A PRELIMINARY SEISMOLOGICAL REPORT

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Introduction

The Inangahua earthquake of 1968 May 23 (May 24, 5.24 a.m. local time) was the first New Zealand earthquake to reach magnitude 7 since that in Fiordland on 1960 May 24. (Unless otherwise stated all dates and times in this paper are expressed in Universal Time. To obtain New Zealand Standard Time add 12 h.) It became the sixteenth New Zealand earthquake believed to have reached magnitude 7 or greater since 1848, since when all such earthquakes should have been observed. Earthquakes of this magnitude, therefore, occur somewhere in New Zealand on an average of about once every eight years, and cannot be considered unusual events.

The epicentre of the Inangahua earthquake lies near the southern limit of the main seismic region of New Zealand, which covers the northern part of the South Island amd most of the North Island, the Northland peninsula being less active. To the south of the epicentre, in the waist of the South Island, a region of lower seismicity separates the main region from the highly active Fiordland region. It must be noted, however, that the less active region is traversed by the Alpine Fault which has been geologically active in recent times.

In the northern part of the South Island, this fault marks a boundary between two dominant structural trends. To the southeast, the major structures share the northeasterly strike of the fault, but to the northwest the dominant strike is more nearly north and south. There is no significant difference in seismicity on the two sides of the fault. Four known shocks of magnitude 7 and above lie to the southeast (Marlborough, 1848; Amuri Pass, 1888; Cheviot, 1901; and Arthur's Pass, 1929), and two (Buller, 1929; and Inangahua, 1969) lie to the northwest. Minor seismicity also appears unaffected by the change in geological structure.

The epicentre of the magnitude 7.6 Buller (or Murchison) earthquake of 1929 is approximately 25 km east of that of the Inangahua earthquake, and in 1962 there was a series of earthquakes about 40 km to the west, near Westport, with the largest having a magnitude of 5.9. There seems no reason to attribute special significance to this grouping of earthquakes, which can be paralleled in other parts of the country.

Main earthquake

The earthquake was recorded at all 23 stations of the New Zealand seismograph network, and phase-arrival times were obtained from all stations except Onerahi. As could be expected for an earthquake of such magnitude, at most stations overloading of the instruments prevented any phases after the initial P onset from being identified. The earthquake was extensively recorded overseas, and the preferred preliminary origin, based on readings at 60 stations, including 21 in the main islands of New Zealand, is as follows:

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Origin Time:	1968 May 23d 17h 24m 16.7±0.2s (U.T.)
Epicentre:	41.72°±0.03°S, 171.94°±0.02°E
Depth:	12 km (restrained)
Magnitude:	7.0 (M_L).

The epicentre is shown in Fig. 1 in relation to stations of the New Zealand seismograph network, and on a more detailed map in Fig. 2, from which it is seen to be about 15 km (9 miles) north of Inangahua. Although the formal standard errors of the epicentre are about 3 km, the true epicentre could be up to about 8 km from the position given because of uncertainties in knowledge of local seismic velocities.

The location of this earthquake has given added justification for the use of seismic velocities of 8.1 km/sec for P_n, and 4.7 km/sec for S_n in the New Zealand region, as suggested by Hamilton (1967), for their adoption allows excellent agreement to be obtained between origins determined by local and overseas stations. In the determination of the adopted origin, Hamilton's velocities have been used for paths to New Zealand stations, and the standard velocities of Jeffreys and Bullen (1958) for paths to stations overseas. The preliminary epicentre given by the U.S. Coast and Geodetic Survey (Earthquake Data Report, No. 31-68), using 54 stations of which only 12 were in New Zealand, is 6 km to the north of that given here, whereas that determined from New Zealand stations alone is less than 4 km to the south. Use of standard Jeffreys-Bullen velocities for New Zealand paths would displace the epicentre about 18 km to the east.

