EARTHQUAKES IN THE ARCTIC AREA

By

Beno Gutenberg

Technical Assistant to Chief of Naval Operations
for Polar Projects
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There are two types of sources for information on earthquakes. The first consists of reports on the intensity and the extent of the shaken area of felt earthquakes; the second, of data from instrumental records. For the Arctic area the first gives relatively little information. The intensity of an earthquake is estimated from the observed damage and from changes found at the surface of the earth. Even in those instances where earthquakes have been felt in the Arctic area and have been reported by the observers, the information is rather scanty and, except for some regions in Alaska and on Iceland, is not sufficient for an accurate determination of the maximum intensity.

In the second method, the geographic coordinates and the depth at which the earthquake has started are determined by use of instrumental data from stations all over the world. Amplitudes of various types of waves can be used to determine the energy which was released in the earthquakes. For practical purposes, the magnitude of the shocks is calculated and given on a scale devised by Richter (20). Originally he defined the magnitude of an earthquake at average (shallow) depth 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 2,800, damping nearly critical) would register that earthquake at an epicentral distance of 100 kilometers. A magnitude $\underline{M} = 2$ corresponds in shallow earthquakes to a shock barely felt; a shock with $\underline{M} = 5$ causes minor damage; $\underline{M} = 7$ is the lower limit of major earthquakes; $\underline{M} = 8\frac{1}{2}$ is the maximum magnitude determined since 1904.

Gutenberg and Richter (10) 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 J. M. Nordquist) was presented by Gutenberg and Richter (9). Revised tabulations, with the addition of local corrections for the individual stations of the world, were given by Gutenberg (6). Magnitudes of shallow earthquakes were then correlated with amplitudes and periods of waves which had traveled through the interior of the earth, making these available for magnitude determination (5).

In shocks originating at a depth greater than about 30 kilometers, these latter phases alone are to be used for magnitude determination, since surface waves, such as were used for establishing magnitudes of shallow earthquakes, are small or nearly absent in deep shocks. A further definition was required; a deep shock is taken to have the same magnitude as a shallow shock releasing the same energy in elastic waves. The determination of energy requires calculation from the observed amplitudes and periods, involving assumptions as to the propagation of seismic energy in the interior of the earth. This leads to tabulations and charts (7) connecting amplitudes, periods, and focal depth with magnitude. These tabulations and charts constitute the practical definition of magnitude for deep-focus earthquakes.

Magnitudes for well-observed shocks are usually assigned to the tenth of a unit, with an error ordinarily not exceeding two-tenths. For the majority of shocks the magnitude is assigned to the nearest quarter unit.

The relation of magnitude M and energy E was discussed repeatedly; the equation used at present is:

$$\log E = 12 + 1.8M$$

The resulting value of log E may be in error by one unit or even more.

A detailed discussion of all large earthquakes since 1904 (when sufficient data from reliable instruments first became available) and many smaller shocks has been given in the book Seismicity of the Earth, by Gutenberg and Richter (8). The following discussion is based on the results which have been published in this book.

The seismic activity of the Arctic area belongs to two major earthquake belts. One of them is the circumpacific belt, the other the belt following the mid-Atlantic ridge and then passing by way of Iceland and across the Arctic basin toward Siberia. Figure 1 shows the part of the Pacific belt involved in the seismicity of the Arctic area; Figure 2 shows mainly the continuation of the Atlantic belt across the Arctic. In addition to the earthquakes connected with these two major belts, there is a number of usually smaller shocks, many of which are marginal to stable masses such as the Canadian Shield. Other relatively small shocks may be related to the uplift of land after removal of the Pleistocene ice load as, for example, in Scandinavia. Earthquakes in the neighborhood of the Bering Sea may be related to structural conditions off the coasts of the Bering Sea, since practically all the known shocks of this region are close to these coasts. Very small earthquakes may occur anywhere, and there is no region on earth which can be considered completely free of shocks.

The main seismological stations on which data concerning the seismicity of the Arctic area are based are those in northern Europe, especially the stations at Bergen, Norway, and Uppsala, Sweden; the Soviet stations, especially the station at Pulkovo, which was destroyed during the war, and the station at Sverdlovsk, near the Urals; stations in the northern part of Japan; the United States stations at College and Sitka in Alaska; Canadian stations at Saskatoon and Ottawa (with a number of subsidiary stations); the stations at Scoresby Sound and Ivigtut, Greenland, which are operated by the central station in Copenhagen, and the station in Reykjavik, Iceland.

