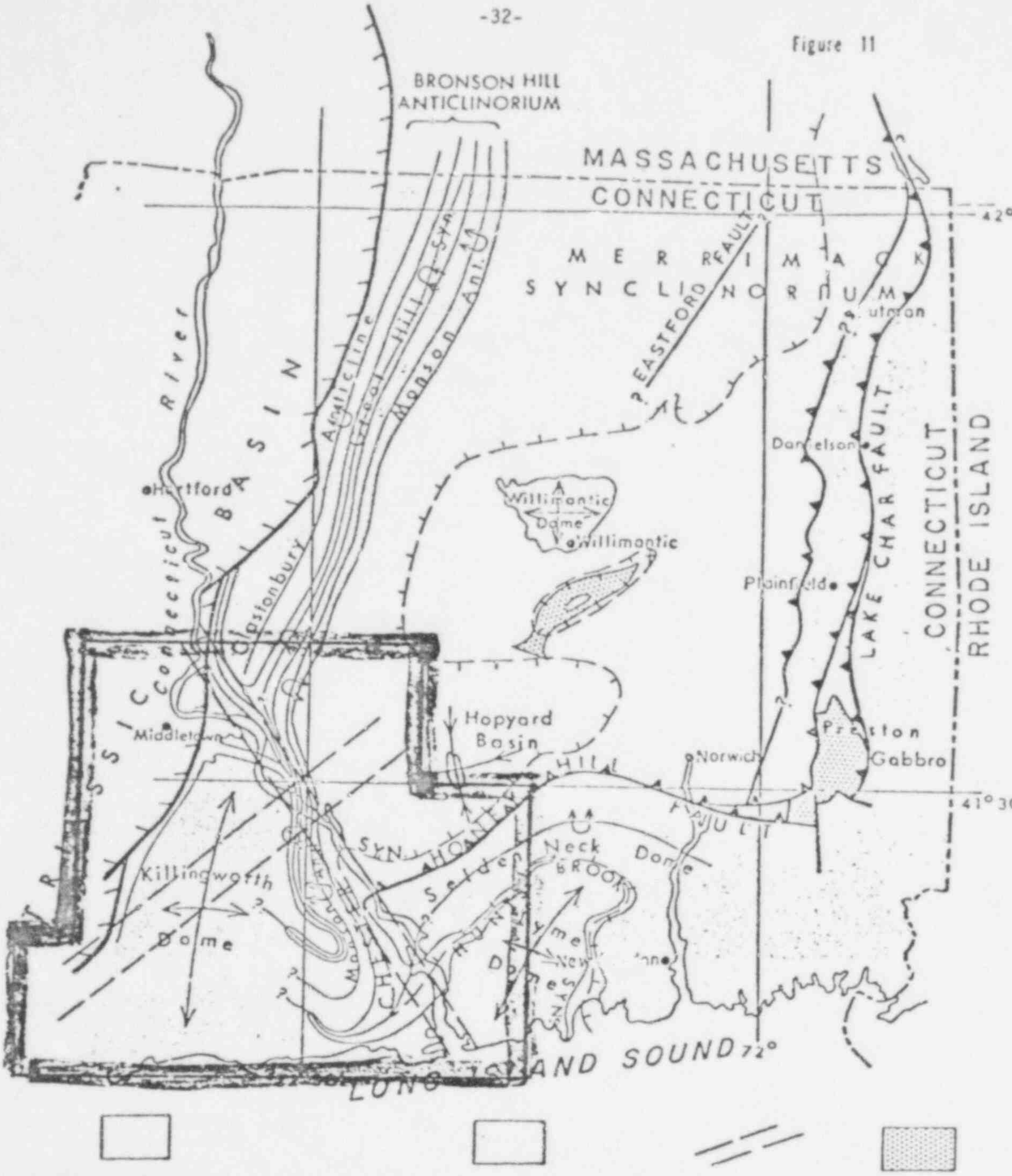
Figure 11



Middle Ordovician and younger metasedimentary rocks and intrusive gneisses

Middle Ordovician and older metavolcanic and metasedimentary rocks and granitic gneisses.

Lineament Zones

Gabbro

Index Map for the Moodus Area, Connecticut showing structural features and zones of lineaments. (after Goldsmith and Dixon, 1968)

POOR ORIGINAL

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GQ	surficial
GQ (patterned)	surficial and bedrock
GQ (boxed)	bedrock

GQ = Geologic Quadrangle U.S.G.S.
QR = Quadrangle Report Conn. Geological and Natural History Survey

• Conn. Survey Bulletin 86
☼ U.S.G.S. Bulletin 1161-I
⊙ N.Y. Map & Chart Series #11
OF = Open filed

FIGURE 12. INDEX FOR PUBLISHED GEOLOGIC MAPS OF CONNECTICUT QUADRANGLES, Apr. 1, 1976.

POOR ORIGINAL

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of the quadrangles in the project area. A preliminary compilation on a 1:62,500 scale topographic base map, "Preliminary bedrock geologic map of south-central Connecticut" and report by R. J. Fahey and S. S. Quarrier are being reviewed. This will be supplemented by additional compilations of selected bedrock data, i.e., lithologies, foliations, joints, faults.

A selected bibliography of the geology of the project area has been collected on file cards and includes approximately 130 entries. A preliminary typed copy of this bibliography will be part of the report.

Published aeromagnetic maps of the 7.5' quadrangles are available, and these have been reduced and composited at the scale of 1:62,500 for the base map. These data and a reduction of them to 1:125,000 are being used to help interpret the bedrock geology.

M. H. Pease of the U.S. Geological Survey, in cooperation with the Connecticut Geological Survey, is conducting an integrated lineament study of the area (Landsat, Skylab, SLAR, high-altitude photography and aeromagnetics).

STRUCTURAL ANALYSIS OF SOUTHWESTERN RHODE ISLAND AND ADJACENT CONNECTICUT

A structural analysis of southwestern Rhode Island and adjacent Connecticut (Figure 9) combining geologic, magnetic, gravity, remote-sensing and radioactivity data is being conducted by P. J. Barosh of Weston Observatory. It provides structural data on the western edge of the Narragansett seismic area, particularly on a large northeast-trending fault and probable faults extending eastward off the Honey Hill Fault

Zone. Few local faults are presently shown on published maps of the areas, yet the data strongly indicate the presence of many, and that igneous rocks have intruded some of the faults, thus providing possible age control. Some may have had movement during the Mesozoic. The study demonstrates how an integration of various data sources can be used to reveal geologic structure. It also provides background information for a nuclear power plant site in southern Rhode Island.

The area appears to be cut by a number of fault zones which bracket large folds with overturned southern limbs. In southeastern Connecticut the faults and folds strike northeast and farther northeast in Rhode Island a different set strikes northwest. These two sets merge together to the north and continue with a northerly trend. Between these two sets in the southwestern corner of Rhode Island, topographic and magnetic lineaments strike both northeast and northwest and suggest faults of both trends are present. One fault, the Watch Hill, appears to continue northeastward into the Narragansett Basin. A 1:125,000-scale map and report are in preparation.

FAULTS OF EASTERN MASSACHUSETTS AND ADJACENT NEW HAMPSHIRE (BOSTON 2-DEGREE SHEET)

The faults of eastern Massachusetts and adjacent New Hampshire (the Boston 2-Degree Sheet) (Figure 9) and, where possible, their history of movement and relative and absolute ages are being investigated by P. J. Barosh of the Weston Observatory. Mapped faults of the region have been compiled, field checked and supplemented by reconnaissance geologic mapping in cooperation with M. H. Pease, Jr. and R. J. Fahey of the U.S. Geological Survey (Figure 13). A knowledge of the structure of eastern Massachusetts is very important in understanding the seismicity of Cape Ann and the relation of Paleozoic tectonic provinces and possible Paleozoic Plate boundaries with modern seismicity.

Exposures along the major and subsidiary faults and intrusive rocks that bear a relationship to the faulting are being investigated for dating purposes. Some fault zones appear to have had repeated movements over a long period of time, and age dating may demonstrate this. Some of the results are: 1) The Clinton-Newbury fault zone shows evidence for a Paleozoic compressional movement and a later extensional movement. 2) The study presents the first comprehensive view of the faulting in the region and demonstrates the importance of a thrust belt between the Clinton-Newbury and Bloody Bluff fault zones. This belt forms a major structural break and could represent a Paleo zoic suture zone. 3) A northeast-trending fault zone with possible large-scale right-lateral movement was discovered in southern New Hampshire. 4) No significant northwest-trending faults were found parallel to the "Boston-Ottawa seismic zone" in the southeast corner of New Hampshire. 5) Present-day seismicity shows some correlation with parts of the Paleozoic zones of faults, but not with entire zones.

Two reports in preparation, partially supported by the Nuclear Regulatory Commission are:

"Preliminary map showing bedrock geology superposed on an aeromagnetic base map of the Worcester Region, Massachusetts, Connecticut and Rhode Island" by Patrick J. Barosh; Weston

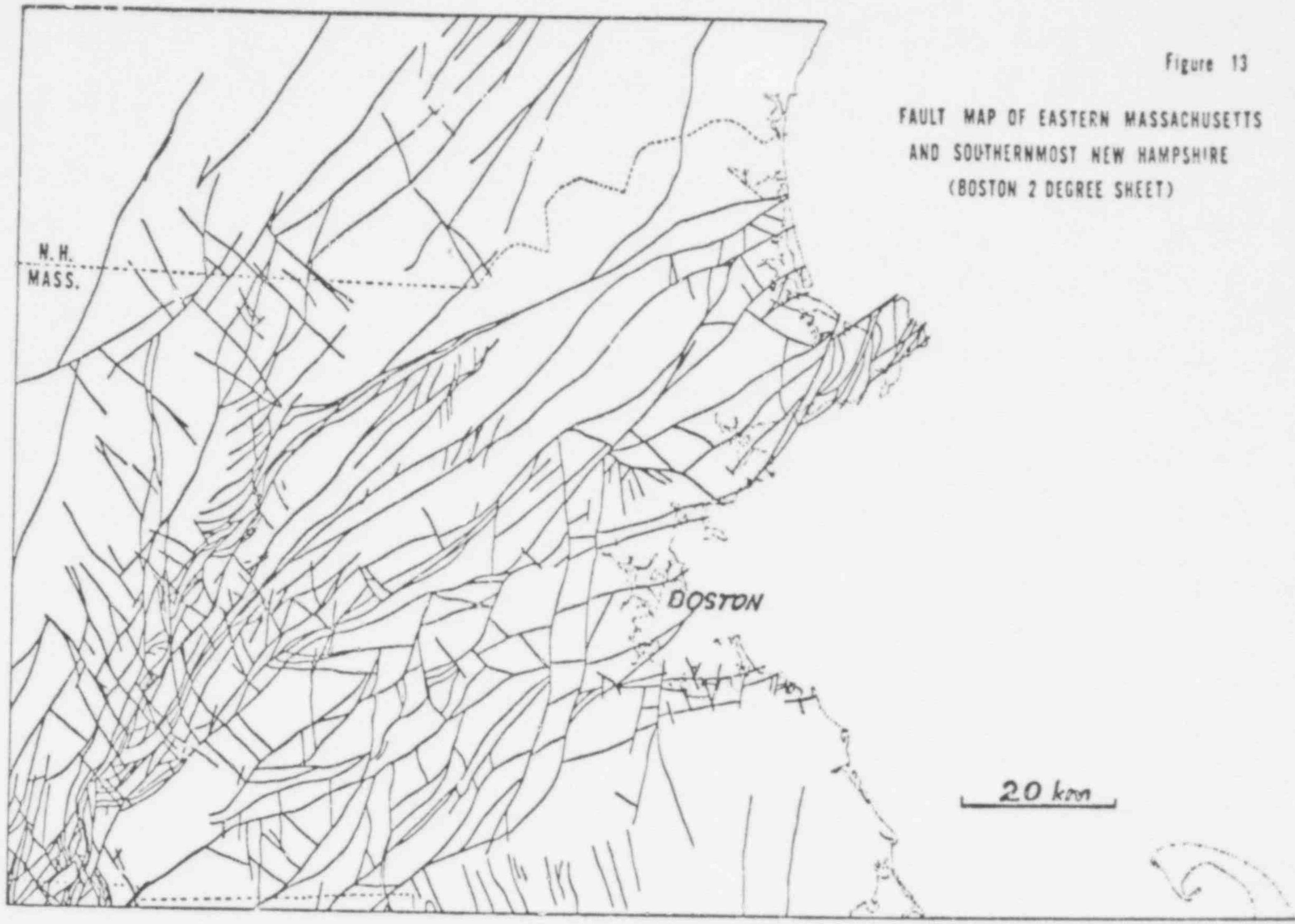


Figure 13

FAULT MAP OF EASTERN MASSACHUSETTS
AND SOUTHERNMOST NEW HAMPSHIRE
(BOSTON 2 DEGREE SHEET)

Observatory, (U.S. Geol. Survey open-file Rept. 77-131).

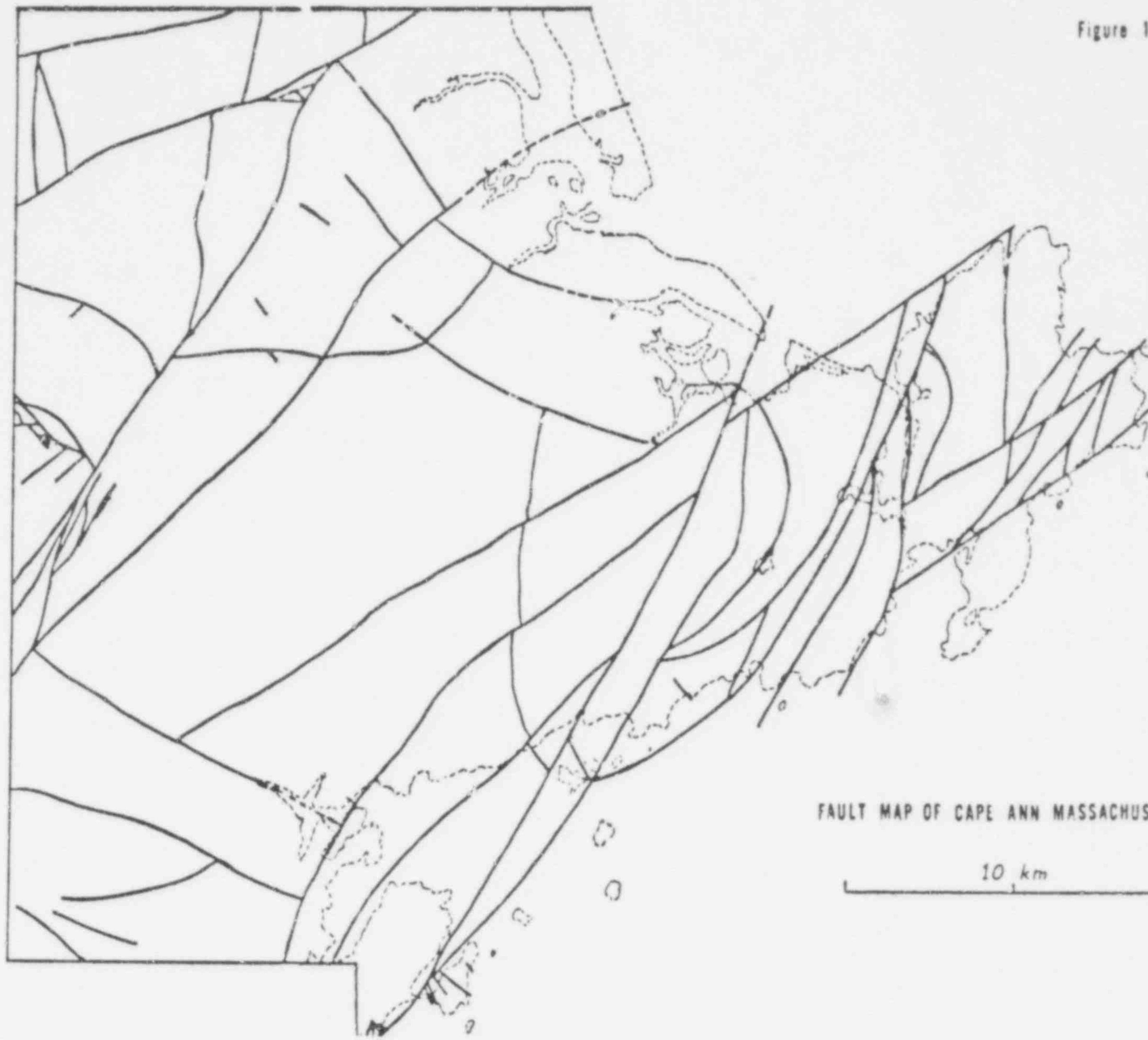
"Preliminary compilation of the bedrock geology of the land area of the Boston 2-degree sheet" by Patrick J. Barosh, Richard J. Fahey, M. H. Pease Jr.
(U.S. Geol. Survey Open-file Rept. 77-285)

STRUCTURAL STUDY OF CAPE ANN, MASSACHUSETTS

The Cape Ann area is in the most seismically active area in Massachusetts (Figures 8 and 9); the epicenter of the 1775 Cape Ann earthquake lies but a short distance offshore, yet little structural information is published on the area. This study is synthesizing the largely unpublished geologic, topographic and aeromagnetic data to obtain structural information. The study is directed by P. J. Barosh of the Weston Observatory who gratefully received the help of W. H. Dennen of the University of Kentucky and A. F. Shride of the U.S. Geological Survey, who have done most of the mapping in the region during the past eight years, and was assisted by B. F. Koch and C. K. Johnson of the Weston Observatory.

A geologic map of Cape Ann, at 1:62,500 scale, covering seven 7 1/2-minute quadrangles was completed. Structural information was available for most of the area, except for the Salem quadrangle, and reconnaissance mapping there by A. F. Shride and W. H. Dennen helped locate the major faults and revised the geologic units to match the adjacent quadrangles (Figure 14). A major northeast-trending fault zone which passes through the northwestern portions of the Salem and Ipswich quadrangles appears to represent the same structural break as does the Bloody Bluff fault to the southwest. This fault zone separates the regionally metamorphosed rocks on the northwest from the unmetamorphosed ones on the southeast. This major fault coincides with a very prominent aeromagnetic lineament, which continues offshore. About 100 small faults, averaging between 0.5 to 1m offset, were noted along the Cape

Figure 14



FAULT MAP OF CAPE ANN MASSACHUSETTS

10 km

Ann shoreline.

Topographic and aeromagnetic maps at the same scale were also compiled. The area has a prominent pattern of northeast- and northwest-trending topographic alignments. Many of the former correspond with faults; the northwest-trending ones probably represent joints and small faults. The aeromagnetic lineaments show a strong northeast trend and several coincide with known fault zones. A report on "The geology of the Cape Ann area, Massachusetts" is in preparation.

GEOLOGY OF THE EASTERN HALF OF THE PORTLAND AND BATH 2-DEGREE SHEETS, MAINE AND NEW HAMPSHIRE

Arthur M. Hussey II, of Bowdoin College, has undertaken a compilation and field investigation of the geology of the eastern half of the Portland 2° sheet and the Bath 2° sheet, Maine and New Hampshire (Figure 9). The new maps, at 1:250,000 scale, represent a significant step in understanding the geology of the seismically active areas in this region. The Portland-Bath area encompasses the principal northeast zone of faults in southern Maine and lies across part of the "Boston-Ottawa Zone;" the structural data obtained here is important in assessing this zone. The mapping clarifies indications of the northeast-trending faults within the area and their relations with those extending towards it from the south. The maps will serve as a base with which to interpret the remote-sensing data, which, in turn, will aid in further improvement of the maps. A major northeast-trending fault zone, which helps explain a number of geologic problems, was found in the Berwick 15' quadrangle, Maine and New Hampshire (Figure 15), but no

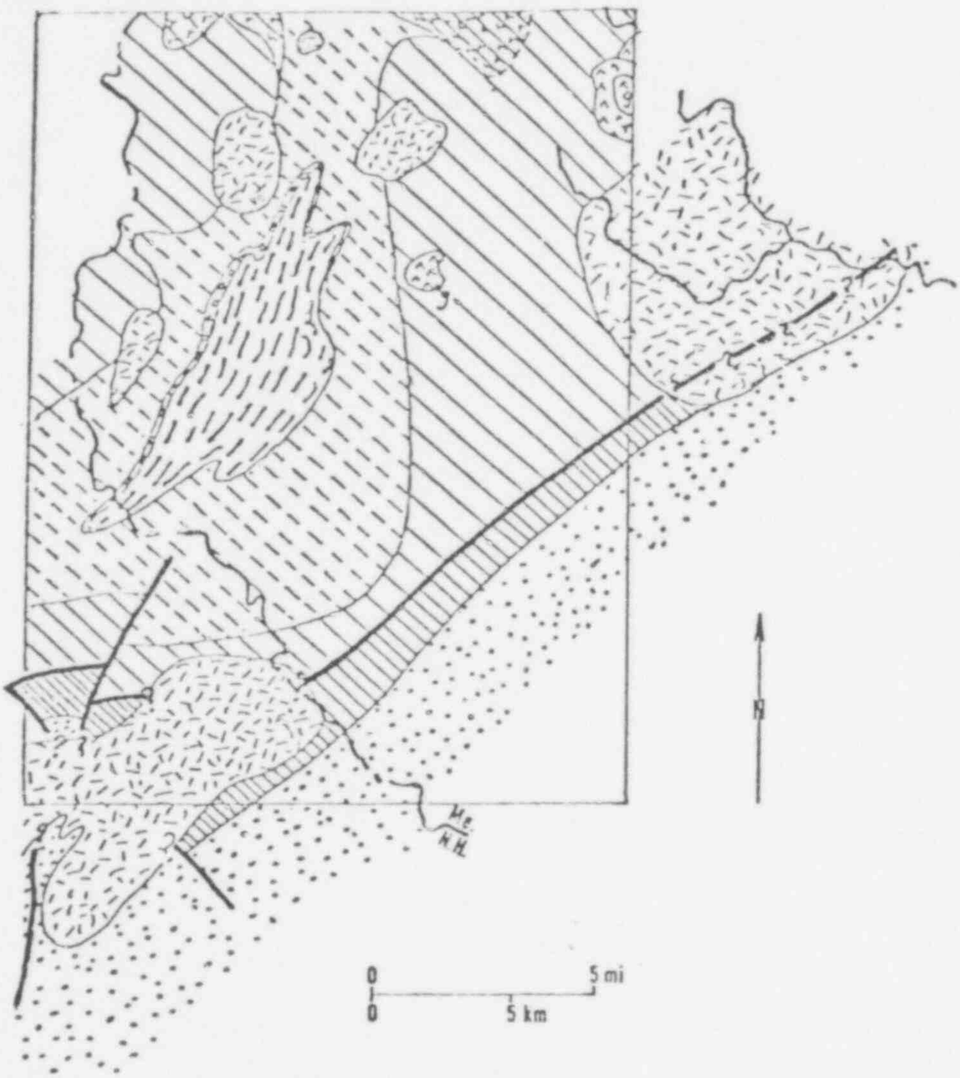


Figure 15. Berwick Quadrangle, Maine and New Hampshire Showing Major Fault Zones

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large northwest-trending faults or other structures were found along the "Boston-Ottawa Zone".

