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WORLD SEISMICITY MAPS COMPILED FROM ESSA, COAST AND GEODETIC SURVEY, EPICENTER DATA, 1961–1967

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ABSTRACT

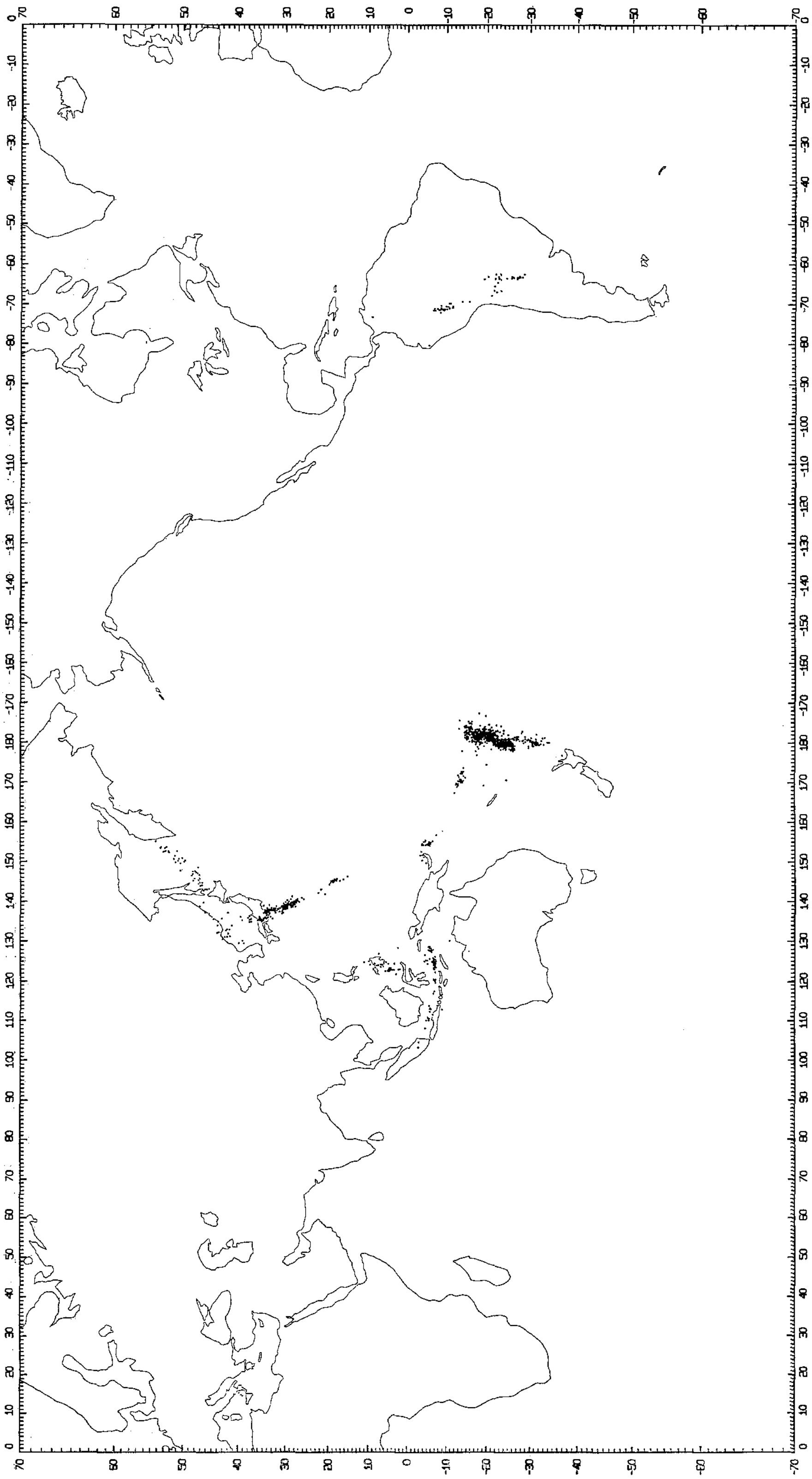
Seismicity Maps are published from the preliminary determinations of hypocenters of the USCGS, Environmental Science Services Administration, Department of Commerce. The seismicity covers the interval January 1, 1961 through December 31, 1967. Two large plates accompany the paper. Plate 1 contains a plot of all epicenters; Plate 2 shows a plot of all events deeper than 100 km.

INTRODUCTION

This note is intended to satisfy the urgent need for new maps of world seismicity based on the best data currently available. The standard work, "Seismicity of the Earth" by Gutenberg and Richter (1954), contains data on about 5100 events for the interval 1904 through 1952. In that monumental work many of the data do not reach the accuracy now attained with superior seismograph coverage and data processing techniques.

Some recent work, notably by Sykes, has clearly shown the value of seismicity maps which have more numerous and accurately located hypocenters. Several recent maps covering selected regions of the world have revealed characteristics of seismicity which are of great interest with reference to major tectonic mechanisms and patterns. Most of these relationships are difficult to see without maps of high quality. Ewing and Heezen (1956) pointed out that virtually all the epicenters reported by Gutenberg and Richter on the mid-Atlantic ridge are located within a degree or so of the topographic median rift, and therefore, considering the uncertainty of epicentral determinations, they might all be ascribed to faults in the median rift itself. Sykes' (1967) more accurate locations confirm this hypothesis. Similarly, Sykes' (1966) data on the Tonga-Fiji region of deep seismicity shows that earthquakes occur along a planar zone no thicker than about 25 km, a fact which could not be inferred from the less precise and less numerous data of Gutenberg and Richter. Examples of this sort clearly illustrate the need for modern, high quality seismicity maps of the entire world.

