Report 284

Australian seismological report 1984

Compiled by KF McCue

Bureau of Mineral Resources, Geology and Geophysics

Department of Primary Industries and Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 284

AUSTRALIAN SEISMOLOGICAL REPORT, 1984

Compiled by

K.F. McCue

(Division of Geophysics)

AUSTRALIAN GOVERNMENT PUBLISHING SERVICE
CANBERRA

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY

Minister for Resources: Senator the Hon. Peter Cook
Secretary: G. L. Miller

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: R.W.R. Rutland AO

Published for the Bureau of Mineral Resources, Geology & Geophysics by the Australian Government Publishing Service

ISBN 0 644 08659 9
ISSN 0084 - 7100

Edited by A. Paine
Line drawings by N. Kozin

Printed in Australia by Graphic Services Pty Ltd, Northfield, South Australia

Contributors

The contributors to this publication are listed below according to the information furnished or service performed:

Hypocentres and magnitudes

R. Cuthbertson, Geological Survey of Queensland, Brisbane, Qld
D. Denham, BMR, Canberra, ACT
M. Douch, BMR, Canberra, ACT
G. Gibson, Phillip Institute of Technology, Bundoora, Vic.
P.J. Gregson, BMR, Mundaring Geophysical Observatory, Mundaring, WA
T. Jones, BMR, Canberra, ACT
C. Krayshek, Research School of Earth Sciences, Australian National University, Canberra, ACT
M. Michael-Leiba, BMR, Canberra, ACT
R. McDougal, University of Adelaide, Adelaide, SA
K. McCue, BMR, Canberra, ACT
National Earthquake Information Service, US Geological Survey (USGS), Boulder, Colorado, USA
E.P. Paull, BMR, Mundaring Geophysical Observatory, Mundaring, WA
J. Pongratz, University of Tasmania, Hobart, Tas.
J.M.W. Rynn, University of Queensland, Brisbane, Qld
R.S. Smith, BMR, Canberra, ACT
J. Vahala, BMR, Canberra, ACT
J.P. Webb, University of Queensland, Brisbane, Qld
J. Weekes, Research School of Earth Sciences, Australian National University, Canberra, ACT
V. Wesson, Phillip Institute of Technology, Bundoora, Vic.
International Seismological Centre (ISC), Newbury, UK

Intensities

B. Gaull, BMR, Mundaring Geophysical Observatory, Mundaring, WA
C. Lynam, University of Queensland, Qld
K.F. McCue, BMR, Canberra, ACT
J.M.W. Rynn, University of Queensland, Brisbane, Qld

Network operations (by institution)

Australian National University, Canberra, ACT (CAN)
Bureau of Mineral Resources, Geology & Geophysics, Canberra, ACT (BMR) and Mundaring, WA (MUN)
Geological Survey of Queensland, Brisbane, Qld (GSQ)
Phillip Institute of Technology, Bundoora, Vic. (PIT)
St Ignatius College, Riverview, NSW (RIV)
University of Adelaide, Adelaide, SA (ADE)
University of Queensland, Brisbane, Qld (UQ)
University of Tasmania, Hobart, Tas. (TAU)
Western Australian Public Works Department, Perth, WA (PWD)

Strong-motion data

B.A. Gaull, BMR, Mundaring Geophysical Observatory, Mundaring, WA
M. Michael-Leiba, BMR, Canberra, ACT
G. Gibson, Phillip Institute of Technology, Bundoora, Vic.
K. McCue, BMR, Canberra, ACT
V. Wesson, Phillip Institute of Technology, Bundoora, Vic.

Nuclear monitoring

P.M. McGregor, BMR, Canberra, ACT
D. Denham, BMR, Canberra, ACT
L. Hodgson, BMR, Canberra, ACT

Table of Contents

Tables

Figures

Figures (cont.)

ABSTRACT

Seismicity in the Australian region in 1984 was below average and similar to that of 1982 and 1983. There were 136 earthquakes of magnitude 3 or more, only one of which exceeded magnitude 5; this was the 16 March earthquake off the northwest coast of Western Australia which was not reported felt onshore. Isoseismal maps were drawn up for the Cooyar, Oolong, and Murgon earthquakes. An intensity of MMVI on the Modified Mercalli Scale was assessed near the epicentre of the Oolong NSW earthquake which also caused the highest ground acceleration, 2989mm.s^{-2}, yet recorded in Australia. Fourteen other accelerograms were collected, all of them from the accelerograph networks in eastern Australia. A nuclear-test monitoring group was established in the BMR during 1984. This followed a Cabinet decision to establish a national capacity to monitor underground nuclear explosions and to develop facilities for an International Data Centre which would be required for monitoring a Comprehensive Test Ban Treaty. In October 1984, an international technical test was carried out to test seismological global communications. This was completed under the auspices of the Geneva Group of Scientific Experts and coordinated by BMR.

During 1984, 58 presumed underground nuclear explosions were detected, an average of more than one per week. The USSR detonated 29, USA 17, France 8, and UK and China 2 each.

INTRODUCTION

This report contains information on all earthquakes of Richter magnitude 3 or greater that were reported in the Australian region during 1984. It is the fifth in an annual series (Denham & Gregson, 1984; Denham & Gregson, 1985; Gregson & Denham, 1986; Gregson & Denham, 1987) to be compiled by the Bureau of Mineral Resources, Geology & Geophysics (BMR), using data provided by various seismological agencies in Australia. Its purpose is to aid the study of seismic risk and to help answer inquiries about earthquakes and nuclear explosions in 1984.

The report comprises five main sections: 'Australian earthquakes', which contains a summary of the 1984 seismicity and brief descriptions of the more important earthquakes; 'Accelerograph data', which contains the results of the accelerograph network; 'Network operations', which gives details of the seismographs that operated in Australia during 1984; 'Principal World Earthquakes, 1984' which lists the largest and most damaging earthquakes that took place during 1984; and 'Monitoring of Nuclear Explosions' which describes the establishment of a new facility in BMR.

Throughout the report we refer to *magnitudes* of earthquakes and *intensities* caused by earthquakes. These terms are defined below.

Magnitudes

The magnitude of an earthquake is a measure of its size and is related to the energy released at its focus. The magnitude scale is logarithmic: thus a magnitude 6 earthquake produces ground amplitudes 10 times as large, and an energy release about 30 times as large, as a magnitude 5 earthquake.

A rule-of-thumb relation between magnitude and energy is

$$\log E = 4.8 + 1.5M$$

where E is in joules.

A shock of magnitude 2 is the smallest normally felt by humans, and earthquakes of magnitude 5 or more can cause major damage if they are shallow and close to buildings.

The following magnitude scales are in common use.

Richter magnitude (ML)

$$ML = \log A - \log A_0$$

as defined by Richter (1958, p. 340), where A is the maximum trace amplitude (zero-to-peak) in millimetres on a standard Wood-Anderson seismogram and $\log A_0$ is a standard value given as a function of distance (0-600 km). Richter's reference earthquake of ML 3.0 produces a trace amplitude of 1 mm, 100 km from the epicentre.

If standard Wood-Anderson instruments (Anderson & Wood, 1925) are not available, an equivalent Richter magnitude can be determined by correcting for the differences in magnification (see Willmore, 1979, para. 3.1.1).

Surface-wave magnitude (Ms)

The surface-wave magnitude is normally applicable only to shallow earthquakes in the distance range 20-160 degrees, and in the period range T = 20 ± 3 s. When these conditions hold, Ms values are calculated from the IASPEI (1967) formula (McGregor & Ripper, 1976)

