MINOR SEISMIC AREAS

GENERAL CONSIDERATIONS

Significant seismic activity is not altogether restricted to the principal active belts and the interior or marginal fractures of the stable masses. Two large areas, and several smaller ones are characterized by fairly frequent minor shocks and occasional larger ones. These areas necessarily fall between the stable masses and the active belts. The trans-Asiatic zone may perhaps belong in this classification, since it lies between the stable mass of northern Asia and the Alpide active structures. However, its shocks are larger and much more frequent than those of the other regions now discussed.

NORTH AMERICA

Previous discussion has covered the earthquakes of the Pacific coast and Caribbean region, and also the marginal shocks of the Canadian Shield. The remaining shocks of North America occur in the intervening area, which is included in the United States and northern Mexico. For the former, *see* Heck (1938b). The Mexican shocks in question occur in the structural belt which extends north through the United States in the Rocky Mountains, where there is moderate activity. Probably the largest known shock of this belt was destructive at Bavispe, in Sonora (Mexico), May 3, 1887. The larger shocks of recent years (magnitude $6\frac{1}{4}$ to $6\frac{3}{4}$) in this structural province were as follows:

1925, June 28	01^h	46° N.	112° W.	Montana
1928, Nov. 1	04^h	27° N.	105½° W.	Chihuahua, Mexico
1931, Aug. 16	11^h	30.6° N.	104.1° W.	Texas
1934, March 12	15^h	42° N.	112½° W.	Utah
1935, Oct. 19	04^h	46½° N.	112° W.	Helena, Montana
1935, Oct. 31	18^h	46½° N.	112° W.	Helena, Montana

The epicenter for the 1928 shock is revised, with origin time at 04:12:49, and quality C.

Earlier and smaller earthquakes demonstrate a general distribution of moderate seismic activity throughout this region, decidedly lower than that of the Pacific belt to the west of it (which includes the shocks of western Nevada and Owens Valley).

Minor earthquakes are fairly common in the southern Appalachian belt. Probably the largest of these in recent years, the Virginia earthquake of April 10, 1918, was of class *d* at best, as it was recorded only at the few nearer stations in eastern North America.

Near the Atlantic coast is the epicenter of the Charleston earthquake of 1886. The large area over which this shock was perceptible shows that it must have been of class *b*; while the effects near the epicenter were so comparatively moderate, and show so peculiar a distribution and relation to the geology, as to suggest intermediate focal depth, although that can hardly have been so much as 100 km. Other shocks in the same area have all been small.

Off the northeast coast is the Grand Banks earthquake of November 18, 1929 (class *b*, Table 4). Historical data suggest minor activity in the same region. This epicenter is near the edge of the continental shelf, which may here be determined by active structures.

Another exceptional disturbance was the group of earthquakes in 1811 and 1812 in the Mississippi Valley, not far from New Madrid (Missouri). One or more of these earthquakes must have been of magnitude 8 at least. Taking into account the enormous area disturbed and the violent effects near the epicenter, they must be ranked as the greatest shocks in the history of the United States. The structural relations of these shocks are not yet clear but the region is one of continuing minor seismicity.

Occasional notable shocks, still less frequent and in general smaller than those of the Appalachian belt, occur in the central United States.

NORTHEASTERN ASIA

The region of extreme northeastern Asia was not included in the Eurasian stable mass, largely for structural reasons. The geology of this area is little known; most authorities agree in limiting the Angara shield at the Verkhoyansk mountains in the region of the Lena River. This is the area terminal to the known extent of the Arctic active belt. No shocks are known in Siberia east of this district, except along the coasts. This of course should exclude the very active peninsula of Kamchatka, which is a mass belonging to the Pacific belt.

Figure 8 shows two epicenters on Sakhalin (Karafuto). The shock of 1924 was destructive on the island. Revision gives the following:

1924, March 15	10:31:22	49° N.	142½° E.	B	b

The other epicenter is that of July 10, 1932. Both shocks were shallow. This is important, because the region is one of frequent deep shocks (discussed with the circum-Pacific belt); these may account for other shocks felt in this region and in Manchuria west of it, where no shallow shocks have been located. The few other shallow shocks placed in this region in the Summary are either imperfectly recorded or are misplaced deep shocks.

At 56° N. 130° E. is the shock of January 22, 1939 (Table 4).

Two shocks (July 15 and October 10, 1931) are known from the epicenter at 59.3° N. 147.8° E., on the north shore of the Sea of Okhotsk.

An important epicenter (unmapped) is on the Arctic coast northwest of Bering Strait at 67° N. 172° W. The principal shock occurred on February 21, 1928, at 19:49:04 (revised; quality A, class *c*). Aftershocks from the same epicenter occurred on February 24 and 26 and on May 1, 1928. Not far to the east is another unmapped epicenter. Revision gives:

1926, July 14	22:22:25	66° N.	163° W.	C	d

This is on the north coast of Seward Peninsula, Alaska. It appears that eastern Siberia and this part of Alaska are parts of the same structural and seismic province.

Purely coastal or marginal activity like this is characteristic of the stable masses, as well as of other minor seismic areas. However, any conclusions must be drawn with caution. Northeastern Asia is almost uninhabited, and there are no seismological stations near it. Seismicity comparable with that of most of northern Europe could not be detected there. Probably the region is analogous to the other areas discussed in the present section.

CENTRAL AND WESTERN EUROPE

The exceptional circumstances of our information about the seismicity of Europe call for special treatment. Figure 14 shows epicenters selected on principles not applied to the other regional maps. Within the limits of the map every reliable epicenter given in the International Summary for January 1931 to March 1934 has been plotted. This includes a number of minor shocks of class *e*, not otherwise considered.

A further list of epicenters (Table 20) resulted from a search through the International Summary and later bulletins for the large European shocks from 1918 to 1939. It contains only shocks well recorded out to 45° at least. The two Italian shocks of 1930 are of class *c*; the others are in the upper range of class *d*, with magnitudes probably all 6 or larger. Smaller shocks of class *d* in Figure 14 are as follows:

1931, April 24	15^h	31.1° N.	19.9° E.
1932, Jan. 2	23^h	39.0° N.	17.5° E.
1932, May 22	17^h	38.5° N.	15.0° E.
1932, Aug. 3	11^h	40.0° N.	19.5° E.
1933, March 7	14^h	41.1° N.	15.4° E.
1934, Feb. 4	9^h	41.4° N.	19.3° E.

African shocks shown on Figure 14, are from Table 15. All but two of these (1920, 1923) are comparable with those of Table 20. Almost all were reported strong or destructive on the African coast. The shock of April 19, 1935 on the coast of Libya, is far the largest shock of recent years in this region.

The shocks of Table 20 were destructive in the localities named. Epicenters for the first two have been revised; those following, down to 1933, are taken from the International Summary, and the later ones are approximately as given by the central office at Strasbourg.

The European area is divisible into several provinces of different character, some of which have been discussed in previous sections. In order of decreasing seismicity, these may be listed as follows:

(1) The Balkan and Aegean area.
(2) Italy and adjacent areas.
(3) The Rhine region.
(4) Great Britain, Scandinavia, and the North Sea.
(5) The remainder of western Europe.
(6) The Baltic shield.

The limits of the Balkan active area are roughly the meridian of 20° E. and the parallel of 41° N. (Fig. 10). This is a part of the trans-Asiatic zone, comparable with many other parts of it in seismicity. North and west of the indicated limits activity is far smaller. The northwestern

TABLE 20.—*Larger shocks in western Europe, 1918–1939*
Limits 37°–55° N., 5° W.–20° E.

Day	Time	Epicenter		Region
		Latitude, degrees	Longitude, degrees	
1920, Sept. 7	05^h	44 N.	10 E.	Carrara, Italy
1927, Feb. 14	03^h	43 N.	18 E.	Herzegovina
1928, March 7	10^h	38.6 N.	15.8 E.	Calabria, Italy
1928, March 27	08^h	46.5 N.	13.0 E.	Udine, Italy
*1930, July 23	00^h	41.1 N.	15.4 E.	Irpino, Italy
*1930, Oct. 30	07^h	43.6 N.	13.5 E.	Off Ancona, Italy
1930, Nov. 21	02^h	40.0 N.	19.5 E.	Albania
1931, June 7	00^h	53.8 N.	1.2 E.	North Sea
1933, Sept. 26	03^h	42.0 N.	14.2 E.	Abruzzi, Italy
1936, Oct. 18	03^h	46.2 N.	12.5 E.	Venetia, Italy
1938, March 27	11^h	45.8 N.	17.0 E.	Croatia
1938, June 11	10^h	50.6 N.	3.6 E.	Belgium
1939, May 20	09^h	41.1 N.	19.3 E.	Albania

* Of class *c*; all others of class *d*.

corner is in a quite active district, near the coast of Albania; two shocks in Table 20 fall close to it. Another shock, just to the east and consequently not mapped, was that of January 28, 1931, 05^h, at 40.1° N. 20.5° E., destructive at and near Koritza.

The Italian seismic area includes Italy and Sicily, the Adriatic, and the Dinaric mountains to the east. The activity is higher than that of northwestern Europe, but decidedly lower than that of the principal seismic regions. The two largest shocks of Table 20, in Italy, are still only of class *c*. The Messina earthquake of 1908 was approximately of magnitude 7, on the border between classes *b* and *c*. The area belongs to the Alpide zone, *Neo-Europa* of Stille. The shocks of North Africa and of the Betic mountains in southeastern Spain belong to the same group. So do the rare and minor shocks of the Pyrenees and southern France, from the geological point of view; the seismologist would rather group them under the slightly active regions of western Europe.

The shocks of the Alps are not easily included with the "Alpide" activity of Italy; they are smaller and less frequent. (*See* Wanner, 1934.) They are classified more naturally as members of the belt of epicenters extending northwest from Switzerland parallel to the Rhine structures, in the trend of the Italian and Adriatic zone. This is a region of minor seismicity, such as would not even be noticed in general discussion if it were anywhere else. In a region like northeastern Asia, such activity would be quite unknown.

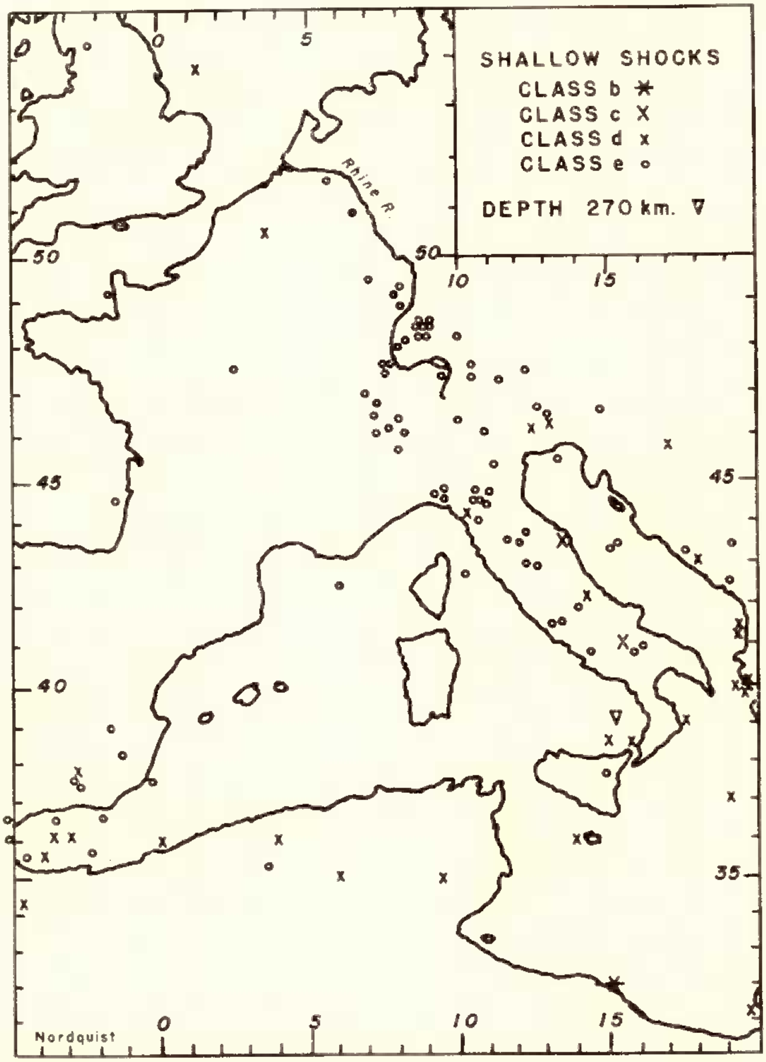

FIGURE 14.—*Map of epicenters, western and central Europe*

For a recent discussion of the Rhine structures considered as rifts *see* Cloos (1939, p. 445–462). The Rhine region is capable of producing an occasional shock comparable with those of Table 20. (*See* Sieberg, 1940.) Such were the strong shock at Basel in 1356, and the South German earthquake of November 16, 1911. The latter provided much valuable seismological information bearing on the crustal structure of Europe (Gutenberg, 1915). The Belgian earthquake of 1938 (Table 20) perhaps belongs with the following group.

