ENGINEERING GEOLOGY OF THE NORTHEAST CORRIDOR
WASHINGTON, D. C., TO BOSTON, MASSACHUSETTS
EARTHQUAKE EPICENTERS RECORDED IN AND NEAR THE NORTHEAST CORRIDOR FROM 1534 TO 1965

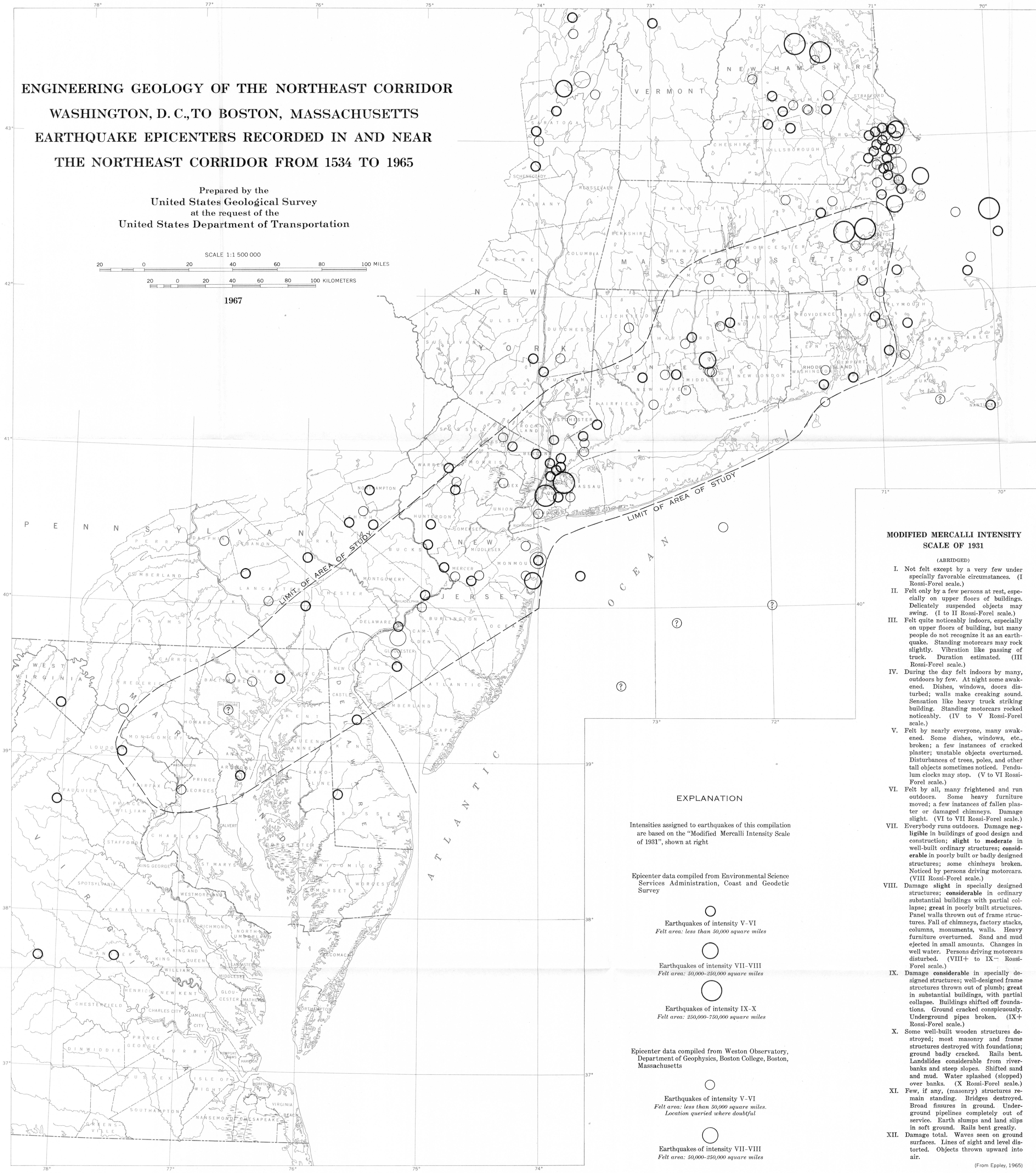
Prepared by the
United States Geological Survey
at the request of the
United States Department of Transportation