Much of the field investigation has been involved with remapping in the Berwick quadrangle, and adjacent parts of New Hampshire. This has resulted in significant revision of the geology of southwestern Maine and southeastern New Hampshire. The results of this work are preliminary in nature and wait upon detailed field mapping to confirm and refine the new interpretations. The principal structural and stratigraphic findings are summarized below:

1. The contact between the Gonic Formation and the lower member of the Rindgemere Formation is a major northeast-trending fault, possibly an extension of the Norumbega Fault System. The relation of the fault to the Lyman Pluton (calc-alkaline granite assigned to the New Hampshire Magma Series) is uncertain. Outcrops are not abundant enough to determine whether the contacts of the Pluton with the country rock are offset. Within the southern part of the Pluton the 15' topographic map shows a 1/8 by 1 mile shallow linear enclosed depression essentially on strike with the Gonic-lower Rindgemere fault. The trend of this lineament is nearly at right angle to the direction of glacial movement in this region and thus the lineament is not likely the result of glacial activity. The lineament is tentatively considered the result of post-intrusion faulting along the Gonic-Rindgemere contact fault, but that the major movement along the fault predated the intrusion of the Lyman Pluton.

2. In the Rochester, New Hampshire, area the Gonic-Rindge-

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mere contact seems to be offset by a north and a northwest-trending fault. No evidence has yet been found indicating whether the granite pluton in the Rochester area is offset by either of these two faults, although a conspicuous stream linear across the pluton coincides with the alignment of the northwest-trending fault as mapped on either side of the pluton. This same fault strikes toward a narrow lens of quartz diorite northwest of Rochester, but does not appear to offset that pluton. The quartz diorite has a well-developed, moderately dipping foliation parallel to inferred contacts with the lower Rindgemere; the granite is essentially unfoliated and is interpreted to be the younger of the two intrusives. Detailed mapping in the Rochester area is clearly needed to resolve these ambiguities.

3. The Lebanon Syncline, strongly overturned to the west and northest has been traced from the Lebanon-Acton area in the Berwick Quadrangle southwestward across the Alton quadrangle in New Hampshire. No major north or northwest trending faults interrupt the continuity of this structure.

4. Northwest fold trends in the Berwick quadrangle do not appear to be superimposed on northeasterly folds as a later structural event; local bedding trends are uniform and lack any suggestion of interference fold patterns, particularly in the outcrop belt of the upper Rindgemere and Towow formations. I tentatively interpret the change from northeast to northwest structural tends in the Berwick quadrangle to be related to the intrusion of the Sebago batholith and possible large scale strike-slip movement on the Gonic Rindgemere contact fault.

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5. A new stratigraphic unit here assigned as an unnamed member of the Towow Formation, was newly recognized and mapped during this project. This unit is a thin micaceous granule conglomerate lying between the Rusty Towow and the non-rusty upper Rindgemere. This conglomerate has been mapped on the northwest flank of the Lebanon syncline in the Berwick quadrangle. The same granule conglomerate in the same lithic sequence is present in the very western part of the Alton quadrangle in another deeper part of the Syncline.

6. The Flint Hill Fault in the Pawtuckaway quadrangle in New Hampshire is marked by several aligned silicified zones as described by Freedman, and by strong retrogressive metamorphism in which the biotite of the Berwick and related formations is altered to chlorite. The Flint Hill Fault does not appear to juxtapose contrasting rock types on either side of it, nor does it truncate stratigraphic units. The Fault does not appear to be offset by north or northwesterly trending faults.

7. No preferred orientation of joint sets is apparent in the Berwick quadrangle. Slickensided joint surfaces are very rare.

COMPLEMENTARY RESEARCH PROGRAMS IN THE NEW ENGLAND REGION

The New England Seismotectonic Study is coordinated with and complementary to a number of investigations in the region which are not receiving support under the same U.S. Nuclear Regulatory Commission contract. The Study is tied in closely with the program of the Northeastern U.S. Seismic Network, funded by both the U.S. Nuclear Regulatory Commission and the U.S. Geological Survey. The network has the responsibility of maintaining seismograph stations and monitoring earthquakes in the region. Earthquake epicenters in the region recorded by the network are now being published quarterly by the U.S. Nuclear Regulatory Commission. The Seismotectonic Study has an emphasis on geologic and geophysical investigations, as the basic seismological information is being well supplied by the network.

Other complementary projects in the region include the studies on the Clarendon-Linden fault zone, present day vertical uplift of the Adirondack Mountains, and the compilation and study of brittle structures by the New York Geological Survey, the seismic array investigations in New York by the Lamont Doherty Geological Observatory, geophysical and remote sensing studies in Maine by the U.S. Army Corps of Engineers and gravity surveys in eastern Massachusetts by Boston College and Massachusetts Institute of Technology. Coordinated investigations by the U.S. Geological Survey include structural geologic studies in eastern Connecticut, eastern Massachusetts and northwest Maine, engineering geologic studies near Penobscot Bay, Maine, and geophysical surveys in Lake George and off the southern New England coast. These and a number of other studies by university personnel and consultants are contributing greatly towards the understanding of the seismicity and structure in the region.

SECOND YEAR'S PROGRAM PLANS

The second year's program, outlined below, represents the first full program of studies which consists of 29, highly varied, individual studies (figure 16, table 2, appendix A) that will be intergrated to provide both general information on the tectonics of the region and more detailed information on the seismically active areas. These involve 25 investigators and over 20 assistants and require 17 subcontracts. The State Geological Surveys of New York, Connecticut and Maine, the U.S. Geological Survey and personnel from Bowdoin and Boston Colleges, the Universities of Rhode Island, Massachusetts, Kentucky and Delaware and the Rensselaer Polytechnic Institute are participating. They are scheduled to begin July 1, 1977. A symposium presenting results will be held during the winter. A full program for the following year will be planned and organized.

The program developed for 1978 intergrates seismological, geophysical, geological and remote sensing studies to complement the program of the Northeastern U.S. Seismic Network. The program is designed to provide: 1) regional information needed to acquire a general understanding of seismicity and its relations with geologic and geophysical features and the delineation of seismotectonic provinces, and 2) more detailed data in the areas of higher seismicity to attempt to reveal specific relations of seismicity with geology and to identify active features. Both regional and detailed studies will be used to evaluate the various hypotheses proposed to explain the causes of earthquakes in the region.

TABLE 2

PROPOSED STUDIES FOR 1978

(numbers keyed to figure 16)

1) EARTHQUAKE CATALOG OF INSTRUMENTALLY DETERMINED EVENTS IN NEW ENGLAND
Principal Investigators: Edward F. Chiburis and Russell O. Ahner
Weston Observatory, Concord Road, Weston, MA. 02193

2) INVESTIGATION OF THE NORTHERN FALL LINE ZONE
Principal Investigator: Allan M. Thompson
University of Delaware, Newark, Del. 19711

3) INVESTIGATION OF INFERRED HOLOCENE FAULTS IN LAKE GEORGE
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Building,
Albany, New York 12234

4) GEOLOGY OF THE HUDSON RIVER FROM NEW YORK CITY TO LAKE GEORGE
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Building,
Albany, New York 12234

5) ANALYSIS OF FAULTING ALONG THE DELAWARE AQUADUCT TUNNEL
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Building,
Albany, New York 12234

6) INVESTIGATION OF SEISMICALLY ACTIVE AREAS IN NEW YORK AND THEIR RELATIONS WITH FAULT PLANES INFERRED FROM INSTRUMENTAL DATA
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Building,
Albany, New York 12234

7) STRUCTURAL STUDY OF THE MOODUS AREA, CONNECTICUT
Principal Investigator: Sidney S. Quarrier
Connecticut Geological Survey, Department of Environmental
Protection, State Office Building, Hartford, CO. 06115

8) A GRAVITY INVESTIGATION IN THE METAMORPHIC TERRAIN OF SOUTH CENTRAL CONNECTICUT
Principal Investigator: John F. Kick
P.O. Box 6, Pleasant St., Dunstable, MA. 01827

9) CORRELATION OF MARINE AND LAND MAGNETIC SURVEYS WITH KNOWN TECTONIC FEATURES AND BEDROCK TYPES IN THE NARRAGANSETT BAY AREA, RHODE ISLAND
Principal Investigators: Barclay P. Collins and Robert L. McMaster
Graduate School of Oceanography, University of Rhode Island,
Kingston, RI 02881

10) MAGNETIC SURVEY OF THE NEAR-SHORE OFF EASTERN CONNECTICUT, RHODE ISLAND, AND SOUTHEASTERN MASSACHUSETTS
Principal Investigators: Robert L. McMaster and Barclay P. Collins
Graduate School of Oceanography, University of Rhode Island,
Kingston, RI 02881

11) MAGNETIC STUDY OF THE NARRAGANSETT PIER GRANITE AND ITS CONTACTS
Principal Investigator: Reinhard K. Frohlich
Department of Geology, University of Rhode Island, Kingston, RI 02881

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12) STRESS ANALYSIS OF THE CAPE ANN AREA, MASSACHUSETTS
Principal Investigator: William H. Dennen
Department of Geology, University of Kentucky, Lexington, KY 40506

13) GRAVITY INVESTIGATION OF THE CAPE ANN AREA, MASSACHUSETTS
Principal Investigators: Edward F. Chiburis, Russell O. Ahner, and John F. Kick
Weston Observatory, Concord Road, Weston, MA. 02193

14) GEOLOGICAL SYNTHESIS AND ANALYSIS OF NEW HAMPSHIRE
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

15) POSSIBLE LARGE-SCALE RIGHT-LATERAL FAULTING IN SOUTH-EASTERN NEW HAMPSHIRE
Principal Investigators: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193
Arthur M. Hussey II
Dept. of Geology, Bowdoin College, Brunswick, ME 04011

16) LINEAMENT, STRUCTURE AND STRESS STUDY OF COASTAL MAINE
Principal Investigators: Arthur M. Hussey, Allen Ludman, Olcott Gates, Davis S. Westerman, Kost A. Pankiwskyj and Donald Newberg
Maine Geological Survey, State Office Bldg, Room 211, Augusta, ME 04330
Fitzhugh T. Lee
Engineering Geology Branch, U.S. Geological Survey, Denver, CO
Dennis W. O'Leary
Branch of Petrophysics and Remote Sensing, U.S. Geological Survey, Denver, CO.;
Cleaves L. Rodgers
Sedgwick, ME 04676

17) STUDY OF THE PENOBSCOT LINEAMENT
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

18) BEDROCK GEOLOGY OF THE SHERBROOKE 2-DEGREE SHEET, MAINE AND NEW HAMPSHIRE
Principal Investigators: Gary M. Boone and Bradford A. Hall
Maine Geological Survey, State Office Bld., Room 211, Augusta ME 04330

19) STRUCTURAL STUDY OF EASTERN CONNECTICUT
Principal Investigators: Sidney S. Quarrier
Connecticut Geological Survey, Dept. of Environmental Protection, State Office Bldg., Hartford Conn. 06115
H. Pease, Jr. and Richard J. Fahey
Branch of Eastern Environmental Geology, U.S. Geological Survey, 150 Causeway St., Room 1304, Boston, MA 02114

20) AEROMAGNETIC LINEAMENT ANALYSIS OF NEW YORK
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Bldg., Albany, NY 122[illegible]

21) AEROMAGNETIC LINEAMENT ANALYSIS OF THE OFFSHORE AREAS SOUTH OF NEW ENGLAND
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

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22) INTERPRETATION OF AEROMAGNETIC LINEAMENTS OFFSHORE OF EASTERN MASSACHUSETTS AND NEW HAMPSHIRE AND THEIR POSSIBLE STRUCTURAL SIGNIFICANCE
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

23) LANDSAT LINEAMENT STUDY OF THE NORTHERN FALL LINE
Principal Investigator: Allan M. Thompson
University of Delaware, Newark, Del. 19711

24) MAJOR FRACTURE SYSTEMS OF WESTERN MASSACHUSETTS FROM LANDSAT IMAGERY
Principal Investigator: Donald U. Wise
University of Massachusetts, Amherst, MA 01003

25) LANDSAT LINEAMENT STUDY OF VERMONT
Principal Investigators: Thomas W. Jones
Rensselaer Polytechnical Institute, Troy, New York 12181
Yngvar W. Isachsen
New York Geological Survey, State Education Bldg., Albany, NY 12234
Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA 02193

26) LANDSAT LINEAMENT STUDY OF NEW HAMPSHIRE
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

27) LANDSAT LINEAMENT MAP OF SHERBROOKE 2° SHEET, MAINE AND NEW HAMPSHIRE
Principal Investigator: Patrick J. Barosh
Weston Observatory, Concord Road, Weston, MA. 02193

28) LANDSAT LINEAMENT MAP OF COASTAL MAINE
Principal Investigator: Dennis W. O'Leary
U.S. Geological Survey, Branch of Remote Sensing, Denver, CO.

29) STUDY OF A MAJOR LINEAMENT NORTH OF THE ADIRONDACKS
Principal Investigator: Yngvar W. Isachsen
New York Geological Survey, State Education Bldg., Albany, NY 12234

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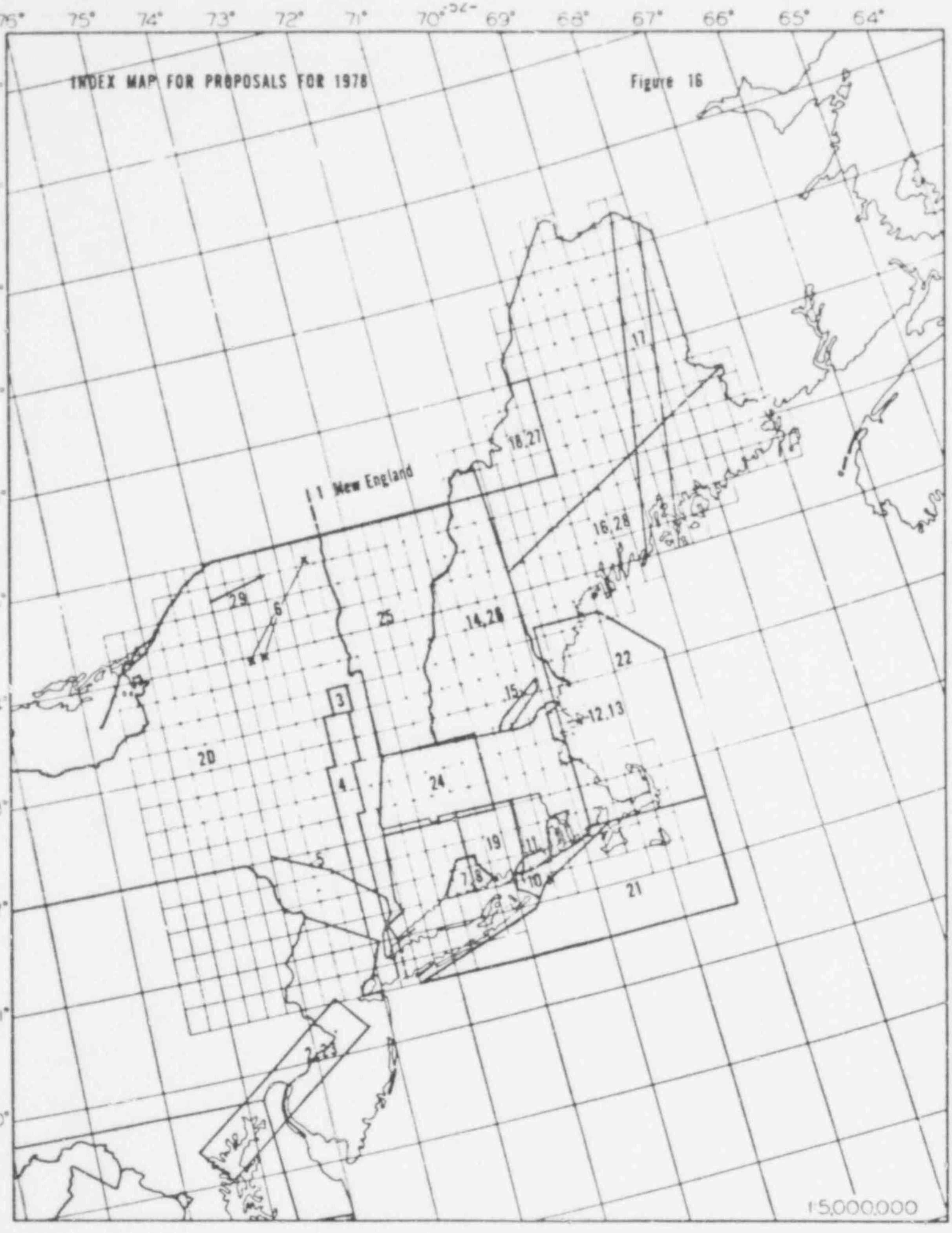

INDEX MAP FOR PROPOSALS FOR 1978
Figure 16
76°
75°
74°
73°
72°
71°
70°
69°
68°
67°
66°
65°
64°
50°
49°
48°
47°
46°
45°
44°
43°
42°
41°
40°
1 New England
17
18,27
16,28
25
14,26
29
6
22
15
12,13
3
20
4
24
19
11
5
7
8
10
21
2,23
1:5,000,000

SEISMOLOGICAL STUDIES

The principal effort this year will be towards completion of earthquake catalogs of the region, improved epicentral maps and the planning for microearthquake studies for the following year. A new epicentral map for New York has recently been prepared by Paul Pomeroy, and a new epicentral map and catalog of historic earthquakes in New England was compiled by Andrew Lacroix. These, along with a proposed study by E.F. Chiburis and R.O. Ahner, Weston Observatory, to reevaluate and catalog the instrumental data for New England, will nearly complete the updating of the data on earthquakes of the region and provide a much firmer basis on which to evaluate the seismicity of the region. The greatly improved Northeastern U.S. Seismic Network (Figure 7) will provide new, more accurate data over the next few years.

GEOLOGICAL AND GEOPHYSICAL STUDIES

SEISMICALLY ACTIVE AREAS

Studies are proposed for all of the more seismically active areas of the Northeast U.S. (Figure 8). The kinds of studies proposed depend on the information known about the area and vary from compilations and analysis of existing data to specifc site investigations of possible active faults.

NORTHERN FALL LINE AREA-SOUTHWEST CONNECTICUT

A concentration of seismic activity exists along the northern Fall Line (Figures 8 and 17), which may be a zone of faults, as summarized in last year's work by Barosh and Pease (in press). This zone probably extends across the Hudson, southeast of and parallel to the Ramapo and adjacent faults, along which seismic activity has occurred (Yash Aggawall, personal communication). The Fall Line Zone appears to connect with very prominent aeromagnetic lineament zones that extend into southwest Connecticut (Figure 6 and 18). A proposed study by A.M. Thompson, University of Delaware, would begin a comprehensive investigation of the northern Fall Line Zone (2) (number here and in following discussion referenced to Figure 16).

CHAMPLAIN-HUDSON

Three proposed studies by Y.W. Isachsen, New York Geological Survey, would investigate the area of higher seismic activity along the Hudson River valley (Figures 8 and 16). A fault in Lake George with possible Holocene movement would be investigated

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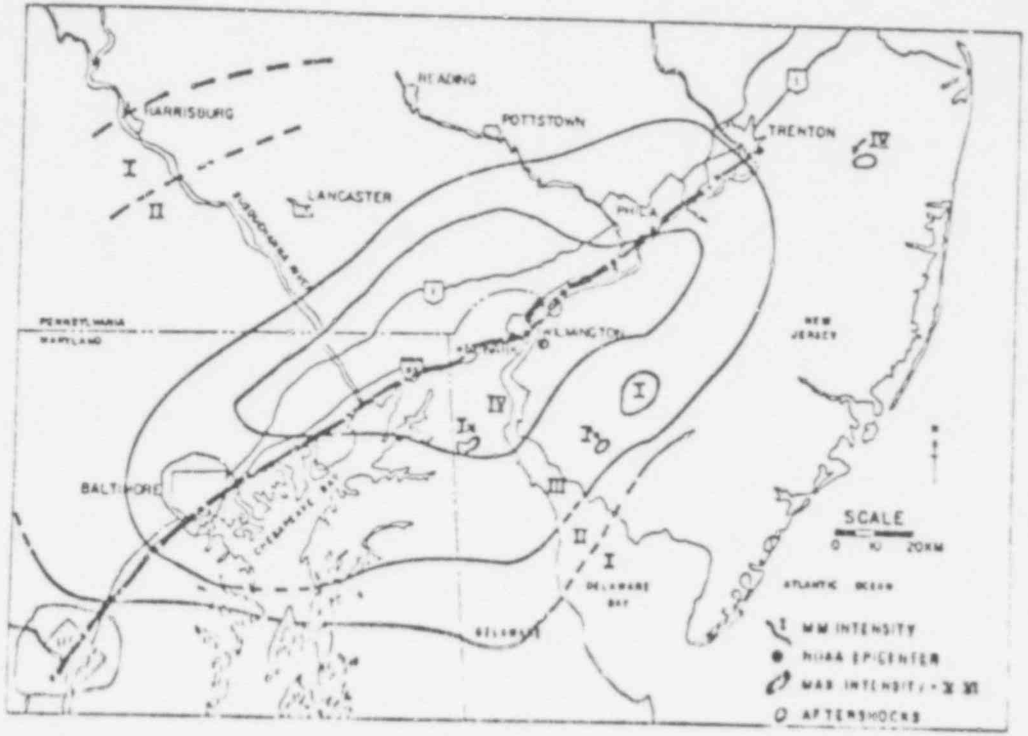


FIGURE 17. ISOSEISMAL MAP FOR THE DELAWARE-NEW JERSEY EARTHQUAKE OF FEBRUARY 28, 1973 SHOWING NORTHERN FALL LINE ZONE (dot-dash line) (after Sbar et. al., 1975)

(3), basic geologic data would be compiled and analyzed for evidence of the Hudson River's course being fracture controlled (4), and detailed information on faulting mapped in a tunnel across the area would be evaluated for its regional implications (5).

