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Seismic Regions of the South Island of New Zealand

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Abstract

The region of less frequent earthquakes that lies between the active Fiordland Region and the Main Seismic Region of New Zealand is separated from the Main Region at a north-west trending boundary that marks a sharp change in the amount and character of the activity. The boundary has no obvious geological expression, but continues the crest of the Lord Howe Rise. The southern boundary of this Central Seismic Region appears to continue the southern flank of the Rise. Maps of epicentres from 1940–64 and of earlier large earthquakes are given. Histograms are used to show the changes in frequency of earthquake occurrence with geographical position.

Introduction

It has become conventional to divide New Zealand seismicity into two parts, the Main Seismic Region, lying roughly between latitudes 36½°S and 43½°S, and the Fiordland Seismic Region, lying south of it and to the west of longitude 169½°E. Both these regions have earthquakes of both shallow and intermediate depth, and the Main Seismic Region has also some true deep-focus activity. Hamilton and Evison (1967) have classified these regions as active continental margins, the tectonic associations of the Main Region being with the Pacific Basin and those of the Fiordland Region with the Tasman Sea (Eiby, 1965).

Between these two regions is an area of lower seismicity, without foci at greater than normal depth (with a single possible exception). It does not seem to have been explicitly considered whether the earthquakes of this region constitute a distinct system with characteristics of its own, or whether they are merely scattered occurrences at the ill-defined boundaries of the major regions. The fact that this part of the country is traversed by the major Alpine Fault, geologically active in Recent time, makes the problem one of geophysical interest.

Existence of a Central Region

There are several reasons for considering that a distinct Central Seismic Region exists, possibly separable into an Alpine and a Canterbury Sub-region. Since 1940, there have been about 12 earthquakes with magnitudes of six and above in the Fiordland Region, and a similar number in the Main Region. All the Fiordland shocks have been to the west of 169½°E and south of 44°S, about 240km from any shocks of comparable size in the Main Region. If the shocks near Lake Coleridge

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are assigned to a newly defined Central Region, as will be here suggested, the distance between the main regions is over 300km.

In 1958, Eiby discussed the distribution of New Zealand earthquakes, and drew attention to the existence of several north-westerly "trend lines", roughly at right angles to the structural axis of the country. Although these lines are still thought to indicate major tectonic boundaries, it now appears unjustifiable to assert a necessary identity with faults. More recent data show the line through Cook Strait less clearly, but there can be no doubt of the marked change in the frequency of earthquake

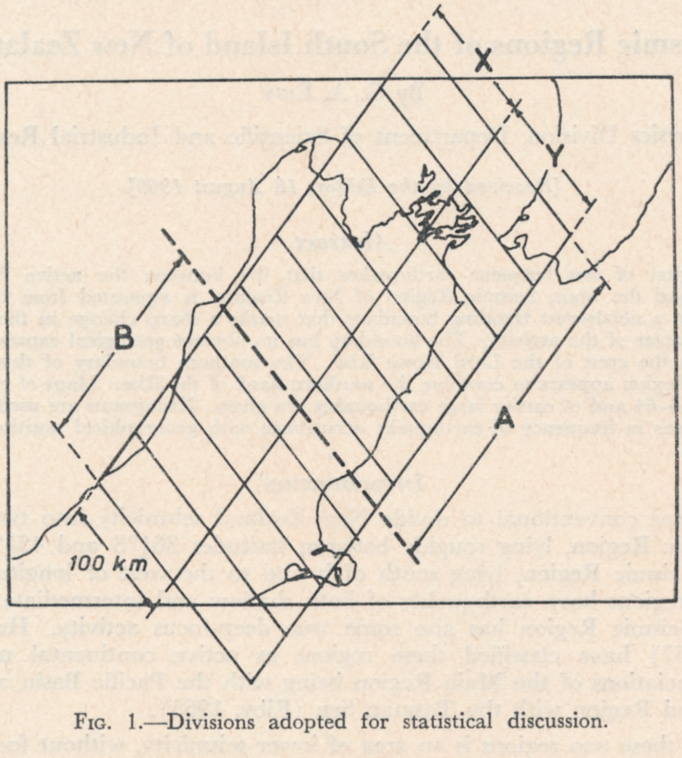

FIG. 1.—Divisions adopted for statistical discussion.

occurrence at the line that traverses the South Island from about Cape Foulwind to a little north of Banks Peninsula. This trend line probably represents the southern boundary of the Main Seismic Region. A map of well-located shallow earthquakes from 1940 to 1953, published but not discussed (Eiby, 1964, fig. 1) suggests that its position would be well approximated by a line through the points 42°S, 172°E, and 43°S, 173°E, shown by a prominent broken line in Fig. 1. It is the aim of this paper to define the position and properties of the boundary.