SCALE 1:1 500 000

20 0 20 40 60 80 100 MILES

20 0 20 40 60 80 100 KILOMETERS

1967



EXPLANATION

Intensities assigned to earthquakes of this compilation are based on the "Modified Mercalli Intensity Scale of 1931", shown at right

Epicenter data compiled from Environmental Science Services Administration, Coast and Geodetic Survey

Earthquakes of intensity V–VI
Felt area: less than 50,000 square miles

Earthquakes of intensity VII–VIII
Felt area: 50,000–250,000 square miles

Earthquakes of intensity IX–X
Felt area: 250,000–750,000 square miles

Epicenter data compiled from Weston Observatory, Department of Geophysics, Boston College, Boston, Massachusetts

Earthquakes of intensity V–VI
Felt area: less than 50,000 square miles. Location queried where doubtful

Earthquakes of intensity VII–VIII
Felt area: 50,000–250,000 square miles

Base by U.S. Geological Survey

Compiled by R. W. Bromery

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(ABRIDGED)

I. Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, especially on upper floors of building, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage **negligible** in buildings of good design and construction; **slight** to **moderate** in well-built ordinary structures; **considerable** in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel scale.)

VIII. Damage **slight** in specially designed structures; **considerable** in ordinary substantial buildings with partial collapse; **great** in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII+ to IX− Rossi-Forel scale.)

IX. Damage **considerable** in specially designed structures; well-designed frame structures thrown out of plumb; **great** in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from riverbanks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air.

(From Eppley, 1965)

EARTHQUAKE EPICENTERS
By R. W. Bromery

Since 1534, more than 1,100 earthquakes are believed to have had their epicenters within the area of the Northeast Corridor. The map compiled from these data shows only a few of the earthquake epicenters of intensity V or greater that could be located with some accuracy on the map. The intensities assigned to earthquakes of this report are based on the "Modified Mercalli Intensity Scale of 1931" shown in explanation. Precise instrumental seismological data have been available only very recently; a considerable number of the earlier earthquake epicenters were reported from testimonies of geographically isolated groups of persons, who in numerous instances were reporting under emotional surprise and fear.

The 175 epicentral locations shown were compiled from an extensive list provided by the U.S. Environmental Science Services Administration, Coast and Geodetic Survey (Eppley, 1965) and the Boston College, Department of Geophysics, Weston Observatory.

Along the route of the proposed Northeast Corridor, minor earthquakes have been reported in Maryland and Delaware as recently as 1944, generally moderate earthquakes have been reported in Pennsylvania, New Jersey, and New York as recently as 1961, and considerable moderate earthquake activity has been reported in eastern Connecticut, Rhode Island, and Massachusetts as recently as late 1963.

The concentrations of earthquake epicenters in the vicinities of New York City and Boston probably reflect the presence of large numbers of people in these areas who reported these seismic events before the advent of instrument-location methods.

In summary, the northeastern United States has been subjected to abundant earthquake activity, as evidenced in both the geological and historical records. A continuing history of seismic activity must be planned for in any large-scale engineering efforts.

ESTIMATES OF THERMAL GRADIENTS
By
R. W. Bromery and W. B. Joyner

Only sparse data are available for estimating temperatures at depths that are of interest for the Northeast Corridor project. Temperature measurements made within a few hundred feet of the surface are completely useless for extrapolation to appreciably greater depths. This is demonstrated by experience with temperature-depth curves in deep wells (Diment and Werre, 1964), which show erratic and abnormally low temperature gradients near the surface. Ground-water flow is probably the main cause, but other factors such as climatic variations and abnormal thermal conductivity also contribute to the unreliability of shallow measurements.

At depths greater than about 500 feet, the temperature-depth curves are more regular, and the thermal gradient G (the change in temperature per unit depth) obeys the relationship

$$G = Q/K$$

where K is the thermal conductivity and Q is the heat flow. In practice, Q is determined by measuring G and K in deep wells and solving the equation above.

The best way of estimating the gradient at a locality where direct measurements are unavailable is to assume a regional value for Q from the nearest available determinations and to divide that value by an estimate of K (thermal conductivity) appropriate for the locally prevalent rock type. Gradient estimates are presented in table 1 for rock types of interest to the Northeast Corridor project. These estimates are admittedly somewhat subjective, but they are about the best that can be done with the data available. Both a "best estimate" and a "probable upper limit" for the gradients are presented to give an idea of the uncertainty.