Fortunately, this need may now be met by use of the preliminary epicentral data compiled by the U. S. Coast and Geodetic Survey, Environmental Science Services Administration, Department of Commerce. With the adoption in 1960 of new techniques of collecting and processing seismic station observations, the Seismology Division, USCGS, has created a "knowledge explosion" in seismicity data. This is now the most important source of numerous and high-quality epicenter data. The establishment of the World-Wide Standard Seismograph Network (Murphy, 1966) under supervision of the same agency, beginning in 1962 marked a significant acceleration of this effort by providing more dense and standardized instrumental coverage in many parts of the world. We now count 29,553 epicenters for the interval January 1, 1961 through December 31, 1967 in the file already received from the USCGS by Lamont Geological Observatory. All of these epicenters, except those in the polar regions not mapped, have been used in preparing the accompanying seismicity maps. A map of all the data (Plate I) and maps of events deeper and shallower than 100 km (Plate II and Plate III) are folded in a pocket on the inside back cover of this BULLETIN. Other maps



SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

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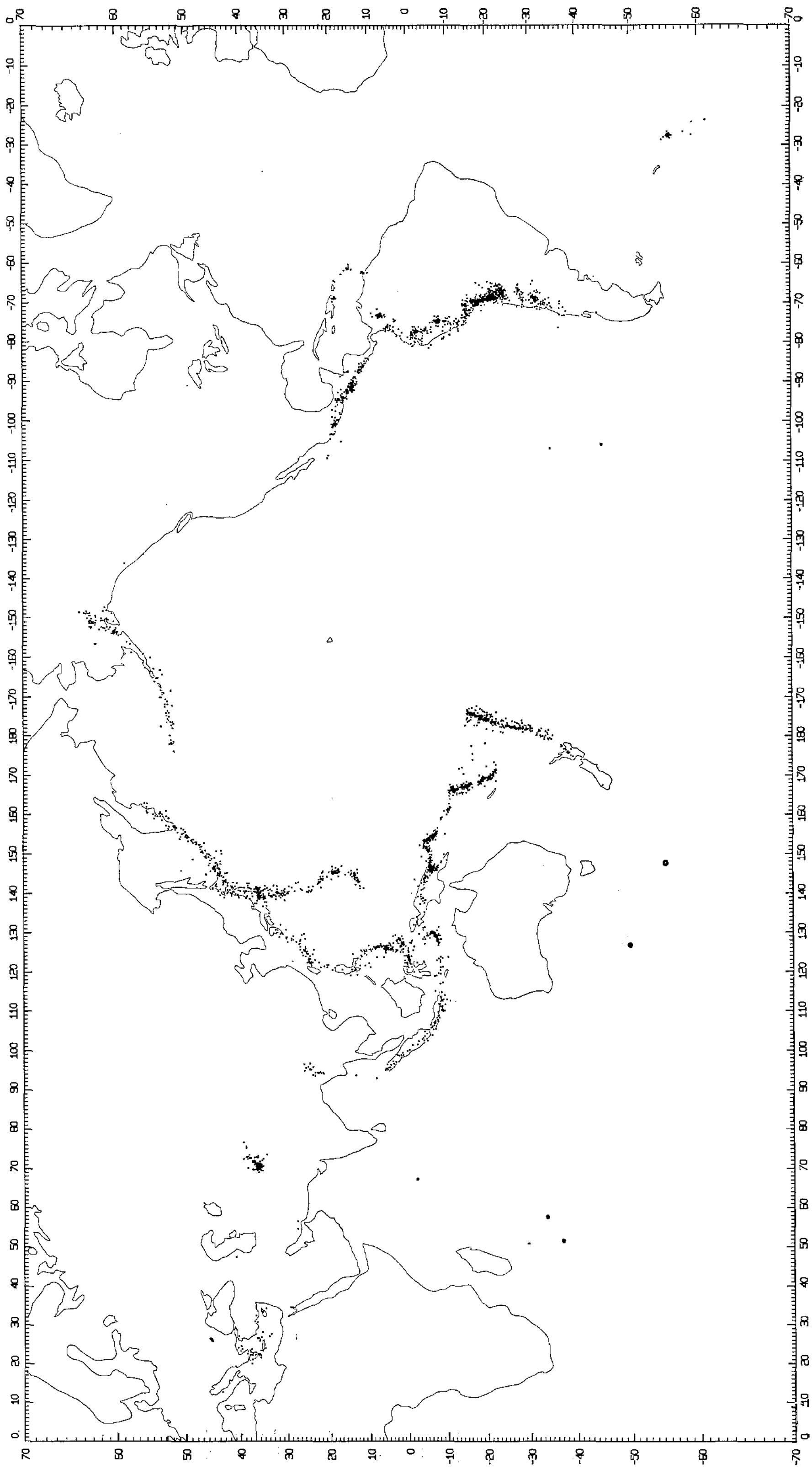

SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

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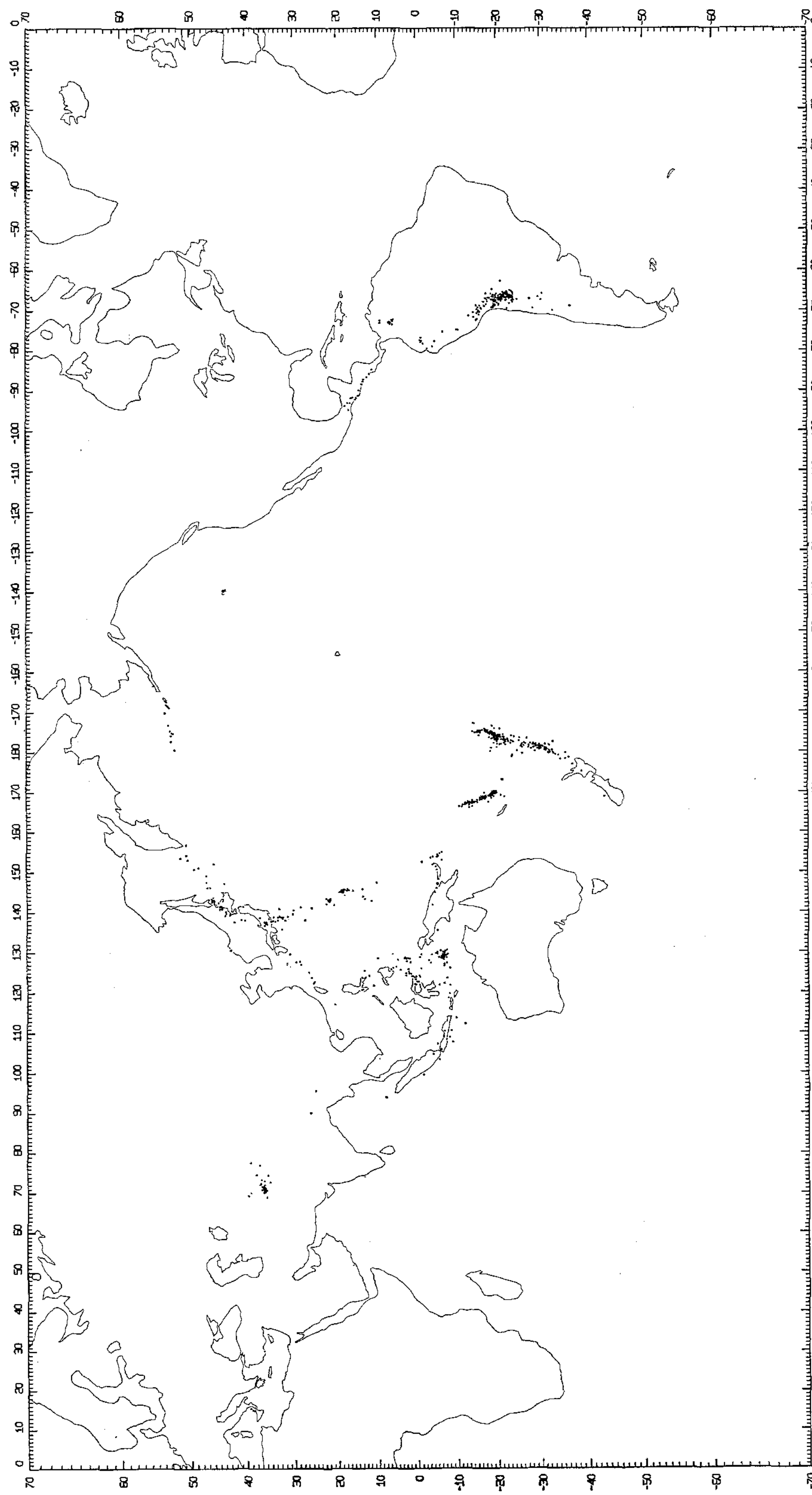