The northern region of Caledonian folding (Stille's *Palaeo-Europa*) shows notable minor seismicity. In view of the complete quiescence of much younger structures, it is highly improbable that these shocks represent any persistence of the Caledonian orogeny to the present time. Stresses of more recent origin have produced fractures in the Caledonian mass, or have rejuvenated old faults of Caledonian age. In Scandinavia these stresses are generally attributed to the uplift of the land after removal of the Pleistocene ice load. (*See* Gutenberg, 1941.)

The history of Norwegian earthquakes was summarized by Kolderup (1913), in a paper which has been followed by a series of annual reports. The available history is comparatively short, Kolderup's earliest shock being dated 1612. Probably none of these shocks were larger than class *d*. Instrumental records are available for the largest (October 23, 1904). This was a shock similar to those of Table 20 in the Skagerrak near $58\frac{1}{2}°$ N. $10\frac{1}{2}°$ E. On March 9, 1866, there was a somewhat smaller shock on the northwest coast near Trondhjem and Kristiansund.

The compilation for Great Britain by Davison (1924) is the most extended critical history available for a region of such low activity. Davison lists the earliest authentic British earthquake as of date 974. His list suggests nearly uniform seismicity in the time covered, as the frequency of listed shocks does not greatly vary until the beginning of scientific investigation in the seventeenth century. The low level of activity is apparent from the fact that from 974 to 1924 Davison lists only 1191 shocks, of all sizes down to the smallest; and over 600 of these are accounted for by swarms of minor shocks at Comrie and Menstrie in Scotland. As Davison points out, the activity in Scotland differs from that in England and Wales; more small shocks are known in Scotland, and the stronger shocks there constitute a large fraction of the total for Great Britain. The Scottish shocks are more plainly associated with known structures than the others; thus many important shocks have occurred along the Great Glen Fault, at Inverness and southwest of it.

The largest shock listed by Davison occurred at Colchester, in the southeast of England, in 1884. The North Sea shock of 1931 (Table 20) was still larger, and thus ranks as the largest shock in the British region for a thousand years. Other shocks have occurred still farther out in the North Sea, such as that of January 9, 1927, near 59° N. 5° E.

The region designated by Stille as *Meso-Europa* is transected by the Rhine belt of activity; otherwise its seismicity is extremely minor. For a discussion of Germany *see* Sieberg (1940). Swarms of small shocks in

Vogtland, Saxony, have been described by Etzold (1919). Small locally damaging shocks have occurred about the coasts of France, particularly near Nantes and in the Channel Islands; similar shocks are known from the coast of Portugal, although some of the destructive shocks affecting that region originated far to the southwest in the Atlantic continuation of the Mediterranean zone.

AUSTRALIA AND OTHER REGIONS

Australia east of the stable mass is a region comparable with the Appalachian belt of North America in structure and seismicity. The known shocks are all small; most of them are on the south and southeast coasts, particularly near Bass Strait. The marginal shocks of the stable mass near the west coast and in South Australia have been previously noted. The small shocks of the interior of Queensland may possibly also be marginal in the same sense. One of these was responsible for the establishment of a station at Brisbane. (*See* Bryan and Whitehouse, 1938.) The seismicity is on a lower level than that usually considered in this study.

The Cape region of South Africa is also one of Palaeozoic folding. Shocks occur in the interior, marginal between the Palaeozoic area and the African stable mass. The shocks of the Mendoza region in Argentina (discussed with the Pacific belt) are similarly placed between the border of the Brazilian shield and the Palaeozoic pre-Cordillera.

MINOR SEISMICITY

Minor earthquakes occur almost anywhere. Practically all existing seismological stations have recorded local earthquakes in their immediate vicinity. However, seismographs with long-period characteristics, such as are suitable for recording distant earthquakes, often fail to write legible records of nearer shocks, even when these are perceptible at or close to the station. Short-period instruments, which are sensitive to small local shocks, have mostly been installed in active areas; comparatively few are in regions of minor seismicity.

This influence of the type of seismographic installation on our knowledge of local seismicity is demonstrated by recent developments in the northeastern United States. This had long been considered as a region of rare seismic disturbance, although a few moderately strong shocks (such as that of 1755) were known. Since the installation of short-period Benioff instruments at several stations in this area an unexpectedly large number of small local earthquakes are regularly recorded. The bulletins of the Northeastern Seismological Association show local disturbances each month. Some of these have been traced to artificial sources such as quarry blasting; but many are undoubted natural earthquakes.

There are few regions where we have both historical and instrumental data on minor activity. Europe is the only area of low seismicity for which both are available, and even in Europe many of the instruments are ill-suited for the study of minor local shocks.

The somewhat different problem of minor activity in a region of marked

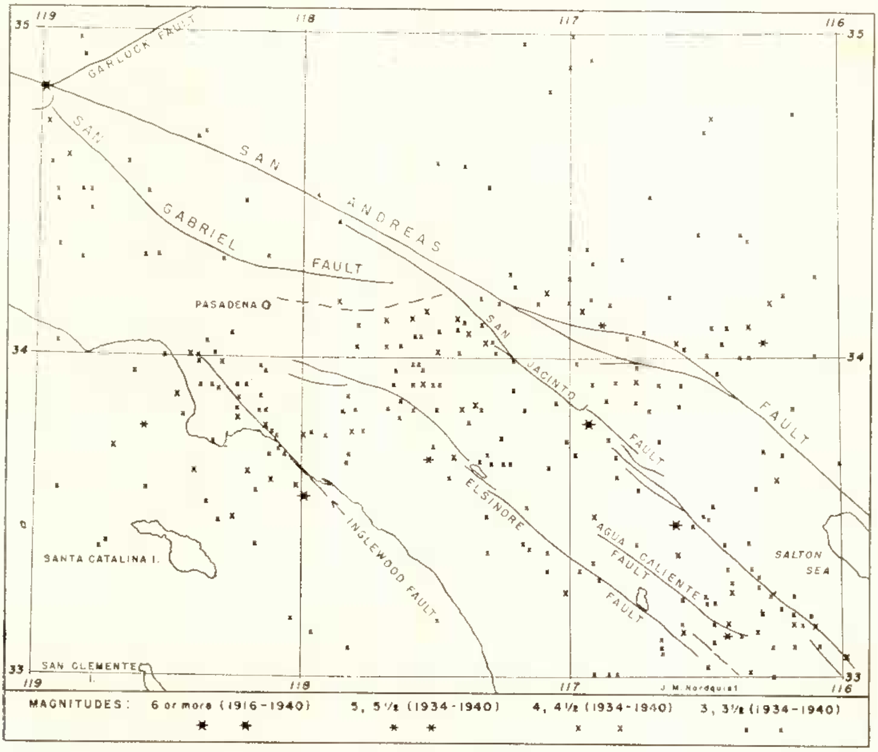

FIGURE 15.—*Map of epicenters and faults, southern California*

seismicity may be studied with the aid of the results in southern California, where a local group of eight stations is in operation, with supplementary data available from temporary installations and stations outside the area.

Figure 15 shows all epicenters for shocks of magnitude 3 or more in the area 33°–35° N., 116°–119° W. during the years 1934–1940 inclusive. Each epicenter is given a symbol indicating the magnitude of the largest shock associated with it in that period. The numerous smaller shocks from identical epicenters are not indicated. In addition, shocks of magnitude 6 and over in recent years have been shown, as follows:

1916, Oct. 23	02^h	34.7° N.	118.9° W.	San Andreas Fault
1918, April 21	22^h	33.7° N.	116.9° W.	San Jacinto Fault
1933, March 11	01^h	33.6° N.	118.0° W.	Inglewood Fault
1937, March 25	16^h	33.5° N.	116.6° W.	San Jacinto Fault

The principal known faults are indicated in the figure; the "foothill fault zone," consisting of a series of disconnected traces along the front of the San Gabriel range, is shown as a dashed line. The general lack of clear association between minor shocks and important faults should be noted. Most of the many small shocks are located close to one or another of the numerous minor faults which are common throughout the region. Only the larger shocks show definite association with the larger fractures. It should be added that the only major earthquake known to have occurred in this area, that of January 9, 1857, originated on the San Andreas Fault. There was probably displacement along all that part of the fault shown on the western half of our map, extending northwest far beyond its limits. In recent years most of this part of the fault has been almost completely quiescent (note the absence of epicenters for small shocks); the same applies to most of that segment of the same fault zone along which displacement took place in the major earthquake of 1906, farther north.

In a later section it will be shown that the larger earthquakes represent a dominant fraction of the seismic energy released. Thus it follows that most of this energy is released along the major structures.

GEOGRAPHICAL SUMMARY

The results of the study are presented in summary form in Figure 16. Instead of using individual epicenters, this map represents the active zones as continuous, though care has been taken to break them where present evidence does not seem to warrant drawing them through. The zones are shown as widened where activity is intense. Shallow, intermediate, and deep earthquake zones are distinguished by different shading.

Deep shocks, in the restricted sense, show a distribution which is difficult to interpret. Like the shallow shocks, they occur chiefly in belts or zones, although it is not known whether the limited active areas in South America (Fig. 4) are parts of a single belt. These belts are rather plainly associated with the circum-Pacific structural and seismic belt, which must then be taken to include the Sunda arc in the East Indies. Belts of deep shocks often run roughly parallel to surface structures, and generally on the side away from the Pacific basin. In some regions, as near the Sunda arc and the Marianne Islands, this paralleling is at shorter distance than in others, like Manchuria. The transverse belt across the Japan Sea diverges completely from the apparently associated belt of surface structures.

In the Pacific region intermediate shocks occur in belts which are usually parallel to belts of shallow shocks, and almost always run directly along orogenic lines of Cretaceous or Tertiary age. These lines are generally also those of active or recently extinct volcanism; but in many parts of the world, notably in the Atlantic and in Hawaii, volcanoes are not accompanied by intermediate shocks.

Outside the circum-Pacific belt intermediate shocks are known only from a few localities in the Alpide part of the trans-Asiatic zone. Among these are the very active sources in Rumania and in the Hindu Kush; several others are related to the folds surrounding the Indian stable mass.

There are some well-known seismic zones characterized by a large majority of intermediate shocks, with a few shallow shocks, and earthquakes of large magnitude in both classes. Among these are the west coast of South America, the Marianne Islands line, and the vicinity of the New Hebrides.

Especially in the Pacific region there are numerous cases where the belts of shallow, intermediate, and deep shocks have a particular relation to the surface structures. Shallow shocks occur between the oceanic troughs or foredeeps and the nearest land or island chain; intermediate shocks generally under the island chains (the orogenic lines of late date, noted above); and very deep shocks still farther removed from the ocean troughs. In northern Japan and the Marianne Islands line the oceanic front of this structure is that of the deeps bordering the main Pacific basin; in South America and the Philippines the front is on external parts of the Pacific Ocean, probably continental in structure; in the Sunda arc the front is on the Indian Ocean. Finally, in the region of the New Hebrides and Solomon Islands the front, with its foredeeps, is on the southwestern side, away from the Pacific basin, and the whole order of structures is reversed from that prevailing farther east and west.