$$Ms = \log \frac{A}{T} + 1.66\,\Delta + 3.3$$

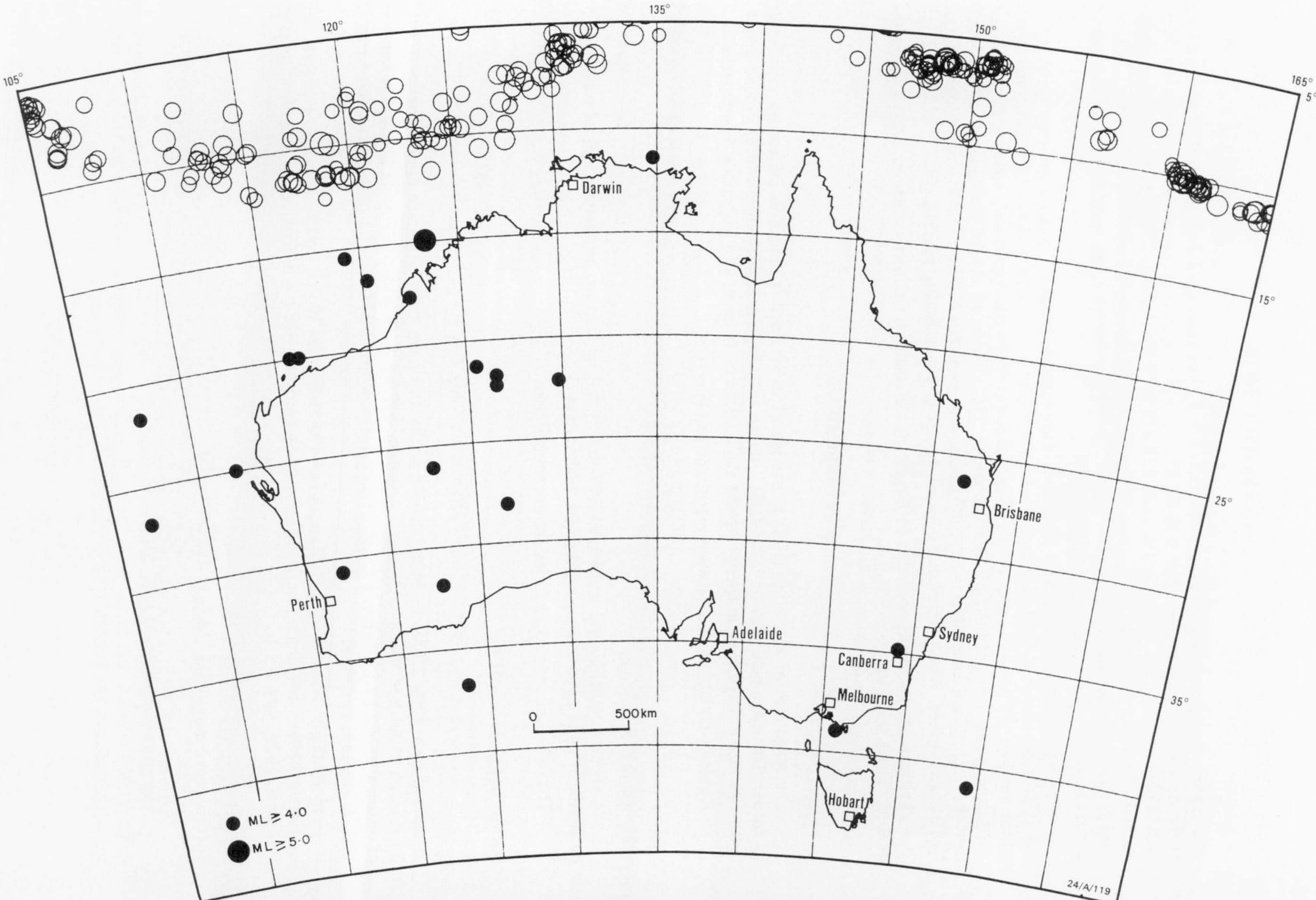


Fig. 1. Australian region earthquakes with magnitudes 4.0 or greater, 1984.

where A is the ground amplitude in micrometres, T is the period in seconds, and Δ the epicentral distance in degrees (see Båth, 1981).

Body-wave magnitude (mb)

$$mb = \log \frac{A}{T} + Q\ (\Delta, h)$$

where A is the maximum mean-to-peak ground amplitude in microns of the P, PP, or S-wave trains, T the corresponding wave-period (seconds), and Q (Δ, h) a depth/distance factor. The Q factors were derived by Gutenberg (1945) and are given by Richter (1958, pp. 688-689).

Duration magnitude (MD)

$$MD = a \log t + b\, \Delta + c$$

where t is the length of the earthquake coda in seconds, Δ the distance from the epicentre, and a, b, and c are constants for a particular recording station.

Seismic moment magnitude (Mw)

$$Mw = \frac{\log M_o}{1.5} - 6.0$$

where M_o is the seismic moment (in Nm) and defined as

$$Mo = \mu\, AD$$

where μ is the rigidity, A the surface area displaced, and D the average displacement on that surface. This magnitude scale was proposed by Kanamori (1978).

Magnitude from isoseismals

In some cases where reliable magnitudes cannot be determined instrumentally (from seismograms), it is possible to calculate magnitudes from macroseismic data. In these cases McCue's (1980) formula was used

$$M(Rp) = 1.01\ ln(Rp) + 0.13$$

where Rp is the radius of perceptibility (in kilometres) of the MM(III) isoseismal. M(Rp) is equivalent to ML below magnitude 6 and Ms at magnitude 6 and above. Magnitudes found by this method should be treated as approximate only, and may be revised as a result of further research.

Further information on magnitudes is available in McGregor & Ripper (1976), Båth (1981), and Denham (1982).

Intensity

The intensity of an earthquake is determined from its effects on people, buildings, and the Earth's surface. In this report we use the Modified Mercalli Scale (MM) as presented by Eiby (1966) for New Zealand conditions and listed in the Appendix. Essentially the MM scale is an assessment of how severely the earthquake was felt and the damage that was caused at a particular place. Some earthquakes are large enough to be felt over a wide area and an isoseismal map can be prepared. These maps indicate in detail the extent of the shaking. They are prepared mainly from information compiled from questionnaire canvasses, newspaper reports, and personal interviews and inspections. Isoseismal

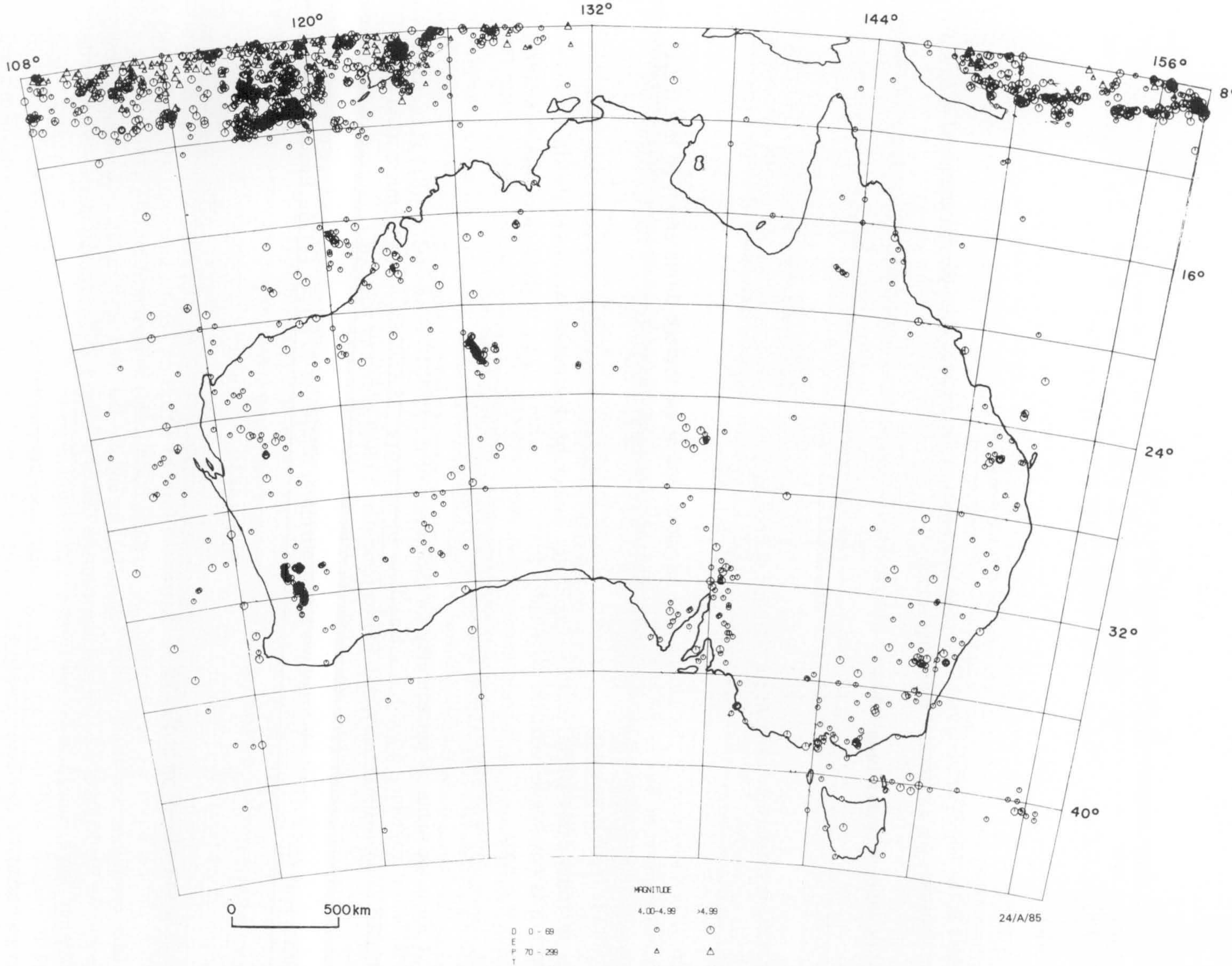


Fig. 2. Australian region earthquakes with magnitudes 4.0 or greater, 1873-1984.

maps for many pre-1984 earthquakes have been collated in Everingham & others (1982) and Rynn & others (1987).

(DAVID DENHAM, PETER GREGSON, & KEVIN McCUE)

AUSTRALIAN REGION EARTHQUAKES, 1984

Table 1 lists the parameters of all 136 earthquakes of ML 3.0 or greater that were detected in the Australian region in 1984. Only four earthquakes, all in eastern Australia, were damaging or felt widely enough to justify distributing isoseismal questionnaires: the 3 March, Cooyar (Qld); 9 August, Oolong (NSW); 20 October, Cape Liptrap (Vic.); and 30 October, Murgon (Qld).

Notwithstanding the large Meckering (1968), Lake MacKay (1970), Cadoux, (1979) and Marryat Creek (1986) earthquakes of the last two decades, Australia is generally regarded as an aseismic continent. This is despite Clarke's (1869) perceptive observation of more than a century ago that 'shocks are far more numerous in Australasia than many persons imagine.' Since 1960 the average frequency of earthquakes exceeding ML 4.9 has been 4.0 / year and of those exceeding ML 5.9 has been 0.33 / year. This latter frequency is double the average of 0.16 / year over the last 86 years.

In terms of energy release or the number of earthquakes exceeding ML 4.9, Australia in 1984 experienced the least seismic activity of any year since 1966. The largest earthquake of the year was that off the northwest Australian coast on 16 March; its magnitude was ML 5.2 and as far as is known it was not felt ashore. Epicentres of earthquakes exceeding ML 3.9 are plotted in Figure 1; eight of the twelve that occurred onshore were in Western Australia with a further seven off the coast of Western Australia. Only three were in eastern Australia, with one east of Tasmania in the same locality as the 1983 Tasman Sea earthquake (Denham, 1985). Figure 2 shows the distribution of ML 4 and greater earthquakes for the period 1873-1984.

For a State by State comparison of seismic activity, earthquakes exceeding ML 2.4 are plotted in Figures 3 to 9, though coverage down to this level is probably complete only in Tasmania, Victoria, southeastern New South Wales and the Australian Capital Territory, the southwest of Western Australia and southeastern South Australia.