ADIRONDACK AREA

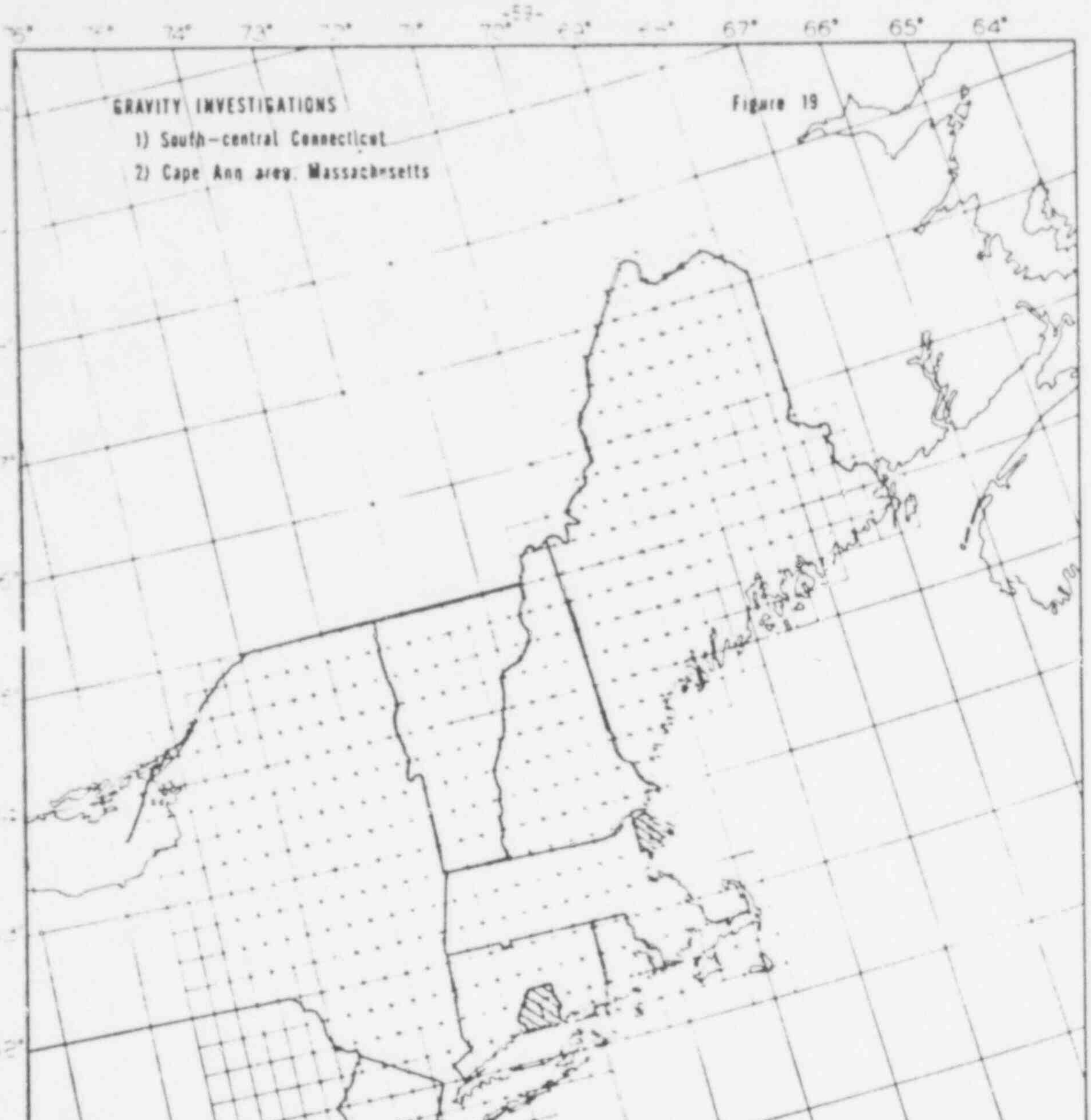
Some of the more precise locations of recent seismic events in the northeast are in the Adirondack area. The precision is such that it is reasonable to conduct field investigations to look for surface effects. In addition, fault planes have been inferred from instrumental data by Yash Aggarwall (personal communication) and projected to mapped and possible surface faults. These narrow traces will be checked on the surface. Three such investigations are proposed by Y.W. Isachsen, New York Geological Survey (6, Figure 16). Investigations of this type are extremely important for the understanding of seismicity in the region and should become more common as the precision of epicentral location improves in the region. The size of the earthquakes, however, is too small to expect any significant surface fracturing, but some may have occurred and, if movement has been repeated along the same zone, some geomorphic expression should be present, although individual movements might be small.

MOODUS AREA

The available basic geologic data on the Moodus area, Connecticut, was assembled and lineaments studies conducted last year in a cooperative program with the Nuclear Regulatory Commission (Figures 16 and 11). This year field investigations of a number of possible structures at specific sites are necessary to try to gain an understanding of the faulting in the area: a proposed study by S.S. Quarrier, Connecticut Geological Survey (7), would do this. The present reconnaissance gravity map of the Moodus area shows some interesting changes and suggests further work would be most beneficial. A much more detailed gravity map of the area than now exists is proposed by J.F. Kick, Lowell Technical Institute (8) (Figure 19). This map may help bring out the major structural changes.

NARRAGANSETT AREA

Many faults in New England are expressed as magnetic lineaments so that magnetic lineament studies provide a useful guide to possible structures in the region. New large aeromagnetic surveys are beyond the limits of the present budget, but smaller magnetic surveys with more specific goals can be accomplished and new magnetic maps that become available can be analyzed. The seismically active area of southern Rhode Island (Figures 8 and 20) with its extensive water and glacial-debris cover is an area where magnetic surveys can be of great benefit. The elongation of the isoseismals from the recent Portsmouth, Rhode Island, earthquake in eastern Narragansett Bay (Albert, Chiburis and Frohlich, 1977) parallel the probable main structure trend suggest some structural control. Three integrated proposed studies, from the University of Rhode Island, on the magnetics in southern Rhode Island and adjacent offshore areas will fill in



GRAVITY INVESTIGATIONS
1) South-central Connecticut
2) Cape Ann area, Massachusetts
Figure 19
74°
73°
67°
66°
65°
64°
42°
40°

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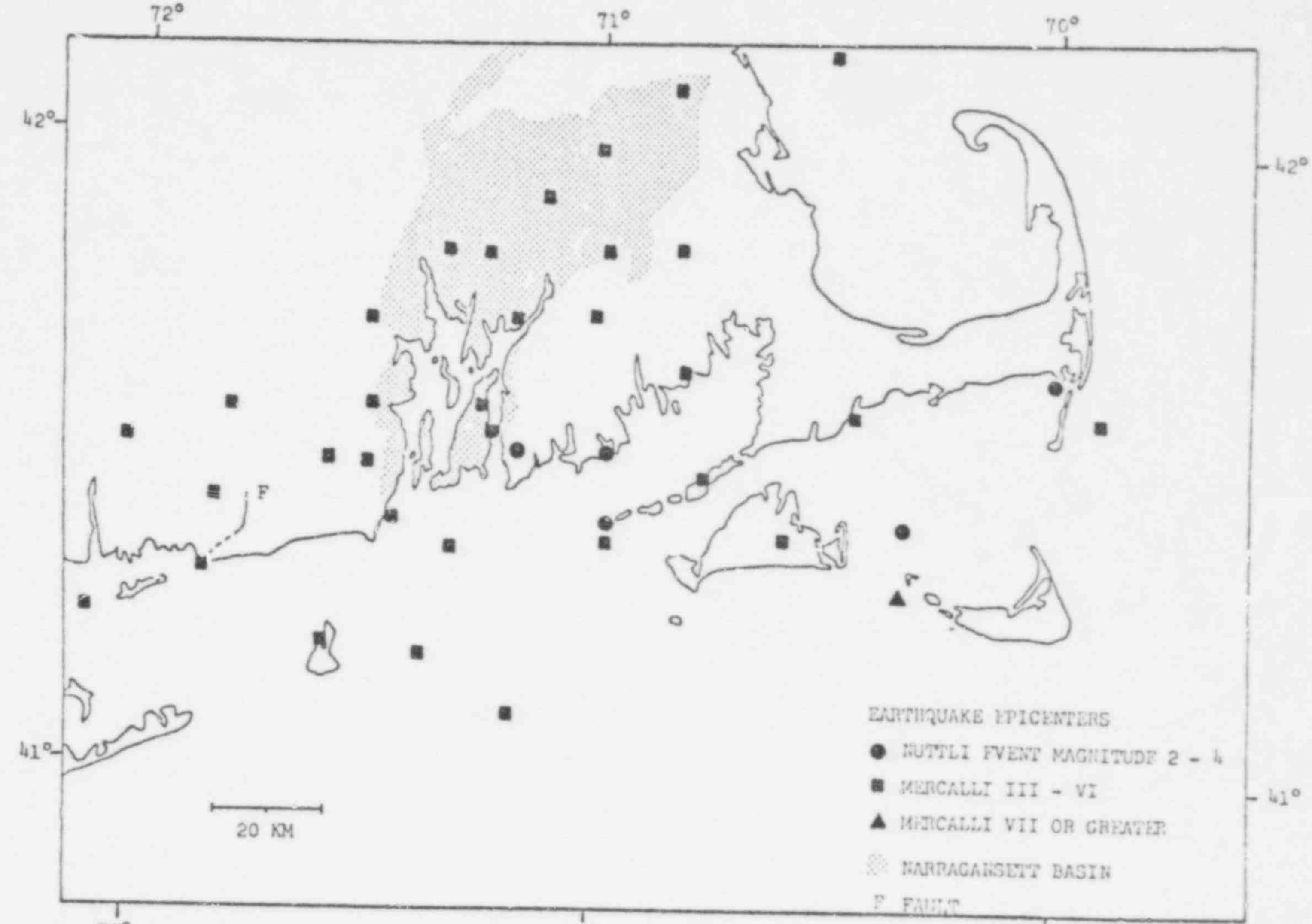

Epicenter Map of the Narragansett Bay Area (New England Power Company 1976)

Figure 30

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gaps in the present coverage and provide far more detail to aid in the unraveling of the structure in the coastal area and the seismically active Narragansett Bay (9, 10 and 11 Figures 16 and 21). There is uncertainty regarding the continuity of faults, bedrock contact trends beneath the Narragansett Bay, as well as the existence and strike of undisclosed structural features under the bay which may extend onto land. The structural relations of the newly dated fossiliferous Cambrian rocks at the south end of the Bay are as yet unknown. The present aeromagnetic data provides insufficient information. A marine magnetic survey of part of the Bay by B.P. Collins and R.L. McMaster provides far more definitive data. A proposed study by B.P. Collins and R.L. McMaster (9) to continue this work should contribute greatly to the understanding of the structural geology of the area.

Documented or inferred faulting in coastal Rhode Island that crosses the shore is restricted to the Rhode Island-Connecticut border where the Westerly Fault trends southwest offshore and in the Narragansett Bay where several unnamed faults have been mapped at the southern end of Aquidneck Island-- two trending southward, parallel to the Bay's borders, and one directed eastward toward Sakonnet Point (Quinn, 1971). Other fracture zones have undoubtedly gone undetected in this part of the Bay as well as along the coast.

Magnetic studies on the near-shore area by R.L. McMaster and B.P. Collins (10) and on the poorly exposed onshore portions of coastal Rhode Island by R.K. Frohlich (11) will establish a more comprehensive understanding of the extent and scope of faulting

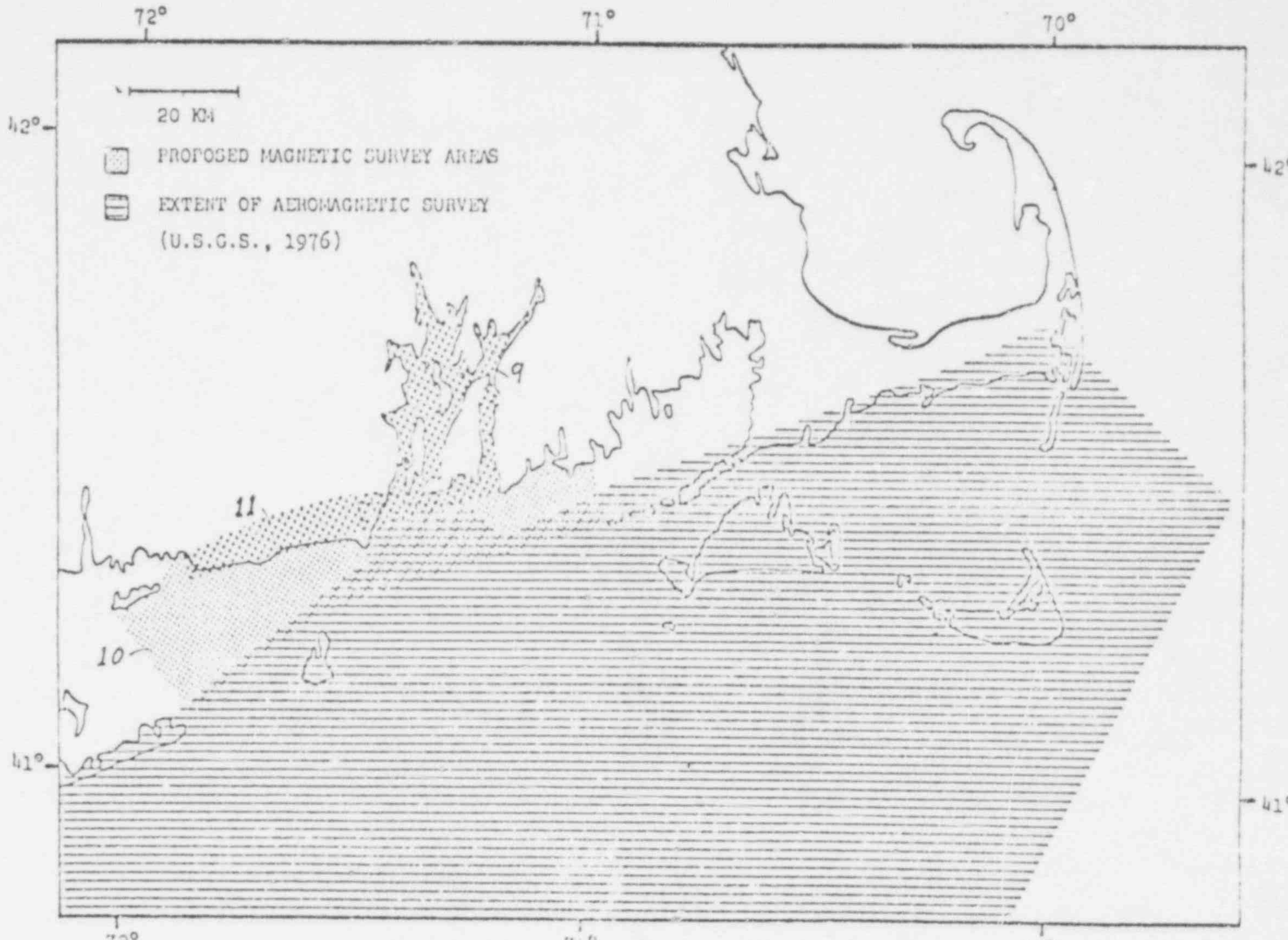


FIGURE 21. MAGNETIC SURVEYS NEAR NARRAGANSETT BAY, RHODE ISLAND
(numbers correspond to Figure 16 and Table 2)

and zones of possible faulting than presently exist. A more realistic correlation can be made with the known seismicity by acquiring more details of the tectonic fabric in the area. Furthermore, knowledge can be gained as to the significance of pre- or post-Carboniferous tectonic events relative to presently active or potentially active fractures.

CAPE ANN AREA

The geologic mapping of the Cape Ann area (Figure 16) is complete, except for a few places in the Salem Quadrangle, and the major faults are well delineated onshore (Figure 14). The acquisition of this basic data now allows more specialized studies to begin. Some detailed mapping of the joints was begun last year. The initial results showed a good grouping of trends of different types of joints and indicated that cooling and tectonic joints could be separated. These data along with some additional joint data and the analysis of the numerous dikes in the area would serve as a basis for a stress analysis of the Cape Ann area. Such an analysis would provide some information on the present-day stress field and a firm basis upon which to add other stress measurements such as overcoring. A far more detailed gravity map of the area than is presently available should help in bringing out the more important fault zones and in gaining more information on a gabbroic body that has been postulated to underlie the Cape. Vertical movement due to density differences between the gabbroic and granite rocks in the area is one of the hypotheses for earthquake mechanisms. The study proposals for a stress analysis by W.H. Dennen, University of Kentucky (12), and gravity measurements by E.F. Chiburis and R.O. Ahner, Weston Observatory, and J.F. Kick (13) (Figure 19) outlined below would greatly enhance our knowledge of the area.

MERRIMACK VALLEY-WHITE MOUNTAIN AREA

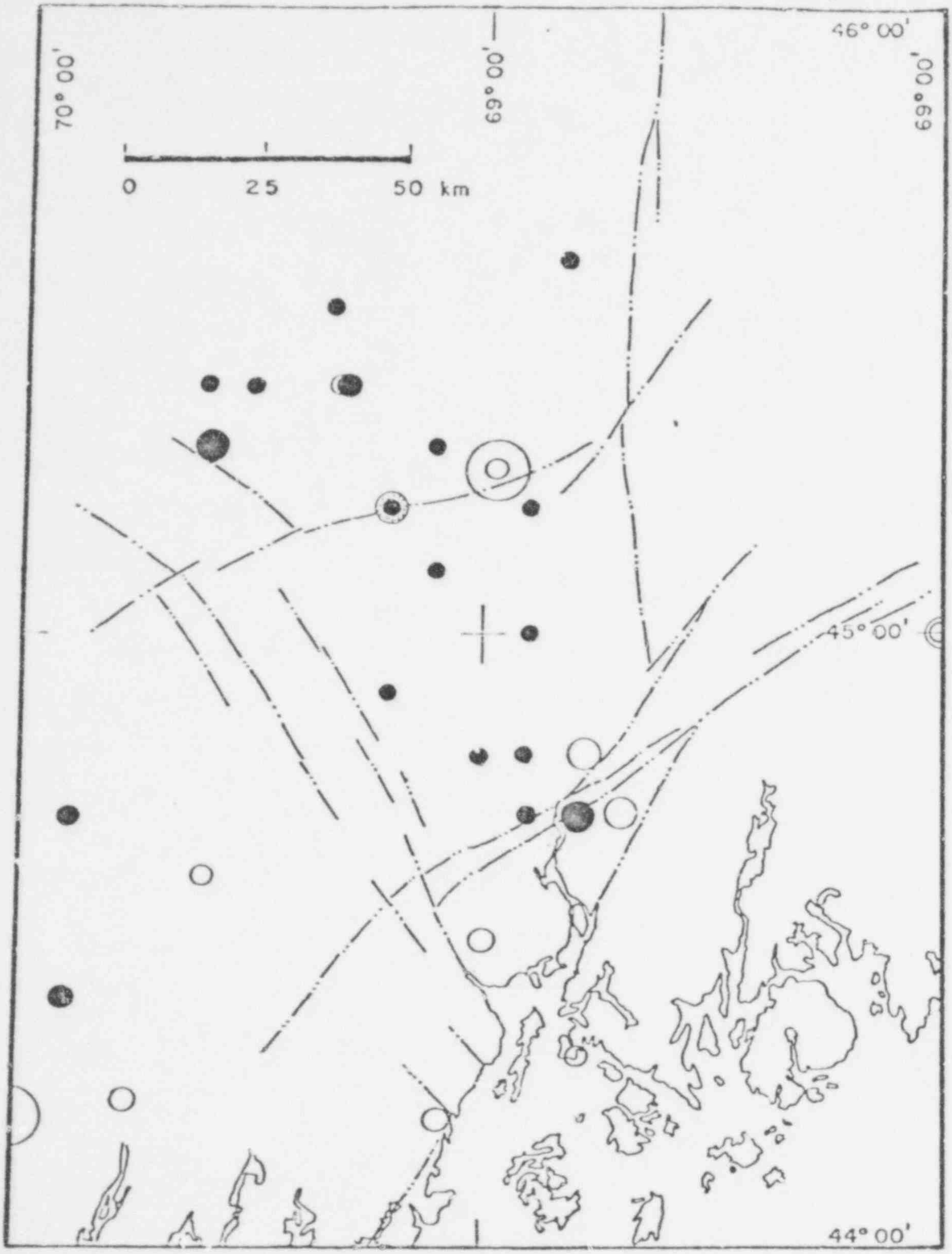
The geologic and remote sensing data on the more seismically active area in the White Mountains and Merrimack Valley needs to be carefully assessed before initiating specific studies to be most efficient and economical. A great deal of mapping sponsored by Boston Edison in the area was done last year and these reports are just now becoming available. These and other recent studies in the area, such as the drainage pattern investigation by L.R. Page (personal communication), need to be compiled and analyzed before selecting areas for further work. A study (14) is proposed by P.J. Barosh, Weston Observatory, to do this and also to include a review of other recent work in the state of New Hampshire. A planned Landsat lineament study (26) of the state will also aid in selecting the critical areas for investigation.

One specific geologic feature of possible major importance, that was discovered during reconnaissance mapping in the Boston 2 Degree sheet during last year's effort should be investigated. Field evidence suggests the possibility of a northeast-trending zone of faults, with major right-lateral movement, that cuts across the "Boston-Ottawa" trend and may bound the seismic area on the southeast. This offers the first possibility to document large-scale movement in the region. A study is proposed to investigate this by P.J. Barosh, Weston Observatory, and A.M. Hussey, Bowdoin College (15, Figure 16).