Earthquakes are usually classified in three groups: shallow shocks at depths not exceeding 60 km. (normally about 20 km); shocks at intermediate depth between 60 and 300 km.; and finally very deep shocks with depths greater than 300 km. and a maximum observed depth of slightly in excess of 700 km. Shocks at depths greater than about 60 km. have been found thus far only in the circumpacific belt and the Alpid belt. Shocks at depths greater than 300 km. are known only in connection with the Pacific belt. There are no such shocks in the Arctic area proper, the nearest being southwest of Kamchatka; however, a number of shocks at intermediate depth have been located in Kamchatka and also to the north of the shallow belt which follows the Aleutians into the Alaska Peninsula. These shocks are marked by triangles on Figures 1 and 2. In general, such shocks occur approximately along the same lines as the active volcanoes. Lists of the larger shocks which have been located in the Arctic area since 1904 are given in the Seismicity of the Earth. They are listed there mainly under region numbers 1, 2, 40, and 42.

The Aleutian arc extends from the Commander Islands to central Alaska. In general, seismicity at shallow depth follows the northern concave side of the Aleutian Trench. Activity is lower in the area of the Commander Islands. Near the east end of the arc there is higher activity in the vicinity of Kenai Peninsula (near 150° W.). The arc as a whole is one of the more active sectors of the Pacific belt, although its seismicity is exceeded by those of Japan, Mexico, the Solomon Islands, and others. The largest shocks in the region of Kamchatka and the Aleutian arc are the following: several shocks on June 25, 1904, (near 52° N., 159° E.) off Kamchatka (21), two of which had magnitudes of about 8; shocks on August 17, 1906, (51° N., 179° E.) (22), magnitude about 8; and November 10, 1938, (55°30' N., 158 W.) (16), magnitude 8.3.

