SEISMICITY OF THE EARTH

SEISMICITY OF THE EARTH AND ASSOCIATED PHENOMENA

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PREFACE TO SECOND EDITION

EXHAUSTION of the first edition presents an early opportunity for revision. To reduce costs, the original text and tables have been reproduced by offset, with a minimum of changes. New material has been supplied in the form of addenda, inserted following the text, References, and Tables 17, 18, and 19 of the original. Tables 14, 15, and 16 have been extended chronologically. Asterisks in the text indicate the presence of new material in the addenda; asterisks attached to a reference indicate that it also is an addendum; an asterisk added to the serial number of an earthquake indicates that it is in the addenda to the tables. Maps now include all shocks in the tables; the Ben Day screen for shading has been omitted.

In the section "Frequency and energy of earthquakes," Tables 4 and 6 have been extended through 1952; the remaining tables in this section are unchanged, since the new material will not significantly change the results. An incomplete list of large shocks for 1899-1903 appears as an addendum.

Most of the textual changes are concerned with revised ideas on the structure of the earth's crust, and the velocity distribution for seismic waves. The expression, "granitic layer," has been replaced to some extent; where it remains, the reader should not take "granitic" in too specific a sense.

All known errata in the first edition have been corrected; this includes some revision based on later information. Errata were mostly minor; the most likely to mislead was a misprinted longitude on page 135 for the large shock of February 1, 1938.

Pasadena, 1953

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INTRODUCTION

THE present work is intended: (1) to evaluate the present relative seismicity of various parts of the earth, and (2) to discuss the geography and the geological character of the zones and areas of seismic activity. This includes correlation with alignments of active volcanoes and gravity anomalies, and with oceanic deeps, mountain structures, and other topographic features. Mechanism is discussed, particularly with reference to crustal folding and block faulting.

This book supersedes two earlier publications (Gutenberg and Richter, 1941, 1945) and incorporates the results of two papers on the geography of deep-focus earthquakes (Gutenberg and Richter, 1938a, 1939a). There has been thorough correction and revision. Much new material has been added, including shocks of earlier date as well as those which have taken place since the previous papers were written. Certain technical details, referring chiefly to methods used in locating shocks and to the accuracy of the results, have not been repeated here. This does not imply rejection or modification of our previous judgment on these points.

Complete tables of all shocks investigated, segregated by regions, will be found in Tables 17 and 18 in the Appendix. A selection of data, appropriate for statistical discussion, is presented in Tables 13 to 16. These list large shocks in specified ranges of magnitude and depth; each list is fairly complete for the world in the period it covers. In addition, an attempt has been made to include all shocks of magnitude 6.0 to 6.9 from the beginning of 1932 through June 1935; magnitudes for most of these shocks are newly determined. Magnitudes for deep-focus earthquakes are assigned for the first time.

Except in the most recent literature, maps purporting to show the geographical distribution of earthquakes have been based at least in part on historical and macroseismic data. Historical data are in general available only for land areas, and are much influenced by the present and past distribution of culture. Maps based uncritically on instrumental data are likely to show a concentration of shocks where seismological stations are most numerous (as in Europe and Japan), and are exposed to gross errors of location, including those which arise when a deep shock has been taken to be shallow. Location and listing have always been comparatively incomplete for the southern hemisphere.

While reliable historical and macroseismic data have been considered in the textual discussion, the maps are based exclusively on revised instrumental data. Shocks have been distinguished carefully according to magnitude and focal depth. Where possible, errors in the source material have been corrected, and doubtful locations have been rejected.

The study is not geographically homogeneous. In each separate region detailed investigation of seismicity has been carried as far as the data warrant. In certain regions, especially where there are a number of good stations, this has led to a more complete coverage of the minor shocks than elsewhere, particularly (as in Europe) where large shocks are infrequent. In regions such as Japan, where the seismicity is high, many well-observed and accurately located smaller earthquakes have been omitted from the study, since they add nothing to the general information on seismicity and only crowd the maps and tables.