POSITION OF THE BOUNDARY

Figs. 2–6 show the epicentres of all shallow earthquakes of magnitude 4 and above for each five-year period from 1940-64 inclusive. The term "shallow" here includes all those shocks whose records show crustal pulses, and those that the data do not clearly show to have foci below the crust. Data have been taken from the annual *New Zealand Seismological Reports*. Fig. 7 shows the recording stations in the area, identified by their conventional three-letter codes, the major historical earthquakes, and those of magnitude 6 and above since 1940. The accuracy with which both positions and magnitudes could be determined has improved throughout the period, but there are not likely to be significant omissions.

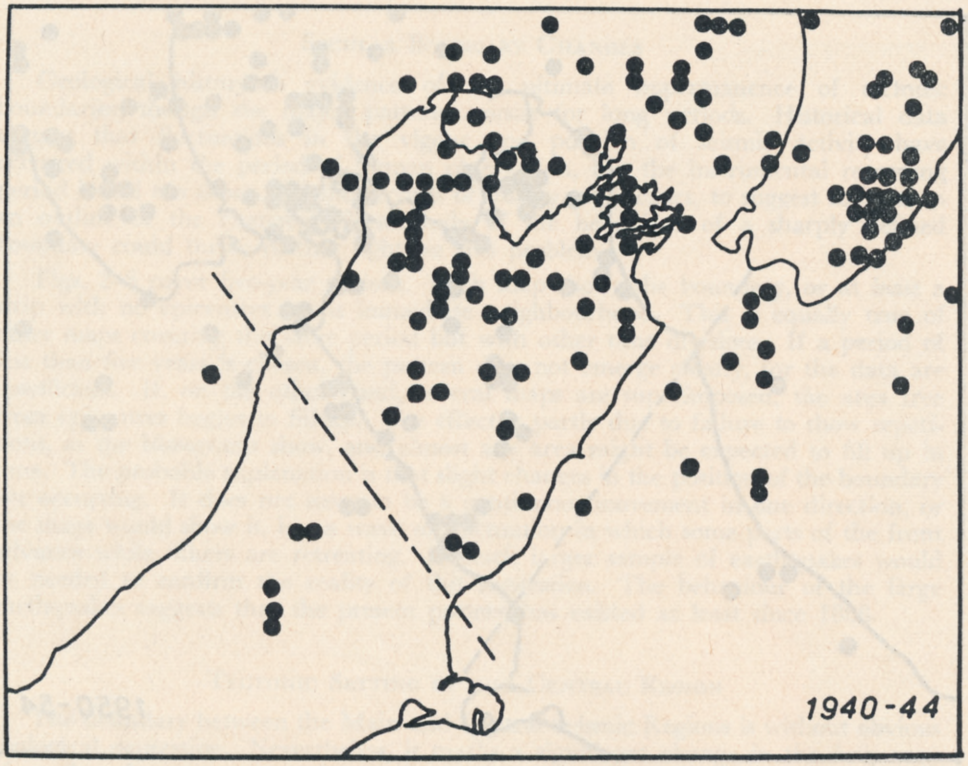

Fig. 2.—Shallow earthquakes, M ≥ 4, 1940-44.