Focal depth

The depth of the focus below the surface of the earth, formally determined by the U.S.C.G.S., is 21±5 km, but as the nearest station is about 100 km from the epicentre, such a direct determination of focal depth in the crust cannot be considered particularly reliable. At Gisborne a later phase on the seismogram was identified as P_g, a phase which is excited only by earthquakes in the upper crust; on the Jeffreys-Bullen model of crustal structure it is conventional to assign a depth of 12 km to earthquakes exciting this phase. This depth is consistent with the felt effects observed for the main shock, and has been provisionally assumed as its depth. The depth of some of the larger aftershocks, determined with the aid of readings from additional close stations, does not differ greatly from this value. The stated origin time of 17h 24m 16.7s is consistent with a depth of 12 km and would require a small adjustment if some other conventional depth were adopted.

Magnitude

The only Wood-Anderson seismograph of the New Zealand network that was not grossly overloaded by the shock was that at Onerahi, which gave a magnitude of 7.0 on Richter's local magnitude scale (M_L). Estimates of magnitudes determined by overseas agencies vary widely. U.S.C.G.S. give a surface-wave magnitude of 7.1 determined from three stations, but a body-wave magnitude of only 6.1, determined from 10 stations with individual magnitudes ranging from 5.0 to 7.3. To be consistent with magnitudes quoted for other New Zealand earthquakes, the locally determined value of M_L, 7.0, will be adopted as the magnitude of the earthquake.

Direction of first motion

Of the 33 definite readings of the direction of initial motion already available, 28 are of compressions. Dilatations were reported only from the four Tasmanian stations, and from one of the five stations of the New Caledonian network. Of the definite compressions reported, 9 are from New Zealand and 6 from Antarctica. The remainder comprise readings from the southwest Pacific area, and three observations of the phase PKP. A fuller analysis of the first motion pattern will be deferred until more observations are available.

Aftershocks

For this preliminary study only the larger aftershocks in the first month after the main earthquake have been located. Table 1 gives the origins computed for these shocks, and is believed to include all aftershocks up to 23 June that attained a magnitude of 5. The magnitude of the smallest shock listed is 4.4, but many shocks of magnitude larger than this should be located in subsequent fuller analyses.

Two temporary stations, at Cape Foulwind and Denniston, were installed to aid in the location of aftershocks. The station at Foulwind was operating from May 24d 10h, and that at Denniston from 25d 10h, although satisfactory timing was not achieved there until 26d 04h. Both stations remained in operation until July 2.

These temporary stations allowed the aftershocks to be located with much greater precision than would otherwise have been possible. The region of aftershocks occurring before the installation of the temporary stations is not significantly different from the region of later shocks, indicating that positions determined using the permanent stations alone are not greatly in error. The earliest two aftershocks listed, within half an hour of the main shock, could not be assigned formal origins because of interference on the records from the main shock itself.

The epicentres of the 26 located aftershocks are shown in Fig. 2 with that of the main shock, and the positions of the temporary stations. The epicentres have standard errors of less than 5 km, except for those of the earliest four earthquakes, which are located with less precision. The aftershocks cover an area of about 45 km by 25 km, oriented in a NNE-SSW direction, with the main shock near its northern end. The largest aftershock, on May 24 at 20h 57m (magnitude 5.9), was also the most southern of those studied here, being 35 km to the southwest of the main shock and 25 km to the southwest of Inangahua, which is near the centre of the area of the aftershock activity.

The origins listed in Table 1 have all been computed with the focal depth restrained to 12 km, with P-wave velocities of 5.5 km/sec above this level, and 6.3 km/sec below. Readings at Denniston, which were available for the last 12 shocks, show that this depth is not greatly in error. All these 12 events were within 30 km of Denniston, and seven were closer than the assumed focal depth of 12 km. The arrival times of the closest seven events all have residuals of 0.5 sec or less, the mean residual being less than 0.1 sec. Depth variations corresponding to the extreme values of these residuals would be less than 3 km, limiting the extreme focal depths of the shocks to 9 and 15 km. S-P intervals recorded at Denniston for some of the smaller of these events range between 2 and 4 sec, giving added confirmation of the shallow depth.