In the tabulations, times of all shocks are given in Greenwich Civil Time (Universal time). Where historical shocks are mentioned in the regional discussion, the date is usually according to local time which may differ by a day from the GCT date.

MATERIALS USED

FUNDAMENTAL data for instrumental location of earthquakes are times recorded at the various stations. The chief source is the *International Seismological Summary* (Turner *et al.*, 1923-1952) which now (Dec. 1952) covers shocks from the beginning of 1918 through 1941. It is a careful and accurate compilation of recorded times (but not amplitudes) from the individual bulletins of the stations, also including data otherwise unpublished. The *Summary* gives epicenters and origin times for each shock whenever the data appear sufficient; these results generally improve in number and quality from the earlier to the later years. This is due to an increase in the number of stations reporting, as well as to more accurate time-keeping which followed the establishment of radio time signalling. Otherwise, improvement reflects the progress of seismological science, and the effect of accumulated experience. An important contribution was made by Turner (1922, 1930), who discovered deep-focus earthquakes in the course of preparing the *International Summary*. With the year 1930 revised travel-time tables were brought into use; from this point the general accuracy of the *Summary* results is higher.

In the present publication no result has been accepted from the *International Summary* without careful examination and revision for epicenter, origin time and focal depth. Amplitudes reported by the stations have been applied to distinguish deep from shallow shocks; improved technique (Gutenberg, 1945a, p. 127) has developed this into a powerful criterion, and identification of shocks at intermediate depth is much more positive than in previous studies. However, assignment of numerical depths still depends on travel-time data. A number of small shocks, for which there is good evidence of deep focus, have been passed over because the time data were not adequate.

Epicenters have in general not been determined more closely than the nearest quarter degree of latitude and longitude except for unusually favorably situated shocks. More accurate revision would involve considering the effect of geocentric latitude, which may amount to as much as 0.4 degree in extreme cases (Gutenberg and Richter, 1933). The method used for revision has been described by Gutenberg and Richter (1936b, 1937). Travel times here used for *P* in shallow shocks are those given by Gutenberg and Richter (1934c, p. 82).

Origin times for recent shallow shocks given in the *International Summary* have usually been decreased by 5 or 6 seconds. Beginning with 1930 the Summary compilers have used tables (*Summary* for 1930, p. 10-18) with an arbitrary time zero 5 to 6 seconds later than the true origin time of the shock, very roughly coincident with the arrival of the first wave at the surface. This is not the case for deep-focus earthquakes. Data from atomic bomb tests show that the zero of the travel-time curves used for the present paper is accurate within the limits of error, estimated at about 2 seconds (Gutenberg and Richter, 1946).

Effective registration of distant earthquakes began on April 17, 1889, when an instrument at Potsdam wrote a record identified as that of a shock in Japan (Rebeur-Paschwitz, 1894, p. 436). The early instruments were very imperfect by present standards, and there were few observing stations; for years preceding 1904, despite the efforts of Milne and others, there are not even enough data to ensure reasonably complete cataloguing of the largest earthquakes. Milne (1912b, 1913) published epicenters for many shocks in the years 1904-1910 inclusive. Observed times have been taken from other sources. The principal compilations are by Rosenthal (1907) and Szirtes (1909a, 1910, 1912, 1913) for 1904-1908 inclusive with separate lists of small shocks (without epicentral determinations) and large shocks (epicenters and origin times worked out). For 1908 only part I, giving the small shocks, was published. For 1909 and 1910 Kurt Wegener (1912) has given determinations and some station data for a number of large shocks.

Epicenters for all the better-recorded shocks of 1913 were worked out by Turner (1917). For 1913, 1914, 1915, and 1917 he issued epicenters and time data in monthly bulletins of the British Association for the Advancement of Science. For 1916 Turner (1919) gave epicenters and times for the better-recorded shocks and incomplete information for others.