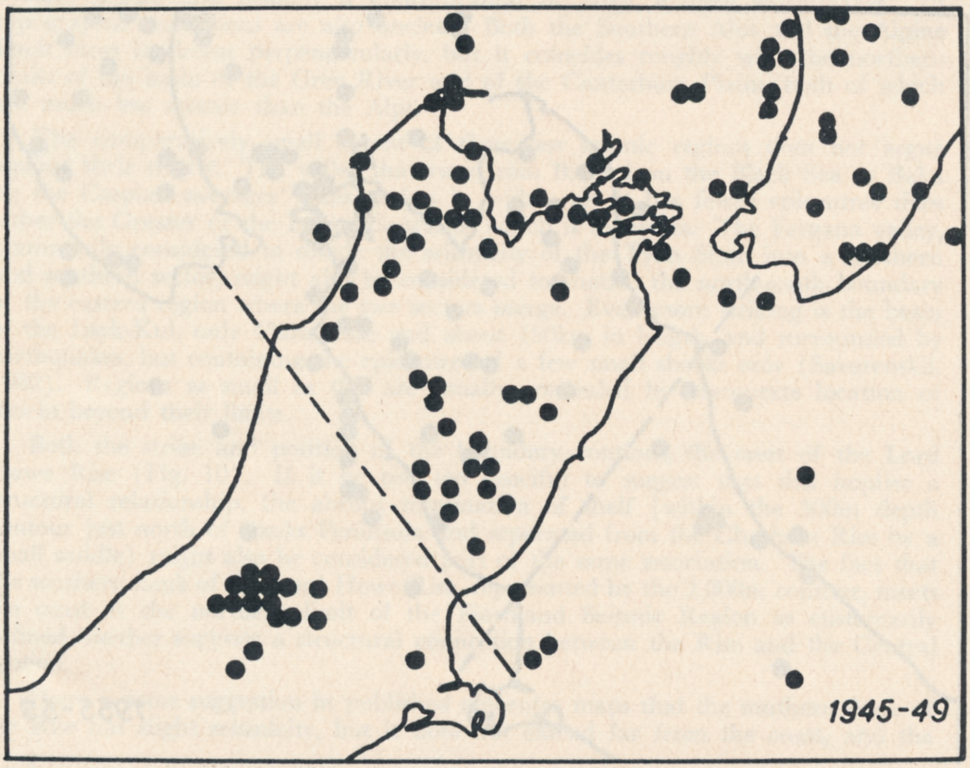

Fig. 3.—Shallow earthquakes, M ≥ 4, 1945-49.

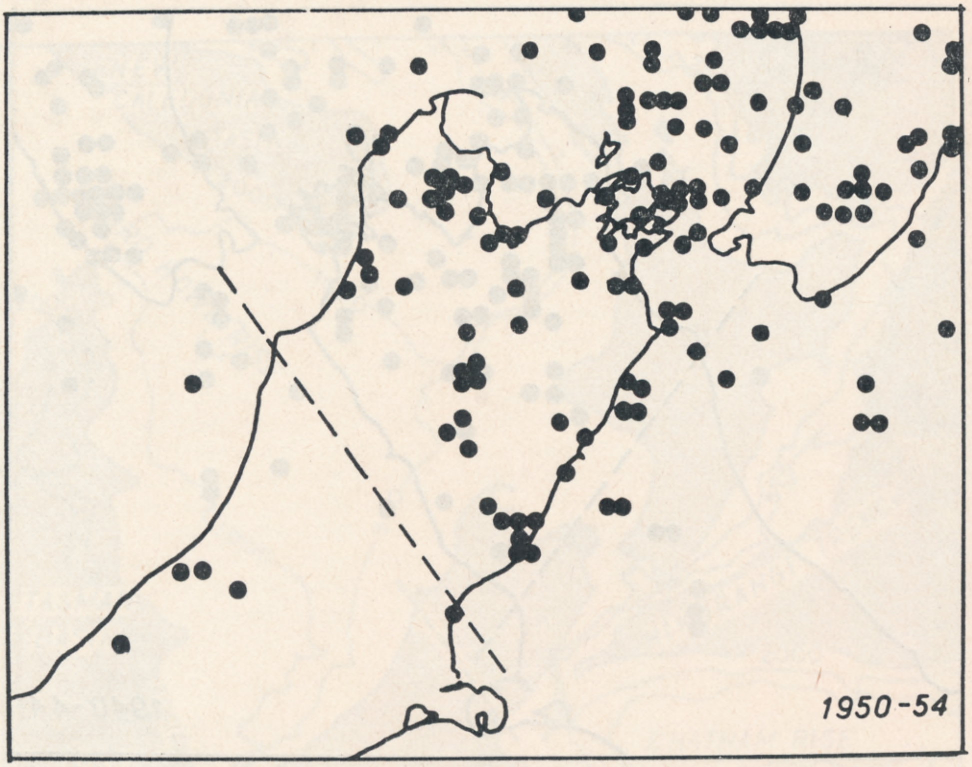

FIG. 4.—Shallow earthquakes, M ⩾ 4, 1950-54.