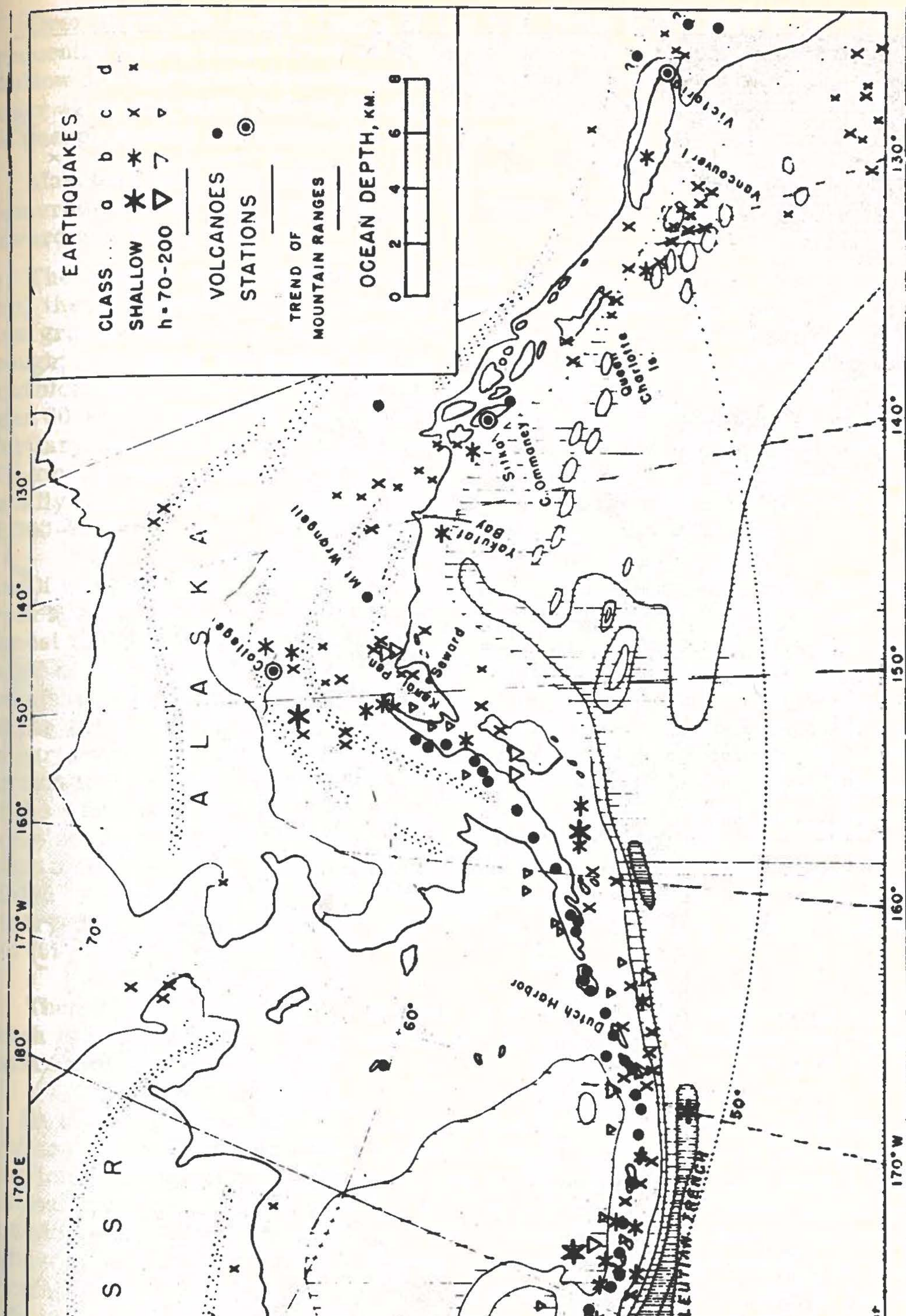

Figure 1
SEISMICITY OF THE NORTH PACIFIC AND ALASKA.