For all this earlier period, but especially for 1908-1912, it has been necessary to supplement the compiled material by reference to numerous individual station bulletins (see Table 1). Further information has been obtained by special correspondence.

Table 1 presents a conspectus (with some minor omissions) of data from individual station bulletins available at Pasadena for this investigation as of December 1952. One column is assigned to each year, 1904 to 1918. A capital letter indicates that the writers have had access to the complete data published or otherwise furnished by the station for the year; a small letter, that there are considerable gaps in the available files. A number of stations were equipped with small or insensitive instruments; a capital letter assigned to such a station may mean much less information for the year than a small letter for a better-equipped station.

Letters *A*, *a* indicate that the amplitudes of

TABLE 1

Time and amplitude data for 1904-1918 used in the present study.
(For symbols see text.)

Station	1904	05	06	07	08	09	10	11	12	13	14	15	16	17	18
Summaries	T	T	T	T	t					T	T	T	t	T	T
Alger												C	C	C	
Apia			A	A	A	A	A	A	A	A	t	t	t	t	t
Athens									B	B	B	B	B		
Baku							c			c	c				
Balboa Heights						x	x	x	x	x		C	C	C	C
Barcelona											d	D	D	D	D
Batavia						C	C	c	c	c			c	c	c
Belgrade								a			a				
Berkeley							c	C	C	C	C	C	C	C	C
Budapest			C	C	C	C	C	C	C	C	c				
Cartuja					c	C	C	C	C	C	A	A	a		
Catania					C	C	C	C							
Cheltenham						c	c	c	c	c		C	C	C	
De Bilt	t				a	A	A	A	A	A	C	C	C	C	C
Ekaterinburg										c	c				
Eskdalemuir												c	c		
Florence (Xim.)	B	b			c	c	c	c	c	c	c				
Frankfurt										c	c				
Georgetown												C	C	C	C
German Stations								t							
Göttingen	A	A	A	A	A	A	A	A	A	A	a				
Graz											a	a			A
Hamburg	C	C	C	C	B	B	B	B	B	C	C	c			
Hohenheim											A		A	A	A
Honolulu										c		C	C	C	C
Irkutsk								t	c	C	c				
Italian Stations									C						
Jena		a	A	A	A	A	A	A	A						
Jugenheim									a						
Ksara										D	D				
La Paz										a	A	A	A	A	A
Laibach				t	T	t									
Lick								c	C	C	C	C	C	C	C
Manila					C	C	C	C	C	C	C	C	C	C	C
Mileto						c	c	c							
Mizusawa						t	t	t							
North American Stations											c	C	C	C	C
Osaka	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Ottawa					a	c	c	c	d	d	d	T	T	T	T
Paris							C	B	B	C	C	C	C	C	
Pilar	X	X	X	X	X	X	X	X	X						
Pulkovo					c	C	C	C	c	C	c				
Riverview						a	A	A	A	A	A	A	a	A	A
San Fernando		X	X	X	X	X	X	X	X	X	X	C	C	C	C
Sitka		T				c	c	c	c			C	C	C	C
St. Louis							C	C	C	C	C	C	C	C	C
Stonyhurst								x	X	X	X	X	X	X	x
Strassburg	x	A	A	A	A	A	A	A	A	A	A	A	a		
Tacubaya						B	C	C	C						
Tiflis	C	C	C	C	C	C				C	C	C	c		
Tucson								c	c	c		C		C	C
Upsala	a	a	a	A	A	A	A	A	A	B	B	B	B	B	B
Vieques						c	c	c	c	c				C	C
Wien						A	A	A	A						
Zikawei			C	C	C	C	C	C	C	C	C	C	C	C	C

maxima are regularly reported, and those of *P, S*, etc., are given for most of the shocks; *B, b* that the amplitudes of maxima are usually given, with an occasional amplitude for *P, S*, etc.; *C, c* that amplitudes are frequently reported for maxima but not for other phases; *D, d* that an occasional amplitude is given; *T, t* that only time data are reported but that these are detailed and generally accurate; *X, x* that time data are approximate or very scant.