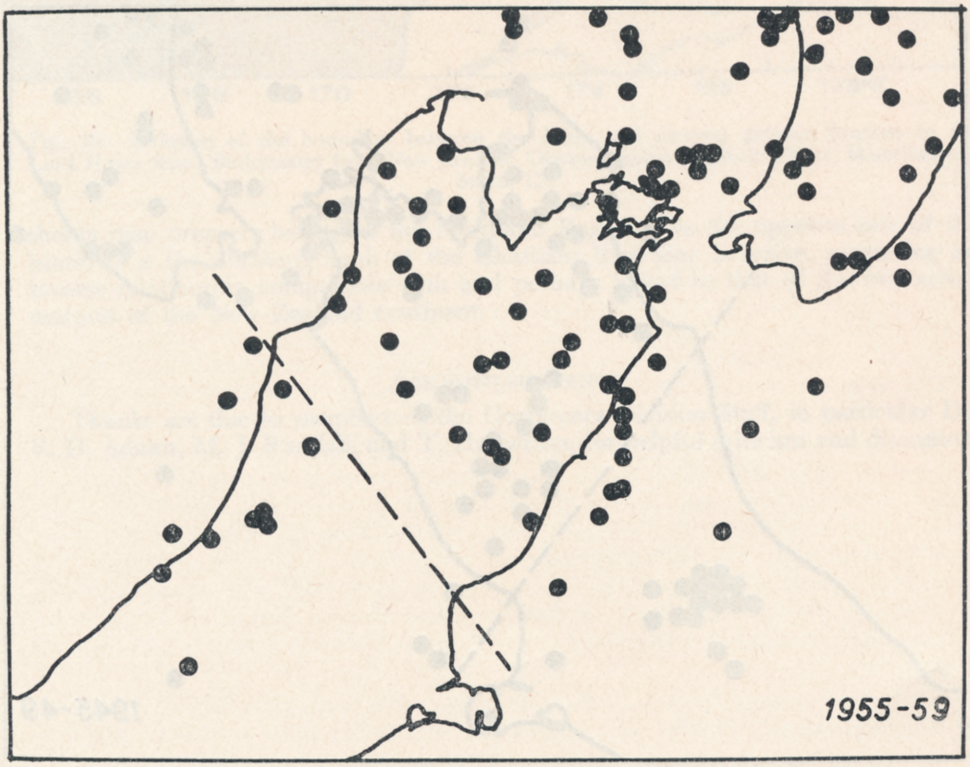

FIG. 5.—Shallow earthquakes, M ⩾ 4, 1955-59.

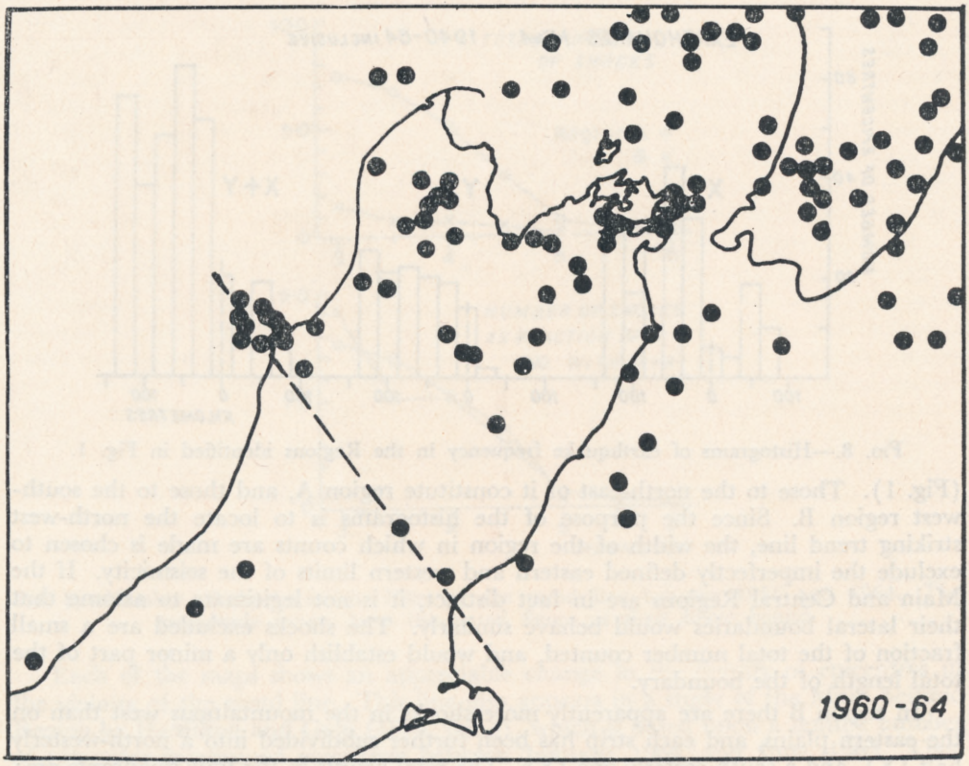

FIG. 6.—Shallow earthquakes, M ⩾ 4, 1960-64.