In several regions, such as Japan and South America, there are two separable groups of intermediate shocks; one at depths near 100 km., the other at 200 to 300 km.

Shallow shocks chiefly occur on the circum-Pacific belt with its various branches, the trans-Asiatic zone, and the Arctic-Atlantic and Indian Ocean belts. The latter two, as well as the Easter Island branch of the Pacific belt, follow oceanic ridges which are in reality submarine mountain ranges, corresponding to the manner in which other seismic belts follow known mountain systems and island chains.

Some other important shocks have been described as marginal to the continental stable nuclei. In general these shocks do not fall on the edges of the continental shelves, save for a few cases where there is reason to suspect that the edge of the shelf coincides with that of the stable shield. Apart from this, the limits of the shelves are nonseismic; if they are determined by structures, those structures are now inactive.

The seismic zones divide up the entire surface of the globe into blocks, the interiors of which are relatively nonseismic. One of these blocks is the Pacific basin; the others, at least the larger ones, are continental in character. In the central region of each continental block is the stable shield or continental nucleus, with active interior fractures and marginal seismicity.

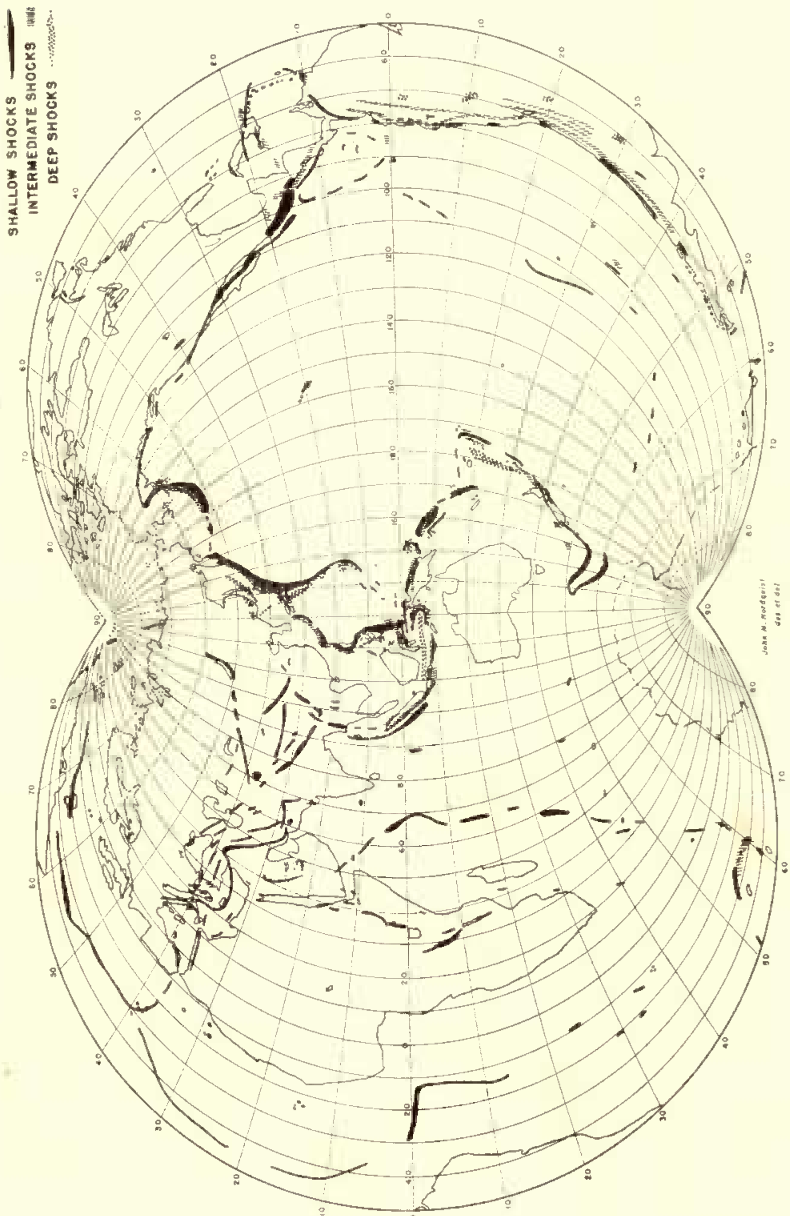

FIGURE 16.—*World map showing seismic belts*

Between this stable shield and the active zones bounding the block is a wide zone which is not quite as inactive as the stable shield itself. That part of this substable zone adjacent to the stable shield often contains an old mountain system, such as the Appalachian system or the mountains of eastern Australia; in such a mountain system the seismicity is often slightly higher than in surrounding areas.

The exact boundaries of the blocks are not always clearly defined. Thus, the North American block lies between the Pacific and Arctic-Atlantic belts. Should it include the substable region of northeastern Asia as well as northern Alaska? There is nothing to separate the North and South American blocks on the Atlantic side. The African block is not well defined on the northeast, where its relation to the Arabian mass is uncertain, and may be compared with that of North America to Greenland. The mutual boundaries of India, Australia, and Antarctica fall in the Indian Ocean where shocks are few and other data incomplete.

There are isolated areas of Pacific structure. The two most definite of these are the Caribbean and the region surrounded by the Southern Antilles between South America and the Antarctic; the former is definitely closed, while the latter may not be. The status of the similar Macquarie Island loop is uncertain. It is not known how much of the Antarctic Pacific is continental in character, but the region may contain several areas of Pacific type. Evidence from amplitudes of reflected seismic waves suggests an area of Pacific type in the Arctic basin off the northwestern American coast.

FREQUENCY AND ENERGY OF EARTHQUAKES

Very little can be stated about the frequency of occurrence of deep-focus earthquakes. Even the larger deep shocks are catalogued with reasonable fullness only since about 1931. Small deep-focus shocks are hard to identify, and the magnitude of the smallest such shock which can be listed in a given region depends largely on the number and equipment of the local stations. Thus, the numerous local stations in Japan, together with the close attention of Japanese seismologists to the problem, makes the listing for the vicinity of Honshu, at least, more complete than anywhere else in the world; while in South America, the possibility of studying simultaneously the records written at Huancayo and at Pasadena has led to listing many shocks, especially at intermediate depths, which otherwise would have been overlooked. On the other hand, it is well established that deep shocks have been lacking in California, at least in recent years.

Table 21 shows the total number of known deep-focus shocks; the depth ranges are within 25 km. of the depths given at the head of each column. Numbers are listed separately for the chief active areas. Shocks less than 80 km. deep have been omitted; in many regions it is nearly impossible to separate them from shallow shocks, and their number is undoubtedly greater than that indicated by the small representation in our lists.

TABLE 21.—*Number of shocks listed at various depths*

Region	Depth in km. (Range ±25 km.)												
	100	150	200	250	300	350	400	450	500	550	600	650	700
Mexico, Central America	20	4	2		1								
South America	46	22	18	7	2					1	5	11	
New Zealand, Tonga, Samoa	11	3	3	1	2	1	4		6	9	10	5	1
New Hebrides to New Guinea	22	16	9	1	2	3	3	1					
Sunda Islands	21	12	9	1		1	3		1		10	1	5
Celebes to Mindanao	3	6	10	2	4		1		2	1	3	1	1
Luzon to Kiushiu	10	7	4	3									
Japanese Islands	33	26	12	5	12	27	25	12	14	14	6	1	
Hindu Kush	1		14	25									
Others	11	13	1	1									
Total	178	109	82	46	23	32	36	13	23	25	34	19	7

The number of shocks falls off rapidly with increasing depth, down to the lower limit of intermediate shocks at 300 km.; below this the general distribution for the whole earth is fairly uniform with depth until the greatest depths are approached. This is not true of the individual regions, since nearly every limited area has two or more characteristic depths near which shocks are most frequent.

The range in magnitude for deep shocks appears to be about the same as for shallow shocks, but no safe criterion has been applied to assign magnitude to a deep shock. Even from the greatest focal depths known, some shocks are recorded with body waves as large as those of the largest shallow shocks.

The following discussion refers exclusively to shallow shocks so that conclusions with reference to the general seismicity of the earth are subject to modification whenever it becomes possible to take account of deep shocks systematically.

For the larger magnitudes, data are given in Table 22. From $8\frac{1}{2}$ to 8 the shocks are all from Table 5. There are 36 in 37 years. For $7\frac{3}{4}$ there are 18 shocks in Table 5; 2 shocks given in Table 4 as 7.7 have been added to this total. Combined averages are 1.0 shocks per year of magnitude 8 or over, and 8.3 shocks per year of magnitude 7 to 7.9. Classification of shocks in the International Summary for 1931–1933 gives about 284 earthquakes of magnitude 6 to 6.9 or about 95 per year.

The shocks of lowest magnitude in each table are probably slightly too few in number, as doubtful cases have generally been omitted. At these lowest levels in the respective tables it is probable that the geographical coverage is incomplete, so that shocks in remote regions have escaped inclusion. This is certainly true for the shocks of class *d*.

TABLE 22.—*Frequency of large shallow shocks*

Magnitude	No. of shocks		No. per year
$8\frac{1}{2}$	4	37 years	0.1
$8\frac{1}{4}$	8		0.2
8	24		0.6
$7\frac{3}{4}$	20		0.5
7.6–7.4	12	8 years	1.5
7.3; 7.2	24		3.0
7.1; 7.0	26		3.3

To sum up, there are roughly: one shock per year of magnitude 8 and over, 10 shocks of magnitude 7 to 7.9, and 100 shocks of magnitude 6 to 6.9. Over this range there is approximately a tenfold increase in frequency for every decrease in magnitude by one unit.

No reliable statistics for shocks of magnitude less than 6 can be set up for the world as a whole. Such shocks must be studied in limited regions, on the assumption that in general they bear a constant proportion to the larger shocks of the corresponding areas.

At present Southern California is the only area for which shocks of the smaller magnitudes are recorded, located, and catalogued with sufficient regularity for the purpose. Data used in the following paragraphs have been compiled by Mr. R. E. Rogers, who is also responsible for a majority of the epicentral determinations, and for routine assignments of magnitude to the nearest half unit on the Pasadena scale.

For the years 1934 to 1939 inclusive, and for an area selected for its favorable situation with respect to the recording stations, including most of Southern California and a small part of adjacent Mexico, the numbers are:

Magnitude	No. of shocks	Sum
6	2	4
$5\frac{1}{2}$	2	
5	14	65
$4\frac{1}{2}$	51	
4	150	486
$3\frac{1}{2}$	336	
3	677	

Shocks of magnitude less than 3 are omitted, as they certainly are not uniformly catalogued over the area. Those of magnitude 3 are probably not completely covered, particularly in the remoter corners of the area. Noting this, the rule of tenfold increase in the number of shocks for one unit decrease in magnitude still holds approximately.

For smaller shocks the data are fairly complete for the same years, 1934–1939, in the area between the limits 33½°–34½° N., 117°–118° W. This lies just east of Pasadena, and is well covered by the three first-class stations at Pasadena, Mt. Wilson, and Riverside (Fig. 15). The following list probably includes all shocks in this small area down to magnitude 2½. The number for magnitude 2 is probably somewhat too small, but not by any large factor, as shocks of that size write conspicuous records on the sensitive short-period instruments at the stations named. Some of these may be due to blasting operations (even major blasts seldom exceed magnitude 2 seismometrically).

Magnitude	No. of shocks	Sums
5½	1	1
5	0	
4½	8	18
4	10	
3½	23	109
3	86	
2½	122	298
2	176	

This supports the rule of tenfold increase down to magnitude 3; but the smaller shocks are evidently not so numerous as might be expected on that basis. This is of course to be anticipated, as the number of earthquakes cannot go on increasing uniformly with decreasing magnitude, but must have a maximum of frequency at some level.