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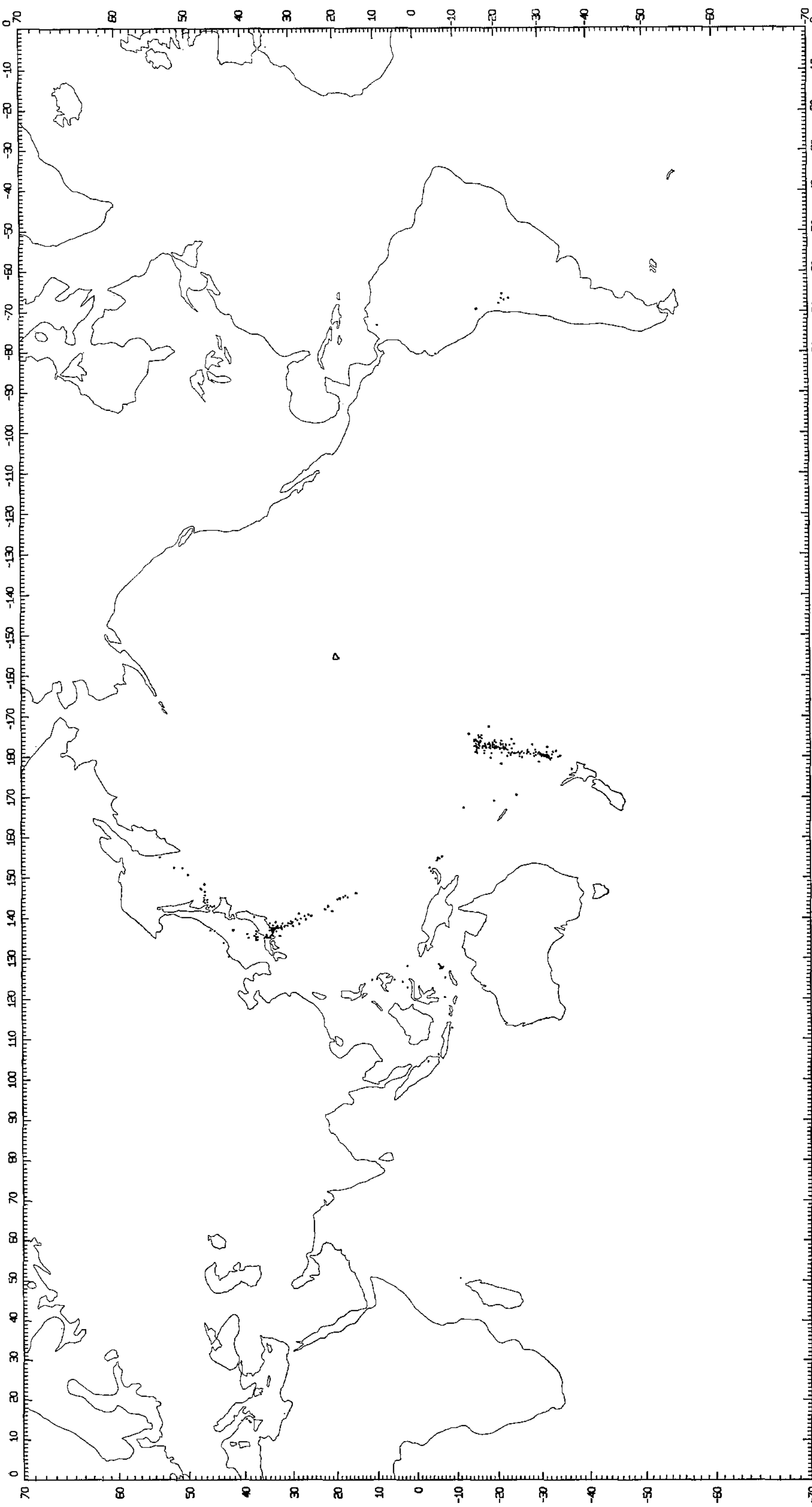

SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

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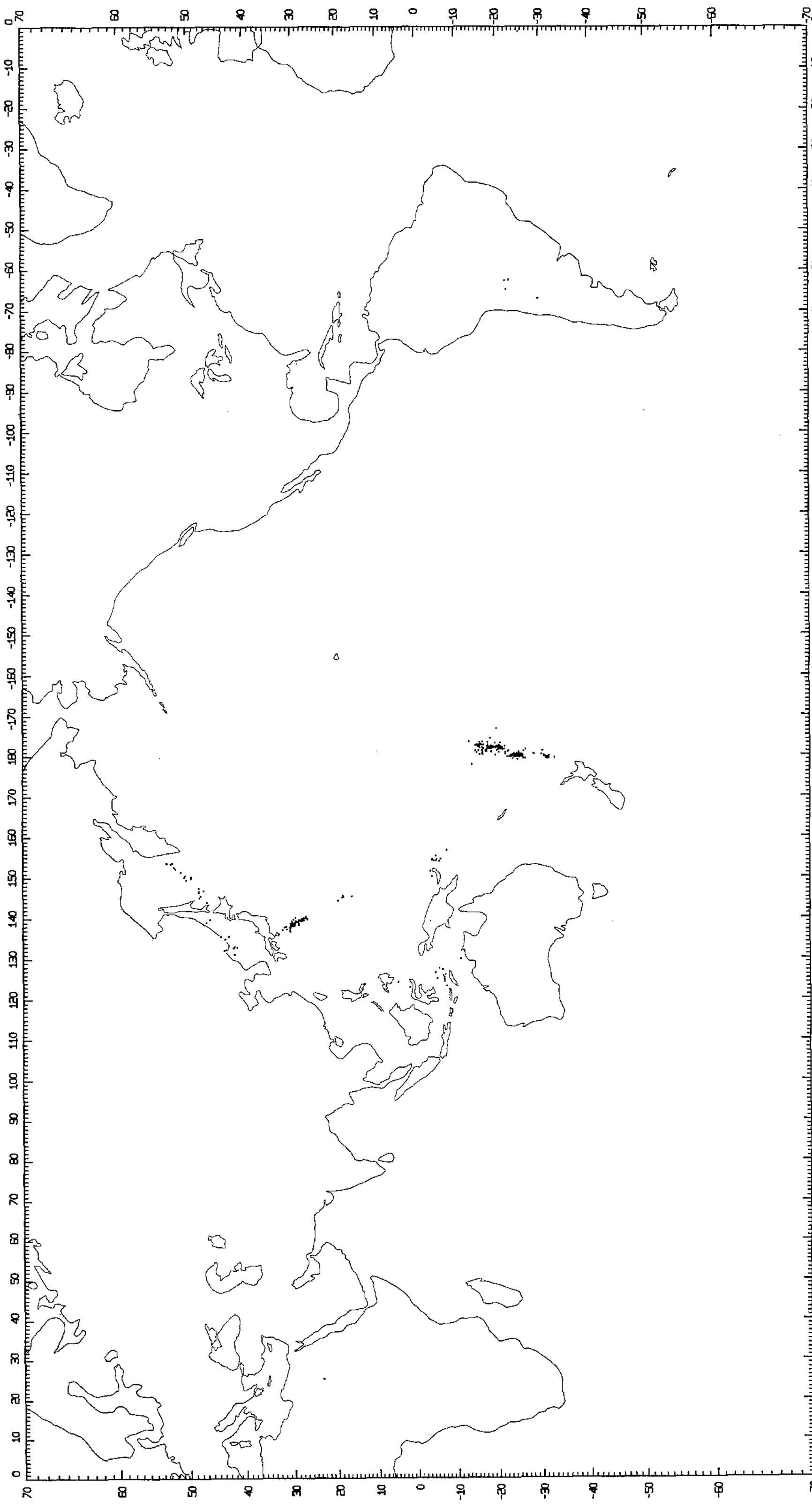
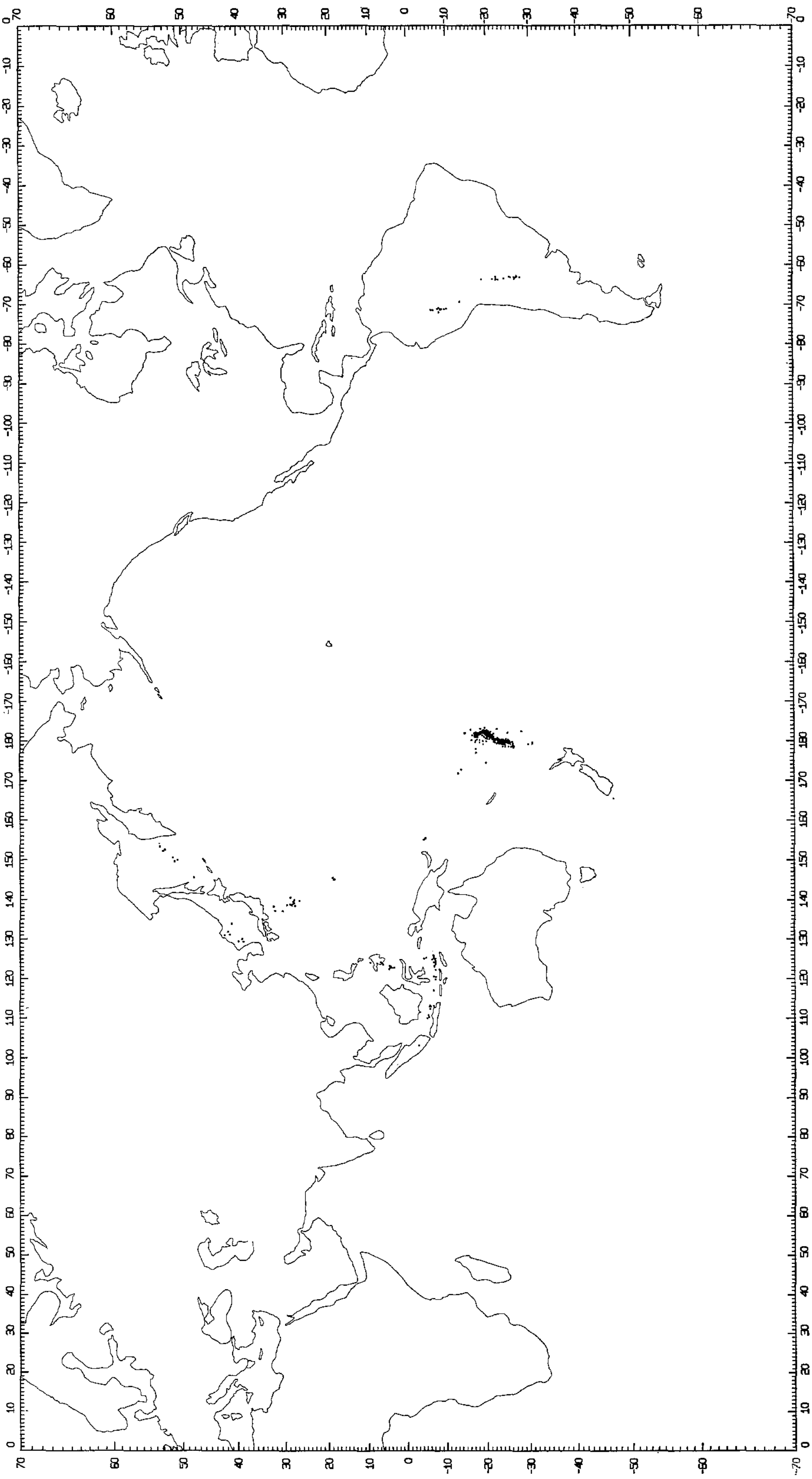