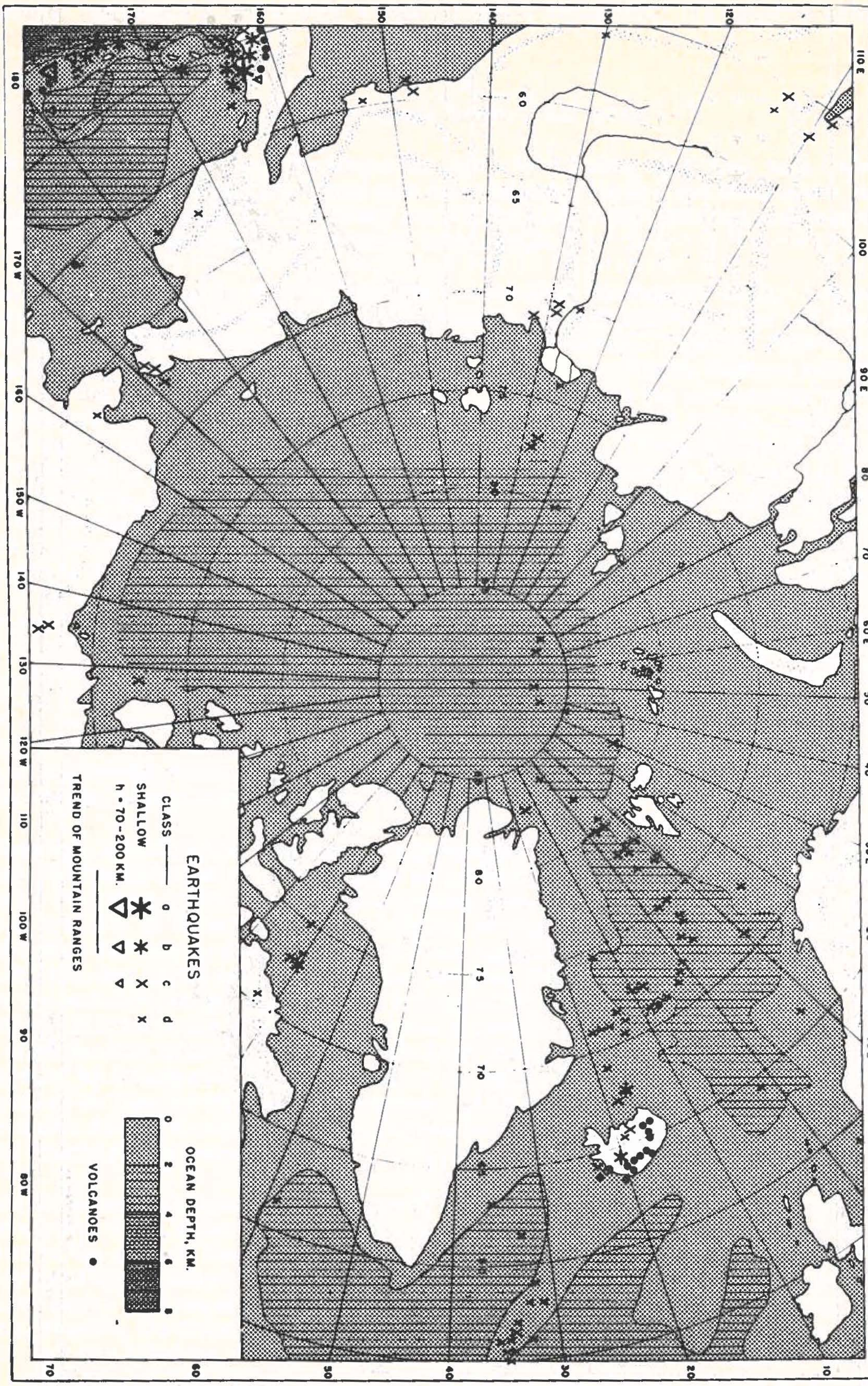

Figure 2
SEISMICITY OF THE ARCTIC SEA AND THE NORTH ATLANTIC OCEAN.

Over the whole active length of the arc, from about 175° E. to 145° W., shocks are frequently in the range from 50 to 80 km. in depth, which crosses the boundary between shallow and intermediate earthquakes. Intermediate shocks at depths from 100 to 170 km. occur along the north side of the island arc and the Alaska Peninsula from 176° to 160° W. No deeper shocks are known in this region.

Macroseismic data for most of the Aleutian arc consist of shocks felt on shipboard. Numerous shocks are reported felt at Dutch Harbor on Unalaska, and in the regions of Seward and Fairbanks.

The Pacific arcs show characteristic features. Starting from the convex side of the arc, there is usually: (1) an oceanic trench or foredeep; (2) shallow earthquakes and negative gravity anomalies, occurring in a narrow belt on the concave side of the submarine trough; frequently the ocean bottom here rises in a ridge, which may emerge into small nonvolcanic islands; (3) maximum of positive gravity anomalies; earthquakes at depths near 60 km., frequently large; (4) the principal structural arc, of Late Cretaceous or of Tertiary age, with active or recently extinct volcanoes; shocks at depths of the order of 100 km.; gravity anomalies decreasing; (5) a second structural arc; volcanism older and usually in a late stage; shocks at depths of 200-300 km.; and (6) a belt of shocks at depths of 300-700 km.

Of the characteristic Pacific arc features, (1) is the Aleutian Trench, which extends from about 170°E. south of the island arc and the Alaska Peninsula into the Gulf of Alaska almost to Yakutat Bay (17, with maps and profiles). Feature (2) is expressed in the occurrence of shallow earthquakes between the island arc and the Trench; it is more easily distinguishable from (3) and (4) at the east, where there is an outer chain of nonvolcanic islands off the Alaska Peninsula, accompanied by some shallow seismicity. Feature (3) is indicated by earthquakes at depths near 70 km.; it extends along the whole arc; in the main western portion it is closely limited between the belt of shallow earthquakes and the volcanic islands. At the eastern end, in the region of Kenai Peninsula and Cook Inlet, these shocks occur well to the southeast of the volcanic line. Feature (4) is this volcanic line, including the entire chain of the Aleutian Islands and extending up the coast of the Alaska Peninsula, accompanied by shocks at depths of 100 km. and deeper. Of these, the most westerly now known occurred on February 4, 1946, near 53° N., 176° W., at a depth of 150 km. Features (5) and (6) are not represented.

The shallow shocks in the interior of Alaska are connected with an interior structure which is related to the Pacific coastal arc as the Rocky Mountains are related to the Pacific coast ranges.