Readings from Foulwind were used in the location of the last 18 of the listed shocks, which range in epicentral distance from 20 to 50 km from this station. Because of its greater distance, arrival times recorded at Foulwind are not as sensitive as at Denniston to variations in focal depth, but again the mean time-residual obtained by assuming all foci to lie at a depth of 12 km is small, having a value of -0.1 ± 1.0 sec. The arrival from the most distant earthquake was 2.5 sec early, and all others were between 1.4 sec late and 1.8 sec early.

In considering the significance of the small residuals recorded at the near stations, it must be noted that the standard error of the residuals of all readings used in the determination of each origin is in general between 1 and 2 sec, and the standard error of the origin time between 0.2 and 0.6 sec. Although no direction determination of focal depth has been made for these aftershocks, observations made at the close stations show that their depths cannot differ by more than a few kilometers from the assigned value of 12 km. If later studies of smaller aftershocks confirm the volume of aftershock occurrence already established, this would appear to be in the form of a plate some 30 to 40 km in horizontal extent, but considerably less thick.

A preliminary analysis of the magnitude-frequency relationship of 68 earthquakes of magnitude 4 and greater, occurring up to June 11, gives a value of about 0.9 for the parameter b in the expected relationship $\log N(M) = a - bM$, where $N(M)$ is the number of shocks of magnitude N or greater. This value is in accord with those found for other earthquake sequences both in New Zealand and overseas.

Macroseismic observations

The macroseismic effects of the Inangahua earthquake were pronounced and widespread. In the immediate vicinity of the epicentre few structures were undamaged; chimneys were damaged and destroyed at distances of more than 150 km, and all of the country with the exception of northeasterly parts of the North Island and southeastern Otago experienced intensities of at least MM IV. Because the shock occurred at 5.24 a.m. local time, when most people were sleeping, lower intensities were observed in only a few cases. The earthquake resulted in three deaths, and injuries to 14 people. More than 10,000 insurance claims have been lodged with the Earthquake and War Damage Commission, who estimate that the cost of repairs to insured property could exceed NZ$2,000,00.

Fig. 3 shows the generalised isoseismal pattern, and Fig. 4 the details of the pattern in the region of high intensities. The information on which they are based was gathered in several ways. In the outer parts of the felt area reports by regular observers entered upon the Seismological Observatory's standard reporting form predominate. There were over 100 of these. Officers of the New Zealand Geological Survey who visited the damaged area collected another 110 reports, also on the standard forms. All of these, together with press reports, many of which are authenticated by clear photographs, and some private correspondence have been assessed at the Observatory in a uniform manner, in terms of the 1965 New Zealand version of the Modified Mercalli Scale (Eiby, 1966).

The maximum intensities reported are close to Inangahua, some 15 km south of the epicentre. Large landslides (one of them responsible for two deaths and another temporarily blocking the river), serious damage to wooden structures including houses and bridges, bending of railway lines, breaking of underground pipes, slumping and cracking of roads, and ejection of groundwater clearly establish an intensity of MM X. Some of the heaviest damage would possibly justify a rating of MM XI, but it is impossible to be certain how typical this is and over what area it extends. The MM X isoseismal clearly includes the Buller Gorge between Inangahua and Berlins, and presumably the epicentre; but this lies in mountainous country from which observations are lacking.

There are several observations of MM IX in the vicinity of Reefton, and about Te Kuha near the western end of the Buller Gorge, where the formation of earthquake fountains and mud craters was among the reported effects. In Westport also there are observations of MM IX and one of MM X. These are based upon damage to buildings and to the sewerage, water and gas reticulation, but since they appear to be associated with localised areas of bad ground, and most observations are classified as MM VIII, it has been decided to draw the MM IX isoseismal between Westport and Te Kuha. The observations of MM VIII at Sergeant's Hill, Waimangaroa, and Denniston apparently support this decision.

The MM IX isoseismal has been drawn to include Denniston because of better agreement with the overall pattern and the fact that the settlement lies on sound rock with less than the normal proportion of bad ground. To the north and east the isoseismal is poorly determined, the only control being a report from a camper in the Upper Buller who was in danger from serious rock-falls. This isoseismal marks the approximate boundary of the aftershock epicentres shown in Fig. 2.