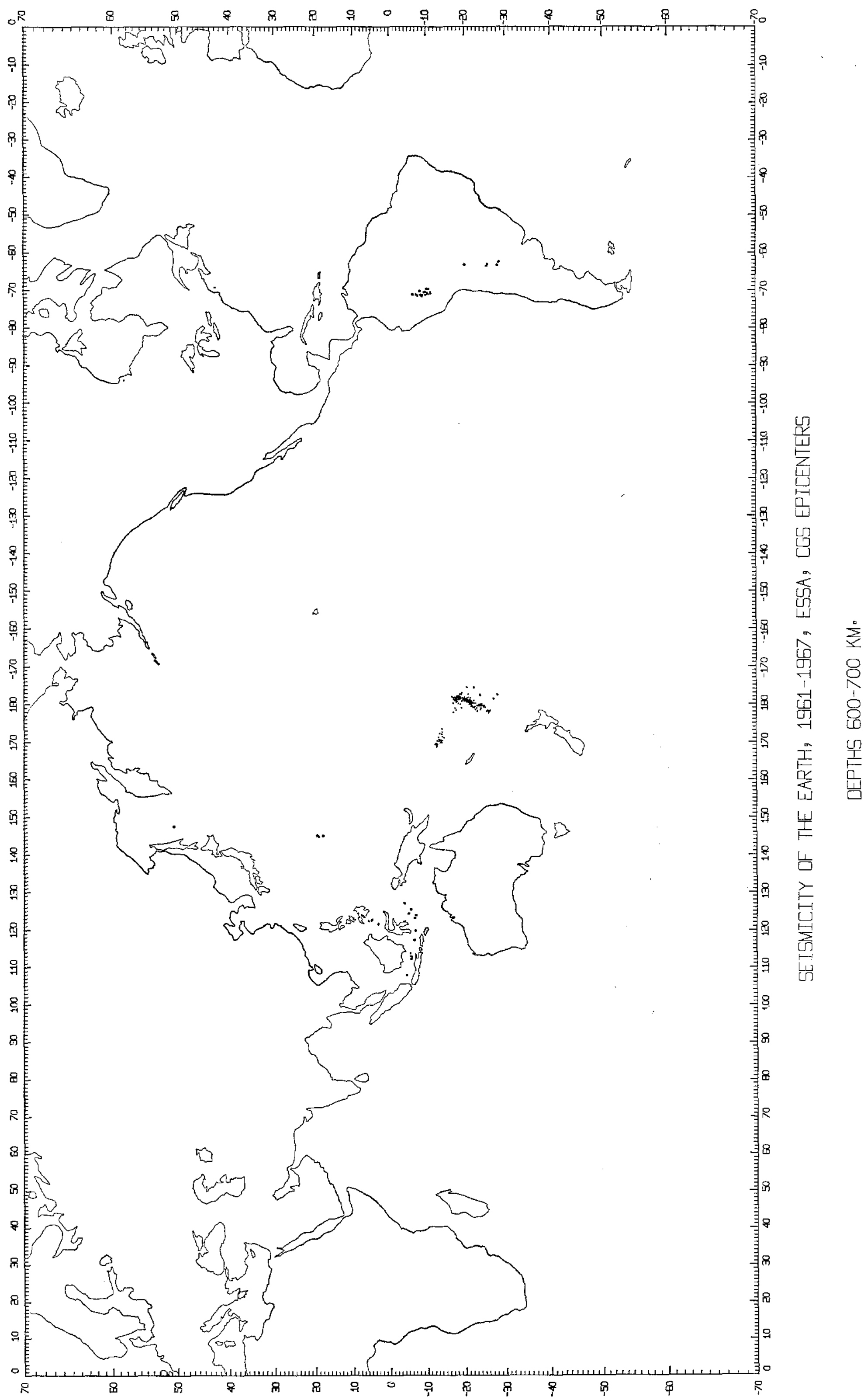
SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

DEPTHS 400-500 KM.



SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

DEPTHS 500-600 KM.


SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS
DEPTHS 600-700 KM.

of events in selected depth range are included as page size figures. Maps of the events of 1964, 1966, and 1967 have already been published in the BULLETIN (Lander, 1965, 1967, 1968). We are indebted to Mr. Leonard Murphy, chief of the Seismology Division, USCGS, for making this data available to us on punched cards and for his encouragement in preparing this publication. Without the generous cooperation of the USCGS the present maps could not have been drawn.

The epicenter data are now so numerous and so detailed in many regions of the world, that we comment briefly below but make no attempt here to compare them in detail with relevant geological, geophysical and bathymetric data. J. Lander (1966) discussed the significance of the ESSA epicentral file in the determination of the seismic belts. The maps will be the basis of numerous discussions until better ones are made. For example, their value in the development of the "new global tectonics" of Isacks, Oliver and Sykes (1968) which is based on the "plate hypothesis" discussed recently by McKenzie and Parker (1967), Morgan (1968), and LePichon (1968) is obvious.

The extraordinary interest generated by our first machine-plotted maps convinced us of the importance of publishing them in the present, admittedly limited, format. Only the geographic locations are utilized fully. Depth of focus is represented in a limited way, magnitude and chronology of events, not at all. We regard location and depth as the most important parameters with respect to problems of large-scale tectonics. Inevitably, one must compromise in attempting to represent such a vast amount of data on maps. The folded maps are published on the scale of the U. S. Navy Hydrographic Office chart number H.O. 1262A on which it may be overlain for comparison with topography. The omission of all data for years prior to 1961 is unfortunate but necessary since virtually no world-wide data is available in machine-readable form for earlier years. It was necessary to confine ourselves entirely to machine methods in order to put this large amount of data onto maps at an early date.

DATA

Gunst and Engdahl (1962) have described the method used by ESSA for preparing the file of epicentral data used in this paper. The location of an epicenter is determined from *P* readings. A set of five stations that are well distributed in azimuth and distance for each earthquake is used to give a preliminary hypocenter. The consistency of all readings within the time interval where arrival of *P* or *PKP* is expected is tested against the preliminary hypocenter. If these readings are inconsistent *pP* readings may be used to calculate the depth of the hypocenter. Finally, the parameters of the hypocenter are calculated by a modified version of Geiger's method. The result of each epicentral determination is punched with other data on a card.