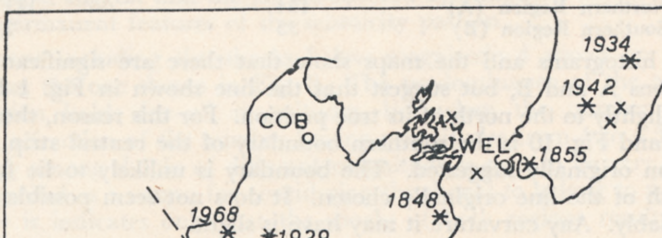

FIG. 7.—Seismograph stations. WEL, Wellington; COB, Cobb River; KAI, Kaimata; CHR, Christchurch; GPZ, Gebbies Pass. Earthquakes of magnitude 7 and above since 1848, shown with dates, and of magnitude 6 since 1940. The large circle below the 1929 earthquake is the epicentre assigned by the Dominion Observatory at the time.

Fig. 8 is a histogram showing counts of the epicentres lying in a series of 50km wide strips centred on the provisional position of the trend line already defined

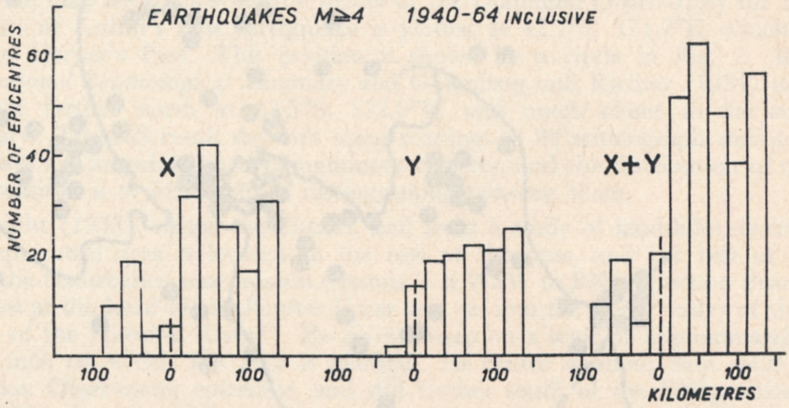

FIG. 8.—Histograms of earthquake frequency in the Regions identified in Fig. 1.

(Fig. 1). Those to the north-east of it constitute region A, and those to the south-west region B. Since the purpose of the histograms is to locate the north-west striking trend line, the width of the region in which counts are made is chosen to exclude the imperfectly defined eastern and western limits of the seismicity. If the Main and Central Regions are in fact distinct, it is not legitimate to assume that their lateral boundaries would behave similarly. The shocks excluded are a small fraction of the total number counted, and would establish only a minor part of the total length of the boundary.

In region B there are apparently more shocks in the mountainous west than on the eastern plains, and each strip has been further subdivided into a north-westerly half (X), and a south-easterly one (Y). The total counts in the four quadrants are:

	Western Region (X)	Eastern Region (Y)
Northern Region (A)	154	111
Southern Region (B)	33	2

Both the histograms and the maps show that there are significant differences between regions A and B, but suggest that the line shown in Fig. 1 has probably been drawn slightly to the north of its true position. For this reason, the line marked on Figs. 2–7 and Fig. 10 is the southern boundary of the central strip, 25km south of the position originally suggested. The boundary is unlikely to lie farther south, or to be north of the line originally chosen. It does not seem possible to adjust its trend appreciably. Any curvature it may have is slight.

Epicentre maps cannot show repetitions from a single focus. These do not greatly change the picture. Repetitions are more common after large shocks, and since these predominate in region A, they would emphasise rather than blur the differences. The number of epicentres in region A is at least four times that in region B, and the transition is sharp, the uncertainty in the position of the boundary being of the same order as that in the position of the poorer epicentres.

The status of the Westport earthquakes of May, 1962, perhaps calls for special remark, since they lie close to the boundary, but outside the area on which the histograms are based. It is possible to see some similarity in character between them and the earthquakes of the Lake Coleridge area, but their position makes it more likely that they belong to the Main Region, in which case the contrast in seismicity at the boundary is enhanced.

Fig. 9 shows a count of all shocks (including repetitions) within 75km of the boundary on either side, arranged in half-magnitude classes with their lower bound at the figure plotted. Since the number of earthquakes occurring increases greatly with fall in magnitude, it is clear that shocks below magnitude 4 are not all detected, but there is no reason to suspect regional bias in the coverage.

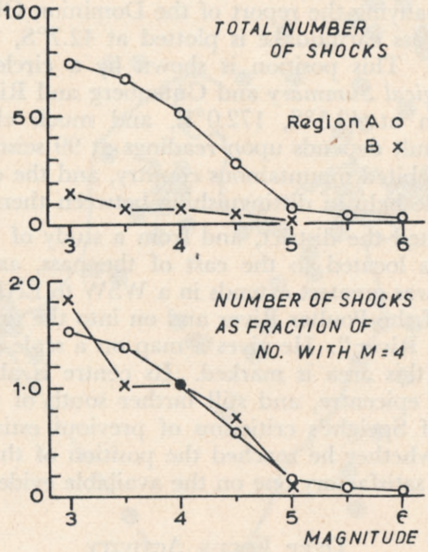

FIG. 9.—Number of shocks within 75km of the trend line between 1955 and 1964. The magnitude ranges have the stated figure as their lower bound.