Collected data for "North American Stations" (Table 1) were published in the *Monthly Weather Review*, beginning with December 1914. Data for Tacubaya and auxiliary stations in Mexico are taken from successive issues of *Parergones del Instituto Geologico de Mexico*, Vols. 3-5 (1909-1913). Data for Italian stations for 1912 are from Cavasino (1934); those for German stations during the first quarter of 1912 are from *Gerlands Beiträge zur Geophysik*, Vol. 13, Kleine Mitteilungen, pp. 81-90 (1914).

Results for 1904 and 1905 depend heavily on the reports for Göttingen. These are extremely detailed, including not merely times and amplitudes but notes on the appearance of the seismograms which have been very valuable in identifying deep-focus earthquakes and in correcting misinterpretations in the work of compilers. A similarly detailed and useful report was that for Upsala, available from October 1904 to May 1905. These two stations supply practically the only data for magnitudes of deep shocks in 1904.

For nearly ten years the most useful station in South America was that first established at Córdoba, and moved in January 1905 to Pilar. This was equipped with a simple Milne instrument without damping, and rather insensitive; but the times are reliable.

Reports from Tiflis in the earlier years are of special value; amplitudes are usually given, and the data of the auxiliary stations Achalkalaki, Batum, Borshom, and Schemacha are occasionally helpful.

In 1931 the station Osaka published a bulletin covering the whole period from 1882 to 1929. Amplitudes are given regularly beginning with June 1901. The time is reliable beginning about 1905. The amplitude data are dependable, and very useful in assigning magnitudes to shallow shocks, although care in interpretation is demanded. Not rarely the amplitudes of *S* for deep shocks are given as those of maxima; these are then valuable for determining magnitudes.

For 1904, the times at all stations and the results derived from them are distinctly less dependable than those for 1905 and following years.

Bulletins from Upsala were resumed in July 1906, with considerable improvement in detail, and are among the most useful for subsequent periods. Reports from Apia are available beginning with 1906; this was the first good station (by later standards) in the southern hemisphere. During the following years there were improvements at Zikawei, Batavia, and Manila which are of much importance in studying shocks in the most active part of the world.

The Jena reports include, beginning with August 30, 1906, data from an exceptional vertical-component instrument (period about 6 sec., magnification about 2000) constructed by R. Straubel (Eppenstein, 1908). This provided records of a type not duplicated elsewhere for many years, and especially valuable for identifying and studying deep-focus earthquakes. The reports are very careful and detailed.

Data for the southern hemisphere were much improved by the establishment of the station at Riverview (near Sydney, Australia), beginning March 18, 1909. Father D. O'Connell has recently revised the readings, with special reference to deep-focus earthquakes (MS, and O'Connell, 1946).

A further improvement followed the installation at La Paz (Bolivia), with reports beginning May 1, 1913. La Paz at once became, and still remains, the most important single seismological station of the world. This is a consequence of its isolated location, the sensitive instruments, and the great care with which records were interpreted and reports issued under the direction of Father Descotes.

The first World War resulted in the discontinuing of some stations and the temporary suspension of others. During the later years of the war there was a notable falling off in the detail of reports. Reported times for these years are covered by the International Summary, which commences with 1918, and its predecessors. Data for amplitudes are comparatively scanty. For 1919 amplitudes of *P* and *S* are available regularly from Riverview; for 1919-1921 from La Paz, with less complete data from Zikawei, Berkeley and other American stations, Manila and Osaka. Amplitudes of maxima were published by a number of other stations. Beginning about 1922 there is a notable improvement in data for both times and amplitudes. Amplitudes of maxima are plentiful from 1922 to 1939.