It is clear that the MM VIII isoseismal must exclude coastal localities between Cape Foulwind and Greymouth, all of which report MM VII. In Greymouth itself, there are a number of reports of MM VIII lying roughly along the boundary between the coastal sands and gravels and the inland hills. Domestic chimneys and older buildings in this area were damaged. Elsewhere in the town MM VII is most often reported. Brunner also lies outside the MM VIII isoseismal, but Blackball and Nelson's Creek are within it. To the north, it passes between Westport and Cape Foulwind, and between Seddonville and Karamea. The road between these places was blocked by slips for some days, but the intensity in Karamea itself was MM VII. To the east, the exact position of the isoseismal again becomes harder to determine. It certainly passes close to Murchison, where there was distortion of wooden buildings, chimney damage, and other effects typical of MM VIII, and to the west of Burnbrae, Maruia, and Springs Junction; but the only control between these places and the Grey River is provided by the pattern of lower intensities to the east.

Beyond the area of damaging intensity, the isoseismals can be established by more evenly spread observations. The narrow strip of MM VII on the west coast extends southwards to Hokitika, where MM VIII was also reported from the poorer ground. Substantial displacement of goods from shelves and minor damage to plaster establish MM VI in Nelson city, in Takaka and Riwaka, and in the foothills west of North Canterbury. There is a pocket of slightly lower intensity south of Golden Bay and an isolated instance of MM VIII in Collingwood.

The MM V area includes the glaciers of south Westland but does not extend as far south as Haast. Banks Peninsula, the Marlborough Sounds, the central and western parts of greater Wellington, and most of Taranaki also report MMV. Most of the rest of the country is covered with observations of MM IV, though the earthquake seems to have been felt only by favourably-placed people in Invercargill. The shock was not reported from northern Hawkes Bay, the Rotorua, Bay of Plenty, and Coromandel districts, and the eastern side of the Northland Peninsula. On the western side of the Peninsula, however, intensities appear abnormally high. There are three independent reports of MM V near Dargaville, and the shock was strongly felt and cracked a window-pane of a well-built bungalow only half a mile from North Cape. Apart from this significant northward extension of MM IV and perhaps the MM V isoseismal, the only feature of the pattern calling for comment is that the commonly observed elliptical form of the isoseismals is present, the major axis lying in a northeast to southwest direction.

Within most larger settlements, the effect of local ground conditions upon intensity is apparent, the range of reported intensities usually being about three scale degrees. Although these variations are related to subsoil conditions, they do not correlate simply with the material apparent at the surface, for thickness and consolidation play an important part. In some cases, the boundaries between areas of different character are marked by higher intensities than those on either side.

Several observers report the unusual behaviour of animals. Two of them, one at Inangahua and the other near Oweka, claim to have been awakened at 5.15 a.m. by cattle and sheep noises. The absence of any small foreshock on the Kaimata seismograph makes it unlikely that an earthquake was responsible. The Oweka observer also reports a flash of light beyond the Buller River in a northerly direction, which is that of the epicentre. A vivid flash of blue light in the sky is also reported from Greymouth, but is attributed by the observer to arcing power-lines. This is a less likely explanation of the flash seen at Oweka.

Reference has already been made to mud fountains and craters. It was noticed that water in the rivers became dirty, and that the ponds in old mining dredge workings were muddied. An artesian spring appeared beneath a cow-shed at Inangahua, with a flow estimated by the owner as "many thousand gallons an hour".

Effects underground in mines do not seem to have been very marked or alarming, the small falls of loose coal and timber framing reported from the Dauntless Mine being typical. It does appear, however, that a few examples of subsidence should be attributed to the failure of old workings close to the surface.

It is of interest to note that the motion in the epicentral region is usually described as instantaneous and upwards, though one Inangahua observer describes it as "horizontal, with vertical movements in the peaks". Observers do not report being thrown over, but at slightly greater epicentral distances they had time to rise and were then thrown, presumably by th S-wave.