Western Australia

The activity appears to have been randomly distributed across the State (Fig. 3), both onshore and offshore, in the sense that there is no obvious correlation with the geology. However, the plot is deceptive in that coverage of the State is in no sense complete down to ML 2.5. Some epicentres, though, do cluster along the edges of discrete blocks, such as those along the Fraser Fault at the southeast edge of the Yilgarn Block, and there were two epicentres near the Diamantina Fracture Zone, southwest of Albany.

In the Southwest Seismic Zone, 75 earthquakes were located with magnitudes exceeding ML 1.9 (Gregson & others, 1985). The activity was spread widely through the Zone, from Latham in the north to Merredin in the east and Mount Barker in the south. The largest, near Cadoux on 28 March had a magnitude of ML 4.2. Twenty-five tremors were recorded during 1984 near Cadoux, compared with 57 in 1983. The largest onshore earthquake, with a magnitude of ML 4.5, had its epicentre in the Great Victoria Desert, 225 km south of Warburton seismograph station on 7 July.

Northern Territory

Historically, the Simpson Desert, southeast of Alice Springs, has been one of the most active seismic zones in Australia, yet most of the activity in 1984 was in the southwest of the Territory (Fig. 4). Three earthquakes occurred east of Darwin in unusual locations, but the seismograph station coverage is inadequate to monitor regional seismicity in the northeast of the Territory. The southwest of the

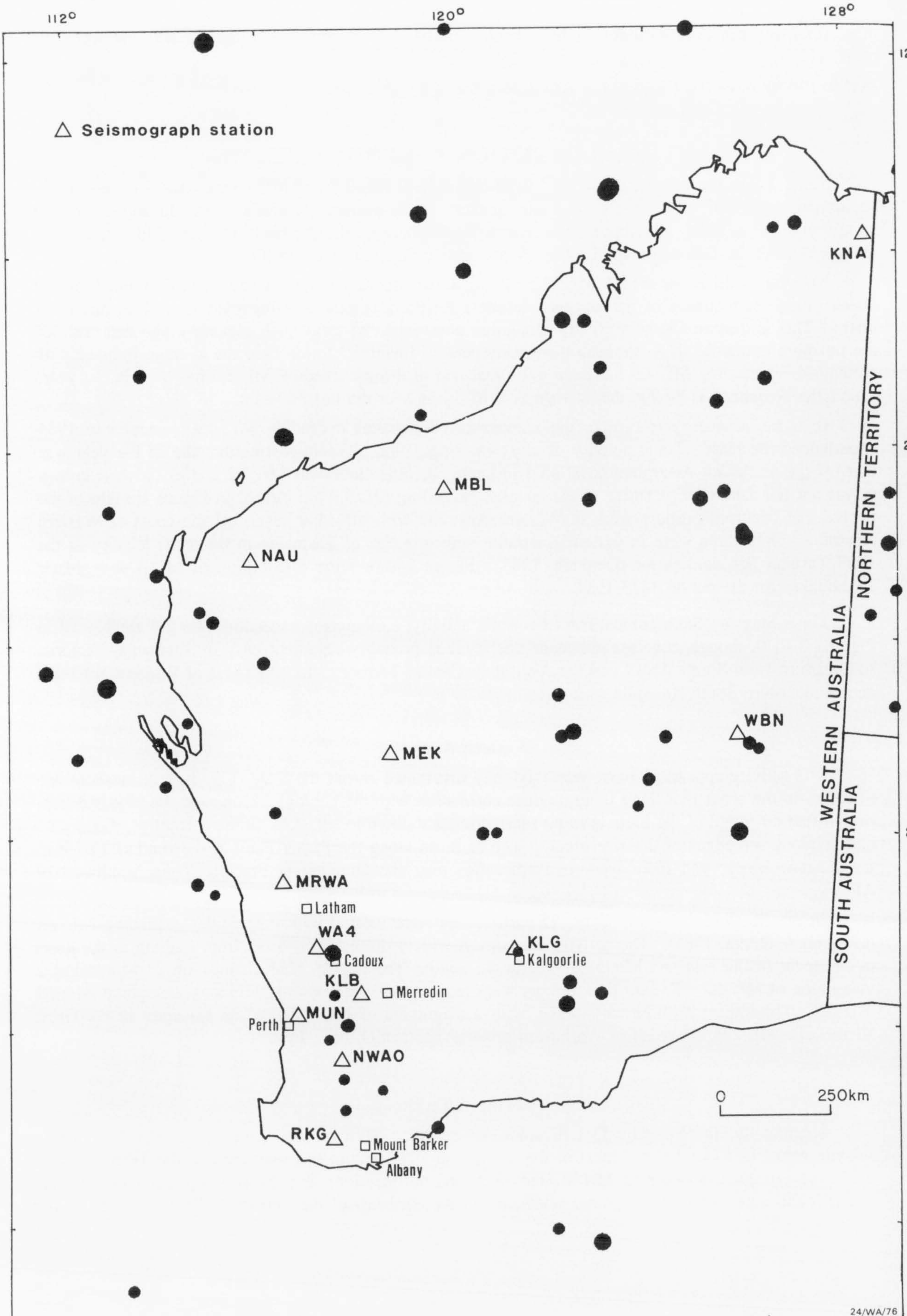


Fig. 3. Western Australian earthquakes with magnitude 2.5 or greater, 1984.

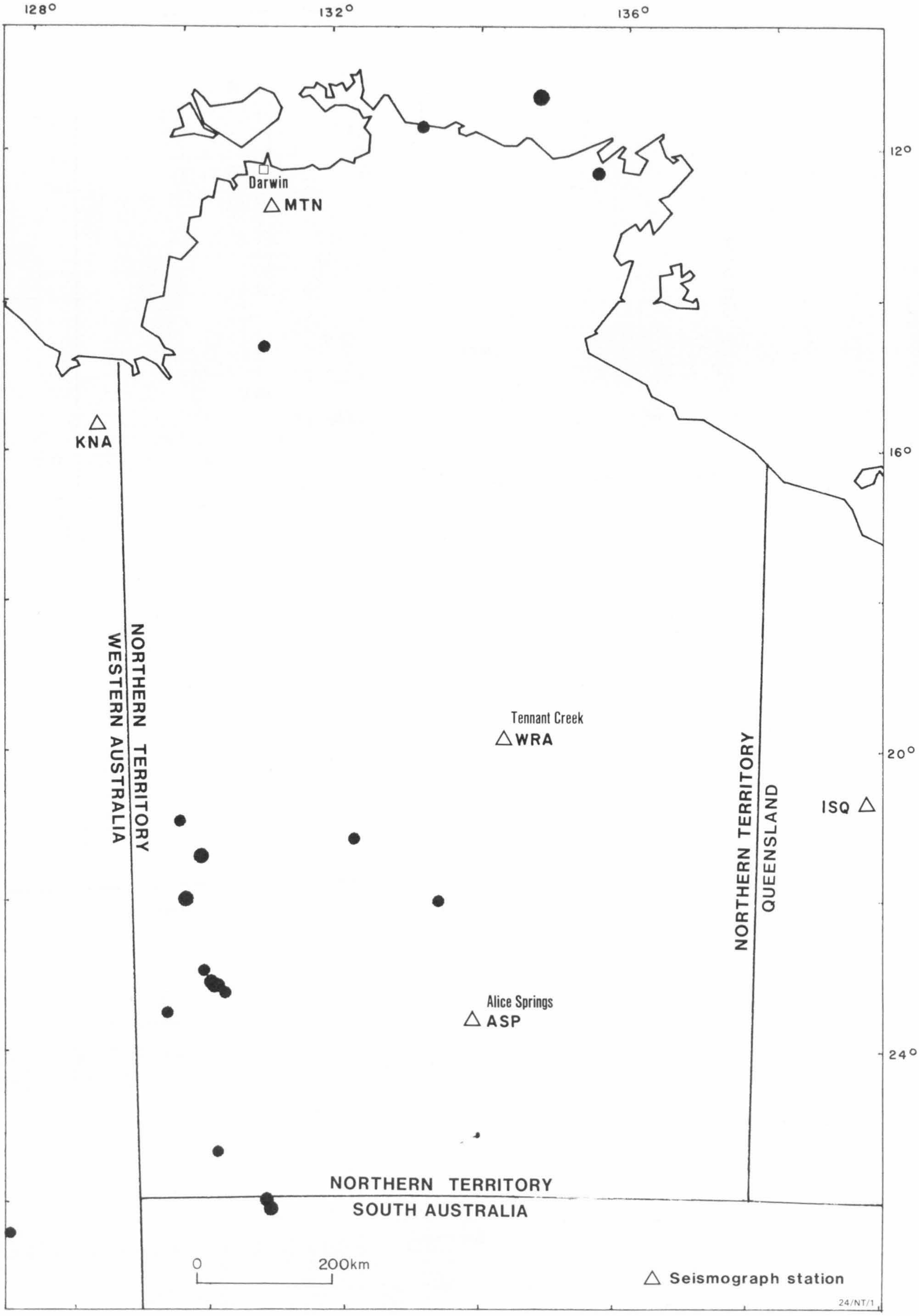


Fig. 4. Northern Territory earthquakes with magnitude 2.5 or greater, 1984.