Assuming that the Californian shocks are representative of general conditions, and attaching the results from California to those found directly for the whole world in the higher magnitude levels, the conclusions follow:

	Magnitude	Annual number
Great earthquakes	8 or more	1
Major earthquakes	7–7.9	10
Destructive shocks	6–6.9	100
Damaging shocks	5–5.9	1000
Minor strong shocks	4–4.9	10000
Generally felt	3–3.9	100000

The total number of shocks potentially strong enough to be perceptible to persons in a settled area (magnitudes 2 and over) must be of the order of several hundred thousand per year. Including aftershocks and swarms of small shocks, the total may be well over a million.

Extrapolation to the high side would suggest one shock of magnitude 9–9.9 about every 10 years. Certainly since 1900 no shock over magnitude $8\frac{1}{2}$ has taken place. None of the greater shocks for which we have reliable historical descriptions appear to have been of much higher magnitude, although a shock of magnitude $9\frac{1}{2}$ would release energy about 100 times that of the largest known shock, and ought to occupy an exceptional place in the historical record. The great Indian earthquake of 1897 apparently showed no effects exceeding those of the Kansu earthquake of 1920; and the seismograms of the Alaskan shock of 1899 suggest a magnitude between $8\frac{1}{4}$ and $8\frac{1}{2}$. A more serious question relates to the magnitude of the Lisbon earthquake of 1755, since the phenomena of seiches indicate that the surface waves were very large over the whole of western Europe. Even this shock could hardly have exceeded magnitude 9.

Presumably the frequency of earthquakes decreases rapidly as the magnitude approaches an upper limit. This limit must be set by the strength of crustal materials, so that it is impossible for stresses to accumulate beyond a certain critical value. From isostatic data, Tsuboi (1940) calculates the maximum energy of an earthquake as 5.6×10^{24} ergs. This agrees within the limits of error with the energy of the largest earthquakes.

At the other end of the scale, there is probably a lower limit for the magnitude of ordinary earthquakes, representing the stress necessary to open a fracture in a weak zone. Just after a large shock, when the zone has already been disturbed and fractured, small stresses more easily produce movement; this partly explains the large number of small aftershocks usually following a large earthquake.

From the figures on frequency given above it is clear that the release of seismic energy occurs chiefly in the shocks of larger magnitude. Thus, although there may be 10 times as many shocks of magnitude 7 as of magnitude 8, each of them releases only 1 per cent of the energy of that released by one of the larger shocks, and the total energy release in magnitude 7 is still only one tenth that in magnitude 8. The relation continues down the scale, as far as the rule of tenfold numerical increase holds. This phenomenon was noted for the lower magnitudes in Southern California in the first paper on magnitudes by Richter (1935). It was found that in any limited district the shocks of largest magnitude occurring during any interval of observation liberate nearly all of the seismic energy for that interval. This result, as shown above, extends to the whole world and to the largest shocks.

Mechanically, it must be concluded that the larger stresses accumulate without reference to the release of energy in minor shocks or along minor structures. In general, it is not true that minor shocks function as a "safety valve" to delay the occurrence of a great earthquake. Rather, minor shocks on minor structures are symptoms of a regional strain, only a small part of which is being transferred away from the major structures along which it will eventually find release in a major earthquake.

The total energy released by a shock of magnitude $8\frac{1}{2}$ has been estimated at 10^{25} ergs (Gutenberg and Richter, 1936). Using this and the corresponding figures for lower magnitudes, Table 22 shows a release in energy, in shocks of magnitude 8 and over, of 9.0×10^{25} ergs in 37 years, or 2.4×10^{24} ergs per year and 0.4×10^{24} ergs per year for shocks from magnitude 7 to 7.9. If we add one tenth of this for magnitude 6 to 6.9, and so on for lower magnitudes, the energy released by all shocks is close to 3×10^{24} ergs per year, or 10^{17} ergs per second. This means performance of work at an average rate of 10 million kilowatts. Nearly one third of this energy release is represented by the four largest shocks (magnitude $8\frac{1}{2}$) in Table 5 and over 80 per cent by the shocks of magnitude 8 and over.

Of 53 shocks in Table 5, one is in California and another in Nevada; of 68 in Table 4, one is in California. This would suggest assigning to California about 1 to 2 per cent of the seismicity of the world. If that of the southern California area chosen for statistical purposes were taken as one fourth of 1 per cent, there would result about 1000 shocks of magnitude 5 and $5\frac{1}{2}$ annually for the world, as given above.

Roughly 80 per cent of the seismic energy of the world is released in the circum-Pacific belt and its branches, over 15 per cent in the trans-Asiatic zone, and less than 5 per cent in the rest of the world.

This energy is not released at a uniform rate, nor regularly distributed over the seismic regions. There are years, and shorter intervals, when activity is abnormally high, and others when it is unusually low. Further, for a period of weeks, significant activity may be concentrated in a limited region. These effects apparently are within the limits of normal statistical fluctuation but may exceed them in certain regions. (*See* Wanner, 1937.) These highly irregular variations bear no evident relation to the minor periodicities which have sometimes been claimed. These periodicities, superposed on the large general fluctuation, are somewhat controversial; the reader should compare the findings of Tams (1931, p. 419–433), Conrad (1932), and Davison (1938).

Few definite changes in seismicity have occurred during historical time. Chronologically long histories for such active regions as Japan, China, the Near East, and Italy indicate activity of about the same character as in very recent years, with shocks of the same range of magnitudes occurring in the same areas, apart from a few individually exceptional events. For less active regions, the best available history is that of Great Britain, extending over about a thousand years with no sign of secular change.

Otherwise comparatively quiet regions may have short periods of unusually high seismicity. The following is quoted from Kunitomi (1937, preceding p. 1):

"Now-a-days, in Tyôsen, slight attention is given to the study of earthquake owing to a minority of local shocks. Nevertheless, about 300 years ago, at an active period, frequent strong shocks were experienced all over the peninsula and inflicted severe damage to the buildings and human beings. Therefore, the seismological observation must not be neglected even in the present time of less activity."

A recent case of this sort is that of the long series of strong shocks in the Indian Ocean, near 34° S. 57° E., from 1925 to 1933. In a settled area such a series of shocks would have brought about a series of disasters. There may have been such a time of increased seismicity on the African Rifts about 1910–1913. An unusual number of very destructive shocks is known from Palestine and Syria during the eleventh and twelfth centuries.

Individual shocks, or brief groups of large shocks, frequently have this exceptional character. Examples are the Mississippi Valley shocks of 1811–1812, the Charleston earthquake of 1886, the Baffin Bay shock of 1933, the west Cuban earthquake of 1880, and the destructive shock at Basel in 1356.

Seismicity must have changed greatly in the course of geologic time. Stresses producing shocks in northern Europe have been attributed to unloading of the Pleistocene ice burden; this may apply to some of the Canadian shocks. Though present seismicity affords almost no clue to the location of the geologically older structures, yet the formation of these structures must have been accompanied by many earthquakes. Present evidence of broad regional association of earthquakes and volcanoes may be applied to stratigraphical and structural evidence of past volcanism in many parts of the world which are now relatively stable. Contemporary shocks at intermediate depths follow volcanic lines, which in their turn follow Tertiary orogenic trends.

How far the present major active belts can be traced back into geological history is an important question, to which only tentative answers are possible. The circum-Pacific belt, in one form or another, has certainly had a long history, corresponding to the geological antiquity of the Pacific basin; its several sections and branches have undoubtedly undergone many changes and much deformation. The history of the trans-Asiatic zone must be connected with that of the inland sea Tethys. The Atlantic and Indian Ocean belts mark the contacts between important sections of the crust, which have certainly existed as units during most of the Tertiary while their remoter history is more doubtful.

EARTHQUAKES AND OTHER PHENOMENA

The association of volcanic and seismic regions is rather general and loose. Both earthquakes and volcanoes are connected with the weaker crustal zones, and consequently show a similar distribution over the world when studied on a small-scale map. Both are most frequent in the circum-Pacific belt of structures and its branches. Proportionately fewer volcanic vents than earthquakes are known in the trans-Asiatic zone; while volcanoes, and islands of volcanic rock, are frequent in the Atlantic and Indian Ocean in association with moderate seismic activity.

Volcanic vents are usually at distances measured in hundreds of kilometers from the principal tectonically active faults and structures. This applies to shallow earthquakes only, since intermediate shocks frequently occur directly under the structures marked by volcanic vents.

Probably no causal connection exists between intermediate shocks and present volcanic activity, since both are very likely due to the same remote orogenic processes.

Large gravity anomalies have been much studied with reference to earthquake epicenters, since such anomalies suggest an abnormal condition of the crust likely to be accompanied by unusual stresses. Narrow belts of large negative gravity anomalies are known to occur off Japan, in the East Indies, and in the West Indies. These anomalies are generally found associated with oceanic troughs or foredeeps, however, the greatest negative anomaly is generally not over the trough, but adjacent to it. This adjacent belt is frequently marked by epicenters of shallow earthquakes.

Troughs, rises, belts of gravity anomalies, volcanic chains, and seismic belts of different classes tend to occur together in a definite order of association, which is best explained with reference to a particular example (Fig. 17). The hypocenters of shallow and deep earthquakes near the section AB are projected onto the plane of the section. Gravity data are taken from Matuyama (1936). (*See also* Kumagai, 1940.)

In this region earthquakes, gravity anomalies, volcanic vents, and structures are aligned along relatively narrow belts with a northeast-southwest trend. The section crosses these belts nearly perpendicularly. Near its southeast end the deep Pacific basin descends into the deeper Japan Trench. Shallow shocks occur chiefly under the steep continental slope west of this trough. Along this slope is the belt of greatest negative gravity anomalies, the greatest seismicity practically coinciding with the center of the belt. On land the gravity anomalies become positive, and are accompanied by volcanism and shocks at intermediate depth down to 250 km. The deeper of these probably form part of a separate belt of epicenters. The second volcanic belt marked in the figure probably coincides only accidentally with the epicenters of certain deep shocks, since it has a nearly north-south trend, while the line of deep shocks crosses it in a northeast-southwest direction (Fig. 8). The still deeper shocks shown under the Asiatic mainland are part of another belt.

The foci of deep and intermediate shocks appear to fall on a single smooth surface dipping at about 30 degrees under the continent. However, in no region where deep shocks can be investigated, is there conclusive evidence of such an active surface; rather, the shocks occur in belts traversing the hypothetical surface, and leaving large parts of it blank. This may be

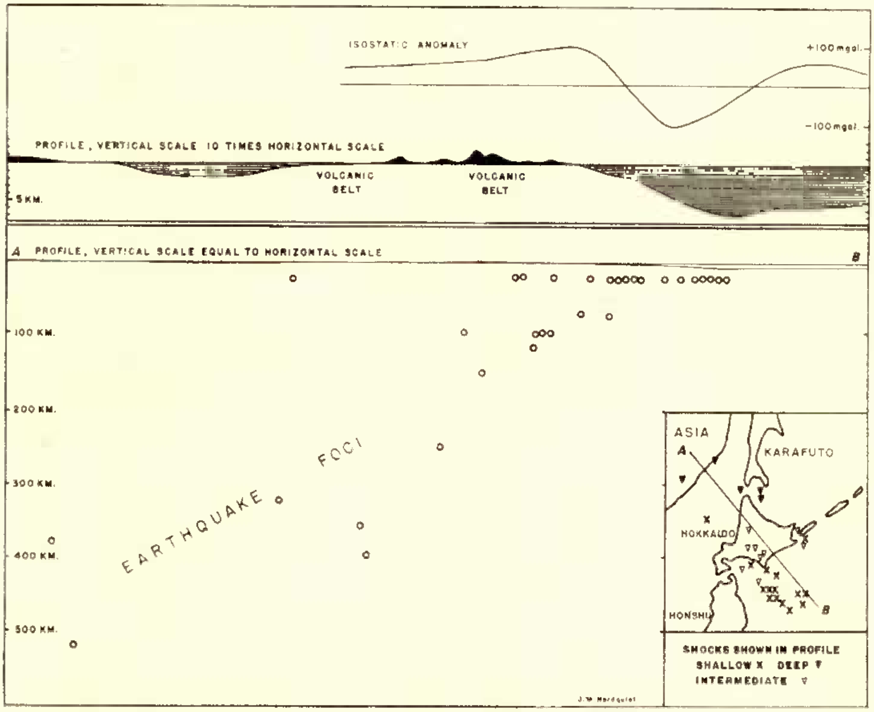

FIGURE 17.—*Profile, northern Japanese region*
Showing earthquakes hypocenters, relief, and isostatic gravity anomalies

due to the incompleteness of our information, or the active belts may be intersections of the supposed surface with other structures. Such an inclined surface need not be a continuous fracture zone, but may simply be a locus of maximum stress.