Conclusion

From the seismological point of view, the Inangahua earthquake has produced effects typical of those expected from a shallow earthquake of magnitude 7. The earthquake has, however, been located with a greater precision than any other New Zealand earthquake of similar magnitude, and further studies of overseas seismograph records may enable its focal depth to be established with more certainty. Similarly, the spread of aftershocks is well established, and their focal depths determined with more than usual accuracy. Further seismological studies remain to be carried out on the location of smaller aftershocks, the time-dependent properties of the aftershock sequence, and the pattern of radiation from the source of the main earthquake. The correlation of this seismological information with observations of ground deformation being collected by the New Zealand Geological Survey should be particularly fruitful.

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Table 1

Preliminary origins of some of the larger aftershocks of the Inangahua earthquake, with focal depths assumed to be 12 km. This list should contain all shocks of magnitude 5 or greater occurring before June 23.

Origin Time d	h m s	Latitude (deg S)	Longitude (deg E)	Magnitude
May 23	17 33			5+
	17 43			5+
	17 45 41.5	41.77	171.88	5.0
	17 50 11.8	41.97	171.73	5.2
	18 44 33.6	41.68	171.94	4.8
	20 04 14.4	41.77	171.90	4.8
	21 09 50.9	41.64	171.88	4.8
	22 36 18.1	41.92	172.00	4.7
	23 03 25.5	41.77	171.95	5.0
24	07 22 46.8	41.85	172.04	5.1
	10 24 11.0	41.72	172.12	4.7
	17 40 53.8	41.87	171.90	5.7
	20 57 27.6	42.01	171.82	5.9
25	02 10 58.2	41.97	171.85	5.0
	11 18 13.9	41.79	171.79	5.2
	23 49 15.9	41.92	171.81	5.6
26	20 37 37.7	41.69	171.91	4.9
29	06 09 07.4	41.71	171.94	4.9
30	04 24 57.3	41.84	171.82	5.3
Jun 02	11 56 43.2	41.69	171.83	5.1
05	12 43 18.1	41.82	171.87	5.4
09	19 06 33.7	41.92	171.93	4.9
14	19 03 27.2	41.80	171.98	5.5
15	12 10 54.0	41.97	171.80	4.8
16	05 58 34.8	41.95	171.71	4.9
	17 25 33.4	41.81	171.90	4.4
18	13 56 28.2	41.80	171.84	4.6
20	03 08 04.6	42.00	171.76	4.7

References

EIBY, G.A. 1966: The Modified Mercalli Scale of Earthquake Intensity and its Use in New Zealand. N.Z.J. Geol.Geophys. 9: 122-9

HAMILTON, R.M. 1967: The Fiordland Earthquake Sequence of 1960 and Seismic Velocities Beneath New Zealand. N.Z.J.Geol.Geophys. 9 : 224-38.

JEFFREYS, H.: BULLEN, K.E. 1958: "Seismological Tables". British Association, London.

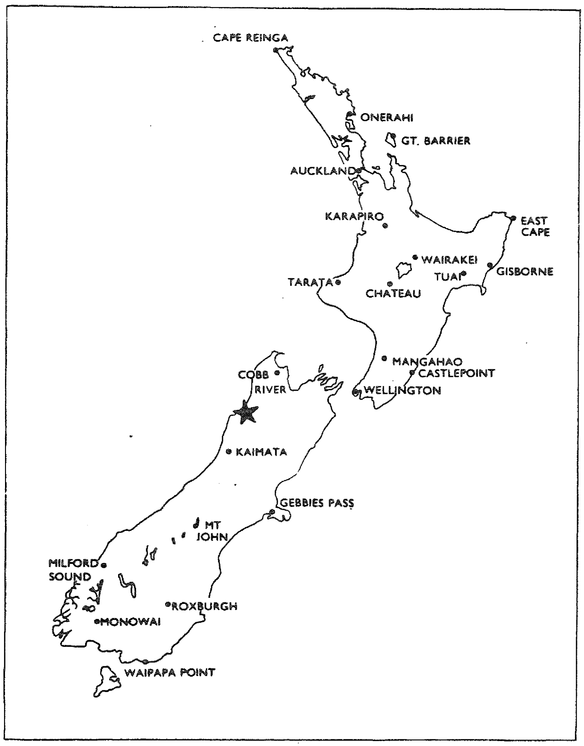

Fig. 1 Seismograph stations operating in New Zealand at the time of the Inangahua earthquake. Epicentre of earthquake shown by star.