ACTIVE AREAS IN MAINE

The three areas of higher seismicity in Maine are, for the most part, only covered by reconnaissance geologic mapping. A great deal more basic geologic data is needed before an understanding of the geologic structure and its relation with seismicity will be known. A Landsat lineament analysis combined with field investigations of prominent lineaments, geologic mapping of selected areas, and an investigation of the present stresses would add much needed knowledge. The three more active areas are around the Casco Bay-Androscoggin River Valley, to the northwest of the northern end of Penobscot Bay and around Passamaquoddy Bay. More is known of the structure around Passamaquoddy Bay than the others and mapping this year to fill in gaps should provide a general picture of the major faulting within the Maine part of this seismic area. Very little is known of faults near Penobscot Bay outside of those seen in the Bay itself. A fault with probable recent movement cuts Sears Island within the Bay. A preliminary lineament study of the area shows prominent lineament zones bounding the higher seismic area (Figure 22) and a field check during last year's work at the south end of one zone showed evidence of faulting. The zone of lineaments extending northward from the head of Penobscot Bay, including the lineament through Orland and those along the Penobscot River (Figure [illegible] and shown passing just right of center on Figure 22) will be investigated in a proposed study (17) by P.J. Barosh, Weston Observatory, in an effort to locate faults. In addition, an investigation of the present stresses in the rocks near the Bay may help in understanding which faults may be active and explain some of the small vertical offsets across joints in

Figure 22



Epicenter Map of the Penobscot Bay Area, Maine, showing some Landsat Lineaments (Epicentral data from Boston Edison Company 1976)

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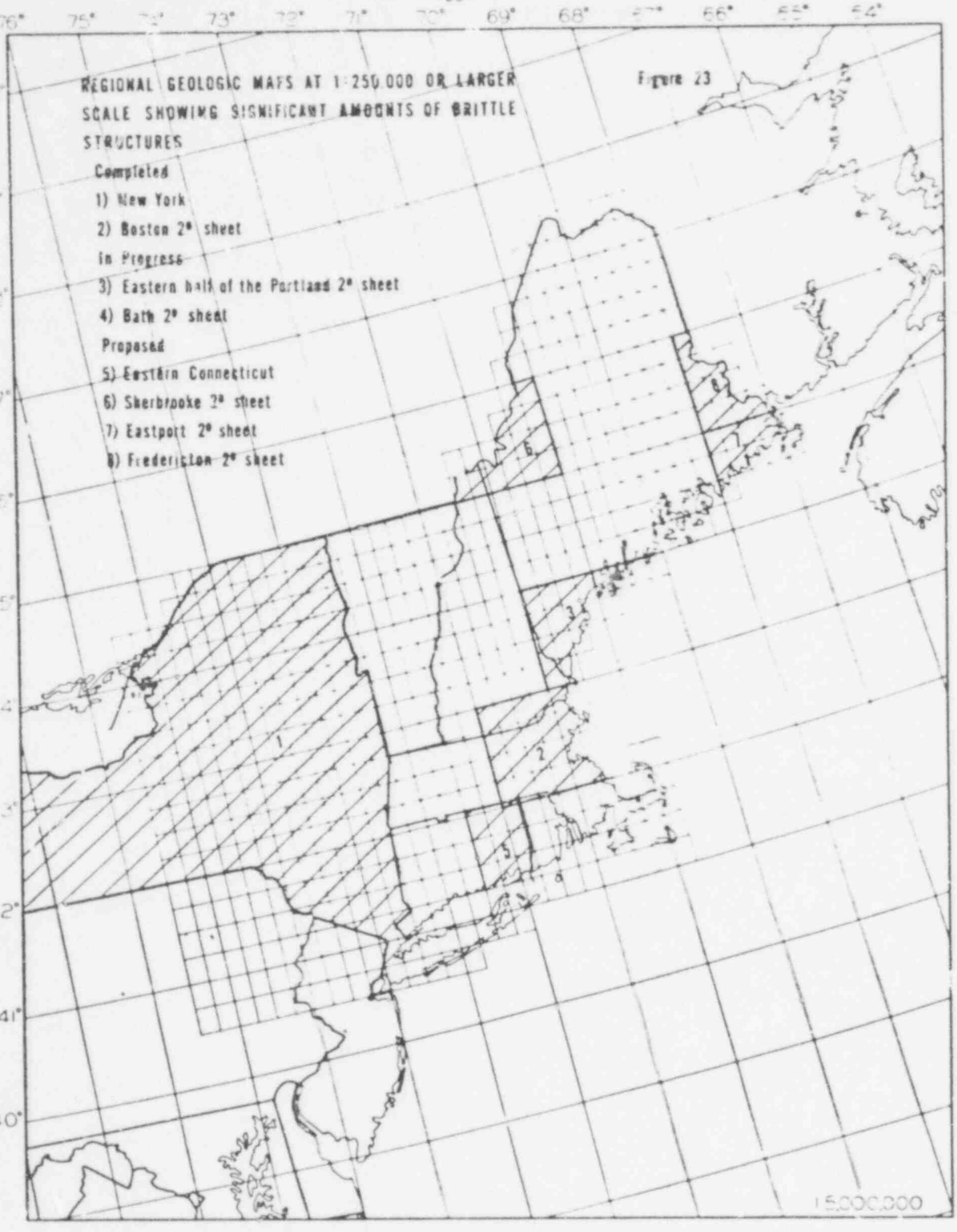
glacially striated bedrock surfaces in the area of the Bay. The lineaments in the southern end of the Casco Bay-Androscoggin River area will be studied, particularly along the river north of Lewiston, Maine, where epicenters of three recent earthquakes are aligned.

A proposed study (16) to investigate the coastal Maine area by the Maine Geological Survey and the U.S. Geological Survey includes work in the Passamaquaddy region by Olcott Gates, D.S. Westerman and A. Ludman, Maine Geological Survey; the Penobscot Bay region by F.T. Lee, D.W. O'Leary and C.L. Rodgers, U.S. Geological Survey; and the Casco Bay Androscoggin River Valley by A.M. Hussey II, K.A. Pankiwskyj and D. Newberg, Maine Geological Survey.

REGIONAL GEOLOGIC STUDIES

Regional geologic studies are very important and should be conducted in addition to those in the areas of higher seismicity. They provide information needed in developing the regional fault pattern, better understanding of the tectonic features and, most importantly, the geologic data necessary to develop criteria for bounding seismic provinces. A very desirable goal would be to have geologic coverage of the entire region with adequate structural data at 1:250,000 scale or better. Studies of two regions are proposed below (Figure 23). A study of the Sherbrooke 2-degree sheet (18) that is proposed by G.M. Boone and B.A. Hall, Maine Geological Survey, working in cooperation with R. H. Moench of the U.S. Geological Survey would add greatly to the understanding of the structure bounding the northern



REGIONAL GEOLOGIC MAPS AT 1:250,000 OR LARGER SCALE SHOWING SIGNIFICANT AMOUNTS OF BRITTLE STRUCTURES
Figure 23
Completed
1) New York
2) Boston 2° sheet
In Progress
3) Eastern half of the Portland 2° sheet
4) Bath 2° sheet
Proposed
5) Eastern Connecticut
6) Sherbrooke 2° sheet
7) Eastport 2° sheet
8) Fredericton 2° sheet
76°
75°
73°
72°
71°
70°
69°
68°
66°
54°
50°
47°
46°
45°
44°
43°
42°
41°
40°
1
2
3
5
6
7
8

447 120

end of the White Mountains. A study of eastern Connecticut by S.S. Quarrier Connecticut Geological Survey and M.H. Pease, Jr., U.S. Geological Survey will help demonstrate the structural connections between the Moodus and Cape Ann areas (Figure 16).

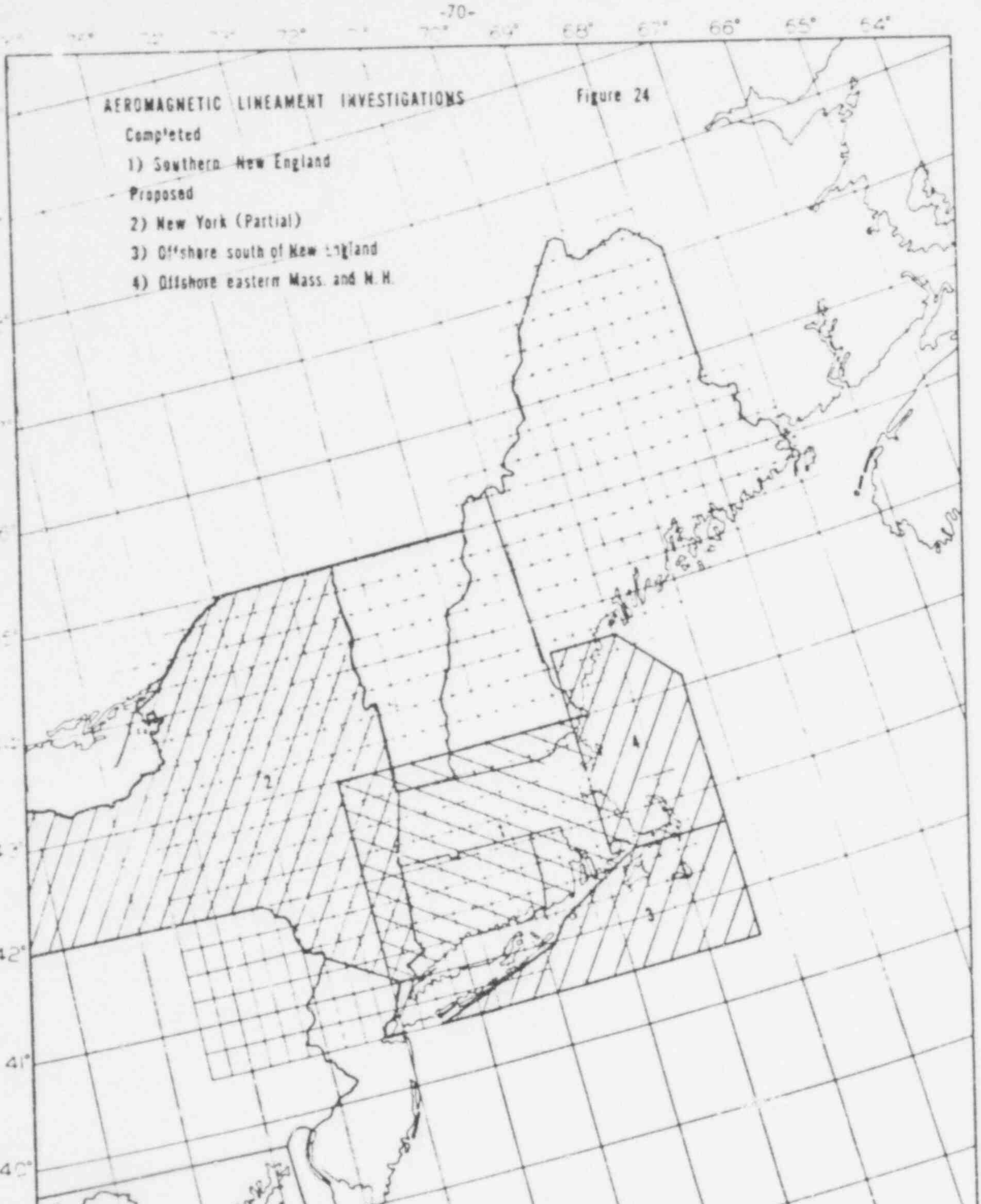
REGIONAL GEOPHYSICAL STUDIES

Analysis of aeromagnetic maps has been demonstrated to be a valuable method in locating possible faults and unraveling structural patterns. New regional aeromagnetic maps have become available for much of New York and areas off the south and east coasts of southern New England. Analysis of these data would delineate many new possible structures, provide the means to extrapolate many onshore structures into offshore areas with a much greater degree of certainty than at present, and would clarify the structural pattern. These studies would extend the aeromagnetic studies of Barosh, Pease, Schnabel, Bell and Peper (1977) and Barosh and Pease (1974) for southern New England to the west, south and east (Figure 24). A study (20) is proposed for New York by Y.W. Isachsen, New York Geological Survey and two offshore (21 and 22) by P.J. Barosh, Weston Observatory.

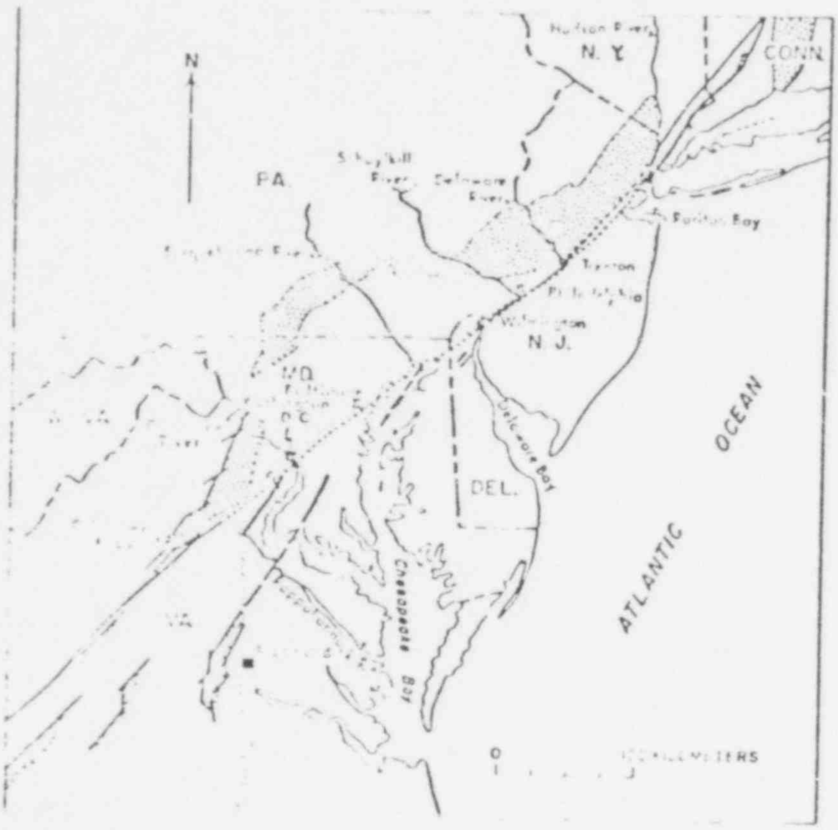
REMOTE SENSING STUDIES

Remote sensing lineament studies are of significant value in indicating probable brittle structures in the region. New faults found in field checking lineaments in both New York and Maine during the first year's program underscores their usefulness. Fractures expressed as lineaments are also more apt to have had recent movement than those not so expressed.

Lineament studies of the region using Landsat, U2 and high-


AEROMAGNETIC LINEAMENT INVESTIGATIONS
Figure 24
Completed
1) Southern New England
Proposed
2) New York (Partial)
3) Offshore south of New England
4) Offshore eastern Mass. and N.H.
-70-
72°
70°
69°
68°
67°
66°
65°
64°
46°
45°
43°
42°
41°
40°
2
3
4
1:5,000,000

altitude photos were planned for in the original proposal to help fill out the brittle fracture pattern and guide the geologic investigations. A lineament map of New York is complete (Isachsen, 1977), and similar maps for the Moodus area, Connecticut, and Penobscot Bay area, Maine, are being compiled. These and the studies planned for this year for the northern Fall Line (23) by A.M. Thompson, University of Delaware; western Massachusetts (24) by D.U. Wise, University of Massachusetts; Vermont (25) by T.W. Jones, Renssellaer Polytechnic Institute, Y.W. Isachsen, New York Geological Survey, and P.J. Barosh, Weston Observatory; New Hampshire (26) and Sherbrooke 2 Degree Sheet Maine (27) by P.J. Barosh, Weston Observatory; and coastal Maine (28) by D.W. O'Leary, U.S. Geological Survey will provide coverage for much of the region (Figure 25). In addition, a major lineament zone near the northern border of the Adirondacks (29) and one extending northward from Penobscot Bay (17) will be investigated by Y.W. Isachsen, New York Geological Survey and P.J. Barosh, Weston Observatory respectively. Landsat lineament studies of the few remaining areas and a lineament map of the entire region are planned to be finished the following year.



[illegible] ...ERN FALL LINE ZONE. Heavy lines, faults, [illegible] where interpretative; heavy dotted line probable fault zone, queried where extended by Hobbs (1904) and [illegible] (1946); fine dotted line, contact of Coastal Plain [illegible]; stippled areas, Triassic-Jurassic deposits. [illegible] data from Stose, 1928; Jacobeen, 1972; Higgins, [illegible] and Fisher, 1974, Spodjaric, 1975, Lewis and Kümmel, [illegible], L. Pavlides and R. B. Mixon personal communication.

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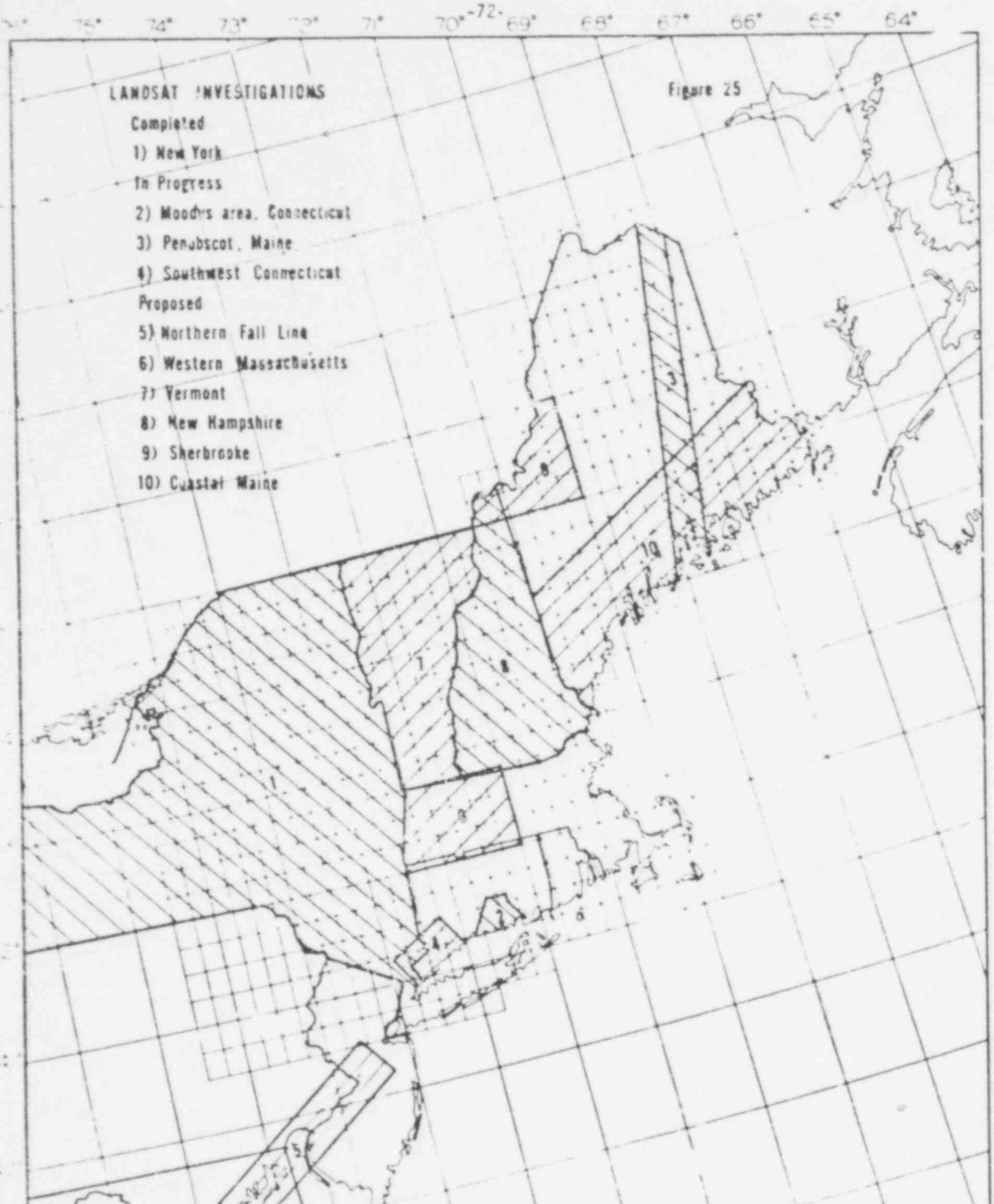

POOR ORIGINAL

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APPENDIX A

PROPOSED STUDIES ACCEPTED FOR 1978

(Indexed on figure 16 in text)

1) Earthquake catalog of instrumentally determined events in New England

Principal Investigators: Edward F. Chiburis and
Russell O. Ahner
Weston Observatory, Boston College
Concord Road, Weston, MA 02193

The objective of this study is to produce a complete catalog of recent earthquakes and a plot of epicenters, 1:500,000 scale, for instrumentally determined events for the New England region. All previously recorded data will be scanned and analyzed to detect, locate, determine magnitudes and, if possible, focal depths of earthquakes in New England. Various velocity models will be tested and evaluated to improve accuracy of locating epicenters, although the velocity model developed for southern New England will be the principle location model. An estimate of accuracy of locations will also be determined. The primary data consists of that from: a) Weston Observatory 1963-68 and 1974-present, b) University of Connecticut 1972-present, c) N.E.S.A. 1938-50 and d) Long Range Seismic Measurement (LRSM) Stations total operating time.

A catalog containing some 400 to 500 instrumentally recorded events and maps showing epicenters will be compiled by June 30, 1978.

Budget contributed by the U.S.N.R.C......$29,600

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2) Investigation of the Northern Fall Line Zone

Principal Investigator: Allan M. Thompson
University of Delaware
Newark, Delaware 19711

The study will compile, analyze and integrate existing aeromagnetic, gravity, satellite imagery and ground geologic information into a unified picture of the current geological and geophysical state of the Coastal Plain-Piedmont contact zone in the Middle Atlantic States. The area of interest, comprises a 30-mile wide strip extending from Annapolis, Maryland to New Brunswick, New Jersey. Geophysical data will be obtained from published and unpublished U.S. Geological Survey reports and maps, and publications of state geological and environmental agencies. Satellite data will be obtained from primary black-and-white imagery, bands 5 and 7, and from false-color imagery. Ground geologic data will be integrated from published reports and maps, and from the extensive personal knowledge of the area. New ground geologic data will be continuously accumulated through monitoring of surface cuts and borings in efforts to upgrade existing knowledge.

The specific goals of the research will be these: 1) compilation and reduction to common scale of aeromagnetic data from existing aerial surveys, 2) compilation of existing gravity and aerogravity data, and correlation with magnetic data, 3) analysis of satellite imagery and band analysis for lineaments and other evidence of structural control, 4) compilation of existing ground geologic data into a coherent

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geologic map consistent with modern ideas of Appalachian and East Coast evolution, and 5) compilation from the literature of the known seismicity of the area.