Like most "typical examples," Figure 17 is exceptional in that all the features which it is desired to illustrate are clearly represented. The choice of such sections is especially limited by the lack of gravity data in many important regions. A more or less continuous belt of negative gravity anomalies runs east of the Marianne Islands and then northeastward in the vicinity of the deep troughs off Honshu (Matuyama, 1936). The known belt begins at about 28° N. 143° E. and trends slightly west of north, following the west slope of a trough, accompanied by shallow shocks (Fig. 8). West of this, along the line of small islands, is the much more active belt of intermediate shocks, accompanied by positive gravity anomalies. Near 35° N. the gravity anomalies are less marked; but they become strongly negative again to the north, where there is very high seismicity.

In a (unpublished) discussion at the 6th Pacific Science Congress in 1939, Professor Matuyama stated that "strong negative anomalies follow the eastern coast of Honsyu at some distance off the coast and turn in the direction of the Marianne Islands in the neighborhood of the Fossa Magna. In the central and southern parts of Honsyu positive gravity anomalies prevail. A line of minimum gravity anomalies which, however, in most of the region still are positive, follows the central part of southern Honsyu and then turns southward. This minimum coincides with the belt of shallow earthquakes in this region."

All these phenomena are well exemplified in the region of Sumatra and Java. The gravity data are those of Vening Meinesz (1940). The structures and attendant phenomena are distributed along a series of curving bands parallel to the trend of the Sunda arc (Fig. 9). Beginning at the south and west, the floor of the Indian Ocean rises gradually to shallow depths, emerging at Christmas Island. North of this belt of shallow sea there is an extremely steep descent into the Java Trough, a typical foredeep. Off Sumatra this descent is not so steep, and the depth reached is shallower. Next inland is a line of small islands, separated by shallow straits, off the Sumatran coast. This line continues as a ridge, which does not emerge, off the coast of Java north of the Java Trough. The belt of strong negative gravity anomalies, discovered by Meinesz, practically coincides with this ridge. Between Java and the Java Trough these anomalies are large, but there is little accompanying seismicity; while in the continuation of the same belt, along the islands west of Sumatra, the negative gravity anomalies are less marked, and the seismic activity is intense, consisting exclusively of shallow shocks. Inshore from this belt slightly greater depths again occur before the coasts of Sumatra and Java are reached. This coastal belt is a region of positive gravity anomalies and earthquakes at intermediate depth. The deepest of these shocks occur under the volcanic belt of the two large islands. Finally, in the seas north of Java there is an east-west belt of shocks at very great depth.

Elsewhere in the East Indies the structural conditions are more complicated, which renders discussion of the meaning of gravity anomalies more uncertain. The belt of strong negative gravity anomalies runs round the Banda Sea from Timor to Ceram, and includes the few well-located shallow shocks, while intermediate shocks are clearly interior to the arc. Such structures as the Weber Deep interior to the arc, and the line of islands through Flores and Weter, complicate the pattern to be interpreted. The gravity anomalies and seismicity of Celebes are still harder to bring under any generalization. Between Celebes and Halmaheira a very strong belt of negative gravity anomalies follows a small submarine ridge northward to the Talaud Islands; there is strong seismicity at shallow depth along the same line. A line of intermediate shocks crosses here from west to east, and there is other activity near by.

A belt of strong negative gravity anomalies also exists in the West Indies, where it is associated with deep troughs, volcanism, and seismicity. For the gravity data and discussion *see* Hess (1938) and Daly (1940, p. 285). Shocks in this region are relatively few, and often not well located. Only in the vicinity of the lesser Antilles do the phenomena simulate those in the East Indies and off Japan. Strong negative gravity anomalies occur to the east, near the Barbados Ridge; while the islands themselves (excluding Barbados) are to the west, and are associated with volcanism, positive gravity anomalies, and at least one intermediate shock.

The few gravity observations available in the Tonga region (*see* Heiskanen, 1936; Daly, 1940, p. 255) fit in well with the existence of an oceanic trough, volcanism, and shocks at all depths, to complete a pattern similar to that of the Sunda arc. The only other region in which available gravity data suggest something of the same sort is in northern India. (*See* Daly, 1940, p. 224–247.) Here there is a narrow belt in which gravity anomalies are strongly negative, although they can be removed in large part by a special choice of isostatic reduction. This is interesting in view of the common comparison of the Ganges depression to foredeeps like the Java Trough. The location of the gravity anomalies, and of the belt of shallow earthquake epicenters, is quite analogous to that found elsewhere. However, the few intermediate earthquakes known here are a poor counterpart for those of the Sunda arc (the active Hindu Kush source is much farther west); no deep shocks occur; and there is no comparable volcanic activity.

Observations in the Atlantic Ocean have not disclosed any gravity disturbances comparable with those noted above. The mid-Atlantic Ridge is not marked by any outstanding gravity anomalies, so far as present information goes. (*See* Meinesz 1939.) Negative anomalies are known from the region of the African Rifts (*see* Heiskanen, 1936), and very large positive anomalies recently have been found on Cyprus (Mace and Bullard, 1939).

The unilateral grouping of oceanic troughs or foredeeps, gravity anomaly belts, shallow and deep earthquakes, and volcanism is most frequently found on the Pacific margin, as in the type case of Japan. The outermost structure usually is the deep trough, with earthquakes and other phenomena occurring in order, successively farther from the Pacific basin. In the case of the Sunda arc, the Indian Ocean plays the part which is elsewhere taken by the Pacific. In the West Indies and in the Southern Antilles, the Atlantic occupies this position.

The polarity of the whole series of structures in any given region can usually be inferred from the relative position of oceanic troughs and land structures; where the structural lines are curved, the troughs are usually on the convex side. In the New Hebrides and Solomon Islands, the polarity is apparently the reverse of that in most parts of the Pacific margin. Here the troughs are on the southwestern, or continental side, the shallow shocks are between these and the island chains, while intermediate shocks are under the islands or beyond them toward the open Pacific, with a few deep shocks still farther out.

The whole complex of related structures and phenomena is plainly produced by stresses which are usually associated with the boundary of the Pacific, but which may locally assume either polarity with reference to it. This polarity, or one-sidedness, excludes symmetrically bilateral physical models. The not fundamentally dissimilar one-sided models of Kuenen (1936) and of Griggs (1939) probably can be modified to fit the facts.

Their frequent association with earthquakes is only one type of evidence indicating that oceanic troughs, or foredeeps, are due to processes still active and continuing, as is required by the mechanical models. This is important since it is sometimes suggested that persistence of these structures, together with large negative gravity anomalies, implies great strength of the crust and the underlying material, or a relatively high viscosity (in excess of 10^{23}). Otherwise, it is argued, the troughs in question would have only a very short term of existence on the geological time-scale. On this basis the crust should adjust itself only very slowly to inequalities of stress; this conflicts with the usual interpretation of the post-glacial uplift in Fennoscandia and Canada, which calls for a relatively rapid return toward isostatic conditions with removal of the glacial burden. Apparently it would then be necessary to seek some other explanation of this uplift, and calculations of the viscosity of the crust based on the rate of uplift would be invalidated. This type of argument ignores the possibility that stresses, such as may be associated with subcrustal convection, are regularly at work maintaining the crust in its deformed state. In such a model it must be noted that deep-focus earthquakes should be expected to occur not at the level of maximum flow, but at that of maximum stress associated with the flow.

Many authors have correlated deep and shallow earthquakes with oceanic troughs and deeps. This is a general correlation like that with volcanic activity; it applies to small-scale maps, but requires modification in detail. Epicenters usually do not fall in the deep troughs themselves, but on their marginal slopes or along the crests of adjacent submarine ridges. Frequently, as occurs south of Sumatra and Java, the ridge adjacent to the deep is not seismically active, but becomes active in another part of its course where the adjacent depths are less marked.

However, most of the greater deeps are in regions where seismicity is at least moderately high. This of course applies to the true structural troughs, and not to the irregular areas of great depth which occur in the oceanic basins, particularly in the Pacific. On the other hand, earthquakes occur in many oceanic regions, as in the Atlantic and Indian oceans, where there are no associated deeps; the seismic belts then follow the ridges.

Structures of somewhat different character, usually associated with seismicity, are the great elongated depressions in the interiors of some of the continents. Examples are the great African lakes, Nyasa and Tanganyika, and in Asia, Lake Baikal, the Turfan basin, and the Jordan Valley. The mechanism which has created and maintained rift depressions of this kind probably differs from that assumed for the oceanic troughs.

MECHANISM

In discussing dynamical implications of the present seismicity of the world, it must not be forgotten that contemporary earthquakes indicate only the fractures, stresses, and displacements now in action. These may well differ, and in some cases they certainly do differ markedly, from those associated with the formation of even late Pleistocene structures. A few tens of thousands of years is ample time for extensive and significant changes in the local distribution of stress. Thus, the fact that the present seismicity of Europe is not mechanically connected with the Alpine folding has been emphasized by Sieberg (1932a), who attributes contemporary shocks to fractures produced in the rigid Alpine mass after the conclusion of folding. However, his ingenious localization of these fractures on the basis of the very limited earthquake data has not found general acceptance.

Except for comparatively superficial volcanic shocks, earthquakes represent a process of fracturing involving shear. Present evidence indicates that this is as true of deep shocks as of shallow shocks. Consequently, in dynamic interpretations of earthquakes the mantle of the earth must be considered capable of first supporting large shearing stresses, and then fracturing as these become still larger; this must be true, at least locally, down to the depths near 700 km., the lower limit of deep-focus shocks as now known. This is not inconsistent with the plastic flow required to maintain isostasy, as all evidence indicates that the material of the mantle flows slowly under long-continued and constant stress, with a more or less incidental accompaniment of sudden fracturing. (*See* Gutenberg and Richter, 1939b.)

Division of the earth's surface into comparatively rigid blocks has an important bearing on tectonic hypotheses. It calls especially for interpretation in connection with any of the forms of the theory of continental drift. Undoubtedly these blocks have not always had exactly their present size and shape, and they may have greatly changed their relative positions. At present we know that in certain regions, as in California, large-scale horizontal displacements continue in the same sense over the whole region, and apparently have operated in the same or a similar way through most of Recent time. Comparison with the direction of similar horizontal displacements on the opposite side of the Pacific, as in the Philippines (Willis, 1939b) and Japan (Tsuboi, 1939), indicates that the continental masses on both sides are being pushed southward relative to the Pacific basin. Many more observations are needed before this can be accepted as an established fact of extended application. There is both seismological and geological evidence in other parts of the world that displacement is occurring continuously in the same direction.

A result not anticipated by the writers is the frequent close coincidence of the active zones, which are found to separate the stable blocks, with the "orogens" of Kober (1933). As he points out, these zones are chiefly mountainous in character; the ridges in the various oceans are submarine mountain chains. The agreement with Kober's zones is not necessarily a confirmation of his interpretation of these contemporary structures in terms of geological history, or of his ideas about the processes now taking place. The agreement chiefly applies only to the larger lines, and frequently is very divergent in the smaller details. Moreover, Kober does not discriminate the Pacific stable area from the structurally different continental blocks; and he draws "orogens" subdividing the Pacific area, which are unconfirmed by this study and frequently conflict with its conclusions.