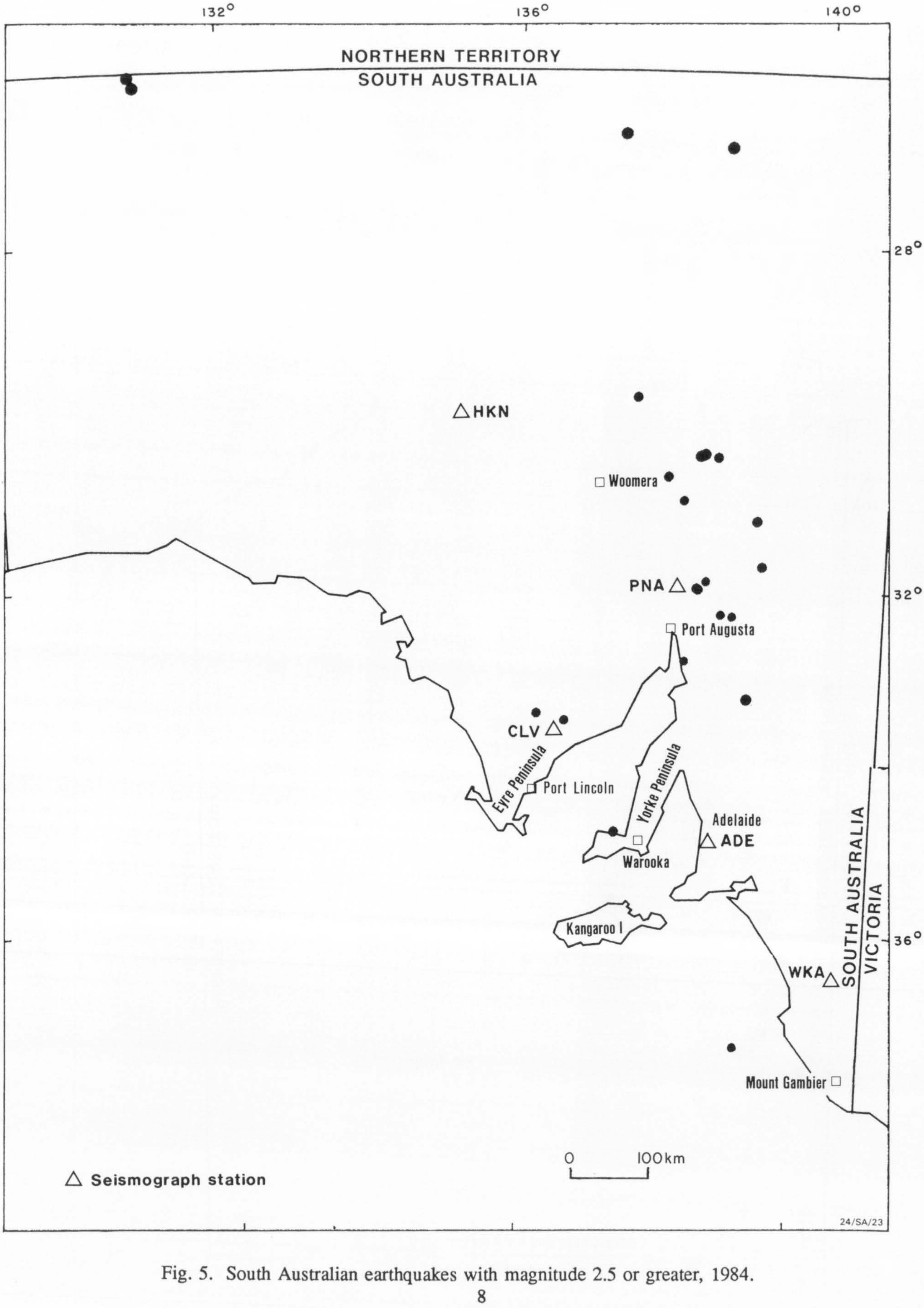


Fig. 5. South Australian earthquakes with magnitude 2.5 or greater, 1984.

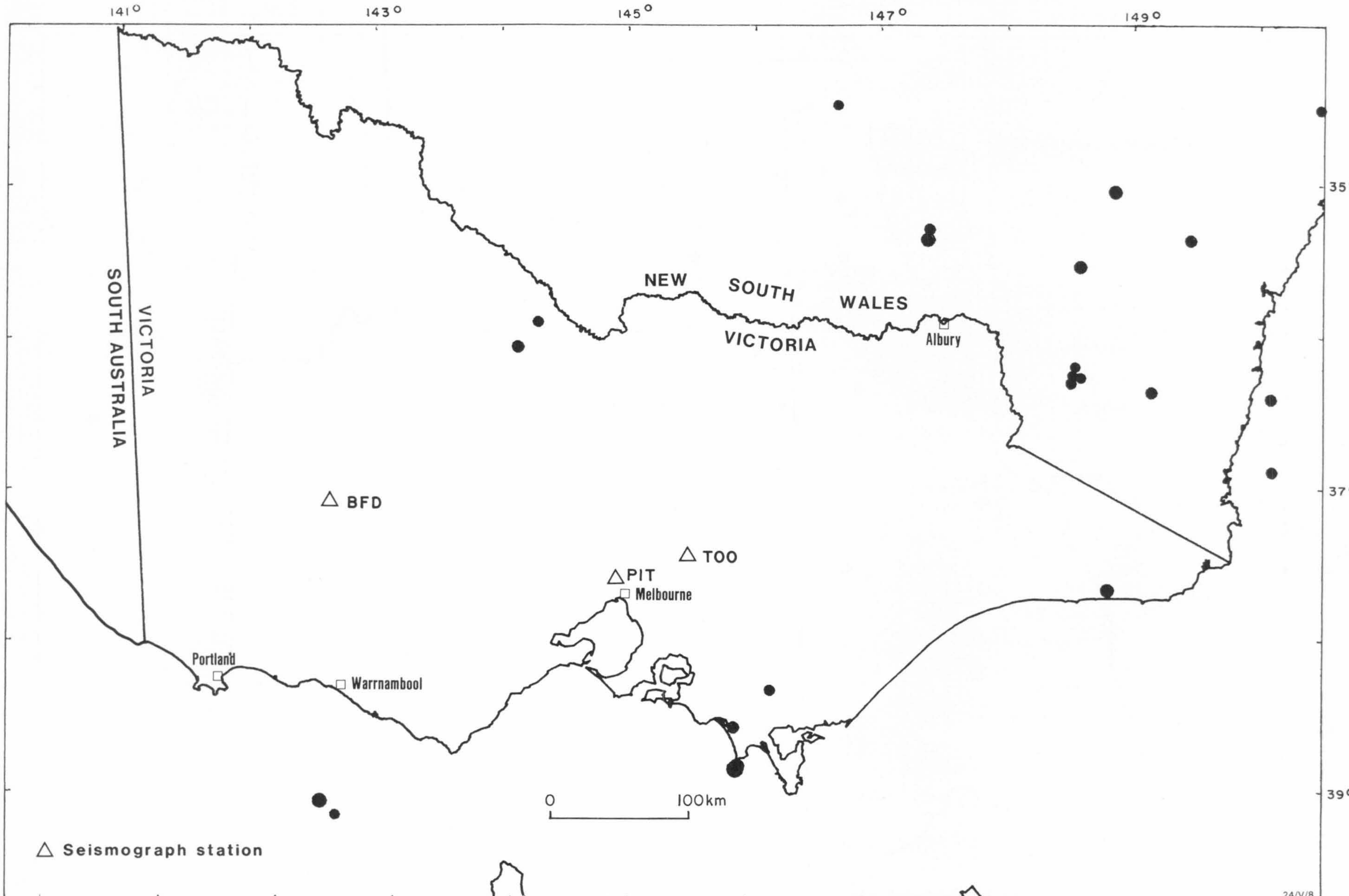


Fig. 6. Victorian earthquakes with magnitude 2.5 or greater, 1984.

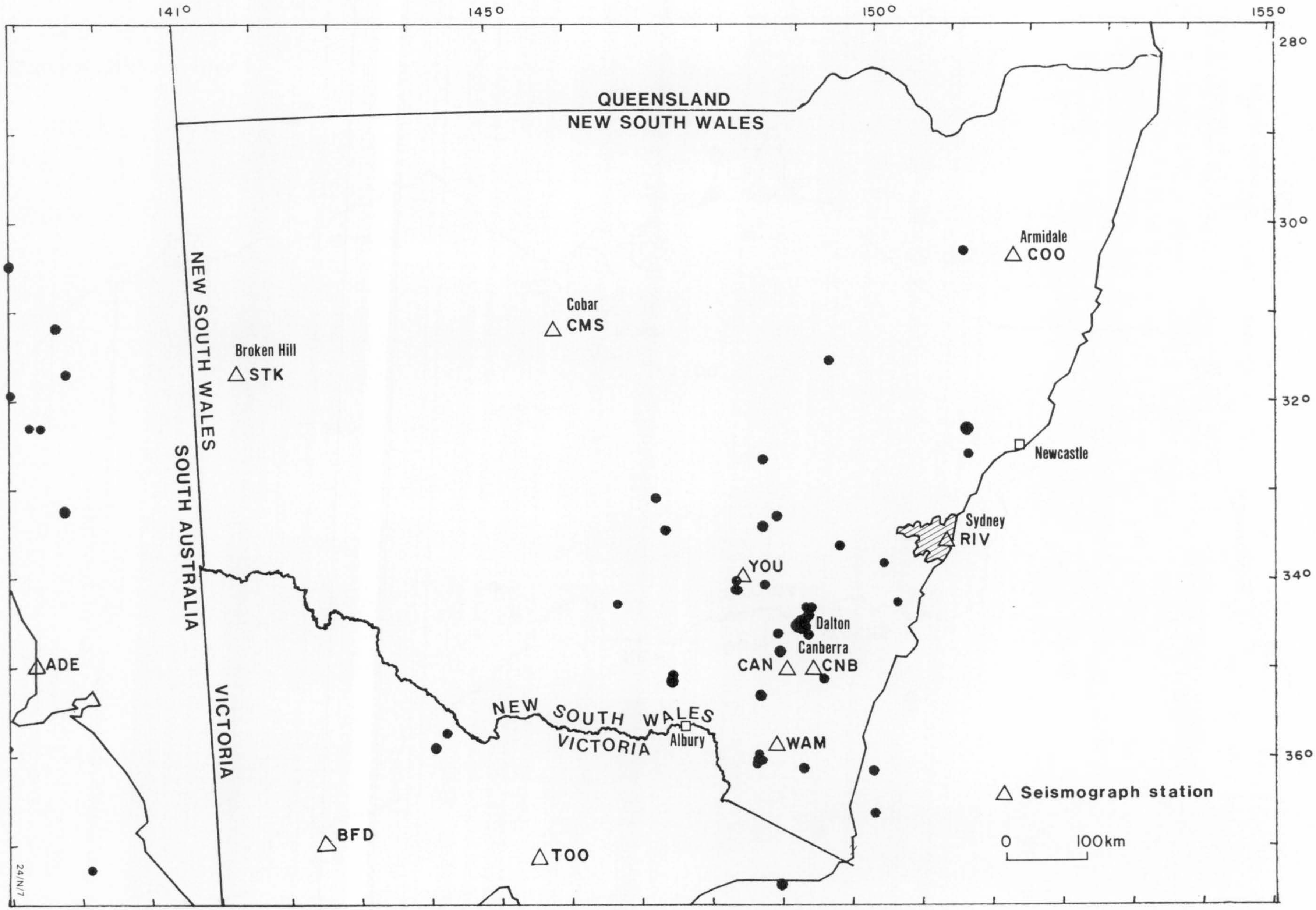


Fig. 7. New South Wales & ACT earthquakes with magnitude 2.5 or greater, 1984.