The research will generate a series of strip maps of probably scale 1:62,500 or smaller showing the above types of data as overlays. The maps will have a short explanatory text, including references for source data and tectonic significance of the features shown.

Budget contributed by the U.S.N.R.C......$4,000

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Geologic and Lineament Studies in New York

Principal Investigator: Yngvar W. Isachsen
New York Geological Survey
State Education Building
Albany, New York 12234

The following six studies will be conducted:

3) Investigation of inferred Holocene faults in Lake George.

Studies will be made of inferred Holocene faulting revealed in Lake George by seismic reflection profiling made last year. The Pleistocene deposits appear faulted at several placed across boundary faults of the horst and graben topography beneath Lake George. The shoreward projection of these inferred breaks will be investigated to look for any possible Holocene movement on the faults around the lake and possibly additional work will be done in the lake.

4) Geology of the Hudson River from New York City to Lake George.

Compilation of a geological strip map along Hudson River using existing data at 1:62,500 scale. The data will be reviewed to investigate the possibility that the straight segments which make up much of the river's course may be fracture-controlled. The relations of the topographic lineaments and other geomorphic features along the river with the geology will be reviewed for structural control. The map will serve as a base for further work along the seismically active belt that coincides with the river valley.

5) Analysis of faulting along the Delaware Aquaduct Tunnel.

A strip map will be prepared of the Delaware Aquaduct Tunnel, which extends from New York City to Cannonsville Reservoir in the Catskill Mountains, by integrating surface projections of the unpublished longwall mapping of the tunnel done by Tom Fluhr and Paul

Bird along the surface data from existing maps. The surface faults are classified into a number of types. These will be statistically analyzed. The relative numbers of observed subsurface faults will be compared to those mapped on the surface for a statistical estimate as to the number of unmapped faults that might be encountered in a large excavation in the region.

6) Investigation of seismically active areas in New York and their relations with fault planes inferred from instrumental data.

Investigation of fault planes inferred from instrumental data by Yash Aggarwall in three areas of recent seismic activity: Blue Mountain Lake, Racquette Lake and Altona (west of Plattsburgh). Geologic, magnetic and gravity features will be studied along the surface projections of the inferred fault planes to search for outcrops of faults and any evidence of recent movement. Strip maps will be prepared as well as structural sections for each area.

20) Aeromagnetic lineament analysis of New York

The available U.S. Geological Survey aeromagnetic maps of the State of New York will be analyzed for aeromagnetic lineaments that will be compared with the surface geology, particularly the brittle fractures, for correlation and interpretation.

29) Study of a major lineament north of the Adirondacks

A field study will be made of a major lineament located near and parallel to the northern border of the Adirondacks. This is one of the larger entirely new lineaments found in the previous Landsat study. It is located in a seismically active area and may help explain the structure of the border of the Adirondack uplift.

Budget contributed by the U.S.N.R.C......$23,000

7) Structural study of the Moodus area, Connecticut

Principal Investigator: Sidney S. Quarrier
Connecticut Geological Survey
Department of Enviromental Protection
State Office Building
Hartford, Conn. 06115

This study would investigate in the field selected locations where discontinuities in the geologic data and prominent remote sensing or aeromagnetic lineaments indicate there may be faults. The basic geologic, geophysical and remote sensing data were compiled for twelve 7-1/2 minute quadrangles around the seismically active Moodus area in south-central Connecticut last year. These data will be analyzed and field work conducted at locations where faults are most likely indicated. The structural data found will be plotted on the existing bedrock distribution map of the area, at a scale of 1:62,500 and a short explanatory text prepared.

Budget contributed by the U.S.N.R.C......$5,000

8) A gravity investigation in the metamorphic terrain of south central Connecticut

Principal Investigator: John F. Kick
P.O. Box 6, Pleasant Street
Dunstable, MA 01827

A detailed Bouguer gravity map will be made around the area of Moodus, Connecticut, using existing data and adding new data. The map will cover approximately nine full 7-1/2 minute quadrangles in south-central Connecticut with a density of about one station per square kilometer and be at a scale of 1:62,500. The quadrangles now under consideration are Moodus, Haddam, Middle Haddam, Deep

River, Essex, Clinton, Guilford, Durham and parts of Hamburg, Middletown, and Wallingford.

The resulting map will be visually analyzed and compared with geologic maps. If necessary, additional gravity readings will be made in critical areas. Leveling surveys will be completed if needed. If feasible, anomalies of special interest will be isolated by regional-residual separation techniques and modeled for quantitative information. The resulting Bouguer map will be processed to continuation and derivation maps if time permits.

The gravity map and derivative maps along with a short explanatory text will be completed.

Budget contributed by the U.S.N.R.C......$12,000

9) Correlation of marine and land magnetic surveys with known tectonic features and bedrock types in the Narragansett Bay area, Rhode Island.

Principal Investigators: Barclay P. Collins and Robert L. McMaster
Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881

This study will complete a marine magnetic survey of Narragansett Bay and tie it into the shore (Figure 21). The primary objective is to correlate known tectonic elements and bedrock types with their individual magnetic signatures. Land magnetometer surveys will be conducted to extend observed marine magnetic anomalies which clearly strike onshore. In this manner, both the landward extension of magnetic lineaments found in the Bay and the bayward extension of known land-mapped bedrock contacts and faults can be ascertained. This will allow a much more detailed bedrock map of the Bay area to be constructed. A second objective is to expand the marine magnetometer survey throughout Mount Hope Bay so that detailed coverage of the Narragansett Bay system will be completed.

A magnetic map of Narragansett Bay will be prepared at a scale of 1:62,500 or larger. The map and a short explanatory text describing the significant features and their interpretation will be prepared.

Budget contributed by the U.S.N.R.C......$4,910

10) Magnetic survey of the near-shore off eastern Connecticut, Rhode Island and southeastern Massachusetts.

Principal Investigators: Robert L. McMaster and
Barclay P. Collins
Graduate School of Oceanography
University of Rhode Island
Kingston, RI 02881

A closely spaced marine magnetometer survey will be conducted to complete the inshore coverage not provided by the recent highly informative USGS (1976) project along eastern Connecticut, Rhode Island and southeastern Massachusetts (Figure 21). A limited seismic refraction - reflection investigation will also be undertaken adjacent to the Narragansett Bay system.

The specific objectives of these studies will be to a) determine whether the Westerly Fault extends seaward toward the southwest into the western Block Island and eastern Long Island Sounds, b) define in greater detail the eastern limit of the Narragansett Pier Granite, c) delineate the seaward extensions of the Newport Neck faults and the Rhode Island Conglomerate from the vicinity of Easton's Point, d) trace the offshore trend of the Narragansett Basin's eastern boundary as defined by the contact between the Rhode Island Formation and Mica Chlorite Schist as well as the Bulgarmarsh Granite - Mica Chlorite Schist contact, e) explore the possible southern border of the Narragansett Basin, f) ascertain the thickness of the metasedimentary rocks in the offshore reach of the Narragansett Basin, and g) identify any magnetic lineaments present and determine whether these lineaments can be traced onto land.

A marine magnetometer survey will be conducted from the vicinity of Watch Hill Point, Rhode Island, eastward to Westport, Massachusetts, a distance of about 45 miles (Figure 21). Individual tracts spaced one mile apart and oriented NW-SE, will be from 5 to 10 miles long depending upon the width of the coastal gap in the USGS (1976) aeromagnetic survey. Navigational control will be maintained with Loran-C. A map will be prepared at a scale of 1:62,500.

Processing these total magnetic intensity data will begin with diurnal corrections based upon Weston Observatory records. The correct values will be plotted on the cruise tracks and contoured on a 10 gamma interval. Existing two-dimensional magnetic modelling and correlation programs will be used to assure continuity of observed marine and land features. In addition, these programs will indicate the geometry of the anomaly-producing bodies.

A sonobuoy refraction investigation will be undertaken in the manner described by Knott and Hiskins (1975). Five reversed refraction lines will be run: a 4 mile line, NE-SW, from the north

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of West Passage across the projected Narragansett Pier Granite - Rhode Island Formation contact; a 5 mile N-S line in the offshore portion of the Narragansett Basin beginning near Beavertail Pt.; a connecting 5 mile E-W line, south of Point Judith, crossing the gradient associated with the Block Island Sound magnetic high (USGS, 1976); a 10 mile N-S line, from Newport Neck across the conjectured southern boundary of the Narragansett Basin; and a 5 mile NW-SE line from the vicinity of Easton's Point across the magnetically-indicated eastern border of the Narragansett Basin.

Refraction data will be recorded on magnetic tape for later computer enhancement of the records. Maps, sections and short explanatory text will be prepared.

Budget contributed by the U.S.N.R.C......$16,608

11) Magnetic study of the Narragansett Pier Granite and its Contacts.

Principal Investigator: Richard K. Frohlich
Department of Geology
University of Rhode Island
Kingston, RI 02881

Ground magnetometer traverses will be conducted across onshore coastal Rhode Island with the objectives of a) providing the data to connect the offshore magnetic surveys of McMaster and Collins onto the shore west of the Narragansett Bay, b) defining the contacts of the Narragansett Pier Granite, and c) delineating pendants of metasedimentary rock that may lie concealed in areas of presumed Narragansett Pier Granite. A ground magnetometer survey covering the entire area of the Narragansett Pier Granite (Figure 21) including the contacts to the west will be made at a scale of 1:62,500. Observations will be at a grid spacing of 500, and if the nature of the anomalies offers more detail, the spacing will be decreased to 250 m. This is to be followed by a lineament study and a quantitative analysis with two-and three dimensional model studies.

A magnetic map and short explanatory text will be prepared.

Budget contributed by the U.S.N.R.C......$5,000

12) Stress analysis of the Cape Ann area, Massachusetts

Principal Investigator: William H. Dennen
Department of Geology
University of Kentucky
Lexington, KY 40506

The study will investigate the stress history of the Cape Ann area, Massachusetts, by analyzing data from detailed joint studies, dike studies and observations of relief cracks from blasting (Figure 16). The study would: a) continue detailed mapping of joints--determining kind, attitude, geographic distribution and relative age to distinguish cooling joints from later tectonically induced joints, b) compile data and map the kinds, attitude geomorphic distribution and relative ages of the dikes to determine their structural control and seek information on changes in stress orientation through time, c) measure relief cracks around drill holes used in highway and quarry blasting in the area to try to determine the modern stress field, and d) integrate the dike and joint data with that on mapped faults and the strong topographic lineaments in the area to try to determine the stress history to the present.

Maps and reports describing the analysis and interpretation will be completed.

Budget contributed by the U.S.N.R.C......$4,000

13) Cravity investigations of the Cape Ann area, Massachusetts

Principal Investigators: Edward F. Chiburis, Russell O. Ahner, and John F. Kick
Weston Observatory, Boston College
Concord Road
Weston, MA 02193

A detailed Bouguer gravity map will be made of the Cape Ann area, Massachusetts, using existing data and adding new data. The map will cover all the landward portions of seven 7-1/2 minute quadrangles and parts of two others with a density of two stations per square kilometer or greater. The quadrangles are Rockport, Gloucester, Marblehead South, Marblehead North, Ipswich, Salem, and Georgetown and portions of Newburyport West and Newburyport East.

Additional gravity profiles will be run in critical areas. Leveling surveys will be completed if needed.

A three-dimensional gravity model will be derived by analyzing the data in conjection with the available geological data.

A gravity map at 1:62,500 scale and an explanatory text describing the main features and possible structural interpretations will be completed.

Budget contributed by the U.S.N.R.C......$9,700

15) Possible large-scale right-lateral faulting in south-eastern New Hampshire

Principal Investigators: Patrick J. Barosh
Weston Observatory, Weston, MA 02193
Arthur M. Hussey

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Dept. of Geology, Bowdoin College
Brunswick, Maine 04011

The study will investigate the possibility that a zone of northeast-trending faults in southeastern New Hampshire may offset a stratigraphic unit about 55 km in a right-lateral direction. Rocks correlated with the Eliot Formation appear to end to the north against a northeast-trending fault zone near the northern boundary of the Pepperell quadrangle at the southern edge of New Hampshire. The Eliot Formation appears to end to the south in the southeastern part of the Mt. Pawtuckaway quadrangle farther to the northeast, and the formation is not known to be present in between. It may well be that the formation is offset by a zone of northeast trending faults. Unusual facies changes and other structures could possibly account for the observations. The study would map the distribution and apparent terminations of the Eliot Formation at 1:62,500 scale and investigate the area between. The mapping is anticipated to be concentrated in the Milford and Pawtuckaway 15' sheets with reconnaissance in the Manchester and Haverhill 15' sheets.

A map and report on the distribution of the Eliot Formation and the structural significance will be completed.

Budget contributed by U.S.N.R.C......$1,500

16) Lineament, structure and stress study of coastal Maine

Principal Investigators: Arthur M. Hussey, Allen Ludman, Olcott Gates, David S. Westerman, Kost A. Pankiwskyj and Donald Newberg
Maine Geological Survey
State Office Bldg., Room 211
Augusta, ME 04330

Fitzhugh T. Lee
Engineering Geology Branch
U.S. Geological Survey
Denver, CO
Dennis W. O'Leary
Branch of Petrophysics and Remote Sensing
U.S. Geological Survey
Denver, CO
Cleaves L. Rodgers
Branch of Eastern Environmental Geology
U.S. Geological Survey (retired)
Sedgwick, ME 04676

The study will be a cooperative investigation of the brittle structure and present stresses in coastal Maine with emphasis on the three areas of higher seismicity: The Passamaquoddy Bay area, the Penobscot Bay area, and the Casco Bay-lower Androscoggin River area. Personnel of the Maine Geological Survey will investigate the Passamaquoddy Bay area and the Casco Bay-lower Androscoggin River areas. Personnel of the U.S. Geological Survey and Weston Observatory will study the Penobscot Bay area.

Passamaquoddy Bay area:

New geologic data on structure will be obtained and Landsat lineaments will be field checked. Available geologic data will be combined with the new data to produce a preliminary bedrock geologic map of the Passamaquoddy Bay area (the U.S. portions of the Eastport and Fredericton 2 degree sheets at a scale of 1:250,000). Other maps will be produced as warranted. Maps of the 2 degree sheets and a short explanatory text, that includes a discussion of the structure and relative ages of faults will be completed. Olcott Gates, Allen Ludman and David S. Westerman of the Maine Geological Survey will work in this area.

Casco Bay-lower Androscoggin River area:

The geologic investigation in this region is expected to take two years. The first year will produce a preliminary report on the Casco Bay-lower Androscroggin River area, with appropriate maps, will describe: 1) the structure of the river valley north of Lewiston, 2) the results of the field investigation of Landsat lineaments, 3) other particular structures deemed significant in the area, and 4) the general structure of the area and relative ages of faults. This will be completed. Arthur Hussey II, Kost A. Pankiwskyj, and Donald Newberg of the Maine Geological Survey will investigate this area.

Penobscot Bay area:

The work in this area will: 1) investigate lineaments near the bay, 2) study the present-day stress in rocks in the Penobscot Bay area and the influence of structure and lithology on this stress; in particular to what extent the high horizontal stress in the granites is present in the metamorphic host rock, 3) relate vertical strike-slip faults and rock burst, both induced by quarrying, and fractures that offset glacial striation on coastal bedrock to in-situ stress and rock conditions, 4) determine and compare the stresses in and adjacent to lineaments. Fitzhugh T. Lee will direct the work around the Penobscot Bay working with Dennis W. O'Leary and Cleaves L. Rodgers (retired U.S. Geological Survey).

The Maine State Geologist, Robert G. Doyle and the Assistant State Geologist, Walter A. Anderson will coordinate the work within the Maine Geological Survey and assist the U.S. Geological Survey in expediting their work.

Budget contributed by the U.S.N.R.C.

1) Maine Geological Survey..........$12,950

2) U.S. Geological Survey...........$ 4,230

3) C.L. Rodgers.....................$ 4,000

18) Bedrock geology of the Sherbrooke 2-degree sheet, Maine and New Hampshire

Principal Investigators: Gary M. Boone and Bradford A. Hall
Maine Geological Survey
State Office Bldg., Room 211
Augusta, ME 04330

A cooperative study will produce a bedrock geologic map of the U.S. portion of the Sherbrooke 2-degree sheet, Maine and New Hampshire at a scale of 1:250,000, showing an integrated picture of the structural geology. A possible cooperative effort with Canadian geologists may provide the geologic data for the non-U.S. portion. The available geologic mapping of the area, both published and unpublished, will be compiled and new geologic data will be obtained wherever possible. A preliminary map will be compiled by the end of the first year. A completed map ready for publication will take an additional year. The study will cooperate with an economic geology investigation of the area under the direction of Frank C. Canney and will receive the assistance of Eugene L. Boudette and Robert H. Moench of the U.S. Geological Survey.

Personnel of the Maine Geological Survey will provide new geologic data for the map in areas deemed most critical and compile the presently available data of the Maine Geological Survey and the U.S. Geological Survey. The Maine Geological Survey will provide a Geologic Map of the area with a short explanatory text including a discussion of the structural geology.

Budget contributed by the U.S.N.R.C......$8,870

19) Structural study of eastern Connecticut

Principal Investigators: Sidney S. Quarrier
Connecticut Geological Survey
Dept. of Environmental Protection
State Office Building
Hartford, CT 06115
M.H. Pease, Jr. and Richard J. Fahey
Branch of Eastern Environmental Geology
U.S. Geological Survey
150 Causeway St., Room 1304
Boston, MA 02114

A comprehensive picture of the structural geology of eastern Connecticut will be developed by compilation and analysis of the available geologic data, field checking and some new mapping. A preliminary bedrock geologic map of Connecticut, east of the Connecticut River Valley at a scale of 1:125,000 will be prepared integrating the geologic, geophysical and remote sensing data along with a brief explanatory text.

Budget contributed by the U.S.N.R.C......$4,500

23) Landsat lineament study of the northern Fall Line.

A lineament study of a 30-mile wide zone along the northern

Fall Line from Baltimore, Maryland to New Brunswick, New Jersey, will be made from Landsat imagery, U-2 and high-altitude photos. This will be done as part of the investigation of the northern Fall Line (2).

24) Major fracture systems of western Massachusetts from Landsat imagery

Principal Investigator: Donald U. Wise
Department of Geology
University of Massachusetts
Amherst, MA 01003

This study will prepare a lineament map of western Massachusetts west of 72° Longitude at 1:250,000 scale or larger from available Landsat, U-2 and high-altitude photos and compare it with the available geologic data. The map will overlap slightly into adjacent parts of New York, Vermont, Connecticut and New Hampshire for continuity at state borders. Brittle fracture data will be compiled, and the lineaments will be analyzed with these and with the detailed fracture data previously collected in the area by University of Massachusetts students. The more prominent lineaments will be field checked and brittle fracture data collected. The "ground truth" data, both previously and newly collected, will be processed by computer programs to examine the sequence of fracture and stress orientations. Of particular interest are the minor fault motion data which are an integral part of the studies. These have begun to yield distinct orientations of principal stresses in the area at some past times and it is hoped that the expanded data base can confirm this stress history for the region and relate it more closely to the regional fracture patterns detected from the imagery. The data from the various sources will be pulled together into a

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report trying to synthesize the fracture and stress history of Western Massachusetts.

Budget contributed by the U.S.N.R.C......$6,079

25) Landsat lineament study of Vermont

Principal Investigators: Thomas W. Jones
Renesselaer Polytechnical Institute
Troy, NY 12181

Yngvar W. Isachsen
New York Geological Survey
and Patrick J. Barosh
Weston Observatory

The study will prepare a lineament map of Vermont using Landsat, U-2 and high-altitude photos at 1:250,000 scale. All available data on brittle fractures will be compiled and the prominent lineaments, especially the prominent northwest-trending lineaments across northern Vermont will be field checked.

Budget contributed by the U.S.N.R.C......$5,000

28) Landsat lineament map of coastal Maine

Principal Investigator: Dennis W. O'Leary,
U.S. Geological Survey
Branch of Remote Sensing
Denver, CO

A lineament map will be prepared from Landsat imagery, U-2 and high altitude photos of a broad area of coastal Maine at 1:250,000 scale with a descriptive analytical text. The lineament map will serve as a guide for fieldwork in coastal Maine and the prominent lineaments will be field checked by the principal investigator and members of the Maine Geological Survey.

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Investigations of lineaments found in previous studies will be pursued.

Included in the budget of the Coastal Maine Study (16) Geologic Investigations and Aeromagnetic and Landsat Lineament Studies in New England

Principal Investigator: Patrick J. Barosh
Weston Observatory, Boston College
Concord Road
Weston, MA 02193

The following six studies will be conducted from the coordinator's office:

14) Geological synthesis and analysis of New Hampshire

The available geologic data on New Hampshire, especially the new data collected in 1976, will be synthesized and analyzed for information on structural geology. These data will also be used along with the lineament analysis to evaluate the need and locate critical areas for further geologic work in the area.

17) Study of the Penobscot Lineament

Field study of a major zone of lineaments extending from Penobscot Bay, Maine, northward to Square Lake near the Canadian border. The lineament bounds the seismically active areas west of the Penobscot River and appears to be a young feature. A preliminary field study of the prominent lineament at the south end of this zone revealed evidence of faulting along it and suggests that other lineaments in the zone may be faults also.

21) Aeromagnetic lineament analysis of the offshore areas south of New England

The newly acquired aeromagnetic data extending from south

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of Long Island to south of Cape Cod (U.S. Geological Survey, 1976) will be analyzed for lineaments of possible structural significance. The presence in this area of one of the youngest known faults in the region, the New Shoreham fault, McMaster 1971 (New England Power Co., 1976) which has a coincident magnetic lineament, makes such study especially important.

22) Interpretation of aeromagnetic lineaments offshore of eastern Massachusetts and New Hampshire and their possible structural significance

The aeromagnetic data obtained last year by Boston Edison will be available for analysis and interpretation. A lineament analysis will be made and an interpretation using all the available coastal and marine geology. These new data should allow many of the seaward projecting structures, on the recently compiled Boston 2-degree sheet (Barosh, Fahey and Pease, 1977), with their known magnetic signatures, to be extended offshore. A preliminary review of the data indicates the zone of the Clinton-Newbury and associated faults can be traced far offshore. In addition, some of the offshore structures shown by Ballard and Uchupi, (1975) may be better delineated.