There are two nearby determinations of heat flow. A value of 1.1 microcalories/cm^2 sec was obtained by Diment and Werre (1964) near Washington, D. C., and a value close to 1.2 was obtained by Robert Roy (oral commun., 1967) at Cambridge, Mass. Accordingly, the 1.2 value was used in computing the "best estimates" in table 1. From a consideration of the available measurements in the eastern United States, it seems unlikely that the heat flow in the Northeast Corridor would exceed 1.4, and that value was used in computing the "probable upper limits."

TABLE 1.—*Thermal gradient estimates for the Northeast Corridor*

Rock type	Best estimate of thermal gradient* (°F per 1000 ft)	Probable upper limit of thermal gradient** (°F per 1000 ft)
Typical basement rocks (schist and gneisses)	10	14
Connecticut Valley Triassic rocks (arkosic sandstones and shales)	13	19
Coastal Plain sediments	13	19

*based on an assumed heat flow of 1.2 microcalories/cm^{2}sec. and a "best estimate" of thermal conductivity

**based on an assumed heat flow of 1.4 microcalories/cm^{2}sec and a probable lower limit for thermal conductivity.

The typical basement rocks in the Northeast Corridor are schists and gneisses. Diment and Werre (1964) measured the thermal conductivity of schist samples from the vicinity of Washington, D. C., and obtained a value of 6.6 millicalories/cm sec °C for the conductivity across the foliation. Higher values were obtained for the conductivity parallel to foliation, but as on the average the foliation is probably more nearly horizontal than vertical, the value measured across the foliation is probably closer to the vertical conductivity. The samples measured by Diment and Werre (1964) are typical of the schists in the basement rocks throughout the Northeast Corridor. Consideration of additional data from Clark (1966) indicated that the gneisses would have similar conductivity, and the rounded value of 6.5 was adopted for computing the best estimate of the gradient in typical basement rocks. In order to compute a probable upper limit on the gradient, one must assume a lower limit on the conductivity, and the value 5.5 was chosen.

The other rock types of importance are the arkosic sandstones and shales of Triassic age in the Connecticut Valley, and the Coastal Plain sediments. Estimating thermal conductivities for these units required a considerable exercise of intuitive judgment. For both units a conductivity of 5 millicalories/cm sec °C was assumed in computing the best estimate of the gradient, and a conductivity of 4 in computing the probable upper limit of the gradient. The same conductivities were assumed for both units despite the grossly different lithologies. It was believed that the greater degree of consolidation in the Triassic rocks would be largely offset by the arkosic nature of the sandstones.

In using table 1 to estimate temperatures at depth, the surface temperature can be approximated by the mean annual air temperature, which is about 55°F in the Northeast Corridor. As an example, the "best estimate" for the temperature beneath 5,000 feet of typical basement rocks would be $(55 + 5 \times 10)$°F or 105°F, and the probable upper limit would be 125°F. At the same depth beneath Triassic rocks the temperature would be higher, 120°F for the "best estimate" and 150°F as the probable upper limit.

Where Coastal Plain sediments overlie typical basement rocks, the estimation of temperature in the basement rocks should be carried out in two steps. The gradient value for Coastal Plain sediments should be used to determine the temperature at the base of the sediments, and the value for basement rocks should be used to determine the increase in temperature from the base of the sediments to the desired depth. The computations show, however, that even the presence of 1,000 feet of Coastal Plain sediments would affect the temperatures in the basement rock below by only a few degrees.

REFERENCES CITED

Clark, S. P., Jr., ed., 1966, Handbook of physical constants: rev. ed., Geol. Soc. America Mem. 97, 583 p.

Diment, W. H., and Werre, R. W., 1964, Terrestrial heat flow near Washington, D.C.: Jour. Geophys. Research, v. 69, p. 2143–2149.

Eppley, R. A., 1965, Earthquake history of the United States—Pt. 1, Stronger earthquakes of the United States (exclusive of California and Nevada): U.S. Coast and Geod. Survey [Pub.] S.P. 41-1 (rev. ed. through 1963), 120 p.

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