Each of the maps shows an appreciable change in the density of epicentres in the vicinity of the trend line. This line also appears in a study of the Main Seismic Region by Hamilton and Gale (1968, fig. 3), which is based upon a limited number of computer-determined epicentres between January, 1964, and June, 1965. They are of high individual accuracy, but the differences between the separate figures in the present paper suggest that the period covered by Hamilton and Gale is too short to establish permanent features of the seismicity pattern.

A histogram including the shocks below magnitude 4 shows an even sharper boundary than the one shown in Fig. 8. The predominance of the activity in the northern region holds for all magnitudes, but when the number of shocks is expressed as a fraction of the number having magnitudes from 4 to 4.5 the distribution of energy among shocks of different magnitude is seen to be very similar. This might be regarded as a reason for considering the shocks to belong to a single region, but probably it indicates only that the shocks of both regions result from similar causes.

LARGE EARTHQUAKES

The belief that a tectonic boundary exists in this region is strengthened by the occurrence of several large earthquakes in the vicinity. The concentration of major shocks at the boundaries of seismic regions has been noticed elsewhere. For example, Koridalin *et al.* (1961, p. 158, translated from the Russian), discussing earthquakes in the U.S.S.R., state: " Another characteristic that was noticed almost everywhere is the location of the large earthquakes on the periphery of the zone of epicentres established by the small shocks."

In this part of the South Island shocks of magnitude 7 or more occurred in 1888, 1901, 1929, and 1968. The accepted epicentre of the so-called Arthur's Pass earthquake of 1929 lies to the south of the suggested boundary, but it is the most uncertain of the set. The felt area of the Cheviot earthquake of 1901 was well determined, and surface faulting at Glynn Wye makes the epicentre of the 1888 shock reasonably certain. For the Inangahua earthquake in 1968 excellent instrumental coverage was available.

In the map accompanying the report of the Dominion Observatory for 1929 the epicentre of Arthur's Pass earthquake is plotted at 42.7°S, 171.7°E, which is very close to Harper's Pass. This position is shown by a circle in Fig. 7. Both the *International Seismological Summary* and Gutenberg and Richter (1954) assign an epicentre farther north at 42.5°S, 172.0°E, and much closer to the suggested boundary. The ISS result depends upon readings at 99 seismograph stations. Both epicentres are in uninhabited mountainous country, and the distribution of reported felt intensities is of little help in distinguishing between them.

Speight (1933) visited the district, and from a study of landslides decided that " the epicentral area is located to the east of the pass, and the belt of country where the disturbance was greatest extends in a WSW to ENE direction through the branches at the head of the Poulter River and on into the upper valley of the south branch of the Hurunui River ". He gives a map on a scale of approximately 20km to the inch on which this area is marked. Its centre is about 8km *south* of the Dominion Observatory epicentre, and still farther south of the ISS position. This is surprising in view of Speight's criticisms of previous estimates as being too far south. It is not clear whether he reached the position of the ISS epicentre, which appears to be the most satisfactory one on the available evidence.

DEEP FOCUS ACTIVITY

The Central Seismic Region does not appear to contain any earthquakes with greater than normal focal depth, with the possible exception of a small shock on 1962 December 26. This was assigned an epicentre at 42.9°S, 171.4°E, and a focal depth of 70km. This depth depends greatly upon a single reading at the Kaimata station (KAI). Although the movement begins during a deflection time-mark, there is no obvious reason to question it. In view of the uncertainty of all depth determinations in this range, and the possibility of abnormally great crustal thickness beneath the Southern Alps, this is not shown beyond doubt to be an intermediate earthquake. Its magnitude was only 3.9, and it is at least 80km south of any other shock that has been assigned a depth greater than normal, until the intermediate depth activity of the Fiordland Region is reached, some 250km farther south.

POSSIBLE SUBDIVISION OF THE CENTRAL REGION

In view of the generally low seismicity of the Central Region, it may be premature to attempt further subdivision, but the counts of epicentres in the X and Y sections of region B emphasise the difference between the Alpine section and the Canterbury Plains. The broad association between high seismicity and mountainous terrain in many parts of the world has been developed by Soviet geophysicists into the concept of tectonic " contrast ". Earthquakes are considered to occur where the rate of deformation is greatest, regions of uplift being replaced by regions of subsidence within a short horizontal distance (Savarenskii and Kirnos, 1955, p. 40). The proposed subdivision would conform with this view. The plains are not inactive, but there have been few shocks approaching magnitude 4 in recent years, and earlier records of more widely felt earthquakes can be explained by epicentres in the active regions. A shock of magnitude 5, on 1968 January 24, with a provisional epicentre at 43.6°S, 172.5°E, is apparently within the Central Region.