In general, the computational precision is quite high, but the accuracy of the final hypocentral determination depends on many factors, e.g., distribution of stations used. Gunst and Engdahl (1962) find a precision of $\pm 0.1°$ in the epicenter location and ± 25 km in depth for most cases during two years of routine computer location of hypocenters.

Recently Engdahl and Gunst (1966) described a single computer program (called COAST, for the IBM 7030) now used by the USCGS. This computes a preliminary hypocenter from only five stations, and then determines the revised final hypocenter and magnitude using a least-square method for all the available relevant data without any intervention by a seismologist. The refined result for each event is punched in a separate card which contains the following parameters: date and origin time, latitude and longitude, (in 10ths of a degree) depth (in kilometers), body-wave magnitude m_b and other data. Since late 1963 a magnitude has been assigned to each event in the file. Prior to that, magnitudes were not assigned to all events. The file contains events of magnitudes about 4.0 and larger only. These computer cards constitute the ESSA epicentral file which was used at Lamont Geological Observatory to draw the maps shown here.

At Lamont, the epicentral file for seven years (January 1, 1961 to December 31, 1967) which contains 29,553 events has been placed on magnetic tape in chronological order. A program developed for the IBM 1800 computer selects all the events in any particular area on the earth and plots them on a Mercator projection using a Calcomp incremental plotting machine attached on-line. The program also can select events of specific magnitude and/or depth. Recently, we developed a sorting procedure that arranges the data on magnetic tape in a geographic order instead of chronological order. This shortens the plotting time by minimizing pen motion. For example, the seismicity map of depths 0–700 km which contains the complete epicentral file for a seven year period was plotted in about four hours when data was taken from a geographically ordered tape. This compares with more than 100 hours for plotting the same map with data taken in chronological order.

Discussion of Maps

The new maps show the seismic belts of the earth more clearly than previous seismicity maps. Old features are more clearly delineated and some new features become obvious for the first time.

A striking feature in the maps is the excellent definition of mid-oceanic ridges. The relationship of this data to a synthesis of crustal plate movements (Morgan, 1968; LePichon, 1968; Isacks, Oliver and Sykes, 1968) is obvious. The distribution of the epicenters along the ridge crests and connecting fracture zones is very striking. Seismic evidence (Sykes, 1967) confirms Wilson's (1965) interpretation of the equatorial Atlantic fracture zones as transform faults. The patterns of the new maps suggest that a similar interpretation can be applied to numerous other portions of the mid-ocean ridge system although in many areas it may still be difficult to decide which segments are ridge crests and which are fracture zones. Some of the regions where the segmented pattern is very clear are the mid-Indian ridge, Blanco fracture zone that connects the Gorda ridge with the Juan de Fuca ridge in the northeast Pacific ("Z" shape), and the Eltanin fracture zone in the South Pacific.

The segmented pattern of the West Chile ridge is clear perhaps for the first time. This seismic feature intersects the belt of South American shallow events, (see Sykes, 1963). Also, the Galapagos rift zone joins the East Pacific rise with the South American seismic belt. These features together clearly define a large, nearly aseismic plate. LePichon (1968) lacked sufficient data on spreading rates to consider this area as a separate plate in his model of plate movements.

There are some conspicuous gaps in seismicity along mid-ocean ridge crests. One of these separates the Eltanin fracture zone from the West Chile ridge and another occurs on the Pacific-Antarctic ridge near 60°S and 150°W. A third possible aseismic zone occurs on the mid-Indian ridge south of Australia.

The seismic connection between the South Sandwich seismic arc and the mid-Atlantic ridge is now fairly clear although no corresponding topographic ridge is known. A connection between the South Sandwich and South American seismic zones is less clear, but a connection from the southern end of the South Sandwich arc through the southern part of Scotia ridge and the South Orkney Islands appears more clearly than a connection from the northern end through South Georgia as suggested by LePichon (1968).

Generally, on the ridge system in the southern hemisphere epicenters scatter more than in the northern hemisphere. For example, compare the northern part of the mid-Atlantic ridge with its southern part (from latitude 10° south), or portions of the mid-Indian ridge north and south of latitude 30° south. This is probably due to the relative scarcity of seismic stations in the southern hemisphere rather than a real characteristic of the ridges there.

All earthquakes on the ridges system, except for very few on the mid-Indian ridge, are reported as shallow. This observation is consistent with hypotheses of sea-floor spreading and existence of a lithosphere (Isacks, Oliver and Sykes, 1968). A map by Stover (1966) is of particular interest because it shows a diffuse linear trend of epicenters in the northeast Indian Ocean between 1906 and 1964. This feature is not clear from the events of the shorter time interval represented by the present maps.

The system of trenches is easily distinguishable on the maps by the great density of epicenters and by the distribution of hypocenters in depth. The Tonga-Fiji area, perhaps best exhibits the classical seismicity features of a trench system which were discussed by Gutenberg and Richter (1954). The definitive maps of Sykes (1966) show that this zone of deep seismicity is perhaps only 25 km thick and contours of iso-depth on the zone are parallel and quite linear. The present maps are less adequate for the purpose of studying the details of seismicity in this region.

The tendency of the shallow events to form two parallel lines appears to be a widespread characteristic of island arc seismicity. This has been noted by Stauder (1968) who finds a systematic difference in the focal mechanisms of these two lines of shallow events in the Rat Islands area. Stauder attributed the outer line to normal faulting and the inner line to thrust faulting. The present maps show this characteristic double line in the Aleutian Trench, in the Kurile area, and in the Tonga-Fiji area also.

The continuation of the Indonesian seismic arc onto the mainland in Burma is obvious. The South American zone lacks earthquakes between 300–500 km deep and the very deep events are limited to two linear zones offset from one another. Also, in about latitude 28° south there is a gap in seismicity except at shallow depth. Thus when details for various regions are known, there appear to be important variations from the classical trench seismicity model of Gutenberg and Richter.

In the western United States the events tend to form a belt extending from Montana, through Utah, Wyoming, Nevada and California.

In the Eastern Mediterranean the epicenters form an arc-like structure circling the Aegean Sea which is bounded by a trench system on its southern border. Here the relatively deep earthquakes (maximum depth is about 220 km near the southern coast of Turkey) form a "C" circling the Aegean Sea while the shallow events are randomly distributed with respect to them. This pattern reveals a nearly aseismic plate in the southern part of the Aegean Sea.