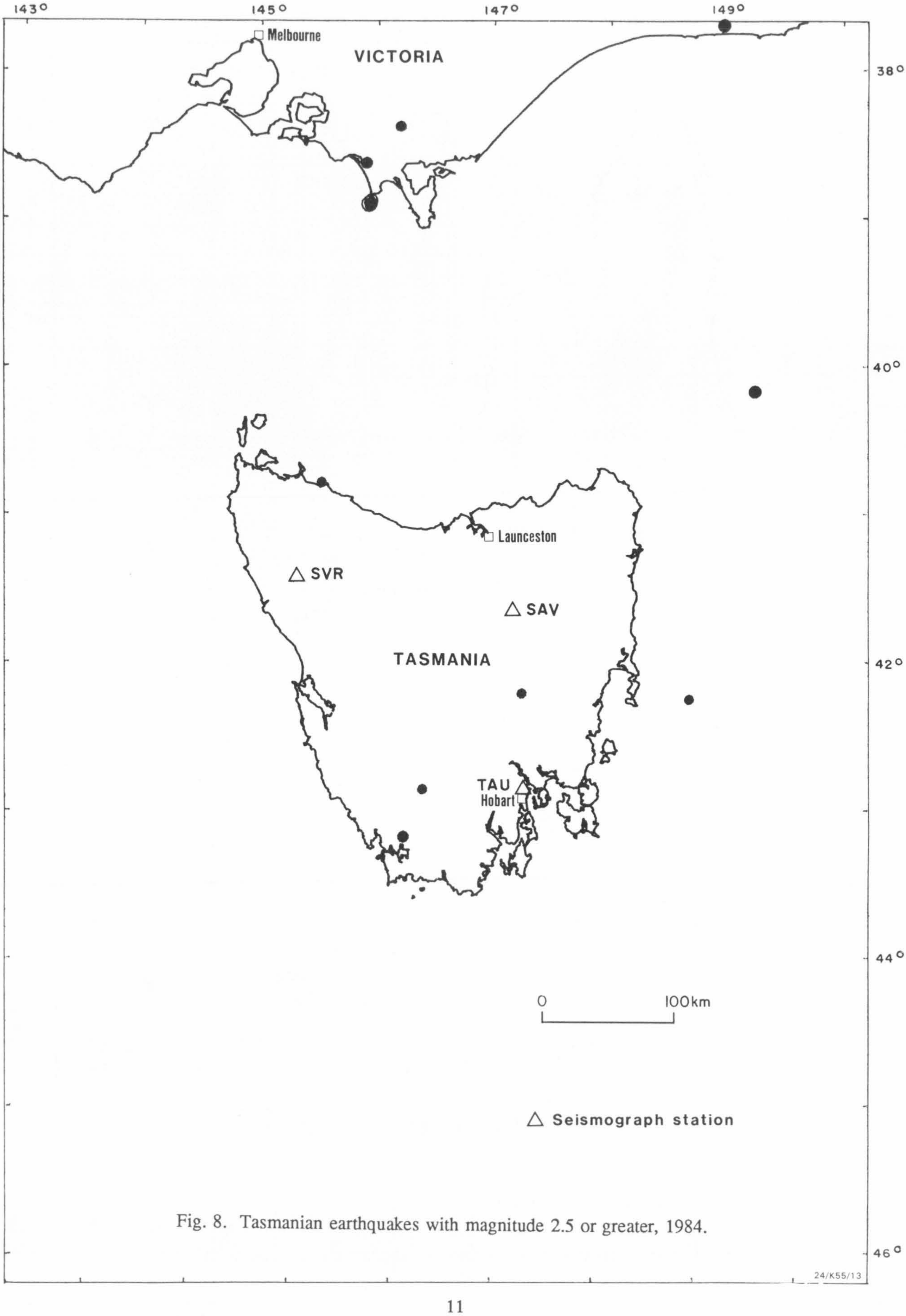


Fig. 8. Tasmanian earthquakes with magnitude 2.5 or greater, 1984.

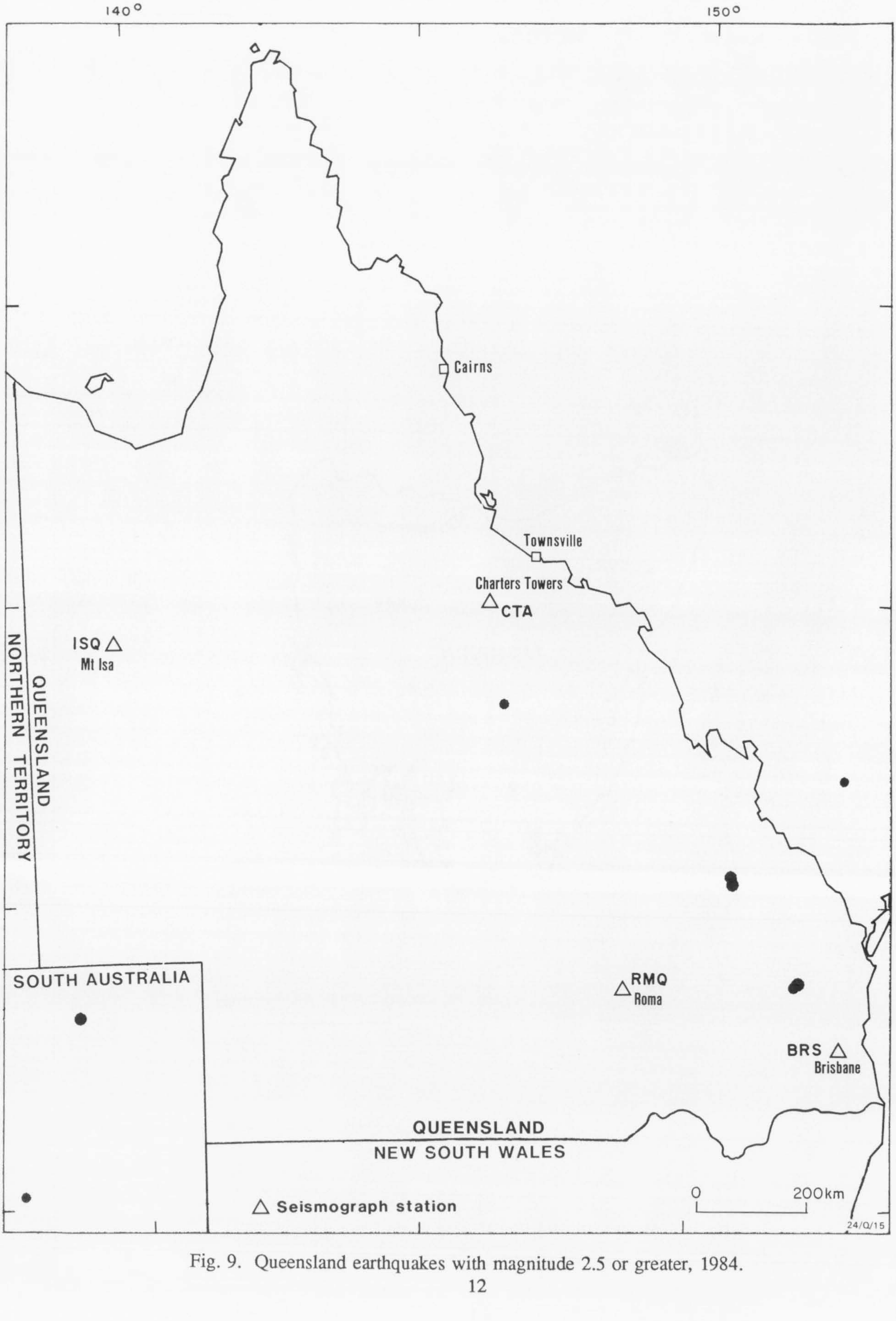


Fig. 9. Queensland earthquakes with magnitude 2.5 or greater, 1984.

Territory is reasonably well covered with the arrays at Tennant Creek and Alice Springs and a high-gain station at Warburton in Western Australia.

South Australia

No earthquake exceeded ML 3.9 in South Australia during 1984. Those small events that were located (Fig. 5) were in recognised seismic zones except for four small earthquakes along the Northern Territory border and one on Yorke Peninsula near the town of Warooka, which was badly damaged during the large 1902 earthquake (Howchin, 1918). Only two small earthquakes occurred in the Eyre Peninsula Seismic Zone and one in the Southeast Seismic Zone; most were in the centre of the Adelaide Geosyncline Seismic Zone in the mid-north of the State. There were no epicentres in the Adelaide region and no earthquakes were reported felt in the city.

Victoria

Statewide, seismicity was at a very low level during 1984 with only five onshore earthquakes exceeding ML 2.4 (Fig. 6). The only earthquake of note was that off Cape Liptrap on 20 October, which caused no damage, but was widely felt throughout southern Gippsland, although the felt intensities were too scattered for an isoseismal map to be drawn up. A useful accelerogram was recorded on a 'Yerilla' triggered digital recorder at PIT, 133 km from the epicentre (Table 5; Fig. 14). The two small earthquakes south of Warrnambool were the first located in this part of the Otway Basin since the damaging earthquakes of 1903 (McCue, 1978).