In the region of College, Alaska (Figure 1), the seismic belt turns to the southeast, crosses the coastal area to the north of Sitka, and continues off the coast toward the Queen Charlotte Islands, where the only known great shock (magnitude near 8) of this part of the belt occurred on August 22, 1949. This is not one of the Pacific active arcs, but a region in which block faulting is dominant. Though shearing may occur, the drowned topography indicates vertical displacement. This is confirmed by the evidence of the visible faulting accompanying the shocks of September 3 and September 10, 1899, in the region of Yakutat Bay; their magnitudes are of the order of 8-1/4 to 8-1/2, as derived from seismograms reproduced by Milne (15) and by Tarr and Martin (25). The latter from evidence of raised shore lines (observed in 1905) established uplifts along fault coasts reaching a maximum of 47 feet, which is the largest known displacement attributable to a single group of earthquakes.

Most of the remaining seismicity of the Arctic is concentrated in a belt which follows a northward continuation of the mid-Atlantic ridge (Figure 2). No intermediate or deep shocks have been found in the whole belt and large shallow shocks are rare; the only major earthquake (magnitude about 7) recorded since 1904 is that of January 22, 1910, at 67°30' N., 17°W. (north of Iceland).

The seismicity in the Arctic region north of Europe was first studied by Tams (24), who recognized this activity as an extension of the Atlantic belt into the polar region. He also published a separate discussion (23) of earthquakes in the region of the Nordenskiöld (Laptev) Sea (near the mouth of the Lena), but refrained from suggesting a direct connection between these and other Arctic shocks. Such a connection seems first to have been emphasized by Raiko and Linden (19) and by Mushketov (18). Their maps show epicenters in the Arctic which clearly fall along a continuous belt. This map has been reproduced by Heck (10a). In Figure 2 every adequately located shock from Spitsbergen to the Lena has been included; between Iceland and Spitsbergen only the better located shocks are shown.

Shocks have been reported felt on Spitsbergen and Jan Mayen. Iceland has a long history of destructive earthquakes.

The most important shocks which remain seem to be marginal to the Canadian Shield. Three groups of such shocks are known: to the southeast, in the region of the St. Lawrence River; to the northeast, in Baffin Bay; to the northwest, in the region of the mouth of the Mackenzie River.

The long-established station at Ottawa was later supplemented by auxiliary stations at Seven Falls and Shawinigan Falls, so that the southeastern group of shocks is well observed. These shocks are also recorded at stations in the northeastern United States. Many small shocks have been located in this area by the workers at Ottawa and by the Northeastern Seismological Association. The catalogue in the Seismicity of the Earth includes only those recorded at more distant stations. A great earthquake in 1663 was violent near Three Rivers (roughly 46°30' N., 72°30'W.; Lefebvre, 1928). The shocks of 1925 and 1935 had depths near 60 km.; the epicenter of the latter is well within the margin of the Canadian Shield.

The rather large shock (magnitude 7-1/2) off Newfoundland on November 18, 1929 (3, 11, 12), is an eastern member of the St. Lawrence group of shocks.

The northeastern marginal shocks, in Davis Strait and Baffin Bay, are more remote from the American stations, and are better recorded in Europe, within close range of the Greenland stations (Ivigtut and Scoresby Sound). The shock of November 20, 1944, (14, 19), of magnitude 7.3 is a good instance of a major earthquake in a region not previously considered active. Small shocks have often been felt on the west coast of Greenland (24) and Tertiary faulting has been found there (1, 13).

Three shocks of magnitude 6-1/2 to 6-3/4 (November 16, 1920, May 29 and June 5, 1940) are referred to the northwestern Mackenzie River group. The station at College (near Fairbanks, Alaska) now makes it more probable that shocks in this remote region will not be overlooked.

The area in the Arctic Sea, north of Alaska, is clearly nonseismic. The possibility has been considered that this is an area with structure similar to that in the Pacific basin.

Earthquakes in coastal areas occasionally produce tsunamis or tidal waves which are scarcely noticeable on the open waters, but may produce considerable damage if they arrive in shallow water, where their height increases rapidly.

The history of tsunamis originating in the Aleutian arc is necessarily short, since in most cases instrumental data are required to locate the corresponding earthquake. That of November 10, 1938, produced only a comparatively small wave, observed at Hilo, Hawaii, and recorded elsewhere on tide gages; but the smaller shock of April 1, 1946, gave rise to a great wave which was destructive at Hilo and rose to observable heights on distant coasts, as in California and Peru (4).

The Yakutat Bay earthquake of 1899, with the largest known vertical fault displacement (47 ft.) produced only a locally destructive wave. Little is known about tsunamis in the Arctic Sea.

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