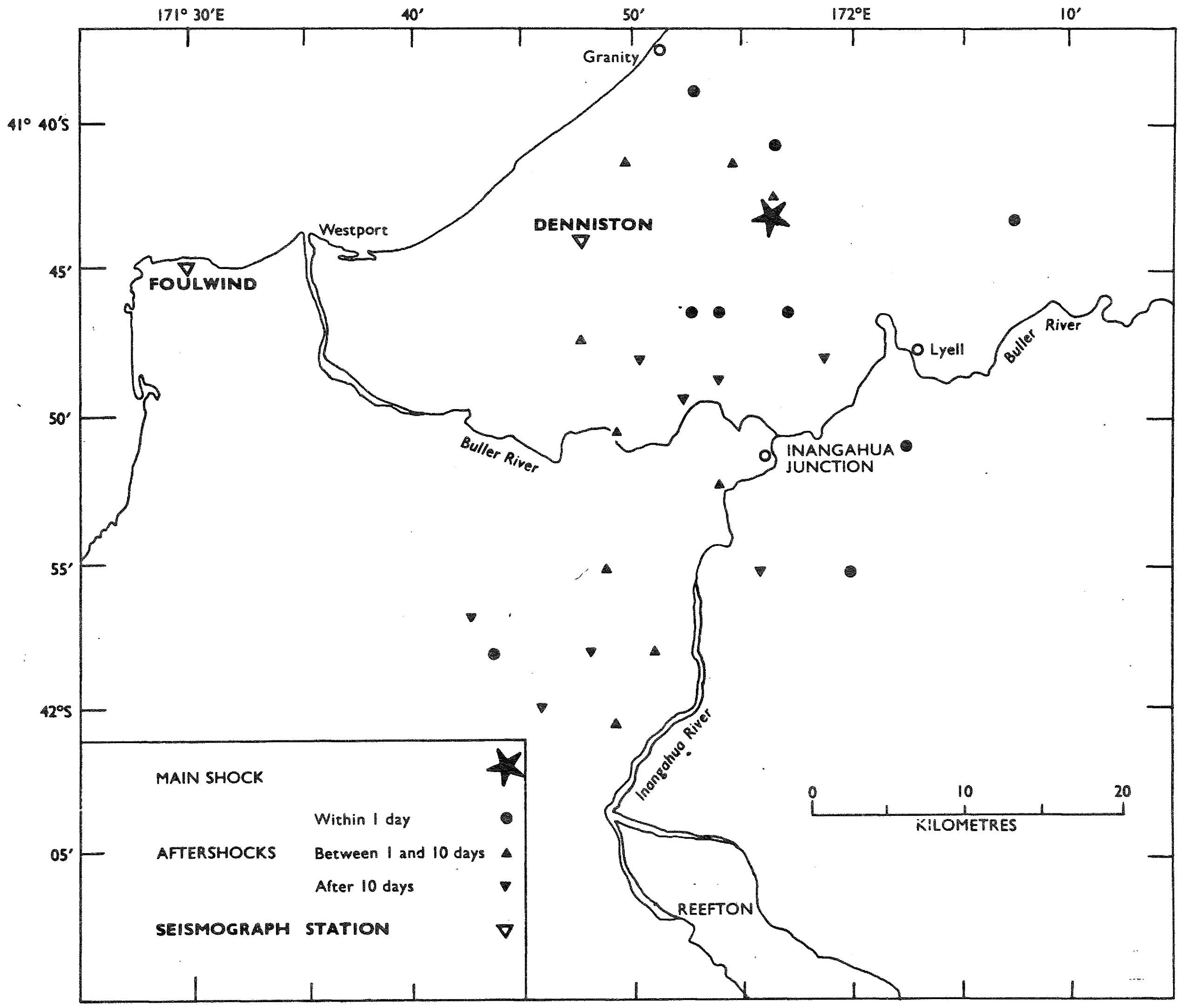

Fig. 2 Epicentral region of Inangahua earthquake, showing positions of main shock, selected aftershocks and temporary seismograph stations.