New South Wales

Activity was greater than in South Australia, Victoria, Tasmania and Queensland; the mapped epicentres (Fig. 7) are mostly confined to the southeast and within the aperture of the ANU seismograph network. The Oolong earthquake on 9 August, (BMR, 1985) and its long aftershock sequence were the most remarkable events during 1984. Two interesting analogue accelerograms of the main shock and an aftershock, see 'Accelerograph data' below, were obtained on the Hillcrest 'Kinemetrics' SMA-1 recorder (Fig. 14), 4 km from the focus.

Tasmania

One ML 4.1 earthquake was located beneath the Tasman Sea on 27 January, near the epicentre of the large 1983 earthquake (Denham, 1985). Only four microearthquakes occurred onshore, three of them in the West Coast Seismic Zone. One of the epicentres is on the Lake Edgar Scarp, a rejuvenated section of a Palaeozoic fault at the eastern end of Lake Pedder. Two other epicentres (Fig. 8) are off the east coast, one in the prominent seismic zone east of Flinders Island.

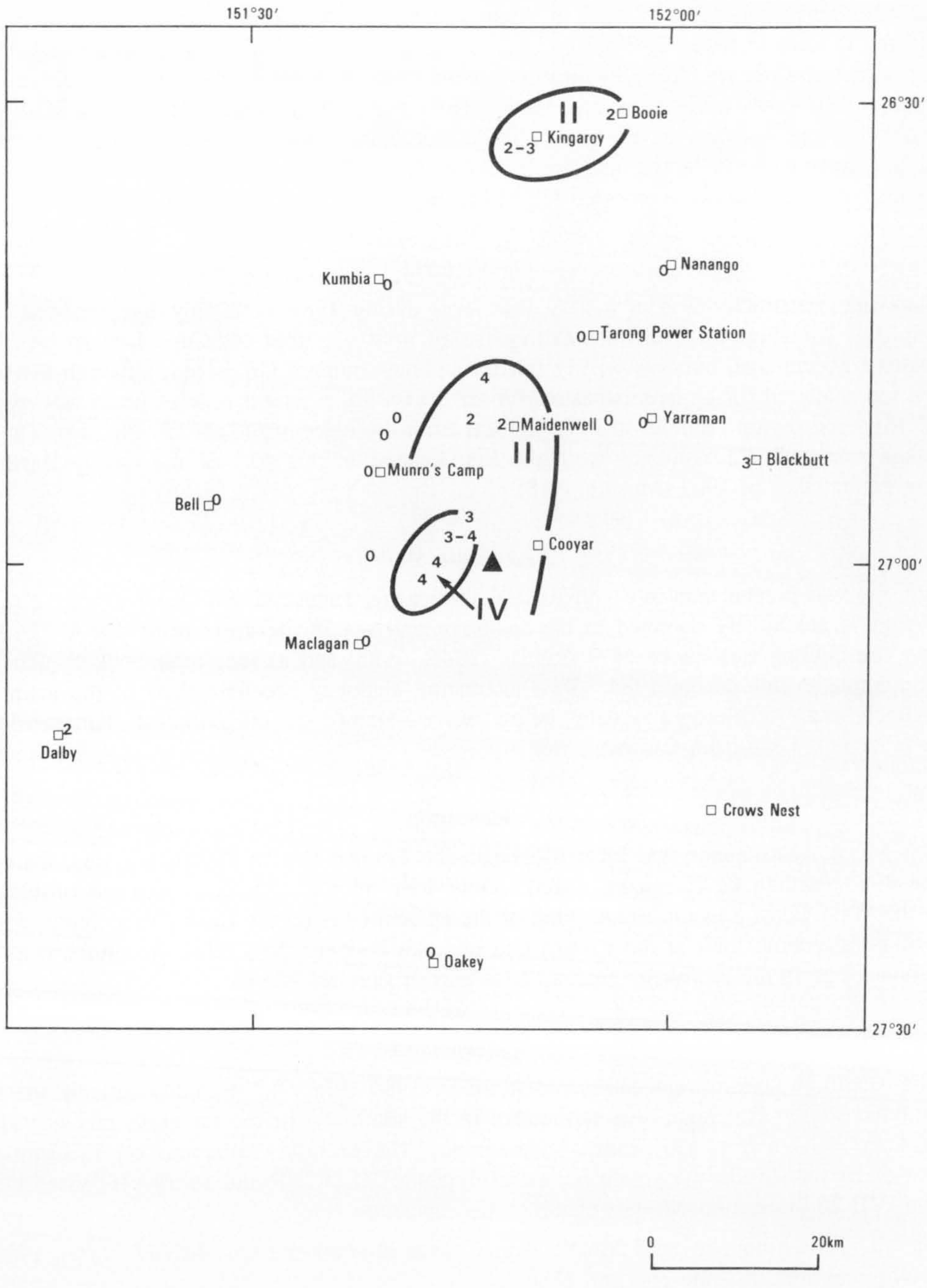
Queensland

The small number of epicentres, only six in 1984 (Fig. 9), probably reflects the inadequate seismographic station coverage. An earthquake in the southwest or the far north of Queensland would be more than 750 km from the nearest seismograph. The Murgon earthquake on 30 October, 170 km northwest of Brisbane, was the year's largest earthquake, ML 4.2 (Rynn, 1986). It caused intensities of MM VI to VII 20 km northnorth-east of the plotted epicentre (Fig. 12).

An ML 2.2 earthquake on 3 March, near Cooyar in southeast Queensland (Rynn, 1986) was felt over an elliptical area of some 300 km^2 (Fig. 10).

(KEVIN McCUE, PETER GREGSON, & GARY GIBSON)

ISOSEISMAL MAP OF THE COOYAR EARTHQUAKE, QUEENSLAND, 4 MARCH 1984



DATE : 4 March 1984
TIME : 07:12:58.2 UT
MAGNITUDE : 2.2ML(UQ), 2.7ML(I)
EPICENTRE : 26.94°S 151.79°E
DEPTH : 4 km

▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*

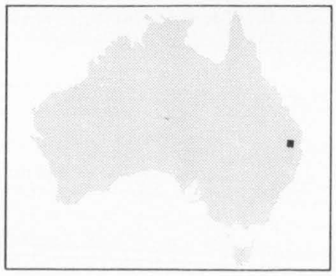
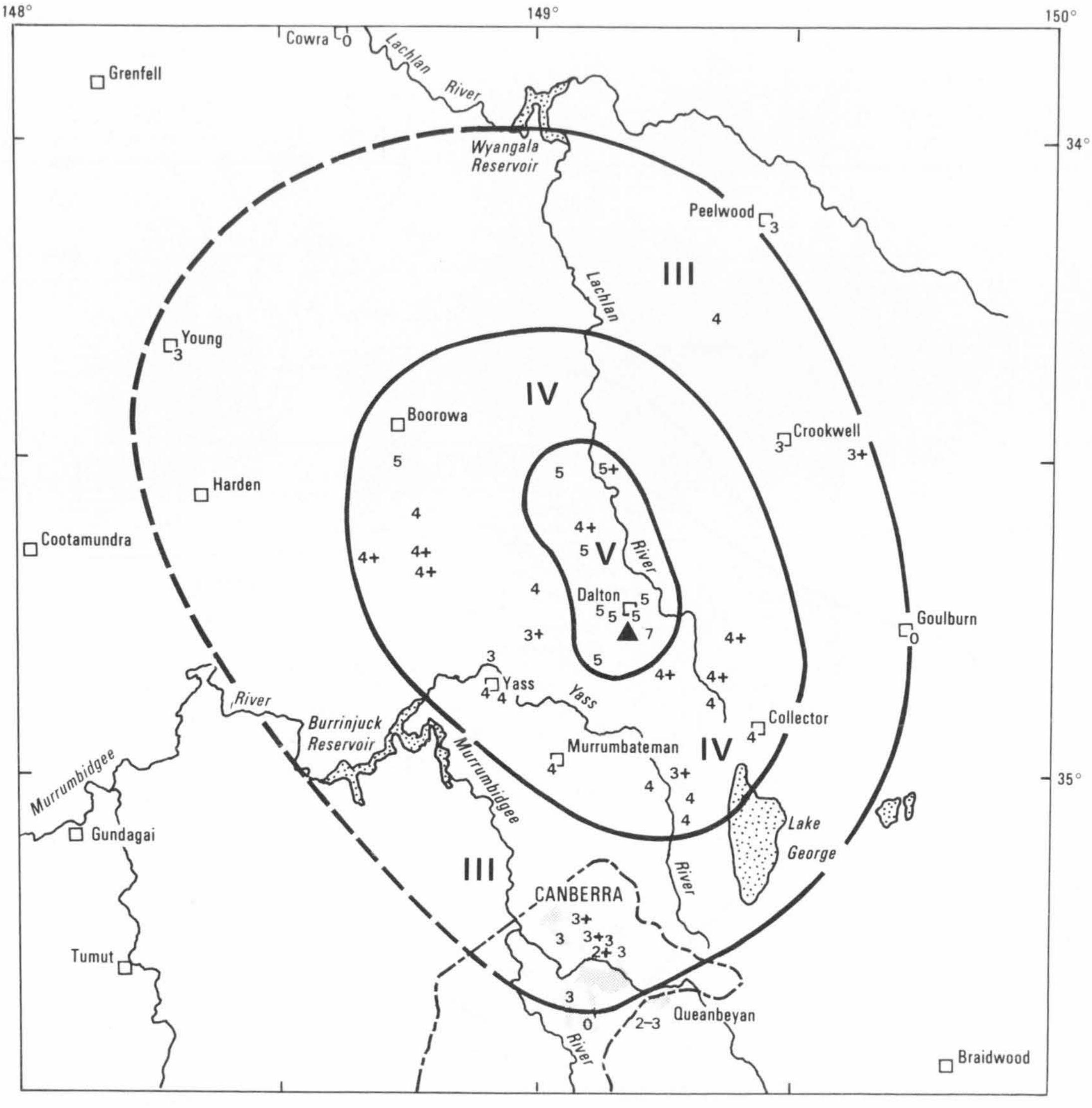
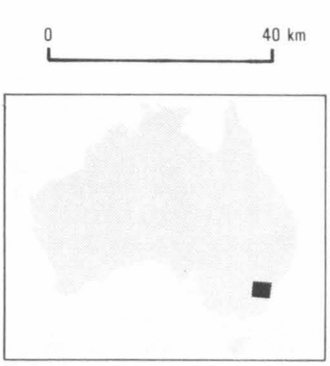


Fig. 10.