Problems of interpretation are especially acute with reference to the existence and seismicity of the Mid-Atlantic Ridge. Its parallelism with the continental coasts is so close that it practically demonstrates a mechanical connection with them. However, it is still possible to consider the Ridge either as a remnant left over from a former connection between America and the Old World, or as a young structure originating at the contact between rigid blocks. (For a summary with references, *see* Du Toit, 1937, Chapter X.) It can hardly be a young structure in the sense in which the very active zones of the East Indies and other similar regions are young, for it lacks many of the associated phenomena found in such regions, which have been taken as evidence for the contemporary occurrence of subcrustal flow. Thus there are no parallel deep troughs, and no belts of negative gravity anomalies; the gravity anomalies over the Mid-Atlantic Ridge are slightly positive (Meinesz, 1939). Intermediate and deep shocks are absent, which indicates that there are no large stresses at great depth. Present seismicity and volcanism do not necessarily imply that the processes which created the Ridge are now in action. The Ridge may represent an orogeny of Tertiary age, in which the folding has at least temporarily ceased, and the now practically rigid structures are being broken up by diastrophic processes, along faults which are either of recent origin or recently rejuvenated. For a discussion from the geological point of view *see* Bucher (1940).

The foregoing discussion is necessarily speculative, and is intended merely as a guide in using the seismological data. In the major part of the paper, which concludes with the Geographical Summary, care has been taken to present facts of observation, with only the minimum of hypothesis necessary to organize them into an intelligible form. The sections following thereafter necessarily include gradually increasing proportions of hypothetical material. With the suggestions just brought forward it is felt that a foundation for geological and geophysical interpretation has been provided.

GENERAL SUMMARY

The relative seismicity of all parts of the earth, for a limited period, is discussed with maps. The data are chiefly instrumental. The paper deals mainly with shallow shocks, but new data on deep-focus shocks are included.

A revised table is given listing 54 great shocks from 1904 to 1939. All large shocks from 1926 to 1933 are listed, and epicenters are given for many others.

The earth's surface consists of relatively inactive blocks separated by active zones of three groups:

(1) The circum-Pacific zone includes a large majority of shallow shocks, a still larger fraction of shocks at intermediate depth, and all the very deep shocks. For shallow shocks the most active regions are Japan, the Aleutian arc, western Mexico, Melanesia, and the Philippines. In Japan the zone divides into an East Indian and a Polynesian branch, the latter following the andesite line. Three loops surround outlying areas of probably Pacific structure: the Caribbean loop, the loop of Suess's Southern Antilles (including South Georgia and the South Sandwich Islands), and a newly identified loop southwest of New Zealand, here called the Macquarie Island loop. A branch passes near the Galápagos group and follows the Easter Island Ridge, along a zone of suspected continental structure.

(2) The Mediterranean and trans-Asiatic zone includes the remainder of the large shallow shocks and of the intermediate shocks. The epicenters fall along structural trend lines.

(3) Narrow belts of shallow shocks extend (a) through the Arctic and Atlantic Oceans, following the Mid-Atlantic Ridge; (b) through the western Indian Ocean from Arabia into the Antarctic, probably connecting with the South Antillean loop; and (c) a similar but less active belt following the African rift valleys.

The Pacific basin (except in the Hawaiian Islands) and the continental

nuclear shields are nearly inactive. Between the stable shields and the active belts are areas of minor to moderate activity, with occasional large shocks.

Small shocks apparently occur everywhere. The relation of minor activity to the larger shocks is discussed, using southern California as an example.

The annual average includes about one great shock, about 100 potentially destructive shocks, and about one million shocks potentially strong enough to be felt in a settled area. Seismic energy is released at a mean rate of about 10^7 kilowatts; most of this is in the large shocks.

There is regular association, with notable regional exceptions, of earthquakes at various depths with volcanoes, gravity anomalies, and oceanic troughs or foredeeps. The several phenomena are frequently found in successive adjoining belts in a particular unilateral order. The persistance of oceanic troughs and gravity anomalies, together with the occurrence of earthquakes, requires that in these regions there is a continuously operating mechanism, such as would be provided by constant subcrustal flow.

WORKS TO WHICH REFERENCE IS MADE

Adams, C. E., Barnett, M. A. F., and Hayes, R. C. (1933) *Seismological report of the Hawke's Bay earthquake of 3rd February, 1931*, Dominion Observatory, Wellington, Bull. 85, 16 pages.

Arni, P. (1939) *Carte tectonique schematique de l'Anatolie et de son voisinage oriental*, Maden Tetkìk ve Arama Enstitüsü Mecmuasi Üç Ayda Bir Çicar, Sene 4, Sayi: 2, p. 28.

Bastings, L. (1933) *Some seismological aspects of the Buller earthquake, 1929, June 16–17*, New Zealand Jour. Sci. Technol., vol. 15, p. 128–142.

——— (1935) *Destructive earthquakes in New Zealand, 1835–1934*, Dominion Observatory, Wellington, Bull. 103, p. 406–411.

Bellamy, E. F. (1936) *Index catalogue of epicentres for 1913–1930*, University Observatory, Oxford, 36 pages.

Berlage, H. P. (1940) *One hundred deep-focus earthquakes in the Netherlands Indies*, 6th Pacific Sci. Congr., Pr., vol. 1, p. 135–138.

Bobillier, Carlos (1933) *La sismicidad de Chile durante el año de 1931*, Universidad de Chile, Bol. del Servicio Sismol. no. 23, p. 6.

Boese, E., Villafaña, A., and García y García, J. (1908) *El temblor del 14 de abril de 1907*, Parerg. Inst. Geol. Mexico, II, p. 136–258.

Born, A. (1933) *Der geologische Aufbau der Erde*, Handbuch der Geophysik, vol. 2, p. 565–867, Berlin.

Bramhall, E. H. (1938) *The Central Alaska earthquake of July 22, 1937*, Seismol. Soc. Am., Bull., vol. 28, p. 71–75.

Branner, J. C. (1912) *Earthquakes in Brazil*, Seismol. Soc. Am., Bull., vol. 2, p. 105–117.

——— (1919) *Outlines of the geology of Brazil to accompany the geological map of Brazil*, Geol. Soc. Am., Bull., vol. 30, p. 189–337.

——— (1920) *Recent earthquakes in Brazil*, Seismol. Soc. Am., Bull., vol. 10, p. 90–114.

Brown, J. C., and Leicester, P. (1933) *The Pyu earthquakes of 3rd and 4th December, 1930, and subsequent Burma earthquakes up to January, 1932*, India Geol. Survey, Mem., vol. 62, p. 1–140.

Brunner, G. J. (1938) *The deep earthquake of May 26, 1932 near the Kermadec Islands*, Gerlands Beitr. z. Geophysik, vol. 53, p. 1–64.

Bryan, W. H., and Whitehouse, F. W. (1938) *The Gayndah earthquake of 1935*, Royal Soc. Queensland, Pr., vol. 49, p. 106–119.

Bucher, Walter H. (1940) *Submarine valleys and related geologic problems of the North Atlantic*, Geol. Soc. Am., Bull., vol. 51, p. 489–512.

Bullen, K. E. (1938) *On the epicentre of the 1934 Pahiatua earthquake*, Dominion Observatory, Wellington, Bull. 137, p. 61B–66B.

Byerly, Perry (1930) *The California earthquake of November 4, 1927*, Seismol. Soc. Am., Bull., vol. 20, p. 53–66.

——— (1935) *The first preliminary waves of the Nevada earthquake of December 20, 1932*, Seismol. Soc. Am., Bull., vol. 25, p. 62–80.

——— (1940) *Seismicity of the northern Pacific coast of the United States*, Geol. Soc. Am., Bull., vol. 51, p. 255–260.

Chubb, L. J. (1934) *The structure of the Pacific Basin*, Geol. Mag., vol. 71, p. 289–302.

Clapp, F. G. (1940) *Geology of eastern Iran*, Geol. Soc. Am., Bull., vol. 51, p. 1–102.

Cloos, Hans (1939) *Hebung—Spaltung—Vulkanismus*, Geologische Rundschau, vol. 30, p. 405–527.

Close, Upton, and McCormick, Elsie (1922) *Where the mountains walked*, Nat. Geogr. Mag., vol. 41, p. 445–464.

Conrad, V. (1932) *Die zeitliche Folge der Erdbeben und bebenauslösende Ursachen*, Handbuch der Geophysik, vol. 4, p. 1007–1185, Berlin.

Daly, R. (1940) *Strength and structure of the earth*, New York, 1940, 434 pages.

Dammann, Y. (1924) *Le tremblement de terre du Kan-Sou*, Bur. Centr. Sismologique Int., sér. B, monographies, fasc. 1, 92 pages.

Davison, Charles (1924) *A history of British earthquakes*, Cambridge, 416 pages.

——— (1931) *The Japanese earthquake of 1923*, London, 127 pages.

——— (1936) *Great earthquakes*, London, 286 pages.

——— (1938) *Studies on the periodicity of earthquakes*, London, 107 pages.

Doyle, Patrick (1882) *Note on an Indian earthquake*, Seismol. Soc. Japan, Tr., vol. 4, p. 78–83.

Dunn, J. A., Auden, A. M. N., and Wadia, D. N. (1939) *The Bihar-Nepal earthquake of 1934* (with seismometric study by S. C. Roy), India Geol. Survey, Mem., vol. 73, p. 1–391.

Du Toit, A. L. (1937) *Our wandering continents*, London, 366 pages.

Etzold, F. (1919) *Die sächsischen Erdbeben während der Jahre 1907–1915*, Sächsische Ges. d. Wiss., Leipzig, Abhandl., vol. 36, no. 3, p. 213–429.

Ewing, Maurice (1938) *Marine gravimetric methods and surveys*, Am. Philos. Soc., Pr., vol. 79, p. 47–70.

Farquharson, W. I. (1936) *Topography*, Brit. Mus. (Nat. Hist.), John Murray Expedition, Sci. Rept., vol. 1, no. 2.

Fisher, N. H. (1940) *The volcanoes of the mandated territory of New Guinea*, 6th Pacific Sci. Congr., Pr., vol. 2, p. 889–894.

Galitzin, B. (1911) *Das Erdbeben vom 3.–4. Januar 1911*. Acad. Imp. St. Pétersbourg, Bull., p. 127–136.

Gee, E. R. (1934) *The Dhubri earthquake of the 3rd July, 1930*, India Geol. Survey, Mem., vol. 65, p. 1–106.

Griggs, David (1939) *A theory of mountain-building*, Am. Jour. Sci., vol. 237, p. 611–650.

Gutenberg, Beno (1915) *Die mitteleuropäischen Beben vom 16. November 1911 und vom 20. Juli 1913*, Veröff. Zentralbureau Int. Seismol. Assoc., Strassburg, 84 pages, 32 plates.

——— (1925) *Bearbeitung von Aufzeichnungen einiger Weltbeben*, Senckenberg. Naturforsch. Ges., Abh., vol. 40, p. 57–88.

——— (1939) *Tsunamis and earthquakes*, Seismol. Soc. Am., Bull., vol. 29, p. 517–526.

——— (1941) *Changes in sea level, postglacial uplift, and mobility of the earth's interior*, Geol. Soc. Am., Bull., vol. 52, p. 721–772.

———, **and Richter, C.** (1934) *On seismic waves* (1st paper), Gerlands Beitr. z. Geophys., vol. 43, p. 56–133.

——— — ——— (1935) *On seismic waves* (2d paper), Gerlands Beitr. z. Geophys., vol. 45, p. 280–360.

——— — ——— (1936) *On seismic waves* (3d paper), Gerlands Beitr. z. Geophys., vol. 47, p. 73–131.