Within the Alpine sub-region, there has been a noticeable concentration of shocks in the vicinity of Lake Coleridge, including the largest, of magnitude 6, on 1946 June 26. The intermittent character of the activity is very noticeable, periods of several years without even a minor shock being succeeded by numerous earthquakes within a few months. Shocks at the western margin of the Main Seismic Region, in the sea to the north of Mount Egmont, behave in a similar way, and this may be a reason for assigning shallow activity to the west of the Sub-Crustal Rift (Eiby, 1964) to a separate region.

SECULAR BOUNDARY CHANGES

Geological history is evidence of the ultimate impermanence of tectonic boundaries, though the major patterns persist for long periods. Historical data suggest that fluctuations in the vigour and position of seismic activity have occurred within the period of human observation, but the instrumental recording period is still too short, and the records of history too inexact, to suggest more than an outline of the changes. Close study of the behaviour of a sharply defined boundary could throw further light on this problem.

Figs. 2–6 cover five-year periods. Each map shows the boundary, or at least a strip with no epicentres in its immediate neighbourhood. This is equally true of other maps covering the same period but with other time divisions. If a period of less than five years is chosen, the pattern does not emerge clearly, for the data are insufficient. If, on the other hand, several maps are superimposed, the area free from epicentres begins to fill up. The effect is partly due to failure to show repetitions, as the histograms show, and almost any area might be expected to fill up in time. The probable explanation is that slight changes in the position of the boundary are occurring. It does not seem to be a continuous movement in one direction, or the maps would show it, but a wave or fluctuation in which some parts of the front advance while others are retreating. A much larger sample of earthquakes would be needed to confirm the reality of this suggestion. The behaviour of the large earthquakes suggests that the present pattern has existed at least since 1888.

TECTONIC SETTING OF THE CENTRAL REGION

The boundary between the Main and Central Seismic Regions is without obvious geological expression. Nevertheless, it marks a significant change in the frequency of earthquake occurrence, the southern limit of earthquakes with greater than normal depth, and possibly a concentration of large shallow earthquakes. Its topographic expressions are also unclear. Both the Southern Alps and the Alpine Fault cross it almost perpendicularly, but it coincides roughly with the northern limits of the basin of the Grey River and of the Canterbury Plains, both of which are much less seismic than the Alps.

The comparatively small extent of these less seismic regions does not argue against their reality. The valley that runs from Batumi on the Black Sea to Baku on the Caspian averages 40km or less in width, yet it has fewer epicentres than either the Greater or the Lesser Caucasus, which it separates. The Fergana valley, customarily considered to divide the seismicity of the Tyan Shan into a northern and southern sector, might also be considered to control the north-south boundary of the eastern region where the two sectors merge. Even more striking is the basin of the Issyk-Kul, only 45km wide and about 150km in length, and surrounded by earthquakes, but containing the epicentres of a few small shocks only (Savarenskii, 1962). Regions as small as this are usually concealed by inaccurate location of shocks beyond their limits.

Both the strike and position of the boundary continue the crest of the Lord Howe Rise (Fig. 10). If it be not too fanciful to suggest that this implies a structural relationship, the abrupt termination of shelf (within the 500m depth contour just north of Banks Peninsula and separated from the Chatham Rise by a small saddle) might also be considered part of the same association. The fact that the southern flank of the Lord Howe Rise, represented by the 2,000m contour, meets the coast at the northern limit of the Fiordland Seismic Region as customarily defined, further suggests a structural connection between the Rise and the Central Region.

There is some suggestion in published epicentre maps that the southern flank of the Rise has slight seismicity, but it does not extend far from the coast, and the