The following is a partial list of other stations regularly reporting amplitudes of *P* and *S*: Cartuja, 1922-1924, 1929-1935; Toledo and other Spanish stations, 1924-1929; Sucre, 1926-1928; Tashkent, 1926-1927; La Plata, 1927-1935, 1940, 1945-date; Jena, 1928-1939; Göttingen, 1929-1937; various Japanese stations, 1930-1939; Perth, 1932-date; Belgrade, 1934-1939.

Beginning with 1942, data for times have had to be collected from various sources. The largest collections of times* with preliminary epicentral determinations, are (1) the *Bulletin of the Union Géodésique et Géophysique Internationale,* currently issued from the Bureau Central Séismologique at Strasbourg (temporarily at Clermont-Ferrand during the German occupation), (2) the preliminary bulletin of the Jesuit Seismological Association, currently issued from St. Louis, (3) the *Seismological Bulletin* of the United States Coast and Geodetic Survey, issued from Washington (available through 1944*; preliminary epicenter determinations, and manuscript data by special arrangement, current) giving readings for many stations in the United States as well as College and Sitka in Alaska, Honolulu, Bermuda, San Juan (Puerto Rico), Montezuma (Chile), Huancayo (Peru), and a few others. Other collections including amplitudes of maxima are: (4) the bulletin of the first-class stations of the Soviet Union (received up to August 1939; a preliminary bulletin was received for part of 1941 and a new series also including data for stations of the second class from June 1946 through July 1947)*; (5) the Indian stations, published by the India Weather Bureau (partly in MS), through 1950. There are several other important smaller groups of stations with current reports giving times and epicentral determinations, but not amplitudes, such as: (6) the New Zealand stations, issued from Wellington; (7) the Canadian stations, from Ottawa*; (8) the northern California group, from Berkeley (to 1951; preliminary data current); (9) the Lake Mead stations, together with Grand Coulee Dam and Shasta Dam, from Boulder City*; and (10) the Swiss stations, from Zürich.* Much use has been made of the station bulletin from De Bilt (Netherlands); the readings are carefully edited, and until 1940 data from other stations were reproduced with determinations of epicenters and origin times.

Most of the North American stations continued active through the second World War with very few interruptions or changes; current reports are generally available. For South America, current reports are received only from Bogotá, La Plata, and La Paz.* Readings for Rio de Janeiro are available through 1944. Huancayo reports important readings by telegraph to Washington. For information on Latin American stations see U.S. Coast and Geodetic Survey (1947).

Many gaps in data from Europe have been filled by receipt of delayed bulletins covering the war period. Fairly complete files, being extended by current reports, are at hand for the Spanish stations, Coimbra, Lisbon, the French stations, Stuttgart, Trieste, Bucharest, Istanbul, Uccle, and Upsala. Several European stations resumed with 1946.* Tiflis is available through September 1939. Ksara (Lebanon) and Tananarive (Madagascar) continue to report regularly. Helwan (Egypt) is available through 1951.

From 1940 to 1946 no data were received from Far Eastern stations. The station at Hong Kong was closed in 1940.* The station at Manila and its records were destroyed in 1945.* The instruments at Amboina and Medan were also destroyed, but those at Batavia continued to operate.* Bulletins for 1941 containing data for the last three were issued in 1947. Data for many Japanese stations down to 1946 for shocks in and near Japan are now available at Pasadena in manuscript, in the Japanese language *Journal of Seismology* (Vols. 1-13) and in the *Seismological Bulletin* of the Central Meteorological Observatory for 1938; monthly bulletins have been received beginning with May 1947.

Current bulletins continue from Apia, Brisbane, Perth, Riverview, and Wellington. Readings for a few important shocks have been supplied on request from Melbourne.

For determinations of epicenter, origin time, and magnitude, full use has been made of the original seismograms for Pasadena (with its auxiliary stations), and Huancayo (records filed at Pasadena). Original seismograms of the Tucson short-period vertical-component instrument have also been highly useful; these are regularly available at Pasadena by arrangement with the U.S. Coast and Geodetic Survey.