26) Landsat lineament study of New Hampshire

The study will prepare a lineament map of New Hampshire from Landsat, U-2 and high-altitude photos at 1:250,000 scale. The lineaments will be analyzed with the available new geologic data. The resulting analysis will be used to evaluate the need and plan for geologic mapping in 1978.

27) Landsat lineament map of Sherbrooke 2-degree sheet, Maine and New Hampshire

The study will prepare a lineamert map of Sherbrooke 2-degree sheet, Maine and New Hampshire, at 1:250,000 scale, using Landsat imagery, U-2 and high-altitude photos. The lineaments will be analyzed in connection with the bedrock map being prepared of this area by the U.S. Geological Survey and Maine Geological Survey personnel. It will be used to aid in the mapping of the area.

APPENDIX B

ABSTRACTS OF TALKS. PARTIALLY SUPPORTED BY
THE U.S. NUCLEAR REGULATORY COMMISSION

GEODETIC, GEOLOGICAL, AND GEOPHYSICAL EVIDENCE FOR HOLOCENE VERTICAL MOVEMENTS IN THE ADIRONDACK REGION, NEW YORK

Isachsen, Y.W., Geological Survey - New York State Museum and Science Service, Albany, New York 12234; Weld, R. J., U. S. Geological Survey Office of Marine Geology, Woods Hole, Mass. 02543

Earlier reported geodetic evidence for contemporary doming of the Adirondack Mountains (Isachsen, 1975, 1976) indicates that the present rate of uplift at the center of the Adirondacks is 3.7 mm/yr. compared with 1 mm/yr. for the Central Alps. Structural evidence has subsequently been found which extends the time span of this contemporary vertical movement into earlier Holocene time. Post-Pleistocene offsets along vertical joints cutting glacially scoured surfaces have been discovered at several Adirondack sites, the most notable being on the grounds of the Adirondack Museum at Blue Mountain Lake. Here, along a gently-curved vertical joint plane striking N 12 W, the west side has been downthrown a distance of 1 cm. Subsequent weathering has widened the joint plane, suggesting that the fault movement may have occurred as long ago as 10,000 years bp, in response to extensional stresses.

Following these discoveries seismic reflection and magnetic surveys were made of the north-northeast-trending Lake George [illegible] system which is located near the southeastern margin of the Adirondack Dome. A major purpose of this survey is to search for evidence of faulted Holocene, Pleistocene, and conceivably Tertiary sediments, which might permit a more precise dating of vertical movements. A preliminary examination of the seismic profiles [illegible] suggests normal faulting of the Pleistocene [illegible] graben-horst complex. Following a detailed [illegible] of the geophysical data, piston coring [illegible] the hope of quantifying the magnitude of vertical [illegible] time span(s) during which it occurred.

1977, Geol. Soc. of America, Abstract with Programs, Northeast Section 12th Ann. Mtg., V.9, no. 3, p. 27[illegible]-27[illegible].

FAULTS AND RELATED DEFORMATION IN THE CLINTON-NEWBURY--BLOODY BLUFF FAULT COMPLEX OF EASTERN MASSACHUSETTS

by

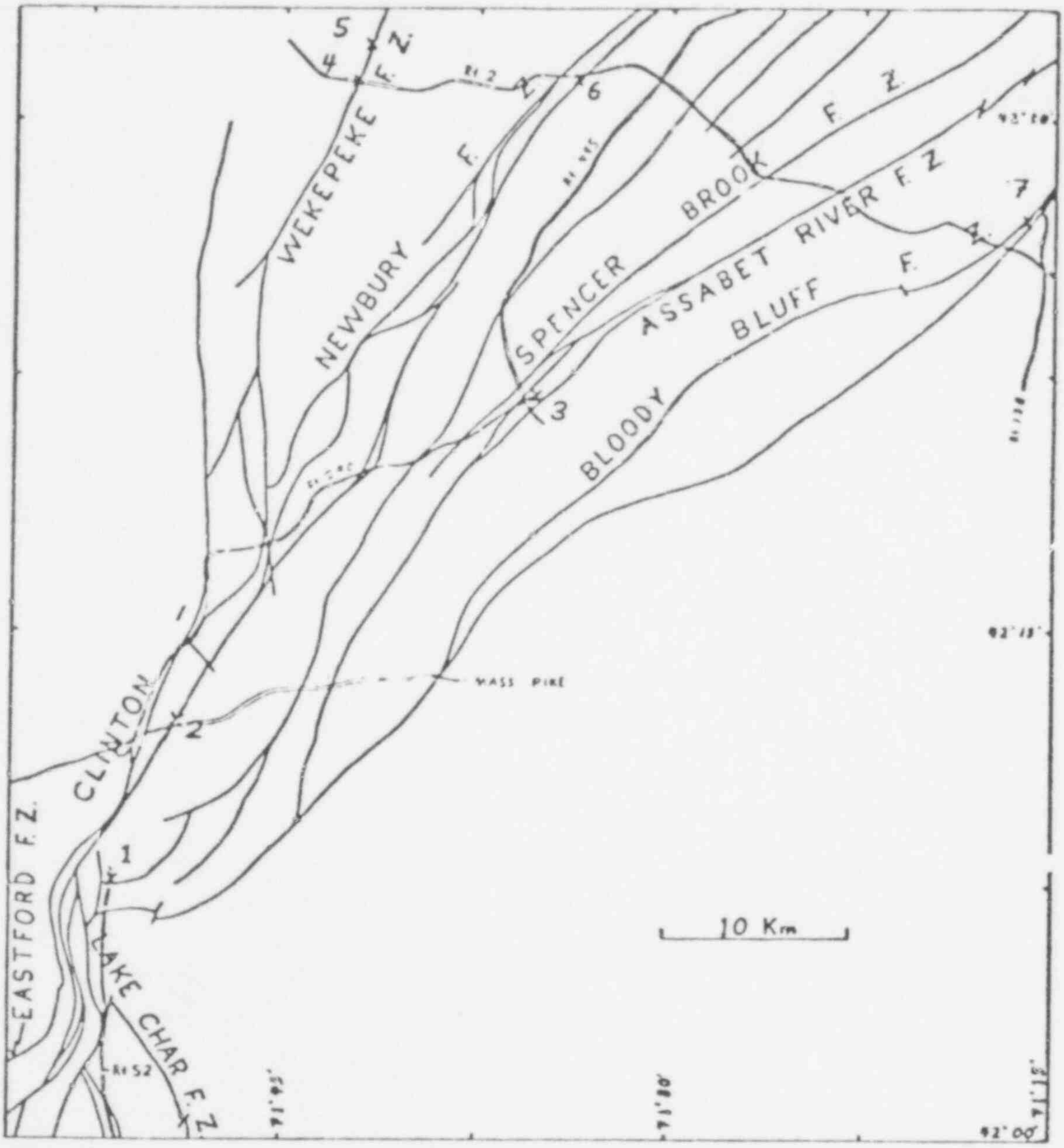
Patrick J. Barosh

Eastern Massachusetts is a highly faulted region (Skehan, 1969, and Barosh, Pease, Schnabel, Bell and Peper, 1974) in which a great deal of mapping has been done to document the structure. The faults are recognized by dislocations of geologic contacts, omissions and repetitions of stratigraphic units, and abrupt changes in metamorphic grade; an unusually large number of faults, which form parts of the major fault zones, are directly observable in natural outcrops, expressway cuts, and tunnels in the region. The faults show a wide variety of types of deformation and degrees of complexity of structures and history. Fault-related features in the region include: shears, mylonite, gouge, breccia, mineralization and alteration effects, silicified zones, and drag folds. Both compressive movements have been recorded. In addition, fault-controlled emplacement of both large and small intrusive bodies can be demonstrated.

The area between the Clinton-Newbury and Bloody Bluff fault zones (fig. 1) forms a northeast-trending, northwest-dipping thrust-fault complex with west over east and right-lateral components of movement (Skehan, 1969, Alvord, Bell, Pease and Barosh, in press). The deformation related to the main faults in this complex and in the subparallel Wekepeke fault zone to the northwest can be directly observed at many places.

1976, p. 301-314 in Geology of Southeastern New England: New England Intercollegiate Geol. Conf.

Figure 1. Major faults related to the Clinton-Newbury--Bloody Bluff fault complex of eastern Massachusetts. Numbers denote stops in the road log. Fine lines and route numbers denote major highways. F.Z., fault zone. Modified from Barosh, 1974, Alvord, Bell, Pease, and Barosh, in press, Nelson, 1975b, Peck, 1975, and unpublished data by P.J. Barosh, K.G. Bell and J.H. Peck.



POOR ORIGINAL

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FAULT TECTONICS OF NEW ENGLAND

BAROSH, Patrick J., Weston Observatory, Boston College, Concord Road, Weston, MA 02193

Concepts of the structure of New England are undergoing a complete revision as modern detailed mapping combined with geophysical and remote sensing data demonstrate the pervasive nature and importance of faulting in the region. The fault pattern is well established in southern New England, where the fault density is similar to that of Southern California and regional fault zones are well documented. Northern New England has a similar, although, less detailed pattern at the present. The pattern is one of major northeast and north-trending faults cut by high angle northwest trending cross faults and in the southeast, a few major east-trending faults. The same pattern is shown by geophysical data to extend off shore without a break to the east into the Gulf of Maine and to the south. The fault pattern appears to have been established in the early Paleozoic and to have been selectively reactivated later during the Permian, Triassic-Juassic and Cretaceous time. The early movements were compressional, and later ones tensional.
Northeast-trending fault zones, generally with a right-lateral component, converge from the Maritime Provinces across New England towards Connecticut and appear to indicate a progressively greater tectonic squeezing to the southwest across the region. The rocks become gradually more metamorphosed, buckled, broken, rotated and thrust up as the area of convergence is approached. This movement is consistent with an Atlantic plate moving relatively west-southwest towards the North American plate during the Paleozoic. Tensional forces operated along a northwest-southwest trend during the Triassic and Jurassic.

1976, Geol. Soc. of America, Abstracts with Programs, Annual Meetings, vol. 8, no. 6, p. 767

POOR ORIGINAL

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THE PENOBSCOT LINE: EVIDENCE FOR A MAJOR LINEAMENT IN MAINE

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The Penobscot Line, first noted by Hobbs in 1904, is a prominent feature on the Landsat 0.8 to 1.1 micrometer band mosaiced imagry of Maine. The line discernable on the imagry consists of a segment trending north-northeast from Orland and a segment that follows the Penobscot River Valley from Old Town to South Lincoln, passes east of Millinocket and Hunt Mountain and ends against a northeast trending line at Square Lake, near the Canadian border. The line has a total length of 300 km (186 mi) on land and, if Hobbs' projection is considered, extends along Penobscot Bay a further 80 km (50 mi). The line coincides with a broad mapped fault zone east of Hunt Mountain, as does its extension into Penobscot Bay. Elsewhere, many lithlogic units end close to the line and geologic contacts bend in crossing it. A gravity map of the area at the north end of the Bay shows a linear feature that corresponds with the location of the line and the aeromagnetic map of the Penobscot Bay region shows a difference in trends on either side of the line. The metamorphic grade also changes across it here. Topographic lineaments splay off the main line near Orland and trend south-southeast into the bay towards Sears Island, where faults with possible recent movement occur. Although the Penobscot Line was recognized in 1904 only now have the data of remote sensing and compiled mapping provided the beginnings of a geological interpretation of this regional feature.

1977, Geol. Soc. of America, Abstracts with Programs, Northeast Section 12th Ann. Mtg., vol. 9, no. 3, p. 241

GEOLOGIC ASPECTS OF SITING NUCLEAR FACILITIES

Sponsored by Environmental Sciences Division

All Papers Invited

3. Faults and Seismicity in Eastern Massachusetts, *Patrick J. Barosh (Weston Observatory)*

This seismically active region is now recognized to have undergone extensive faulting.

Two principal northeast-trending fault zones, the Bloody Bluff and related faults and the Clinton-Newbury zone, separate three tectonically and stratigraphically distinct geologic blocks. The middle block between the two fault zones forms a belt of rocks characterized by thrust faults that dip very steeply to moderately northwest and have west over east movement with some right-lateral component; locally, there is evidence for later normal dip-slip movement. This thrust belt trends northeastward just east of Worchester and enters the sea on the north side of Cape Ann, continuing east-northeast offshore, as indicated by magnetic data. The northwestern geologic block consists of a group of metasedimentary rocks cut and apparently repeated by a set of north to northeast-trending faults. These smaller fault-bounded blocks impinge obliquely to the south against the more easterly trending Clinton-Newbury fault zone, where the blocks to the east are progressively cut out. The southeastern geologic block is characterized by more easterly trending faults, some of which trend obliquely into, and are cut off on the west by the Bloody Bluff fault zone, and some large folds and structural basins.

The fault pattern apparently formed during the Paleozoic due to compressive forces aligned east-northeast/west-southwest. The amount and extent of post-Paleozoic faulting in eastern Massachusetts is difficult to assess because of the tendency for movement to occur along preexisting faults and because the Pleistocene glaciers smoothed the topography here. However, Triassic-Jurassic fault basins offshore to the east and the northeast-trending Triassic dike system northwest of Lowell strongly suggest some Mesozoic tensional faulting. Nevertheless, most exposed faults do not appear to have moved since the Paleozoic, though some with soft gouge and breccia resemble faults with Holocene movement elsewhere.

Most seismic activity in eastern Massachusetts is concentrated in the Cape Ann area, between the North Boundary fault of the Boston Basin and the northern border of the state, a short distance north of and subparallel to the northwest-dipping Clinton-Newbury fault zone, and their seaward projections. Many of the larger earthquakes occurred at sea north and northeast of Cape Ann, including the largest known earthquake in the region, that of November 18, 1755, of approximately epicentral intensity VIII (MM). The epicentral locations, unfortunately, have not been accurate enough to indicate if activity coincides with any one of the numerous faults concentrated in the area.

No large northwest-trending faults cross the area as part of a "Boston-Ottawa" structure, although small ones are present. A circular magnetic and gravity anomaly at sea just north of Cape Ann is suggestive of a basic pluton, which Gene Simmons (personal communication) believes is related to the chain of White Mountain plutons in New Hampshire and that a change in the elastic properties of rock at the borders of this pluton may be responsible for the large earthquakes. However, several large faults also project through the same area.

In terms of the plate tectonic hypothesis, the seismically active area is in a modern intra-plate environment straddling a probably Paleozoic plate boundary—the thrust belt. However, the boundary zone is not [illegible] a locus of earthquakes elsewhere in eastern Massachusetts and Connecticut, so a simple direct relationship apparently doesn't exist between the boundary and seismicity. Modern-day stresses and tectonic provinces probably differ greatly from the Paleozoic ones, but the imprint of the Paleozoic structures is so great they effectively mask modern features. More accurate epicentral locations and, hopefully, some focal depths and fault-plane solutions, will guide future studies.

POOR ORIGINAL

1977, American Nuclear Society Transactions, v. 27, p. 155-156

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REGIONAL GEOLOGIC AND SEISMIC EVALUATION IN SITING NUCLEAR FACILITIES — I

Sponsored by Environmental Sciences Division

All Papers Invited

4. Relationship of Seismicity to Geology in the Northeastern United States, *Patrick J. Barosh (Weston Obs-Boston College)*

Faults are being investigated in the Northeastern United States to find if a causitive relationship exists with the seismicity in the region. No earthquake in the region is known to have been accompanied by surface fault movement and no faults have yet been proven to be active. Also, very few faults were even known in New England until recently, although many were mapped in New York and New Jersey. The apparent lack of correlation of seismic events to faulting led to relating the seismicity to isostatic adjustments due to deglaciation or density contrasts with mafic plutons, changes of physical properties at the borders of plutons, or other aspects of Mesozoic intrusive bodies. None of these hypotheses, however, explains the epicentral distribution pattern in the region.

Eastern Massachusetts and eastern Connecticut are now known to be highly faulted, as demonstrated by detailed geologic maps,[1] expressway cuts, and tunnels. The rest of southern New England is probably equally as faulted. Many faults are well expressed as lineaments on topographic maps, Landsat imagery, or aeromagnetic maps. Little is known of the faulting in northern New England, but the few areas of more detailed mapping and the lineaments present suggest faults are abundant. The present evidence also suggests major northeast-trending zones of faults cross New England. Many of these zones have an apparent right-lateral component of movement.

Earthquake epicenters in the Northeast[2] are distributed in a series of distinct circular to elongated clusters with very few moderate-sized earthquakes occurring outside the clusters. These epicentral clusters appear to correlate well with geomorphic features, bays, and major river valleys in particular. Both the earthquakes and geomorphic features may be related to structural control in the bedrock. Geomorphic features in the Northeast reflect rock types and structure very well, especially faults, as glaciers have etched the land surface.

Groupings of epicenters in southern New England, New York, and New Jersey occur in areas of mapped faults and possible faults, some of which could be causative structures. Accurately located foci of several earthquake swarms in New York and New Jersey are indicated to lie along mapped faults or probable faults by the recent work of Sbar, Sykes, and Aggawal. No simple relationship exists, however, between seismicity and fault distribution. The great majority of faults formed during the Paleozoic with little indication of movement since then. The seismic events in southern New England occur along major zones of faults, but not uniformly and some other feature may be localizing the events; possibly north and northwest-trending cross faults. North to northwest epicentral and lineament trends are associated in New Hampshire along the northwest trending "Boston-Ottawa" seismic zone. This zone, however, does not appear to be a continuous feature. The activity in New Hampshire is separated from that to the northwest by a nearly aseismic zone through Vermont that corresponds with a structural block. Also, no major northwest-trending fault is present where this zone crosses the coast to the southeast.

The more information and accuracy available on epicentral locations and geologic structure in the Northeastern United States, the closer is the association found between earthquakes and faults. Only in areas of inadequate data is the association not found. The size of the earthquakes in the region, however, are generally either too small to expect ground breakage along faults or offsets are small enough to be attributed to other factors.

1. P. J. BAROSH, R. J. FAHEY, and M. H. PEASE, Jr., "Geology of the Boston 2 Sheet," *U.S. Geol. Survey Open-File Map* (1977).
2. Weston Geophysical Engineers, unpub. epicentral map of the Northeastern United States (1976).

1977, American Nuclear Society Transactions, v. 26, p. 127-128

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Association of Engineering Geologists

NEW ENGLAND SECTION

SYMPOSIUM
on the
GEOLOGY OF EASTERN MASSACHUSETTS
April 23, 1977

SCHEDULE

10:00	Welcoming	
10:05	Pat Barosh	The Bedrock Geology of the Boston 2 Degree Sheet
10:3C	Mike Pease	Regional Correlation of the Brimfield Group and other Formations in Eastern Massachusetts
10:40	John Peck	Some Geologic Problems in the Merrimack Synclinorium
11:10	Richard Gore	The Geologic Setting and Characteristics of the Hillsboro Plutonic Series in Massachusetts
11:35	Cliff Kay	Geology of the Boston Basin
12:00	Lunch	
1:00	Gene Simmons	Recent Geophysical Work in Eastern Massachusetts
1:30	Richard Naylor	Isotopic Ages in Southeastern New England
2:00	Paul Lyons	Pennsylvanian Stratigraphy of New England
2:30	Coffee	
2:50	Rev. James Skehan S.J. and Daniel Murray	Recent Geologic Work in the Narragansett Basin
3:20	Raymond Hall and Lawrence Poppe	A Preliminary Report on a Stratigraphic Test Well on Martha's Vineyard, Mass.
3:50	C.J. O'Hara	Geology and Shallow Structure of the Inner Continental Shelf Off Southeastern, Mass.
4:20	Informal Discussion and Closing Comments	

THE BEDROCK GEOLOGY OF THE BOSTON 2 DEGREE SHEET

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Maurice H. Pease, Jr., U.S. Geological Survey, Boston, Massachusetts

Eastern Massachusetts is one of the geologically better known areas in New England. having most of the 7 1/2 minute quadrangles mapped. The compilation of the available published and unpublished mapping in the Boston 2 degree sheet reveals complex geology with a great amount of faulting. The region has a strong northeast-trending regional fabric that is a result of orientation of stratigraphic trends and foliation subparallel to major northeast-trending regional faults. Three tectonically distinct geologic blocks are separated by two principal northeast-trending fault zones, the Bloody Bluff and the Clinton-Newbury, across neither of which can any stratigraphic unit be positively correlated. The grade of metamorphism differs markedly between these blocks. The Clinton-Newbury was suggested to be a plate boundary by Wilson (1962,1966) and Skehan (1969). The mapping since then demonstrates that a belt of thrust faults exists between the Clinton-Newbury and Bloody Bluff and that this belt is even more of a dislocation zone than earlier suspected.

The metasedimentary rocks northwest of the thrust belt consists of a series of northeast striking formations that are northwest topping and generally dip moderately to the northwest. They decrease in metamorphic grade from sillimanite in the northwest to chlorite and biotite against the Clinton-Newbury fault zone. The formations form two groups whose relationship is uncertain. The more westerly group consists of metasiltstone, metasandstone and metapelite of the Brimfield Group, Paxton Group and the Oakdale Formation in descending order. Separated by faults, but presumed older, is a more easterly group consisting of metamudstone, quartzitic rock and volcanic rock of the Eliot, Kittery and Rye Formations, from top to bottom, and their probable equivalents.

Both sequences are apparently repeated by a series of north to northeast-trending faults. These fault bounded blocks impinge obliquely to the south against the more easterly trending Clinton-Newbury fault zone. The blocks to the east are progressively cut out to the south. The eastern sequence is cut out entirely a short distance south of Worcester and does not extend into Connecticut. These rocks are cut by two major northeast-trending zones of quartz monzonite, with radiometric ages of 380 to 460 my, and a zone of diorite.

The belt of thrust faults between the Clinton-Newbury and Bloody Bluff fault zones encompasses a northwest dipping and northwest topping andalusite to sillimanite metamorphic grade sequence of volcanoclastic rock, that contains more andesitic debris near the top and more basaltic debris near the base. These rocks form, in descending order, the Tadmuck Brook Schist, unrestricted Nashoba Formation and Marlboro Formation. Northwest of Boston the sequence appears to be over 18,000 m thick (Bell and Alvord, 1976), but it is cut down by faults to a remnant of a few 100 meters just north of the Connecticut border. Much of the northeast end of the belt has been intruded by quartz monzonite to quartz diorite some yielded a radiometric age of 460 my. A fault sliver of folded, but unmetamorphosed Late Silurian to Early Devonian volcanic rock is also present in the northeast. The thrust belt is indicated by magnetic data to continue offshore in an east-northeast direction. The faults in the belt trend northeasterly, dip very steeply to moderately northwest and show west over east and right-lateral components of movement.