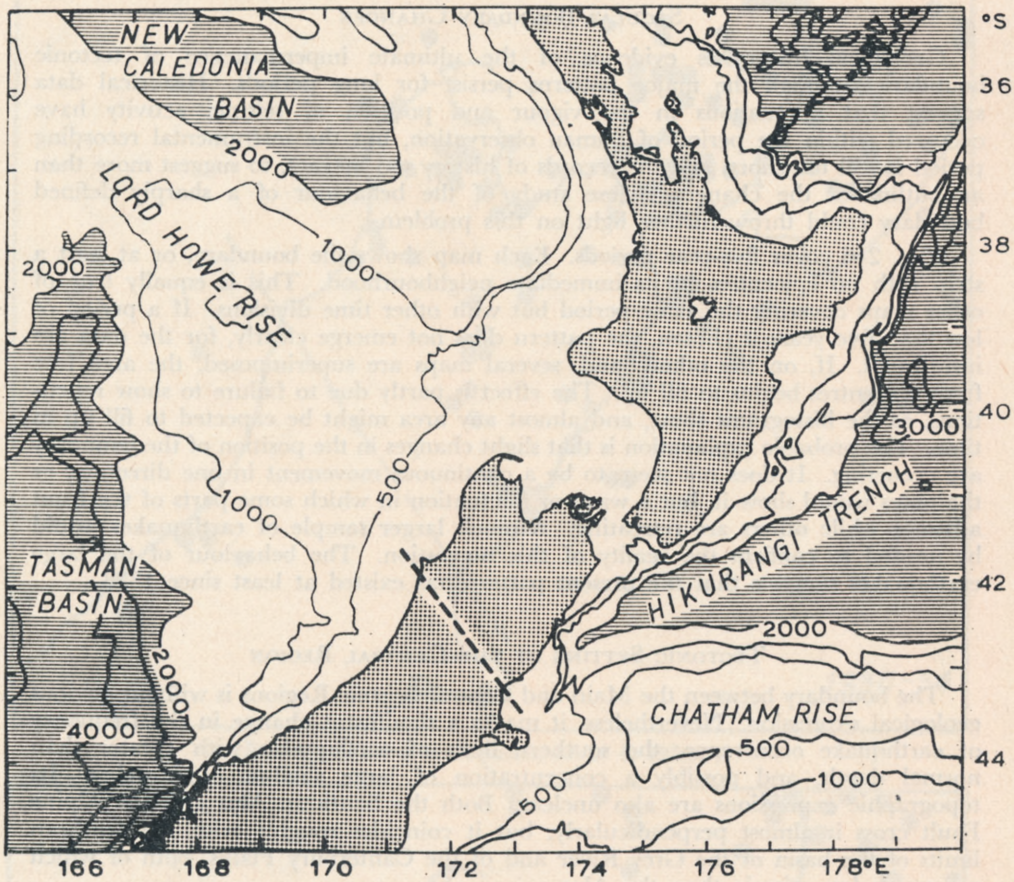

FIG. 10.—Relation of the boundary between the Main and Central Seismic Regions to the Lord Howe Rise. Bathymetry from New Zealand Oceanographic Institute Chart, Miscellaneous Series 15.

shocks may properly belong to the Fiordland Region. On the opposite side of the island it is the northern flank of the Chatham Rise that is active, suggesting an inverse relationship comparable with and perhaps linked to that of the two active margins of the New Zealand continent.

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REFERENCES

EIBY, G. A., 1958. The structure of New Zealand from seismic evidence. *Geol. Rdsch.* 47: 647–62.

——— 1964. The New Zealand Sub-Crustal Rift. *N.Z. Jl Geol. Geophys* 7: 109–33.

——— 1965. Notes on New Zealand seismicity. *Inf. Ser. Dep. scient. ind. Res.* 49: 12–6.

GUTENBERG, B.; RICHTER, C. F., 1954. *Seismicity of the Earth and Associated Phenomena* (2nd ed.). Princeton: University Press.

HAMILTON, R. M.; EVISON, F. F., 1967. Earthquakes at intermediate depths in south-west New Zealand. *N.Z. Jl Geol. Geophys.* 10: 1319–29.

HAMILTON, R. M.; GALE, A. W., 1968. Seismicity and structure of North Island, New Zealand. *J. geophys. Res.* 73: 3859–76.

KORIDALIN, E. A.; MASARSKII, S. I.; NERSESOV, I. L.; KHARIN, D. A., 1961. "Opit instrumental'novo izucheniya mestnikh zemletryasenii" *in* "Zemletryaseniya v SSSR" (Ed. Savarensky, Gubin, and Kharin). Moscow: Izdat. Akad. Nauk SSSR.

SAVARENSKII, E. F. (Ed.), 1962. "Atlas Zemletryasenii SSSR." Moscow: Izdat. Akad. Nauk SSSR, 368 pp.

SAVARENSKII, E. F.; KIRNOS, D. P., 1955. "Elementy Seismologii i Seismometrii." 2nd ed., 543 pp. Moscow: Gos. Iżdat. Tekh.-Teoret. Lit.

SPEIGHT, R., 1933. The Arthur's Pass earthquake of March 9, 1929. *N.Z. Jl Sci. Technol.* 15: 173–82.

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