Up to the end of 1938 there are sufficient data for all the purposes of this study. For 1939, especially the later months, some important information is lacking. For the following years data rapidly become scantier. For the whole period amplitudes of *P* and *S* are available for the larger shocks as recorded at Perth (Australia), at La Paz through 1951 and for most shocks 1940-1951 at Riverview. Further valuable data have been provided by the Coast and Geodetic Survey; for April 1943 and later dates amplitudes at Bermuda and Honolulu have been included in the published bulletins. Amplitudes of maxima are available for Helwan through 1951, Uppsala through 1952, Sydney through 1944, and Spanish stations to date. The U.S.S.R. reports include amplitudes of maxima; recent reports from De Bilt and La Plata include amplitudes for *P, S* and maxima. It is to be hoped that in the future an increasing number of stations will report amplitudes (with corresponding periods) for *P, S,* and *PP*.*

Macroseismic data have been used to supplement instrumental results in the regional discussion. An important source is the catalogue by Milne (1912a). Sieberg (1932a, with many references) has been consulted throughout. Much valuable information with references has been taken from Montessus de Ballore (1906, 1907, 1924). The international summaries published from Strassburg (Oddone, 1907; Christensen and Ziemendorff, 1909; Scheu, 1911; Scheu and Lais, 1912; Sieberg, 1917) have been used. Data for 1944-1945 are given by Rothé (1946).* Numerous papers and short notes in the *Bulletin of the Seismological Society of America* have been consulted; only the most important of these are referred to in the bibliography. Press clippings have been used when the information seemed reliable; large collections of press reports have been issued from the station at Georgetown, printed and mimeographed under the title "Seismological Despatches." Notes and remarks in the various station bulletins have often been very helpful. This is particularly true for shocks in the region of the station itself. Other more regionally limited sources of macroseismic data will be referred to separately at the appropriate points. Only those consulted frequently are cited.

The checklist of active volcanoes given in the Appendix (Table 19) has been compiled from many sources by Mr. J. M. Nordquist. The principal source of general information has been the work of von Wolff (1929; 1930). Comparison has been made with the catalogue and map given by Kennedy and Richey (1947). Other sources, most of them applying to limited regions or to recent years only, include Anderson (1908), Brüggen (1947), Cloos (1936; 1942), De la Rüe (1937), Fisher (1939, 1940), Fujiwhara (1927), Jaggar (1945), Krijanovsky (1934), Milne (1884; 1886), Nielsen (1937), Neumayr (1920), Reck (1929-1936; 1935), Reck and Hantke (1935), Rittmann (1944), Rudolph (1887; 1895; 1898), Russell (1897), Sanchez (1944), Stehn (1927), and Tanakadate (1931-1939; 1937; 1940). The American Museum of Natural History provided a list of volcanoes active within the previous century which was formerly regularly reprinted in the *World Almanac*. This became obsolete and inaccurate; the writers are indebted to Dr. F. H. Pough for revised information.*

Scattered notes from scientific and popular publications have been employed; these are too numerous to be cited individually. Files of the *Geographical Journal* have been searched thoroughly. Information from the press has been used only when it seemed unusually reliable or could be verified elsewhere; as on the most important details press notices are often wholly misleading. Thus in 1932 it was generally reported that a whole group of South American volcanoes were in simultaneous eruption, while in fact there was eruption of only a single volcano, Quizapú (Bobillier, 1932).

Many references and some first-hand information have been obtained by correspondence; these are noticed under Acknowledgments.

General data on gravity are taken from Meinesz *et al.* (1934), Meinesz (1933; 1939), Heiskanen (1936; 1939a; 1939b), and Woollard (1949). References to papers covering individual regions will be introduced in the course of discussion. Whenever possible, isostatically reduced gravity anomalies have been used. These are considered large when approaching 100 milligals. Evans and Crompton (1946) have pointed out the importance of considering the geology in reducing gravity observations.