Southeast of the Bloody Bluff and associated faults marking the southeast border of the thrust belt the rocks and structure again changes. The structure trends more easterly and is more varied; with large folds and structural basins present. Much more of the areas is underlain by intrusive rock than to the west and the metasedimentary and metavolcanic rock outside the basins occur as scattered remnants. Quartzite, schist and metavolcanic rock occur as roof pendents in plutonic rock dated as Late Precambrian. These are the only rocks that have undergone deep seated metamorphism and deformation. The plutonic rocks which underlie more than half the area have generally not been regionally metamorphosed nor have the younger strata, which, for the most part, are at chlorite grade of metamorphism and non-foliated except by cataclastic or protoclastic deformation. These rocks include: Cambrian argillite; volcanic rock, including the Lynn and Mattapan, assigned a Late Silurian to Early Devonian age by Bell (1948), but may be older; the conglomerate and argillite of the Boston Basin considered Devonian or Carboniferous, but may be older (Kaye, person. comm.); and Pennsylvanian clastic rocks of the Norfolk and Narragansett Basins. The younger plutonic rocks have a radiometric age range of 380 to 460 my. The types of intrusive rock are more diverse in this tectonic block and much more dioritic and gabbroic rock is present. The easterly trending faults related to the Boston Basin and some lithologic units of the zone trend obliquely into and are cut off on the west by the southeast border of the thrust belt; similar to the cut off at the northwest border of the belt, but with a rotated orientation.

The deformation across the region during the Paleozoic appears to have been due to pulses of a compressive force aligned in an east-northeast--west-southwest orientation. This caused west over east thrusting on northeast and north-trending faults, with a right-lateral component on the northeast ones and a left-lateral component on the north ones and also north over south movements on east-trending faults. The east-trending anticline in the Boston Basin is probably related to the north over south movement along the northern border fault of the basin. The probably earlier north-northwest-trending anticline east of Oxford, Massachusetts is, however, nearly normal to the stress.

The amount and extent of the post-Paleozoic faulting is difficult to assess, but some was probably envolved in the formation of the basins and in controlling the regional northeast-trending Triassic dike system that crosses the region northwest of Lowell.

SOME GEOLOGIC PROBLEMS IN THE MERRIMACK SYNCLINORIUM

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Abstract

The Merrimack synclinorium in Massachusetts is a wide belt of metasedimentary rocks striking northward or northeastward into southern and southeastern New Hampshire on one hand and extending southward into eastern Connecticut on the other. Structurally, the synclinorium occupies the tectonic zone between the Bronson Hill anticlinorium or dome structures on the west and the Clinton-Newbury fault zone (including the northern portion of the Lake Char fault zone) on the east. The rocks within the synclinorium are mostly metasedimentary units of Ordovician to Devonian age, although there may be older Cambrian rocks locally in Connecticut. The metasedimentary rocks are intruded by a number of plutonic bodies, including the granitic rocks of the so-called "Fitchburg Pluton."

Studies of rocks within the Merrimack synclinorium have been going on for the last 100 yr and nearly as many interpretations as there are people working in the area have been made. The problems I wish to discuss here are not new nor have they been resolved to everyone's satisfaction. However, the purpose of this presentation is to introduce a few geologic problems which are interesting to me and to offer some interpretations which I hope will stimulate discussion and perhaps controversy.

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Metasedimentary rocks on the east side of the synclinorium are mostly fine-grained. The relative positions of rock units in the stratigraphic section are difficult to decipher and present the first problem for discussion. Although stratigraphic position may be argued, the fact that sedimentary structures are retained in the rocks yields clues to the original depositional sequence and helps greatly in piecing together a reasonable picture of the original tectonic setting. Turbidite sequences, channeling, submarine slumps, and intraformational conglomerates are present within the section in the Clinton, Shirley, Townsend, and Pepperell quadrangles. These features help to decipher the local section, but do not provide wide-ranging key beds for long distance correlations. Unfortunately, fine-grained sedimentary sequences are typified by vertical repetition of lithologies as well as lateral facies changes. In regions of complex structure, such as eastern Massachusetts, it has always been difficult to decide whether repetition of similar lithologies in outcrop belts is due to structural or depositional history.

Apparent on-strike changes of lithology occur along the east flank of the synclinorium northeastward from the Worcester area toward New Hampshire. These changes may be due to lateral facies change or could also be accounted for by complex fold and fault structures. The solution to this problem is going to require much more detailed work.

The Harvard Conglomerate is a problematic unit on the east border of the synclinorium. Many people have studied the Harvard to some extent but interpretations vary considerably. The thesis I wish to present is that the Harvard Conglomerate is a Silurian or Devonian intraformational breccia. The keys to this interpretation are the monolithologic nature of the clasts, the angular nature of the clasts and their similarity to bedded siltstones in nearby rock units, and the possible occurrence of trilobites within slaty interbeds.

Another problem in the Merrimack synclinorium is the belt of rocks called the "Fitchburg Pluton." Dating has shown that some of the pluton is younger than Acadian metamorphism. However, many of the rocks comprising the "pluton" are high-grade metasediments and, in some locations, older gneisses which may be parts of a basement complex beneath the original Merrimack depositional basin. The "Fitchburg Pluton" could be a structural ridge within the synclinorium along which post-Acadian magmatic activity was concentrated.

The fault pattern east of the "Fitchburg Pluton" is another problem worth discussion. The east edge of the synclinorium is marked by a wide zone of thrust faults and related high-angle faults (the Clinton-Newbury zone). This zone is as much as 2 1/2 miles wide and contains large blocks of rock difficult to correlate with rock units east or west of the fault zone. Splay thrusts within the synclinorium seem to cause imbrication of stratigraphic units along the east flank but die out toward the west. The Wekepeke fault is west of the Clinton-Newbury. Although it does not coincide with the east edge of the "Fitchburg Pluton," it runs parallel to it a few miles to the east. The Wekepeke is an en echelon normal fault system running northwestward into southern New Hampshire and shows as strong lineaments on ERTS imagery. This fault zone is certain post-Acadian and is probably a Late Paleozoic feature. The tectonic significance of the Wekepeke fault system is possibly related to the cessation of activity along the Clinton-Newbury zone. However, the feature may be related to initial rifting leading to the opening of the Atlantic in early Mesozoic time.

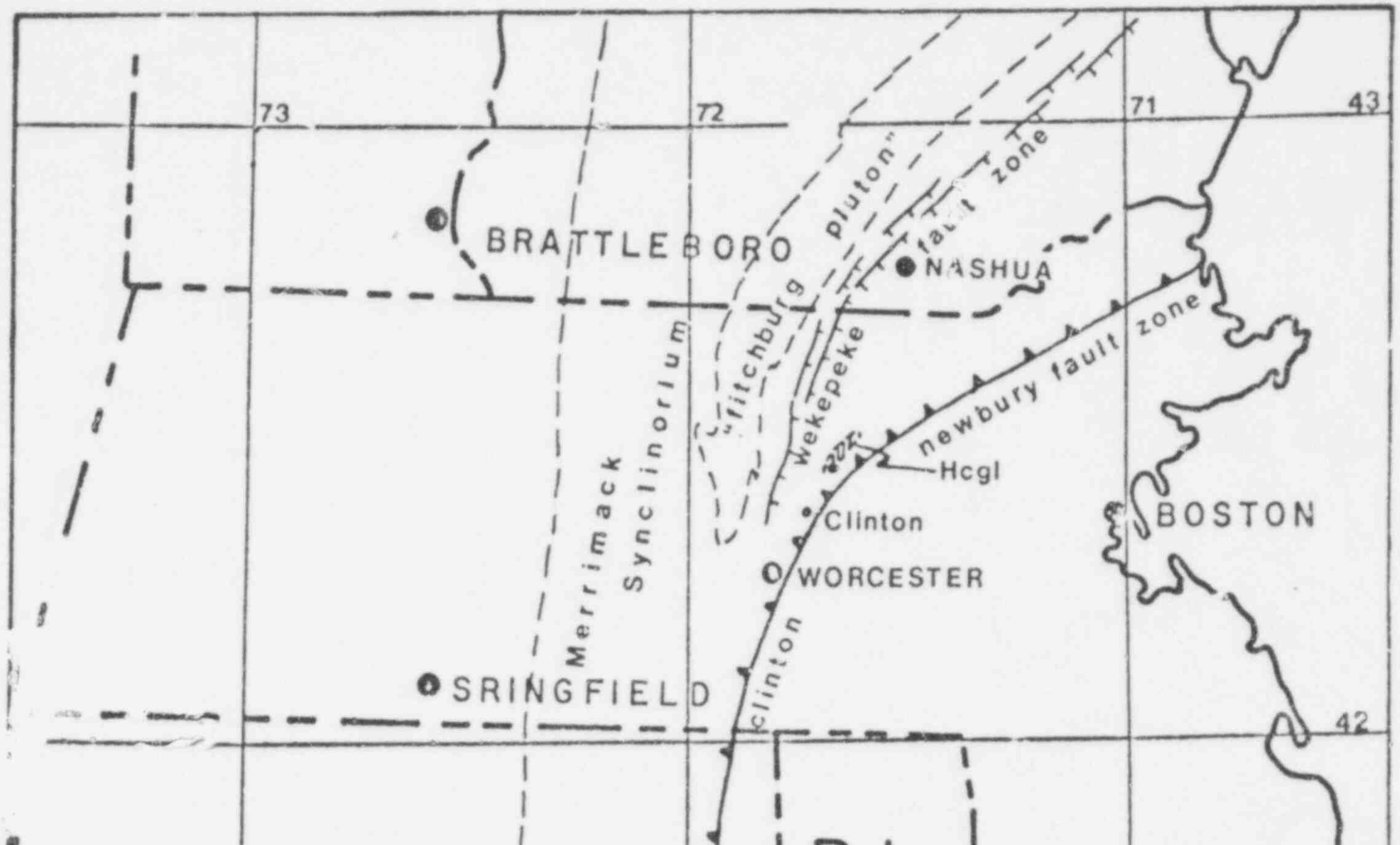


FIGURE 1
Index Map
Merrimack Synclinorium

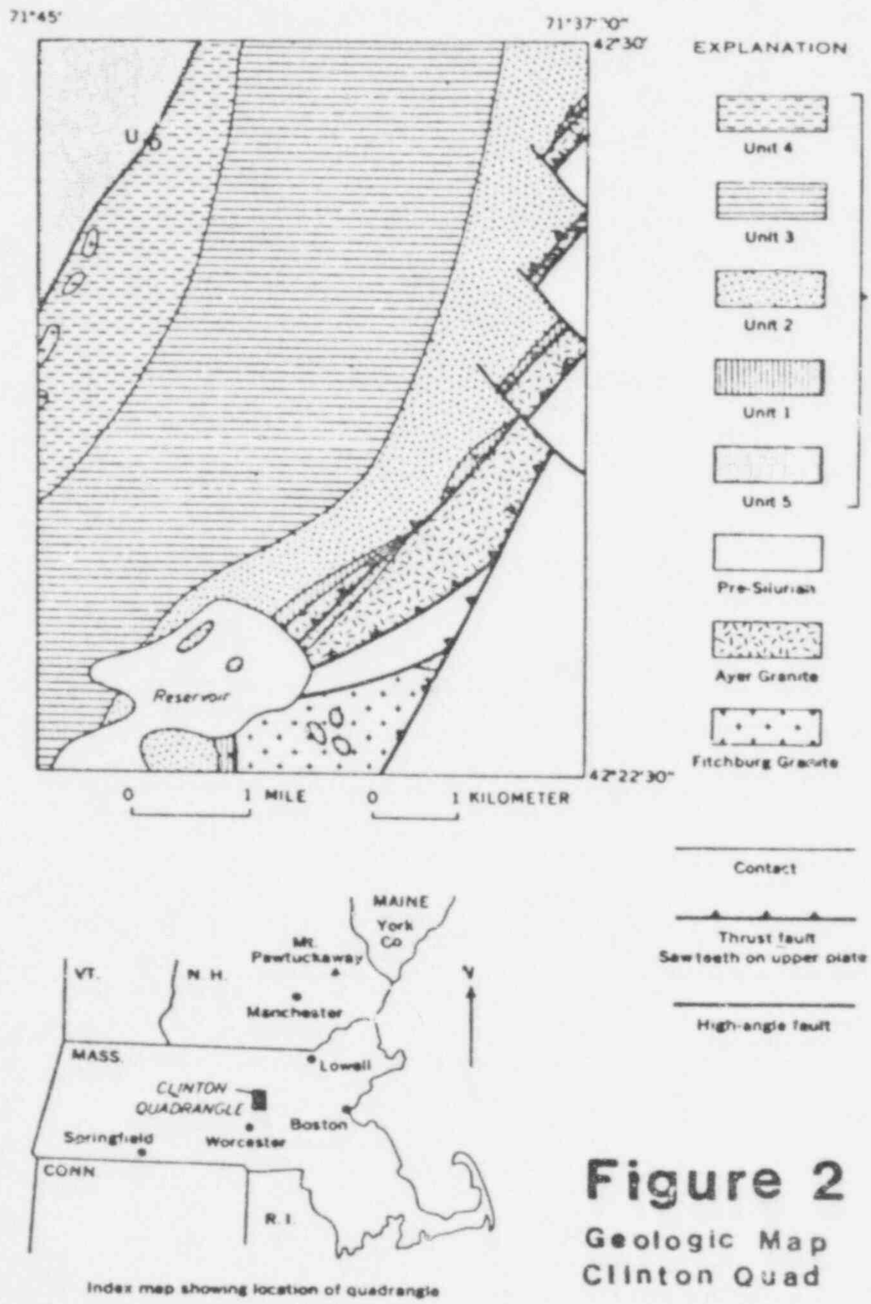
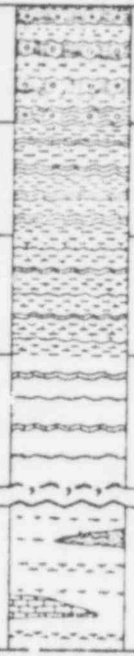


Figure 2
Geologic Map
Clinton Quad



UNIT	THICKNESS IN METRES	SECTION	PRESENT LITHOLOGY	ORIGINAL LITHOLOGY	PRIMARY STRUCTURES	ENVIRONMENT OF DEPOSITION
4	1220-1830		Gray chiastolite-bearing phyllite; interbedded metagraywacke.	Carbonaceous mud-stone and graywacke.	Tabular beds 1.25 cm to 1.25 m thick; graded bedding; low-angle crosslaminations in graywacke.	Low-energy deep marine basin with periodic currents and restricted circulation.
3	1830-2440		Dark-gray slate and phyllite, minor meta-graywacke.	Carbonaceous mud-stone and minor graywacke.	Tabular beds 0.6 cm to 0.6 m thick, graded beds; thin laminations, crosslaminations in graywacke.	Low-energy deep marine basin; reducing conditions; turbidity currents.
2	1220-2130		Laminated metasiltstone and greenish phyllite, calcareous metasiltstone.	Thinly laminated siltstone, shale, and calcareous siltstone.	Crossbeds, thin parallel laminations; tabular beds 0.3 cm to 0.3 m thick; cyclic banding.	Low-energy deep marine basin, with few currents; cyclic deposition.
1	0-91		Light-gray quartzite; some interbedded gray phyllite.	Quartzose siltstone and silty mudstone.	Tabular beds 5 cm to 1.5 m thick, thin laminations in phyllite.	Winnowed shelf area at moderate depth; muds accumulating adjacent to silt shoals.
5	1830+		Biotitic, feldspathic quartzite; calc-silicate beds, minor biotite schist.	Arkosic siltstone and fine sandstone; limy siltstone and minor shale.	Tabular and lenticular beds up to 7.6 cm thick, crossbeds, rare ripple marks, thin laminations.	Moderately deep marine with some currents, reworked volcanic debris, carbonate.

Figure 3 Generalized columnar section, Clinton quadrangle

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THE GEOLOGIC SETTING AND CHARACTERISTICS OF THE HILLSBORO PLUTONIC SERIES IN MASSACHUSETTS

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General Setting

The crystalline rocks on the east side of the Merrimack synclinorium exhibit similar syntectonic and early-late tectonic features that are accompanied by a time-composition curve classically interpreted as a magmatic differentiation sequence. Workers(Sriramadas, 1966; Sundeen, 1971) in southeastern New Hampshire have generally accepted these relationships by continuing to group these rocks under Billings'(1956) original designation, the Hillsboro plutonic series. Plutonic rocks in Massachusetts on strike with the Hillsboro series of New Hampshire exhibit similar structural, textural, and compositional characteristics to those of the New Hampshire Hillsboro rocks. It is very likely that the Massachusetts plutonic rocks on the east side of the Merrimack synclinorium are extensions of the Hillsboro plutonic series and should be included under this designation.

The rocks of the Hillsboro plutonic series occupy a low grade metamorphic belt bounded by the Clinton-Newbury fault on the southeast and apparently by the unnamed fault of Novotny (1961)(in part the Wekepeke fault of Peck, 1974) on the northwest. The intrusives, and possibly mobilized migmatites, of this structural trough appear to have been passively injected since extensive brecciation of the country rock and/or numerous xenoliths are generally lacking. Most of the bodies appear to have a mesozonal character that has been modified by a postconsolidational metamorphic and tectonic event.

Hillsboro-Fitchburg Relationships

The relationship of the Hillsboro plutonic series to the Fitchburg pluton is uncertain but both the higher metamorphic grade associated with the Fitchburg, and its greater area of intrusive and migmatite development, suggest either a deeper or more moble crustal zone. The two belts share some similar lithologies, particularly the more felsic rocks. The possibility that Sriramadas'(1966) Massabesic gneiss represents a remobilized basement within the Fitchburg pluton indicates caution in correlation.

Lithologic Subdivision of the Hillsboro Plutonic Series

Using a simple first order subdivision, the Hillsboro plutonic series may be divided into three lithologic subdivisions:

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<u>Subdivision 1</u>: Lithology- Nonfoliated to moderately foliated, mainly fine to medium-grained, quartz diorite to gabbro. These rocks rarely contain significant amounts of potassium feldspar.
Local Units- Straw Hollow diorite(Clinton, Mass.), Dracut diorite, Sweepstakes diorite, Island Pond diorite, Exeter diorite, and numerous unnamed bodies.

<u>Subdivision 2</u>: Lithology- Medium-to very coarse-grained, quartz monzonite to quartz diorite. Foliation can range from slight to intense.
Local Units- Ayer crystalline complex(contains the Clinton quartz monzonite and the Devens gneiss), Island pond porphyritic quartz monzonite, Newburyport pluton, probably part of the Fitchburg pluton, and numerous unnamed bodies.

<u>Subdivision 3</u>: Lithology- fine-to medium-grained(coarse-grained varieties not uncommon), primarily binary, granite to quartz monzonite. Foliation ranges from nonfoliated to intenely foliated.
Local Units- Millstone Hill two mica granite, Chelmsford granite, probably portions of the Fitchburg pluton, and numerous unnamed bodies.

<u>Relationship of Subdivision 2 to Subdivision 3</u>

The existence of any consistent time relationship for all units either within a given subdivision or between subdivisions is still uncertain. However, Zartman(1976, personal communication) has dated rocks falling into subdivision 2 from Shrewsbury, Bolton, and Ayer and obtained ages ranging from 410 to 425 million years. He also dated the Millstone Hill two mica granite and the Chelmsford granite of subdivision 3 and obtained a consistent date of 380 million years.

The limited isotopic data suggests that subdivision 2 is generally older than subdivision 3. This is also supported by Page(1968), who in his general review of the New Hampshire plutonic series(in which he includes the Hillsboro plutonic series) noted that the more mafic rocks are generally cut by the more felsic rocks. Locally, Gore(1976) has established that the subdivision 3 Chelmsford granite cuts the subdivision 2 Devens gneiss.

<u>Relationship of Subdivision 1 to Subdivision 2</u>

Novotny(1969) and Sundeen(1971), using the degree of foliation as a criterion, concluded that in New Hamphire the diorites and gabbros(subd. 1) postdate the proximate units of subdivision 2. In northeastern Massachusetts, the degree of foliation has not been found to be a dependable criterion in establishing relative ages between plutonic rocks. Gore(1976) determined that the Clinton quartz monzonite crosscuts the Straw Hallow diorite and a recent unpublished study suggests that the Devens gneiss either crosscuts or grades into the Dracut diorite. In the Clinton-Ayer region, I have concluded that much of the foliation of the plutonic units is secondary and post dates all the subdivisions of the Hillsboro plutonic series.

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Conclusion

In conclusion, the rocks of the Hillsboro plutonic series appear to have been generated by distinct episodes of plutonic activity. The general compositional trend of this activity has been from more basic to more acid rock. However, I do not see these rocks as the product of a progressive differentiation of a deep seated parent magma but rather as a mobilization sequence, in large part anatectic.

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Geology of the Boston Basin

by

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Abstract

The age of the Boston Basin is in doubt. For much of the 19th century it was Cambrian to agree with the age of the only fossils found in it. Towards the end of the century opinion shifted to Carboniferous to make it conform to the age of the nearby Narragansett and Norfolk basins with which it has lithologic and structural affinities. The finding of a fossil tree-trunk in the Roxbury Conglomerate at the turn of the century clinched the matter. Or so it seemed. The organic origin of the tree trunk is now seriously questioned. There are other reasons for doubt. One looks in vain for an unconformity between fossiliferous Cambrian strata and beds generally labelled "Boston Basin." Quincy granite of probable Ordovician age intrudes argillites and sandstones lithologically indistinquishable from Boston Basin argillites and sandstones. Rocks from well within the basin resemble rocks traditionally labelled Cambrian. Another century of diligent search for fossils has gone by without a single find in the Boston Basin other than from the known Cambrian beds. The possibility that the similarities of the Narragansett and Boston basins is just another one of those vexing coincidences designed to plague geologists is becoming a probability (not to be confused with certainty!). Radiometric dating of volcanic rocks within the basin is also pointing that way.