The maps show important differences between oceanic and continental seismicity. Lines of activity bordering the oceanic aseismic blocks are very narrow and well-defined, while in the continental seismic regions the events tend to scatter more widely, frequently without a pattern which is obvious from the density of data yet available. Sykes and Landisman (1964) and Sykes (1965) show clearly that the wide scatter of epicenters on the continent is indeed real where the rift system extends into

East Africa and Northern Siberia. A similar example on the present maps is the pattern of epicenters in central Asia. The geologic stability and great age of continental shields is consistent with the seismic quietness of the Canadian, Brazilian, Australian, Indian, Arabian, South African and Siberian shields as shown on these maps.

Acknowledgments

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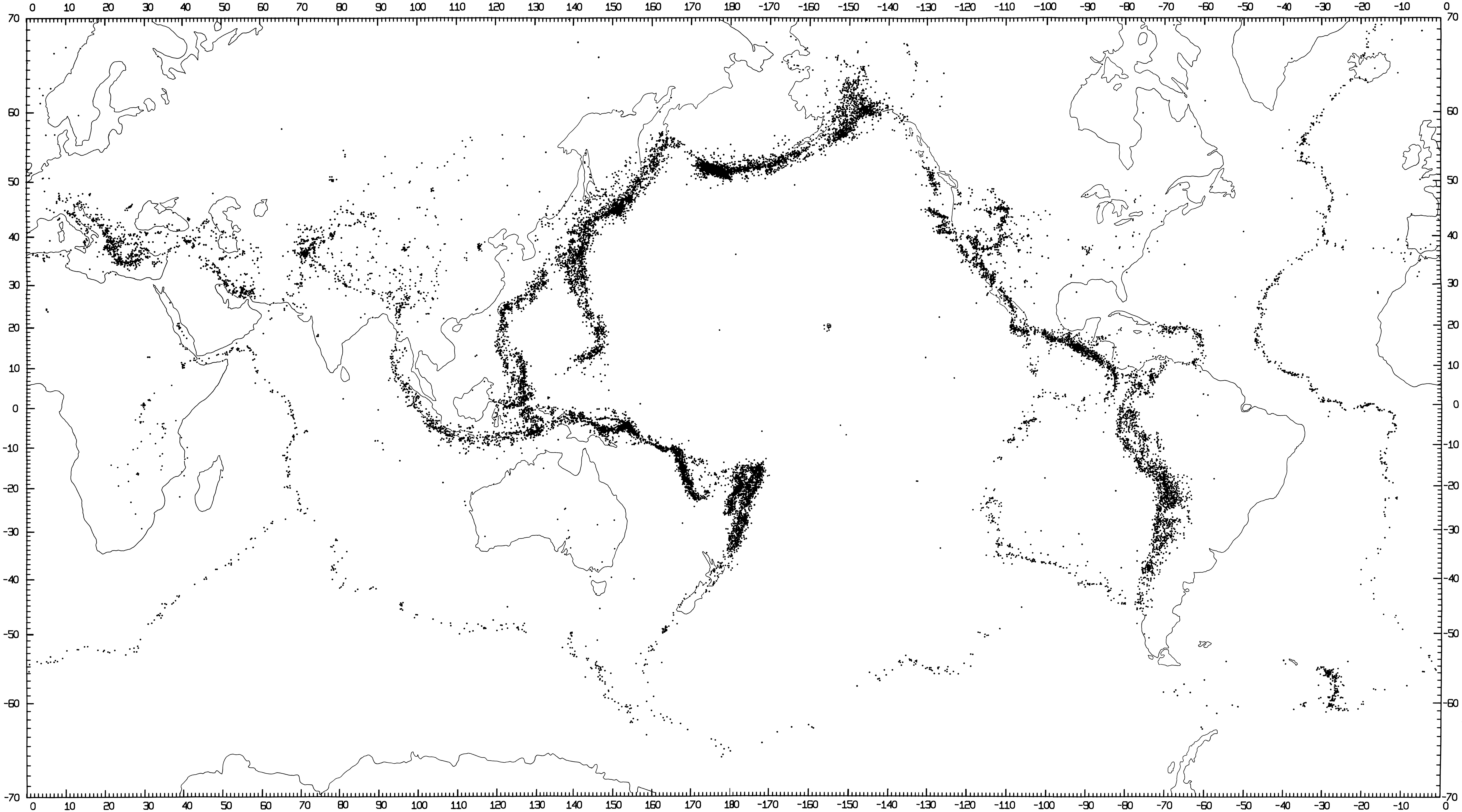

SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

DEPTHS 000-700 KM.

PLATE 1 in "World Seismicity Maps Compiled from ESSA, Coast and Geodetic Survey, Epicenter Data, 1961–1967" by MUAWIA BARAZANGI and JAMES DORMAN. *Bulletin of the Seismological Society of America*, Vol. 59, No. 1, February 1969.