24/G56/18

ISOSEISMAL MAP OF THE OOLONG EARTHQUAKE, NEW SOUTH WALES, 9 AUGUST 1984





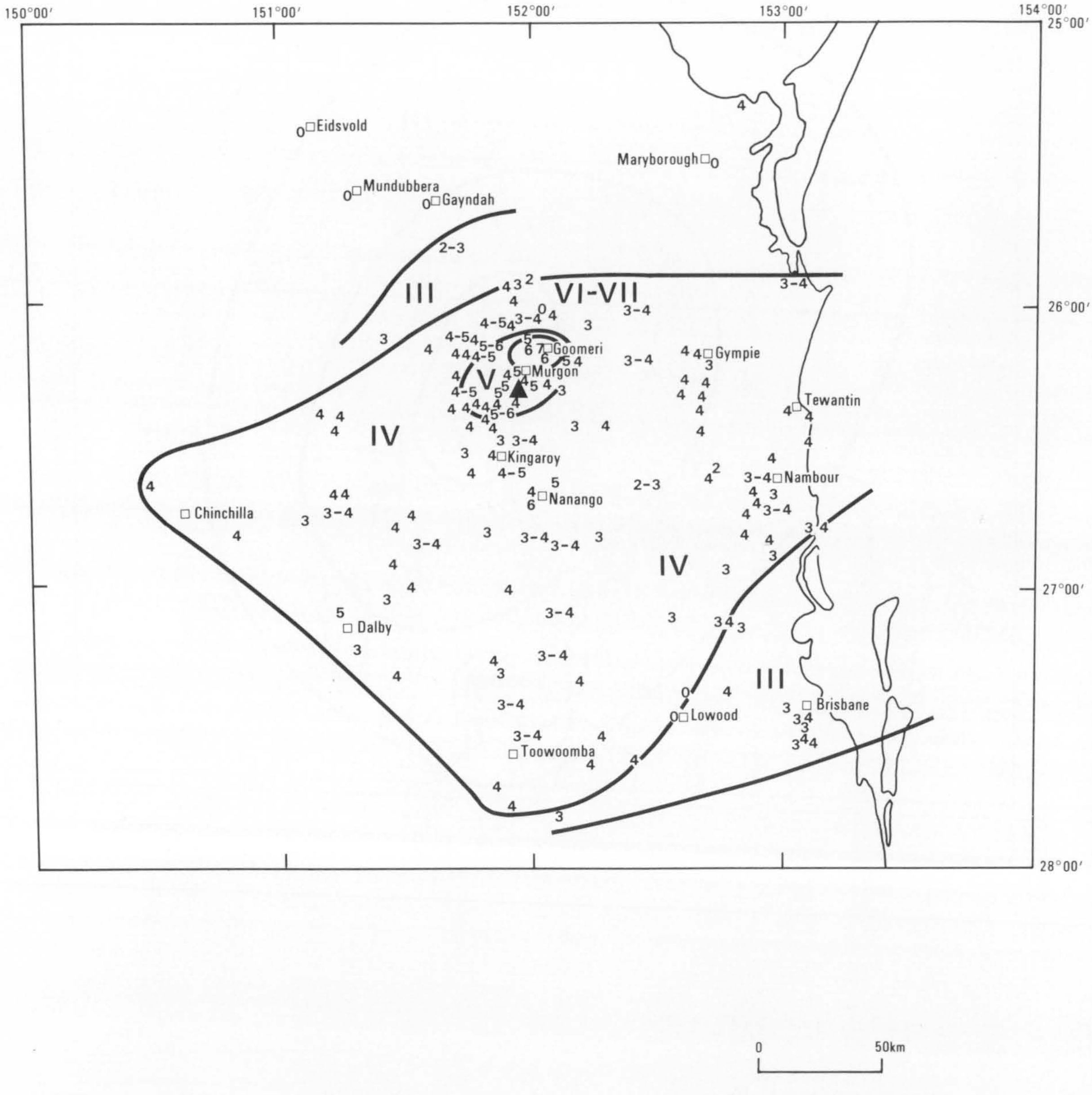
DATE : 9 AUGUST 1984
TIME : 06:30:14.0 UT
MAGNITUDE : 4.3 ML (BMR)
EPICENTRE : 34.81°S 149.17°E
DEPTH : 5 km

▲	*Epicentre*
IV	*Zone Intensity Designation*
4	*Earthquake Felt (MM)*
0	*Earthquake Not Felt*

Fig. 11.

24/155/13

ISOSEISMAL MAP OF THE MURGON EARTHQUAKE, QUEENSLAND, 30 OCTOBER 1984



DATE : *30 October 1984*
TIME : *06:29:48.2 UT*
MAGNITUDE : *4.2ML(UQ), 4.7ML(I)*
EPICENTRE : *26.31°S,151.96°E*
DEPTH : *6 km*

▲ *Epicentre*
IV *Zone Intensity Designation*
4 *Earthquake Felt (MM)*
0 *Earthquake Not Felt*

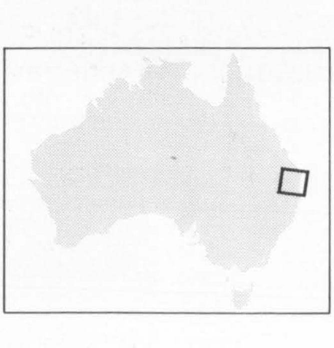


Fig. 12.

24/G56/19

ISOSEISMAL MAPS

Isoseismal maps were prepared for three earthquakes, the fewest since 1980, and all of them in eastern Australia.

Cooyar, Qld (Fig. 10)

At 0711 hours UT (5.11 pm EST) on 4 March, an ML 2.2 earthquake occurred near Cooyar, about 120 km north of Toowoomba. It was felt over an area of about 300 km^2 with the strongest intensity, MMIV, 10 km west of Cooyar (Rynn, 1986).

Oolong, NSW (Fig. 11)

At 0630 hours UT (4.30 pm EST), on 9 August an ML 4.3 earthquake shook a large area of New South Wales centred near Dalton and Gunning, causing minor damage to brick and stone buildings, including the Anglican Church at Dalton. About 100 aftershocks exceeding ML 1.9 occurred up to the end of December, most of them with S-P times of 0.5 s or less (BMR, 1985).

Murgon, Qld (Fig. 12)

At 0629 hours UT (4.29 pm EST) on 30 October, an ML 4.2 earthquake struck the South Burnett district of southeastern Queensland (Rynn, 1986). The epicentre was 115 km southeast of Boondooma Dam and approximately 330 km northwest of Wivenhoe Dam. The earthquake was felt over an area exceeding 50 000 km^2, from Maryborough to south of Toowoomba and west to Chinchilla. In the epicentral region an intensity of MMVI-VII was assigned at Goomeri where damage to steel and concrete was noted. In the Murgon, Goomeri, and Wondai districts there were reports that objects fell from walls and shelves, consistent with an intensity of at least MM V. Four aftershocks were recorded, all smaller than ML 2.0.

(JACK RYNN, BRIAN GAULL, MARION LEIBA, & KEVIN McCUE)

NETWORK OPERATIONS

Table 2 gives the co-ordinates of the seismograph stations and the types of seismograph in operation during the year (Fig. 13). The network includes two arrrays at Alice Springs and Tennant Creek in the Northern Territory, five Worldwide Standard Seismograph Stations at Adelaide, Charters Towers, Mundaring, Sydney, and Hobart, and two Seismological Research Observatories at Narrogin and Charters Towers. Another ninety short period vertical seismographs were in operation throughout Australia. At Mawson in Antarctica, the seismographs included a three-component set of short period recorders and one long period vertical instrument. Two new stations were commissioned; at Roma (RMQ) in Queensland and Morawa (MRWA) in Western Australia.

Data from Narrogin, Ballidu and Kellerberrin were telemetered into the Mundaring office and a single vertical component of the Alice Springs array was telemetered into the ASC, Canberra.

Regional epicentres (Table 1) were located by the main institutions listed on p. iii. BMR maintains the definitive Australian earthquake datafile and provides basic earthquake data for the Australian region on request to scientists, insurance companies, engineers, and the general public.