Gutenberg, Beno, and Richter, C. (1937) *Materials for the study of deep-focus earthquakes* (2d paper), Seismol. Soc. Am., Bull., vol. 27, p. 157–183.
——— ——— (1938) *Depth and geographical distribution of deep-focus earthquakes*, Geol. Soc. Am., Bull., vol. 49, p. 249–288.
——— ——— (1939a) *Depth and geographical distribution of deep-focus earthquakes*, (2d paper), Geol. Soc. Am., Bull., vol. 50, p. 1511–1528.
——— ——— (1939b) *Evidence from deep-focus earthquakes. Structure of the crust. Continents and oceans*, in *Internal constitution of the earth*, p. 290–327, New York and London.
Hagiwara, T. (1940) *The Ogasima earthquake and its aftershocks*, Earthquake Res. Inst., Tokyo, Bull., vol. 18, p. 252–263.
Hayes, R. C. (1937) *The seismological aspects of the Wairoa earthquake of September, 1932*, Dominion Observatory, Wellington, Bull. 121, p. 858–865.
——— (1939) *The deep-focus earthquakes of the Southwest Pacific*, 6th Pacific Sci. Congr., Pr., vol. 1, p. 131–134.
Heck, N. H. (1938a) *The role of earthquakes and the seismic method in submarine geology*, Am. Philos. Soc., Pr., vol. 79, p. 97–108.
——— (1938b) *Earthquake history of the United States, part I*, U. S. Coast Geod. Survey, serial No. 609, 83 pages.
Heim, Arnold (1934) *Earthquake region of Taofu*, Geol. Soc. Am., Bull., vol. 45, p. 1035–1050.
Heiskanen, W. (1936) *Das Problem der Isostasie*, Handbuch der Geophysik, vol. 1, p. 878–951, Berlin.
Henderson, J. (1937) *The West Nelson earthquakes of 1929 (with notes on the geological structure of West Nelson)*, Dept. Sci. Industr. Res., Bull. 55, Wellington, New Zealand, p. 65–144.
Hess, H. H. (1938) *Gravity anomalies and island arc structure with particular reference to the West Indies*, Am. Philos. Soc., Pr., vol. 79, p. 71–96.
Hodgson, E. A., and Doxsee, W. W. (1930) *The Grand Banks earthquake, November 18, 1929*, Eastern Sect. Seismol. Soc. Am., Pr. 1930 meeting, Washington, p. 72–79.
Hoffmeister, J. E. (1938) *The John Murray Expedition (1933–1934)*, Geogr. Rev., vol. 28, p. 160–162.
Imamura, Akitune (1931) *Seismometric study of the recent destructive N. Idu earthquake*, Earthquake Res. Inst. Tokyo, Bull., vol. 9, p. 48–49.
——— (1937) *Theoretical and applied seismology*, Tokyo, 358 pages.
Ishimoto, M., *et al.* (1934) *Papers and reports on the tunami of 1933 on the Sanriku coast, Japan*, Earthquake Res. Inst. Tokyo, Bull., Suppl. vol. 1, Part 1, 271 pages and 226 plates; Part II, 250 pages.
Jeffreys, Harold (1923) *The Pamir earthquake of 1911 February 18, in relation to the depths of earthquake foci*, Royal Astron. Soc., Mo. Notices, Geophys. Suppl., vol. 1, p. 22–30.
Jenkins, Olaf P. (1938) *Geologic map of California*, Scale 1:500,000, 6 sheets, Div. Mines, Sacramento, California.
Jones, J C. (1915) *The Pleasant Valley, Nevada, earthquake of October 2, 1915*, Seismol. Soc. Am., Bull., vol. 5, p. 190–205.
Junner, N. R., *et al.* (1941) *The Accra earthquake of 22nd June, 1939*, Gold Coast Geol. Survey, Bull. 13, London, 67 pages, 6 plates, 2 maps.
Keith, Arthur (1930) *The Grand Banks earthquake*, Eastern Sect. Seismol. Soc. Am., Washington, Suppl. Pr. 1930 meeting, p. 1–5.
Kober, L. (1933) *Die Orogentheorie*, Berlin, 184 pages.
Koch, Lauge (1929) *The Geology of east Greenland. Stratigraphy of Greenland*, Meddelelser om Grønland, vol. 73, pt. 2, p. 1–320, København.

Kolderup, C. F. (1913) *Norges jordskjaelv,* Bergens Museums Aarbok 1913 nr. 8 (with summary in German), 151 pages.

Krige, L. J., and Venter, F. A. (1933) *The Zululand earthquake of the 31st December, 1932,* Geol. Soc. S. Africa, Tr., vol. 36, p. 101–112.

Kuenen, P. H. (1936) *The negative isostatic anomalies in the East Indies (with experiments),* Leidsche Geolog. Mededeelingen, vol. 8, p. 169–214.

Kumagai, N. (1940) *Studies in the distribution of gravity anomalies in north-east Honsyu and the central part of the Nippon Trench, Japan,* Japan. Jour. Astron. Geophys., vol. 17, p. 477–551.

Kunitomi, S. I. (1931) *Notes on the North Idu earthquake of Nov. 26, 1930,* Geophys. Mag., vol. 4, p. 73–102, Tokyo.

——— (1937) *Preface,* Weather Bur. Tyôsen, Seismol. Bull. 1934, Zinsen, Tyôsen, Nippon.

Lawson, A. C., *et al.* (1908) *The California earthquake of April 18, 1906,* Carnegie Inst. Washington, 2 vols., atlas, 643 pages.

Lee, A. W. (1937) *On the travel of seismic waves from the Baffin Bay earthquake of November 20, 1933,* Meteorol. Office, Geophys. Mem., No. 74, London. 21 pages.

Lee, J. S. (1939) *Geology of China,* Thomas Murby and Co., London, 528 pages.

Lee, S. P. (1933) *Note on the earthquake of August 10, 1931,* Geol. Survey China, Seismol. Bull., Chiufeng seismic station, vol. 2, p. 51–60.

Lehmann, I. (1930) *P' as read from the records of the earthquake of June 16th 1929,* Gerlands Beitr. z. Geophysik, vol. 26, p. 402–412.

———, **and Plett, G.** (1932) *Untersuchung der europäischen Registrierungen der Erdbeben vom 18. VII. 1928, 24. X. 1930 und 13. XI. 1925,* Gerlands Beitr. z. Geophysik, vol. 36, p. 38–77.

Littlehales, G. W. (1932) *The configuration of the ocean basins,* in *Oceanography,* Nat. Res. Council, Bull. 85, p. 13–60. Washington, D. C.

Mace, C., and Bullard, E. C. (1939) *Gravity measurements in Cyprus,* Royal Astron. Soc., Mo. Notices, Geophys. Suppl., vol. 4, p. 473–480.

Macelwane, J. B. (1930) *The South Pacific earthquake of June 26, 1924,* Gerlands Beitr. z. Geophysik, vol. 28, p. 165–227.

Masó, M. S. (1918) *Great earthquake and tidal wave in southern Mindanao, P. I.,* Seismol. Soc. Am., Bull., vol. 8, p. 125–126.

——— (1924) *The Mati earthquake, April 14, 1924,* Weather Bur. Manila, Bull., reprint p. 1–2.

——— (1927a) *Ancient Philippine earthquakes, 1585–1865,* Weather Bur. Manila, Seismol. Bull., reprint p. 1–35.

——— (1927b) *Destructive and violent (VII–X R. F.) Philippine earthquakes and eruptions 1585–1925,* Weather Bur. Manila, Seismol. Bull., reprint p. 5–8.

Matuyama, Motonori (1936) *Gravity Survey by the Japanese Commission since 1932,* Intern. Union Geod., 6th Conf., Edinburgh, Report, 8 pages.

Matuzawa, Takeo (1935/1936) *Seismometrische Untersuchungen des Erdbebens vom 2. März 1933,* Earthquake Res. Inst. Tokyo, Bull., vol. 13, p. 171–193, 328–334; vol. 14, p. 38–67.

Meinesz, F. A. V. (1933) *Ergebnisse der Schwerebeobachtungen auf dem Meere in den Jahren 1923–1932,* Ergebnisse der Kosmischen Physik, vol. 2, p. 153–212.

——— (1939) *Review of gravity at sea,* Intern. Union Geod. Geophys., Commission on continental and oceanic structure, Adv. rept., p. 33–45. Washington, D. C.

——— (1940) *The earth's crust deformation in the East Indies,* Nederl. Akad. Pr., vol. 43, p. 278–293.

———, **Umbgrove, J. H. F., and Kuenen, Ph. H.** (1934) *Gravity expeditions at sea 1923–1932,* vol. 2, Netherlands Geod. Comm., Publ., Delft, 208 pages.

Middlemiss, C. S. (1910) *The Kangra earthquake of 4th April 1905*, India Geol. Survey, Mem., vol. 38, 409 pages and 28 plates.

Milne, J. (1905) *Preliminary notes on observations made with a horizontal pendulum in the Antarctic regions*, Royal Soc., Pr., vol. 76A, p. 284–295, London.

Minakami, Takeshi (1938) *The Hinomisaki-Oki earthquake of January 12, 1938*, Earthquake Res. Inst. Tokyo, Bull., vol. 16, p. 470–483.

Montessus de Ballore, F. de (1906) *Les tremblements de terre. Géographie Séismologique*, Paris. 476 pages.

Mushketov, D. (1935) *On seismicity of the Arctic*, Acad. Sci. U.S.S.R., Publ. Seismol. Inst., No. 61, p. 9–15.

——— (1936a) *Distribution and extent of seismotectonic zones in the Union of Soviet Socialist Republics*, Intern. Geol. Congr. 1933, Rep., vol. 2, p. 873–884, Washington, D. C.

——— (1936b) *Modern conceptions of the tectonics of Central Asia*, Intern. Geol. Congr. 1933, Rept., vol. 2, p. 885–894, Washington, D. C.

Nasu, Nobuji (1935) *The great Indian earthquake of January 15, 1934*, Earthquake Res. Inst. Tokyo, Bull., vol. 13, p. 417–432.

Obruchev, V. A., *et al.* (1928) *The earthquakes on the coast of the Black Sea in 1927 and the destiny of Crimea*, Library Govt. Botanical Garden, Nikita, Yalta, Crimea, U.S.S.R. (in Russian), 111 pages.

Oldham, R. D. (1923) *The earthquake of 7th August, 1895, in northern Italy*, Geol. Soc. London, Quart. Jour., vol. 79, p. 231–236.

Omori, F. (1907a) *Report on the great Indian earthquake of 1905*, Earthquake Investig. Comm. Publ. in Foreign Languages, no. 23, 16 pages, 22 plates; no. 24, 273 pages, Tokyo.

——— (1907b) *Preliminary note on the Formosa earthquake of March 17, 1906*, Imp. Earthquake Investig. Comm., Bull., vol. 1, p. 53–69, Tokyo.

——— (1923) *Note on the destructive Formosa earthquake of 1922*, Imp. Earthquake Investig. Comm., Seismol. Notes, no. 5, p. 9–16, Tokyo.

Ordoñez, Ezequiel (1931) *The Oaxaca earthquake*, Seismol. Soc. Am., Bull., vol. 21, p. 47–50.

Page, B. M. (1935) *Basin Range faulting of 1915 in Pleasant Valley, Nevada*, Jour. Geol., vol. 43, p. 690–707.

Poisson, Charles (1939) *Un cinquantenaire l'Observatoire d'Ambohidempona à Tananarive, Madagascar, 1889–1939*, p. 62–64 and 104–111, Paris.

Rajko, N., and Linden, N. (1935) *On the earthquake of 20. XI. 1933 in the Baffin Bay and on the distribution of epicentres in the Arctic*, Acad. Sciences U.S.S.R., Publ. Seismol. Inst., no. 61, p. 1–8.

Ramanathan, K. R., and Mukherji, S. M. (1938) *A seismological study of the Baluchistan (Quetta) earthquake of May 31, 1935*, India Geol. Survey, Rec., vol. 73, pt. 4, p. 483–513.

Reid, H. F., and Taber, Stephen (1919a) *The Porto Rico earthquakes of October–November, 1918*, Seismol. Soc. Am., Bull., vol. 9, p. 95–127.

——— ——— (1919b) *The Porto Rico earthquake of 1918 with description of earlier earthquakes*, U. S. House of Representatives, 66th Congr., 1st sess., doc. no. 269, 74 pages.

Repetti, W. C. (1931a) *Philippine earthquake epicenters south of Manila 1920–1929*, Weather Bur. Manila, Seismol. Bull. 1931 (Jan.–June), p. 37–50.