The principal sources for submarine contours are Vaughn *et al.* (1940), charts issued by the U.S. Hydrographic Office, and maps by the American Geographical Society.

Seismological data on crustal structure have been summarized by Gutenberg (1951b*).

The bibliography listing works to which reference is made is as complete as time, space, and library facilities permit. Many papers have been omitted as principally hypothetical or containing only minor items related to the present work.

METHODS USED

FOR all shocks epicenter, origin time, and depth were determined as previously described (Gutenberg and Richter, 1936b; 1937), using times at widely separated stations. Large shocks may be located fairly well with only a few stations in different azimuths; but most earthquakes require a better distribution of data. For example, the normal minimum requirement for locating a shock in South America is about five stations, including Pasadena, Berkeley, or Tucson, one good station in South America itself, one in eastern North America or the West Indies, and one in Europe. The greatest difficulty has always been experienced with locating shocks in far southern latitudes.

There are various causes of discrepancy between apparent epicenters found from macroseismic data and those determined instrumentally. Gross errors have occurred when concentration of population or works of construction in a small part of the shaken region has given an erroneous idea of the distribution of seismic intensity. Often the effect of ground is insufficiently considered; thus higher intensity in an alluviated valley may lead to a false epicenter. The distribution of intensity in deep focus shocks usually shows abnormal patterns not simply related to the location of the epicenter. On the other hand, even microseismic data from a number of stations are often not sufficient for an accurate location. Consequently, great caution is required, especially in regions where there are few local stations, in attempting detailed correlations between microseismic epicenters and geological structures.

Identification of deep shocks is sometimes difficult when the data are incomplete; but for well-observed shocks no such difficulty exists. The occurrence of shocks at all levels down to about 700 kilometers below the surface is established beyond reasonable doubt by concurrent lines of evidence. Any arguments to the contrary may be dismissed as special pleading.

Signs of great focal depth which present themselves in searching through catalogues and station bulletins are (1) difficulty in locating the shock and determining its origin time, supposing that it is shallow; (2) epicenter in an unusual region, or in a region where deep shocks are common; (3) surface waves reported as small at all stations (frequently *S* or *SS* is reported as the maximum of the seismogram); (4) an abundance of additional and usually unidentified readings, often accompanied by the suggestion that two or more shocks are superposed; (5) a distant earthquake mistaken for a local shock near the reporting station.

Accurate assignment of focal depth demands identifiable time observations of the reflected wave *pP*, or of such waves as *P′* and *SKS* which have passed through the core of the earth and consequently arrive as much as one minute earlier in deep shocks than in shallow shocks (Turner, 1922; Gutenberg and Richter, 1934a; 1934b; 1936b; 1937; Banerji, 1925; Berlage, 1924; Blake, 1937; 1941; Brunner, 1935; Byerly, 1925; Hayes, 1936a; Jeffreys, 1928; Miyamoto, 1933; Scrase, 1931; Stechschulte, 1932; Stoneley, 1931; Visser, 1936; Wadati, 1926-1928; 1931). Focal depth in the range 40 to 100 km. is often difficult to determine; in such cases extended use has been made of the relative amplitudes of surface and body waves, or more directly of the magnitudes determined from these (Gutenberg, 1945a, p. 127). In Tables 13, 14, and 17 omission of any remark as to depth does not exclude the possibility of a depth as much as 60 km.

The magnitude of an earthquake was originally defined (Richter, 1935), for shallow shocks in southern California, as the logarithm of the maximum trace amplitude expressed in thousandths of a millimeter with which the standard short-period torsion seismometer (period 0.8 sec., magnification 2800, damping nearly critical) would register that earthquake at an epicentral distance of 100 kilometers. Gutenberg and Richter (1936a) extended the scale to apply to shallow earthquakes occurring elsewhere and recorded on other types of instruments. The physical meaning of the scale was discussed, improvements were introduced, and a nomogram for its application (drafted by Mr. J. M. Nordquist) was presented by Gutenberg and Richter (1942). Revised tabu-