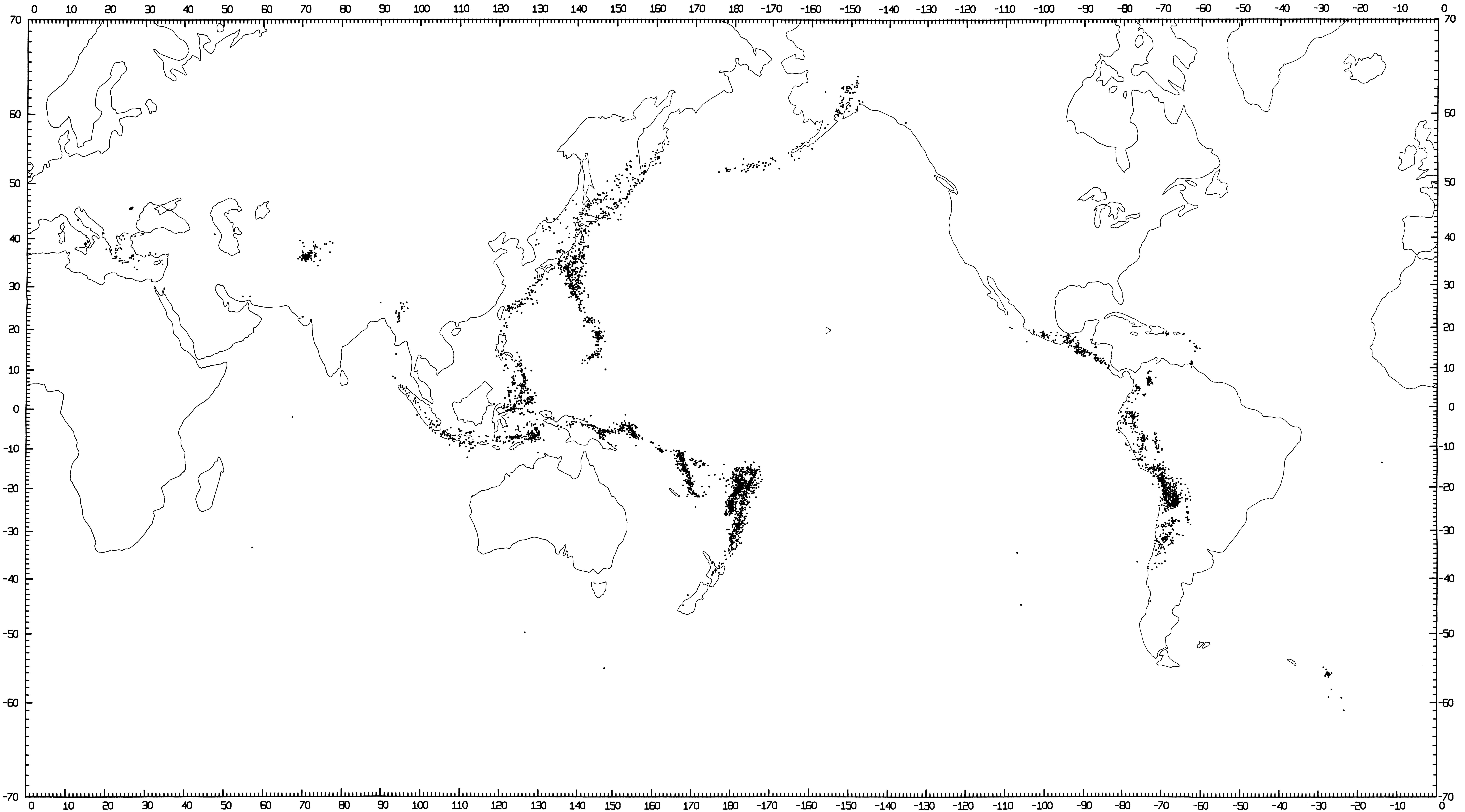

Plate 2 in "World Seismicity Maps Compiled from ESSA, Coast and Geodetic Survey, Epicenter Data, 1961–1967" by Muawia Barazangi and James Dorman. *Bulletin of the Seismological Society of America*, Vol. 59, No. 1, February 1969.

SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

DEPTHS 100-700 KM.

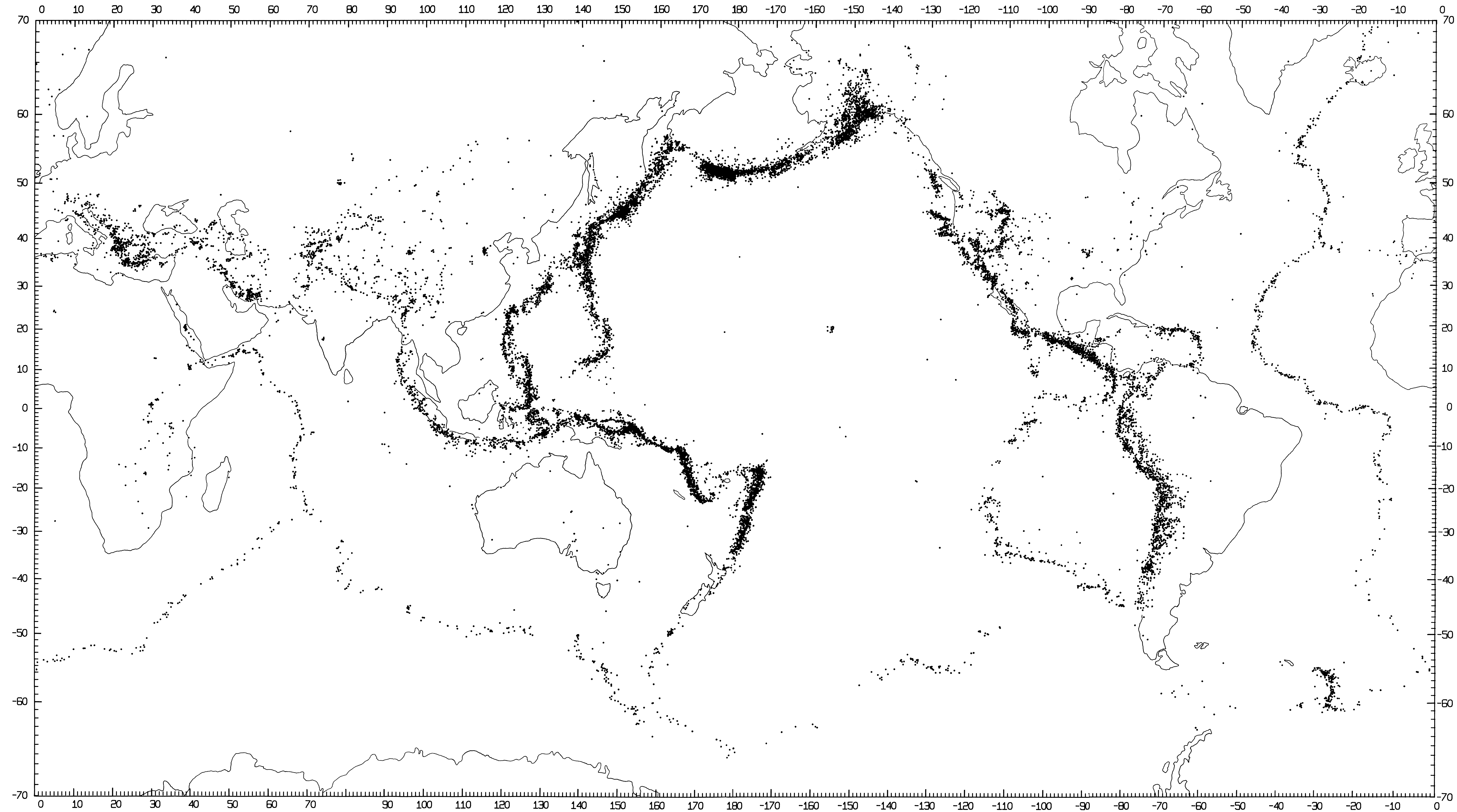

PLATE 3 in "World Seismicity Maps Compiled from ESSA, Coast and Geodetic Survey, Epicenter Data, 1961–1967" by MUAWIA BARAZANGI and JAMES DORMAN. *Bulletin of the Seismological Society of America*, Vol. 59, No. 1, February 1969.

SEISMICITY OF THE EARTH, 1961-1967, ESSA, CGS EPICENTERS

DEPTHS 0-100 KM.