——— (1931b) *Philippine earthquake epicenters*, Weather Bur. Manila, Seismol. Bull. 1930 (July–Dec.), p. 71–85.

——— (1931c) *Philippine earthquakes, marine epicenters 1920–1929*, Manila Observatory, Publ., vol. 3, no. 9, p. 199–204.

Repetti, W. C. (1932) *Philippine earthquake epicenters (1920 to 1929) south of Manila,* Weather Bur. Manila, Seismol. Bull. 1931 (July–Dec.), p. 37–52.

——— (1935) *Tectonic lines of the Philippine Islands,* Weather Bur. Manila, Seismol. Bull. 1934 (July–Dec.), p. 57–71.

——— (1939) *Catalogue of earthquakes felt in Guam 1825–1938,* Weather Bur. Manila, Seismol. Bull. 1939 (Jan.–June), p. 27–43.

——— (1940) *Philippine earthquake epicenters 1930–1932,* Weather Bur. Manila, Seismol. Bull. 1939 (July–Dec.), p. 65–77.

Richter, C. F. (1935) *An instrumental earthquake magnitude scale,* Seismol. Soc. Am., Bull., vol. 25, p. 1–32.

——— (1936) *Earthquake magnitudes and statistics,* Seismol. Soc. Am., meeting April 1936 (not printed).

——— (1940) *Earthquake epicenters and structure of the Pacific region of north America (southern part),* 6th Pacific Sci. Congr., Pr., vol. 1, p. 113–118.

Roos, S. E. (1937) *The submarine topography of the Ross Sea and adjacent waters,* Geogr. Rev., vol. 27, p. 574–583.

Rosenthal, Elmar (1906) *Les tremblements de terre du Kamtchatka en 1904,* Bureau Central de l'Association Internationale de Sismologie, Publ., Strassburg, p. 31–52.

——— (1907) *Katalog der im Jahre 1904 registrierten seismischen Störungen,* Bureau Central de l'Association Internationale de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 145 pages.

Rudolph, E. (1887) *Ueber submarine Erdbeben und Eruptionen,* Gerlands Beitr. z. Geophysik, vol. 1, p. 133–373.

——— (1895) *Ueber submarine Erdbeben und Vulkane (Zweiter Beitrag),* Gerlands Beitr. z. Geophysik, vol. 2, p. 537–666.

———, **and Szirtes, S.** (1912) *Das kolumbianische Erdbeben am 31. Januar 1906,* Gerlands Beitr. z. Geophysik, vol. 11, p. 132–190 and 207–275.

———, **and Tams, E.** (1907) *Seismogramme des nordpazifischen und südamerikanischen Erdbebens am 16. August 1906, Begleitworte und Erläuterungen,* Zentralbureau und Hauptstation für Erdbebenforschung, Strassburg i. E, 98 pages and 58 plates.

Salomon-Calvi, W. (1940) *Les tremblements de terre d'Erzincan du 21. XI. et du 27. XII. 1939,* Maden Tetkik ve Arama, Sene 5, Sayi 1/18, p. 27–30.

Scherer, J. (1912) *Great earthquakes in the island of Haiti,* Seismol. Soc. Am., Bull., vol. 2, p. 161–180.

Sieberg, A. (1910) *Die Erdbebentätigkeit in Deutsch-Neuguinea (Kaiser-Wilhelmsland und Bismarckarchipel),* Petermanns Geographische Mitt., II, Heft 2/3.

——— (1920) *Mitteilungen über Erdbeben im Jahre 1912,* Hauptstation für Erdbebenforschung, Jena, 26 pages.

——— (1932a) *Erdbebengeographie,* Handbuch der Geophysik, vol. 4, p. 687–1005, Berlin.

——— (1932b) *Untersuchungen über Erdbeben und Bruchschollenbau im östlichen Mittelmeergebiet,* Medizinisch-Naturwiss. Ges. zu Jena, Denkschriften, vol. 18, 2. Lieferung, p. 161–273.

——— (1940) *Beiträge zum Erdbebenkatalog Deutschlands für die Jahre 58 bis 1799,* Deutscher Reichs-Erdbebendienst, Mitt., Heft 2, Reichsanstalt f. Erdbebenforschung, Jena.

Sommer, Henrietta (1931) *On the question of dispersion in the first preliminary seismic waves,* Seismol. Soc. Am., Bull., vol. 21, p. 87–185.

Stille, H. (1924) *Grundfragen der vergleichenden Tektonik,* Berlin, 443 pages.

——— (1936) *Tektonische Beziehungen zwischen Nordamerika und Europa,* Interrnt. Geol. Congr., 1933, Rep., vol. 2, p. 829–838.

Szirtes, Siegmund (1909) *Katalog der im Jahre 1905 registrierten seismischen Störungen, II. Teil,* Bur. Central Int. de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 68 pages.

——— (1910) *Katalog der im Jahre 1906 registrierten seismischen Störungen, II. Teil,* Bur. Central Int. de Sismologie, Publ., Sér. B. Catalogues, Strassburg, 85 pages.

——— (1912) *Registrierungen der besser ausgeprägten seismischen Störungen des Jahres 1907,* Bur. Central Int. de Sismologie, Publ., Strassburg, 111 pages.

Taber, Stephen (1920) *Jamaica earthquakes and the Bartlett trough,* Seismol. Soc. Am., Bull., vol. 10, p. 55–89.

——— (1922) *The seismic belt in the Greater Antilles,* Seismol. Soc. Am., Bull., vol. 12, p. 199–219.

Tams, E. (1922) *Die seismischen Verhältnisse des europäischen Nordmeeres,* Centralblatt f. Mineralogie, Geologie und Palaeontologie, Jahrg. 1922, No. 13, p. 385–397.

——— (1927a) *Die seismischen Verhältnisse des offenen Atlantischen Oceans,* Zeitschr. f. Geophysik, vol. 3, p. 361–363.

——— (1927b) *Erdbeben im Gebiet der Nordenskiöld See,* Gerlands Beitr. z. Geophysik, vol. 17, p. 325–331.

——— (1928) *Die seismischen Verhältnisse des offenen Atlantischen Oceans,* Gerlands Beitr. z. Geophysik, vol. 18, p. 319–353.

——— (1930a) *Die Seismizität des Südantillenbogens,* Zeitschr. f. Geophysik, vol. 6, p. 361–369.

——— (1930b) *Das Epicentrum des südatlantischen Grossbebens vom 27. Juni 1929,* Zeitschr. f. Geophysik, vol. 6, p. 480–482.

——— (1931) *Die Seismizität der Erde,* Handbuch der Experimentalphysik, vol. 25, part 2, p. 361–437.

Tarr, R. S., and Martin, L. (1912) *The earthquakes at Yakutat Bay, Alaska,* U. S. Geol. Survey, Prof. Paper 69.

Townley, S. D. (1931) *The New Zealand earthquake of February 3, 1931,* Seismol. Soc. Am., Bull., vol. 21, p. 251–260.

———, **and Allen, M. W.** (1939) *Descriptive catalog of earthquakes of the Pacific Coast of the United States 1769 to 1928,* Seismol. Soc. Am., vol. 29, p. 1–297.

Tsuboi, C. (1939) *Discussion on deep focus earthquakes,* 6th Pacific Sci. Cong., Pr. (not published).

——— (1940) *Isostasy and maximum earthquake energy,* Tokyo Imp. Acad., Pr., vol. 16, p. 449–454.

Turner, H. H. (1917) *The large earthquakes of 1913,* Brit. Assoc. Seismol. Comm., 74 pages.

———, *et al.* (1923–1940) *International Seismological Summary for 1918–March 1934,* Univ. Observatory, Oxford.

Vaughan, T. W., *et al.* (1940) *Report of the Committee on the criteria and nomenclature of the major divisions of the ocean bottom,* Assoc. Océanogr. Phys., Publ. Sci., No. 8, 124 pages.

Visser, S. W. (1934) *Determination from world records of the zero time and the epicentre of the Pegu earthquake of May 5th, 1930,* India Geol. Survey Rec., vol. 65, pt. 2, p. 271–278.

Wadati, K. (1931) *Shallow and deep earthquakes* (3d paper), Geophys. Mag., vol. 4, p. 231–283, Tokyo.

——— (1940) *On deep-focus earthquakes in Japan and vicinity,* 6th. Pacific Sci. Congr. Pr., vol. 1, p. 139–147.

Wanner, E. (1934) *Erdbebenkatalog der Schweiz für die Jahre 1856–1879* (with map *Erdbebenzentren der Schweiz 1856–1933*), Schweiz. Meteorologische Zentralanstalt, Jahresbericht des Erdbebendienstes, p. 16–23, Zürich.

——— (1937) *Zur Statistik der Erdbeben*, Gerlands Beitr. z. Geophysik, vol. 50, p. 85–99 and 223–228.

Weiss-Xenofontova, Z., and Popoff, V. (1940) *Sur les tremblements de terre à la centrale région de l'Oural*, Acad. Sci. U.S.S.R., Publ. Seismol. Inst., No. 104, p. 1–12 (in Russian).

West, W. D. (1934) *The Baluchistan earthquakes of August 25th and 27th, 1931*, India Geol. Survey, Mem., vol. 67, pt. 1, 82 pages.

——— (1935) *Preliminary geological report on the Baluchistan (Quetta) earthquake of May 31st, 1935*, India Geol. Survey, Rec., vol. 69, p. 203–241.

——— (1936) *Geological account of the Quetta earthquake*, Min. Geol. Inst. India, Tr., vol. 30, p. 138–142.

Willis, Bailey (1923) *A fault map of California*, Seismol. Soc. Am., Bull., vol. 13, p. 1–12.

——— (1928) *Earthquakes in the Holy Land*, Seismol. Soc. Am., Bull., vol. 18, p. 73–103.

——— (1929) *Earthquake conditions in Chile*, Carnegie Inst. Washington, Publ. 382, 176 pages and 75 plates.

——— (1933) *Earthquakes in the Holy Land—a correction*, Seismol. Soc. Am., Bull., vol. 23, p. 88–89.

——— (1937) *Geologic observations in the Philippine Archipelago*, Nat. Res. Council Philippine Islands, Bull. 13, 127 pages.

——— (1939) *Wrinkles of Asia*, Sci. Mo., vol. 49, p. 431–451.

——— (1940) *Philippine Archipelago, an illustration of continental growth*, 6th Pacific Sci. Congr., Pro., vol. 1, p. 185–200.

Wilser, J. L. (1928) *Der südrussische Tafelrand in Vorder- und Mittelasien*, Neues Jahrbuch f. Mineralogie . . . . , Beilageband 51, Abt. B, p. 151–184.

Wood, H. E. (1913) *On the occurrence of earthquakes in South Africa*, Seismol. Soc. Am., Bull., vol. 3, p. 113–120.

Wood, H. O. (1914) *On the earthquakes of 1868 in Hawaii*, Seismol. Soc. Am., Bull., vol. 4, p. 171–203.

——— (1933) *Volcanic earthquakes*, in *Physics of the earth*, vol. 6, *Seismology*, Nat. Res. Council, Bull. 90, p. 9–31, Washington, D. C.

Wüst, Georg (1934) *Beziehungen zwischen Bodenstrom und Relief in der Tiefsee des Indischen Ozeans*, Die Naturwissenschaften, vol. 22, p. 241–244.

——— (1939a) *Die Grossgliederung des atlantischen Tiefseebodens*, Geol. Rundschau, vol. 30, p. 132–137.

——— (1939b) *Das submarine Relief bei den Azoren*, Preuss. Akad., Abh., Jahrg. 1939, Phys.-Math. Klasse, Nr. 5, p. 46–58.

——— (1939c) *Bodentemperatur und Bodenstrom in der atlantischen, indischen und pazifischen Tiefsee*, Gerlands Beitr. z. Geophysik, vol. 54, p. 1–8.

California Institute of Technology, Pasadena, Calif.
Manuscript Received by the Secretary of the Society May 7, 1940.
Balch Graduate School of the Geological Sciences, Contribution No. 296.

AUTHOR INDEX

SUBJECT INDEX