Because outcrops of Boston Basin rocks are so few and far between east of the marginal zone, special emphasis has been put on studying rock cores from exploratory boring done for engineering purposes. Another investigation undertaken to learn something about lithologic types and their distributions in the basin has been pebbles in till and particularly in the harbor drumlins. In this way it has been found that basic to acid volcanic rocks and pyroclastics (some superficially resembling argillites and sandstones) are widespread within the sedimentary facies. Li / zones are also common, particularly in the harbor area and to the east. Turbidities are abundant in some zones. Red beds, arkoses, and quartzites are present in fairly broad areas on the north and south of the basin while thick sandstones become important offshore to the east. Layered diabasic sills of great thickness crop out in the harbor where they have been shown on older maps as argillite. One result of this new knowledge is that the traditional formational classification of the basin is now seen to have less time-stratigraphic

significance than previously thought. Detailed field mapping shows that the formations (Roxbury Conglomerate, Cambridge Argillite, Brighton Melaphyre, etc.) are all facies that mutually interfinger and which reoccur at various levels in the sedimentary wedge.

Structure is seen to be more complex than has been shown on published maps. The basin is broken into several E to ENE-striking anticlines and synclines that are separated by faults. Zones of tight folding and even crushing mark the axes of some of these and seem to be the result of the interaction of competent and incompetent rocks within the fold system. The north-boundary fault is now seen to trend east, out to sea, at the latitude of Swampscott, passing north of Nahant, which places that island, with its Cambrian strata and gabbroic intrusion, well within the basin and which again suggests that all of these rocks belong to the same depositional and structural sequence.

RECENT GEOPHYSICAL WORK IN EASTERN MASSACHUSETTS

by

Gene Simmons and Many Others

An extensive geological and geophysical study by Weston Geophysical Research, Inc. for the licensing of Boston Edison's Pilgrim II unit revealed the following:

1. The White Mountain magma series intrusives consist of two sets. In one set, the intrusives are 110-120 m.y. old, have positive residual Bouguer gravity anomalies, have large magnetic anomalies, and consist mainly of mafic rocks overlain by a thin veneer of granite. In the other set, the intrusives are older (150 to 200 m.y.), have negative residual Bouguer gravity anomalies, and consist mainly of granitic rocks.

2. A previously unrecognized intrusive of the young White Mountain magma series is located a few miles off Cape Ann.

3. The large earthquakes of New England - November 9, 1727, intensity VII (MM) and November 18, 1755, intensity VIII (MM) in the Cape Ann region; December 20 and 24, 1940, intensity VII (MM) in the Ossipee region - are associated with the young White Mountain magma series intrusives. This association is probably due to the mismatch in elastic properties of the mafic rock of the intrusives and of the surrounding rocks.

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ISOTOPIC AGES IN SOUTHEASTERN NEW ENGLAND

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The pattern of isotopic ages in southeastern New England has proved difficult to interpret, especially in terms of the Taconic and Acadian disturbances identified in western New England. It now appears that two clusters of ages can be recognized, based on U-Th-Pb dates on zircons: (a) 600 - 650 m.y., and (b) 400 - 450 m.y. The clusters are partially confirmed by Rb-Sr whole-rock dating, but there is a general tendency in southeastern New England for Rb-Sr whole rock and Rb-Sr and K-Ar mineral ages to appear younger than the zircon ages.

Rocks yielding ages in the older cluster include the Dedham Granodiorite and the Milford Granite, which cut the Middlesex Fells Volcanics, the Marlboro Formation, and the Grafton and Westboro Quartzites. The granite at Hoppin Hill, the Northbridge Gneiss, and the core-rocks of the Stony Creek Dome also probably belong to this cluster. In Massachusetts all of these rocks are found southeast of the Assabet River Fault and most occur southeast of the Bloody Bluff Fault. These rocks resemble the older rocks found on the Avalon Platform of Newfoundland. Similar ages are measured further west in the Massabesic Gneiss, the Dry Hill Gneiss of the Pelham Dome, and a variety of possible meta-rhyolites overlying Grenville basement along the Green Mountain Berkshire axis, but these rocks do not have the characteristic Avalonian lithologies and it appears premature to call them "Avalonian".

Units with dates falling in the 400 - 450 m.y. cluster include the Quincy, Peabody, and Cape Ann Granites and probably the Salem Gabbro (southeast of the Bloody Bluff Fault); the Andover Granite and Sharpners Pond Tonalite (between the Bloody Bluff and Clinton-Newbury Faults); and the Newburyport Quartz Diorite, Ayer Granite, and Fitchburg Granite (west of the Clinton-Newbury Fault). The Chelmsford and Millstone Hill Granites yield ages slightly younger than 400 m.y. Some fine-structure is evident among the dates within the cluster but its interpretation is uncertain, and clearly-marked Taconic and Acadian disturbances are not apparent in the data.

PENNSYLVANIAN STRATIGRAPHY OF NEW ENGLAND

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New England has several sedimentary basins and outliers of Pennsylvanian or possible Pennsylvanian age. Only three (including Worcester basin) are certainly Pennsylvanian based on the presence of plant megafossil remains. These remains have allowed precise age dating of most of the stratigraphic units in the Narragansett basin and adjacent Norfolk basin which partly share a common stratigraphic sequence. Four stratigraphic units with thicknesses indicated below were recognized by Shaler and others (1899). These data and age assignments developed by the author and his co-workers are given below, from top to bottom:

Formation	Age	Thickness
Dighton Conglomerate	Stephanian B	1,000-1,500 ft.
Rhode Island Formation	Westphalian C to Stephanian A	10,000 ft.
Wamsutta Formation	Westphalian C	1,000 ft.
Pondville Conglomerate	Westphalian B	100 ft.

These stratigraphic units typically grade laterally and vertically into one another. All except the Dighton Conglomerate have been dated in age ranging from Late Pottsvillian to Conemaughian, equivalent to Westphalian B to Stephanian A in European chronostratigraphic terms.

The upper member of the Pondville Conglomerate in the Norfolk Basin has been dated as Late Pottsvillian on the basis of a Lonchopteris-Neuropteris obliqua plant assemblage (Lyons and others, 1976). The undocumented florule reported by Knox (1944) from the Wamsutta Formation in North Attleboro and the florule reported by Grew and others (1970) from the Worcester basin are close in age to the flora in the lower part of the Rhode Island Formation which is referred to the Lower Allegheny.

The lower part of the Rhode Island Formation, which is typically found along the northwestern margin of the Narragansett Basin, is defined by a plant assemblage of *Neuropteris scheuchzeri*, *Sphenophyllum cuneifolium*, *Mariopteris nervosa*, *Annularia sphenophylloides* plus or minus *Neuropteris heterophylla*, *N. rarinervis*, *Sphenophyllum emarginatum*, *Annularia stellata*, *Alethopteris serli*, *Pecopteris miltoni*, *Cordaites principalis*, *Eremopteris missouriensis*, *Lepidostrobophyllum majus*, and *Lepidophyllum lanceolatum* (Round, 1920; Lyons and Chase, 1976; Oleksyshyn, 19[illegible] The middle part of the Rhode Island shows similar species; the absence of *N. scheuchzeri*, *N. heterophylla*, *S. emarginatum*, *A. serli*, and *P. miltoni*; and the first appearance of *Pecopteris arborescens*, *P. cyathea*, *P. unita*, *P. lamuriana*, *Sphenopteris minutisecta*, and *Odontopteris reichiana* plus or minus *Neuropteris fimbriata* (Lyons and Darrah, in press, 1977). The upper part of the Rhode Island Formation typically occurs on Aquidneck Island in Rhode Island. This part of the section is characterized by the absence of all species found in the lower part of the Rhode Island Formation except *A. sphenophylloides* and *A. stellata*; the first appearance of several species of *Odontopteris*, especially *O. alpina*, *O. deformata*, *O. squamosa*, and *O. schlotheimii*; and the dominance of pecopterids, especially *Pecopteris arborescens*, *P. unita*, *P. cyathea*, and *P. feminaeformis* (Lyons and Darrah, 1977). *Neuropteris agassizi*, a species

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unique to the Narragansett Basin, along with *Mariopteris dimorpha* and *Sphenophyllum oblongifolium* are also present in this upper flora.

The three floral zones that occur in the Rhode Island Formation correspond reasonably well with floral zones 9, 10, and 11 in the zonation scheme of Read and Mamay (1964). These zones correspond, respectively, to Westphalian C, Westphalian D, and Stephanian A.

The Dighton Conglomerate has only yielded poorly preserved plant fragments that have not allowed age determination. Based on its traditionally accepted stratigraphic position at the top of the succession, this formation is assumed to be Stephanian B, corresponding to Monongahelan in the central Appalachians.

The Boston basin, North Scituate basin, and Woonsocket basin are possible Pennsylvanian basins or outliers of Pennsylvanian rocks, but plant fossils have not been found in the latter basins. Plant fossils or possible plant fossils collected from the Boston basin (Burr and Burke, 1900) have not as yet allowed reliable age dating.

GEOL. TIME UNIT:	ROCK STRATIGRAPHIC UNITS: Appalachian region	Narragansett Basin	Maritime Canada	TIME STRATIGRAPHIC UNITS: Europe		Appalachian region
PENNSYLVANIAN (UPPER CARBONIFEROUS)	Monongahela Group	Hiatus	Hiatus	Stephanian	C	Monongahelan
		Dighton Congl.			B	
	Conemaugh Group	Rhode Island Fm.			A	Conemaughian
	Allegheny Group		Pictou Group	Westphalian	D	Late Alleghenian
		Wamsutta Fm.			C	Early Alleghenian
	Pottsville Sup. Gr.: Upper Pottsville Group	Pondville Congl.	Hiatus		B^2	Late Pottsvillian
	Pottsville Sup. Gr.: Middle Pottsville Group	Hiatus	Cumberland Group		B^1	Medial Pottsvillian
	Pottsville Sup. Gr.: Lower Pottsville Group		Riversdale Group		A	Early Pottsvillian
	Pottsville Sup. Gr.: Pocahontas Group		Canso Group	Namurian	C	Pocchontasan
					B	

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ABSTRACT

Recent Geologic Work in the Narragansett Basin

by

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The chief results of the first year of the Narragansett Basin Project are:

1) Recovery of 14,000 of core for petrography, coal analysis, sedimentology analysis, etc.

2) The development of a Pennsylvanian stratigraphy similar to that developed by Mutch (1968). Only the positioning or nature of the several conglomerates is in question. The Rhode Island Formation is upper fluvial in origin.

3) Coal is found to be high BTU (13-14,700) semi-anthracite to anthracite; very low sulfur; moderate ash.

4) The Pannsylvanian-aged basin has been extended to Massachusetts Bay on the basis of outcrop and water well data.

5) A new locality of Middle Cambrian trilobites has been identified in rocks of southernmost Narragansett Bay, previously mapped as Carboniferous. Questions have been raised as to the age of highly metamorphosed rocks on the west shore of the Basin.

6) The Basin structure is complicated; the margin edge is faulted; the qeustion of whether these continue through the basin is unresolved. Fold axes are north-trending in Rhode Island and northeast-easterly trending in Massachusetts. A tentative structural sequence has emerged:

   a) Westerly directed overfolds and thrust faulting with associated northerly striking - easterly dipping cleavage.

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b) Northerly striking, westerly dipping reverse and thrust faulting with associated cleavage (Aquidneck Island) possibly axial planar to refolded folds.

c) Kink banding

d) Block faulting produces horst and graben

7) The structure in the PreCarboniferous and Carboniferous of southern Narragansett Bay is similar. The Avalonian block was probably affected only by orogenic events occurring after Pennsylvanian deposition. The Avalonian block, therefore, probably came to its present position with respect to the rest of New England in late Devonian. The westward-directed overfolding and thrusts may represent a collision of western Europe-Africa with the Avalonian microcontinent. The easterly-directed thrust may represent another collision effect in which rocks of the eastern margin of the American Plate were thrust eastward over the Basin. The overfolding, loading and depression of the southern part of the Narragansett Basin may largely account for the generation of metamorphic zonation.

A preliminary report on a stratigraphic test well on Martha's Vineyard, Massachusetts

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ABSTRACT

A 262-m (860-ft) test well on Martha's Vineyard, Massachusetts, was drilled for the U.S. Geological Survey in fall 1975. Samples were obtained every 3 m (10 ft) by means of a 0.6-m (2-ft) long split-spoon coring device. The well penetrates Quaternary, Tertiary, and Cretaceous sediments, and we believe that the bottom is in strata of earliest Late Cretaceous age (Cenomanian Stage).

The Cretaceous strata, 74-262 m (240-860 ft), are probably part of a deltaic complex. This conclusion is based on the occurrence of: (1) mottled clays (indication of soil), (2) sequences of graded silts and sands, and (3) poor sorting.

Kaolinite and mica are the dominant clay minerals in the Cretaceous section. High concentrations of tourmaline and zircon along with low percentages of feldspars throughout most of the Cretaceous are diagnostic of severe chemical weathering. Below 230 m (780 ft), the sediments are arkosic. The feldspar in this section is probably of detrital origin derived from local erosion of arkosic sandstone.

The Tertiary, 46-74 m (150-240 ft), is represented by a marine sequence of Eocene age containing high percentages of glauconite, also pollen, calcareous nannoplankton, and benthic and some planktic foraminifers. The Eocene age is based on pollen and calcareous nannoplankton analysis.

The clay minerals of the Eocene are principally a mica, smectite, kaolinite, and chlorite assemblage. Light minerals and a large suite of heavy minerals in the sand-size fraction indicate contributions from multiple sources.

The Quaternary beds are composed of moderate to poorly sorted, medium, and coarse sands; fine grain-size fractions are minor. These beds are probably glacially derived.

A strong lithologic correlation exists between the Martha's Vineyard well and a well recently drilled by the U.S. Geological Survey on Nantucket Island (1975-76)--well 6001. Correlation of glauconitic green sand, red, yellow, and gray mottled beds, and a distinctive sphalerite zone shows that equivalent beds on Martha's Vineyard are approximately half as thick as those on Nantucket.

Geology and shallow structure of the Inner Continental Shelf off southeastern Massachusetts

by

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Abstract

High-resolution seismic-reflection profiling data and shallow-sediment cores, obtained by the U.S. Geological Survey as part of a cooperative marine geologic program with the Commonwealth of Massachusetts, have revealed the late Mesozoic and Cenozoic development of Cape Cod Bay, Buzzards Bay, Vineyard Sound, and eastern Rhode Island Sound. Nearshore, the deepest unconformity beneath this part of the Inner Continental Shelf is underlain by pre-Cretaceous crystalline and consolidated sedimentary rocks of the Fall Zone; offshore it is underlain by unconsolidated coastal-pain strata of Cretaceous to early Pleistocene age. This unconformity is believed to have been subaerially cut during Pliocene to early Pleistocene time; some glacial modification took place during Pleistocene time. Beneath Buzzards Bay, Vineyard Sound, and eastern Rhode Island Sound, the coastal-plain sedimentary rocks lie seaward of a deeply eroded cuesta that extends from western Long Island Sound to eastern Georges Bank. Beneath Cape Cod Bay, these deposits appear as isolated erosional outliers of a south-trending subordinate cuesta underlain by sediments of possible Eocene age. Paleodrainage patterns suggest that streams draining the Fall Zone surface and the landward-facing escarpments of the cuestas are tributary to much larger streams that breached the cuestas through water gaps and drained across the shelf to the sea.

Beneath Vineyard Sound and eastern Rhode Island Sound, one or possibly two glacial drifts overlie crystalline basement and coastal-plain strata.

The lower drift may be of early Wisconsin age and correlate with the Montauk Till Member of the Manhasset Formation on Martha's Vineyard, Block Island and Long Island. Locally, the older drift and underlying coastal-plain deposits have been folded and faulted by overriding ice. The upper drift deposits, ubiquitous off southeastern Massachusetts, are inferred to be of late Wisconsin age, correlating with moraines and stratified drift of southern New England, Block Island, and Long Island. The upper drift is believed to consist mostly of ice-contact stratified drift and outwash plain and glaciolacustrine sediments. Beneath Cape Cod Bay, seismic data show that both the Cape Cod Bay and the Great South Channel ice lobes were sources of sediment. Cape Cod Bay lobe deposits are confined to the western part of the bay and contain irregular, discontinuous, and imbricated reflectors, suggesting deposition or modification by overriding ice. Deposits of the Great South Channel lobe overlie the Cape Cod Bay lobe drift and thicken eastward. Internal reflectors are more continuous and uniform and in the lower part mimic underlying relief, suggesting draping during quiet-water lacustrine deposition. In the upper part, the reflectors dip steeply northwest and are inferred to represent the bottomset and foreset beds of a delta built by melt-water streams of the Great South Channel lobe.

Seismic data on the submerged part of the Buzzards Bay moraine, southwest of the Elizabeth Islands, indicate that the moraine may be, in part, of structural origin. The moraine overlies outwash-plain deposits to the south and is overlain by younger stratified drift to the north. Acoustically, the morainal deposits show continuous imbricated reflectors that dip northward, being truncated at or near the sea floor to the south. These north-dipping reflectors may represent thrust planes separating blocks of sediment thrust forward and upward during readvance of ice over outwash. On Martha's Vineyard similar ice-thrust structures are observed in the Gay Head Cliffs.

The moraines of late Wisconsin age suggest that in southern New England, ice retreat was characterized by an oscillating ice margin possibly responding to short-term climatic fluctuations rather than a gradual and steady deglaciation in response to an ameliorating climate.

Prior to postglacial marine submergence of the inner shelf, the glacial drift and older deposits were fluvially eroded. North of Cape Cod, streams drained toward the Gulf of Maine; south of Cape Cod, drainage was toward Block Island Sound. As sea level rose, estuarine sediments were deposited in the valleys. Finally, marine erosion became dominant, planing off topographic highs and filling lows. Locally, 20 to 30 meters of sediment may have been removed, as suggested by the destruction of postglacial valleys. Relict and modern beach and bar deposits, consisting mostly of sand and gravel, overlie the marine unconformity. The modern beach deposits grade offshore to quiet-water marine silt and clay. Radiocarbon dating of freshwater peat indicates that complete marine submergence of this part of the Atlantic Inner Continental Shelf did not take place earlier than 5,000 years before present.

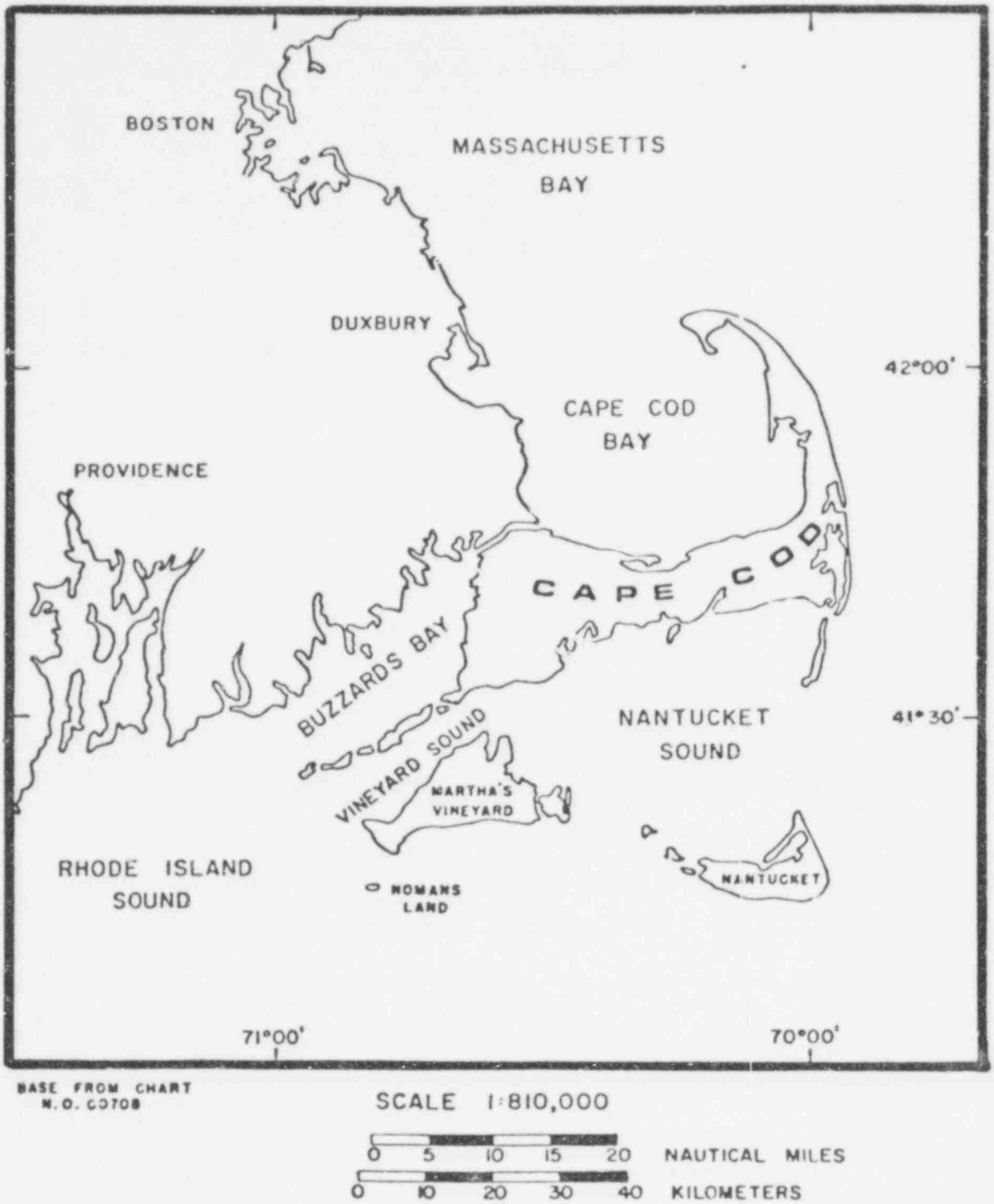
BOSTON
MASSACHUSETTS BAY
DUXBURY
CAPE COD BAY
PROVIDENCE
CAPE COD
BUZZARDS BAY
NANTUCKET SOUND
VINEYARD SOUND
MARTHA'S VINEYARD
RHODE ISLAND SOUND
NOMANS LAND
NANTUCKET
42°00'
41°30'
71°00'
70°00'
BASE FROM CHART
N.O. C0708
SCALE 1:810,000
0 5 10 15 20 NAUTICAL MILES
0 10 20 30 40 KILOMETERS

FIGURE 1