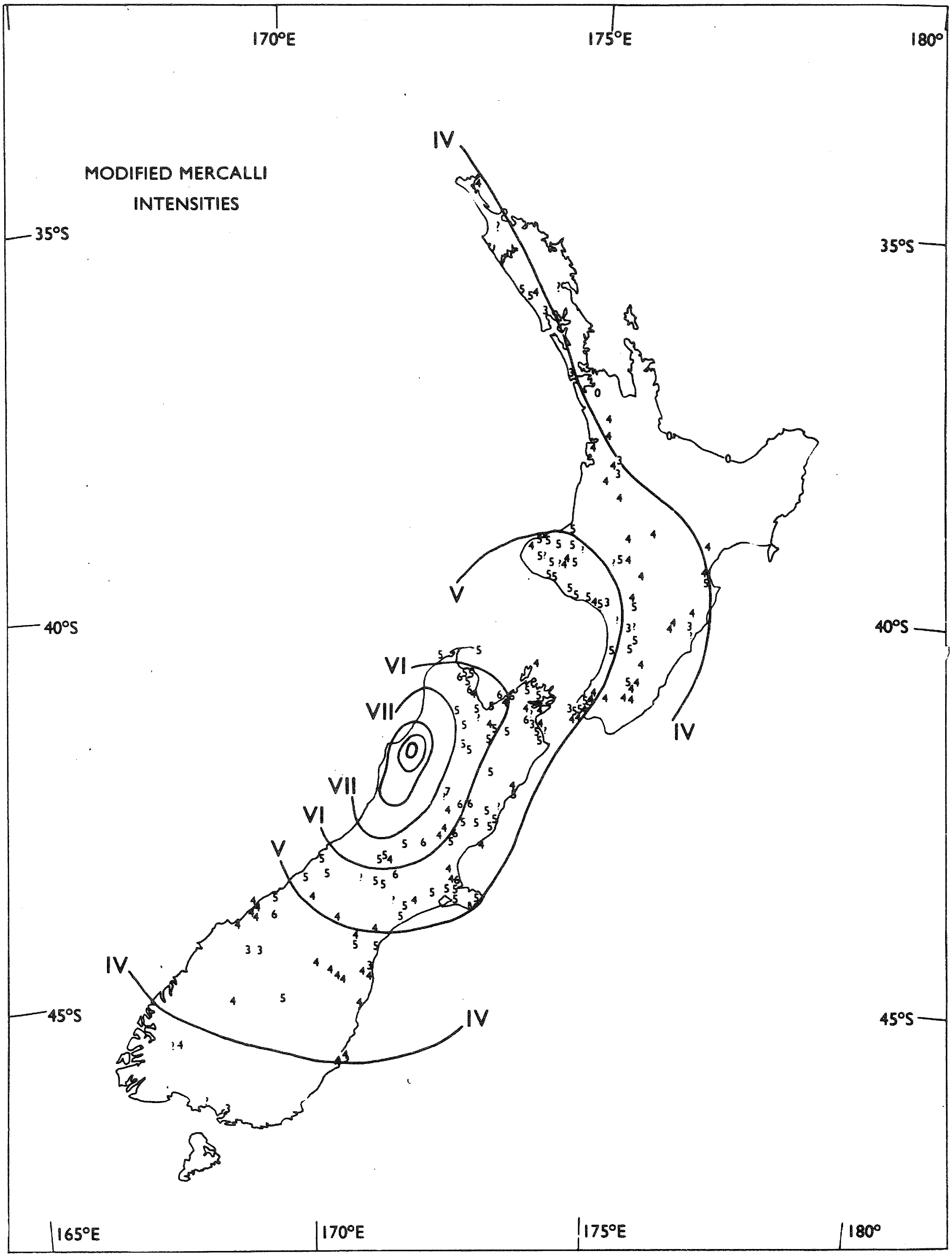

Fig. 3 Felt observations and isoseismals for main Inangahua earthquake. For details of epicentral region see Fig. 4.

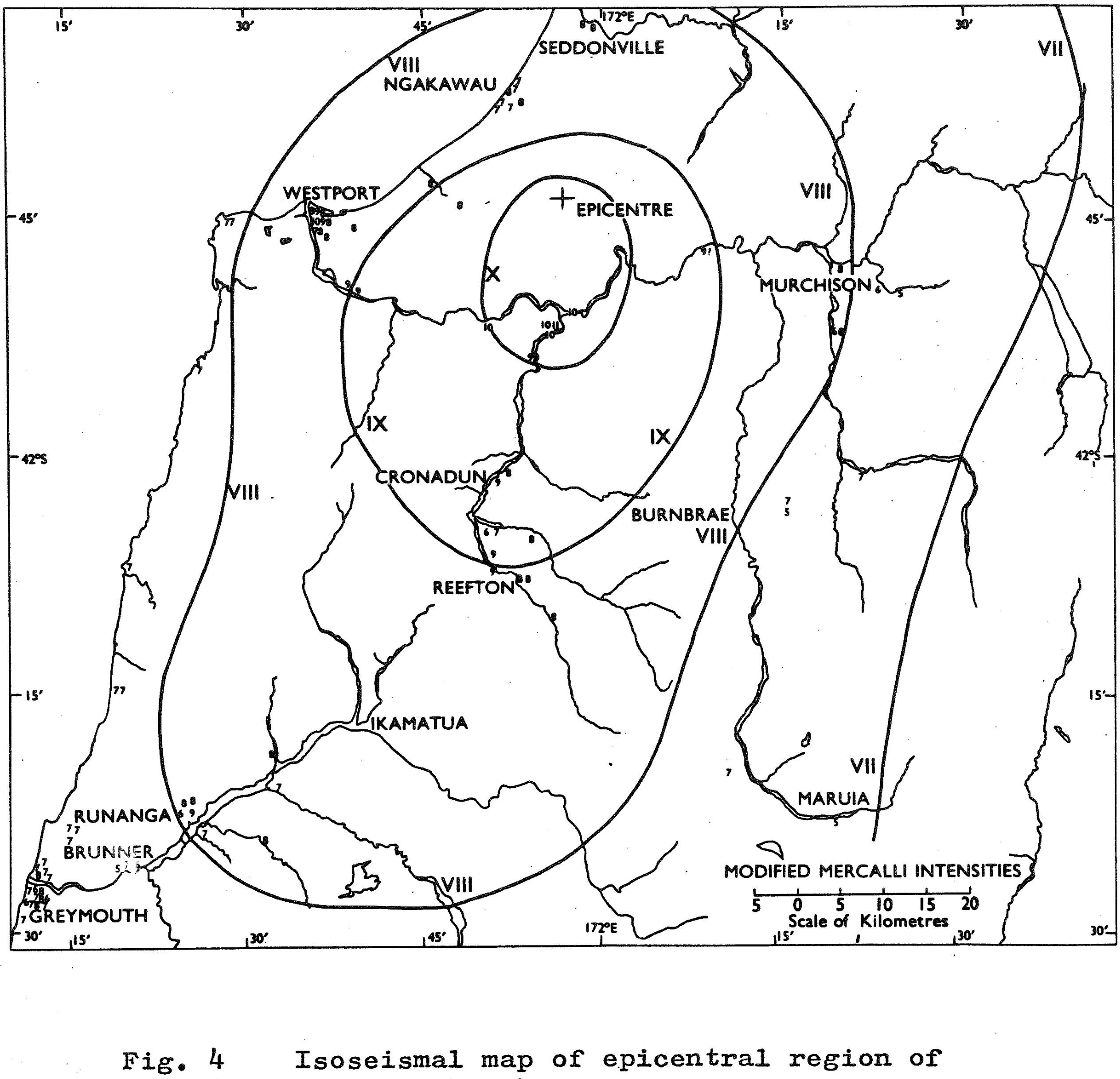

Fig. 4 Isoseismal map of epicentral region of main Inangahua earthquake.