(PETER GREGSON & KEVIN McCUE)

ACCELEROGRAPH DATA

An accelerograph is used to record the strong ground motion near an earthquake source where a seismograph, being much more sensitive, would be saturated. The records or accelerograms are useful to both the seismologist and earthquake engineer. The accelerometers may be permanently installed in a

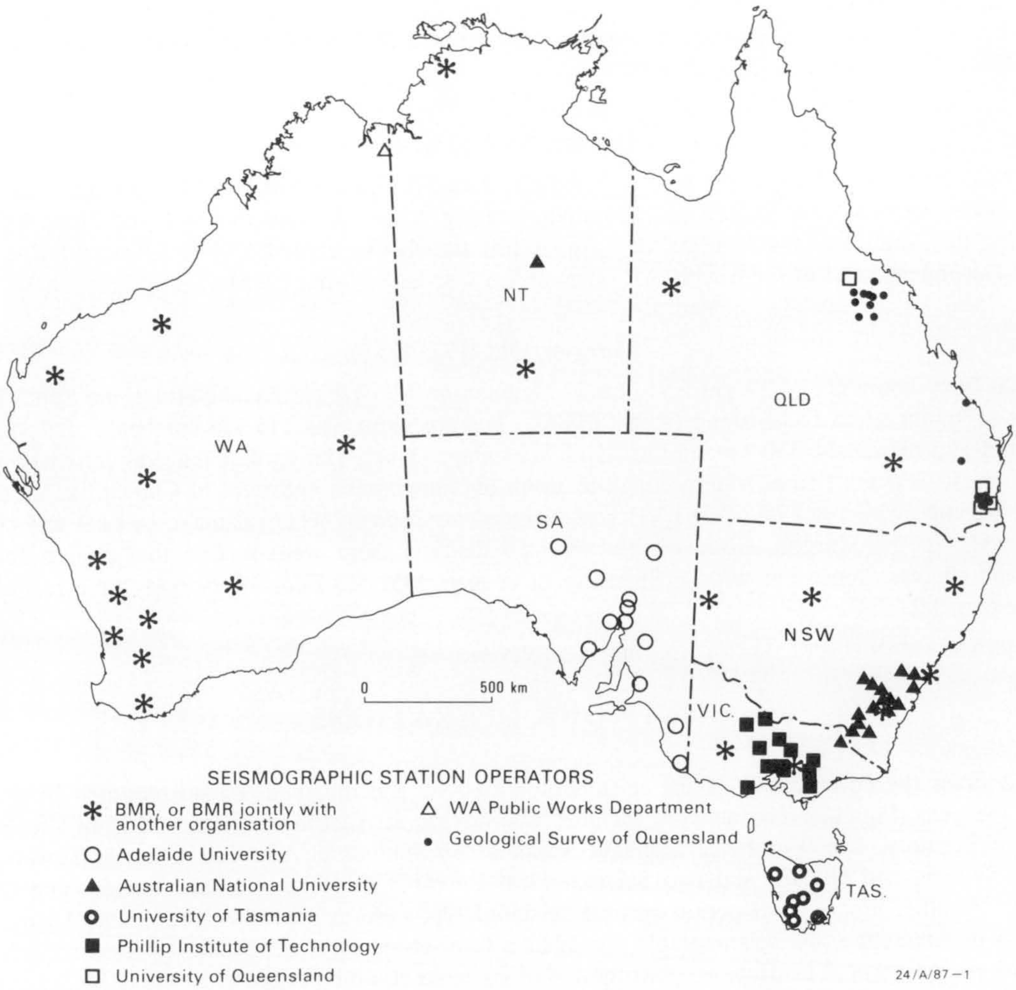


Fig. 13. Australian seismographic stations, 1984

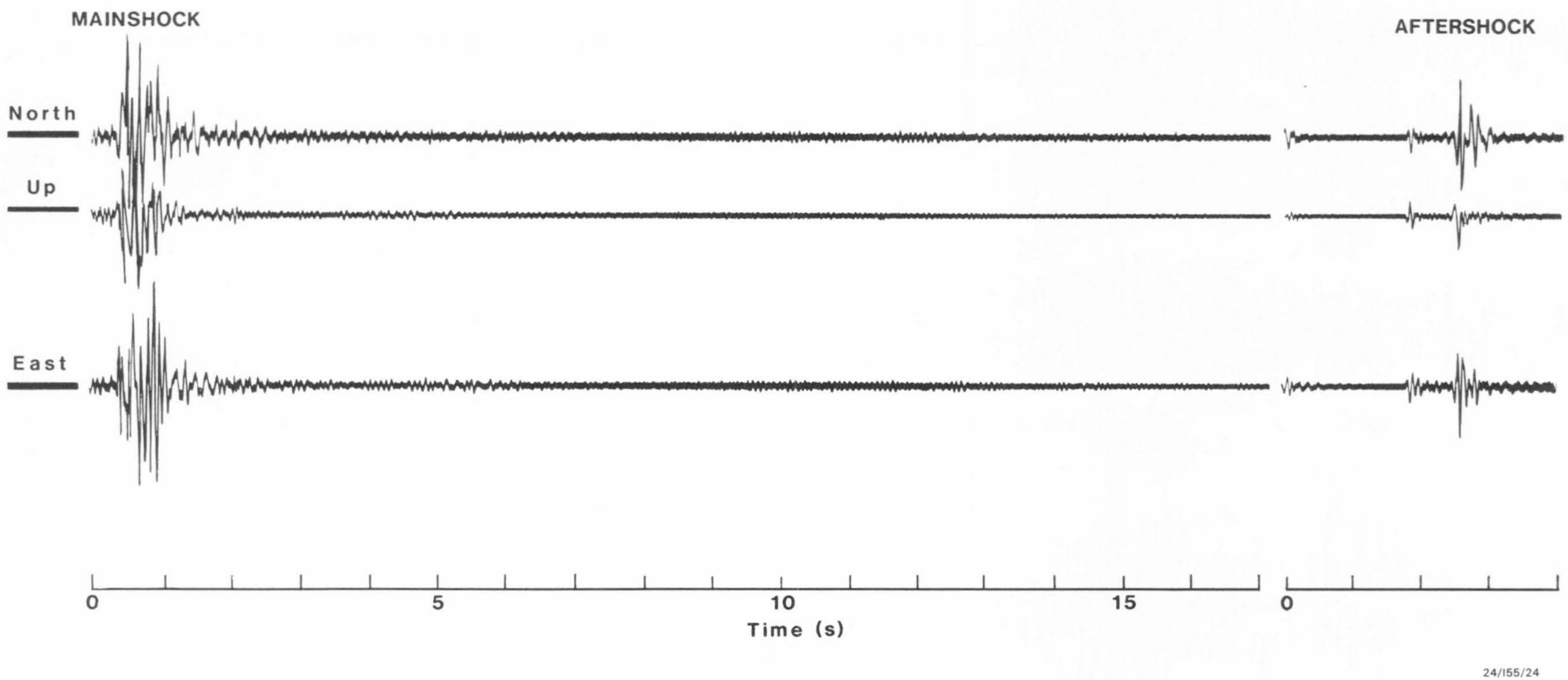


Fig. 14. Accelerogram of the Oolong, NSW earthquake and aftershock, 9 August 1984.

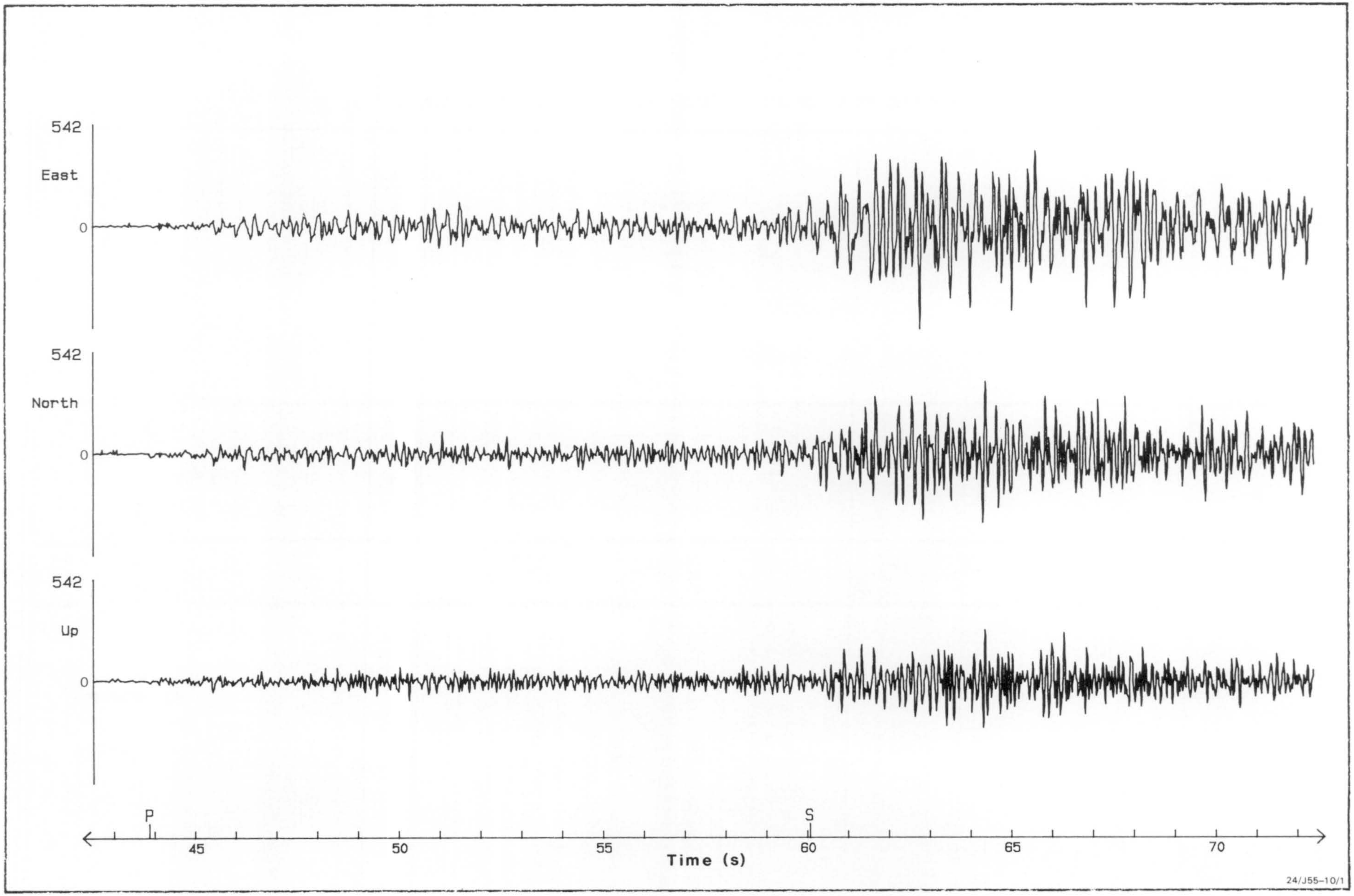


Fig. 15. Accelerogram of the Cape Liptrap, Vic. earthquake , 9 August 1984.

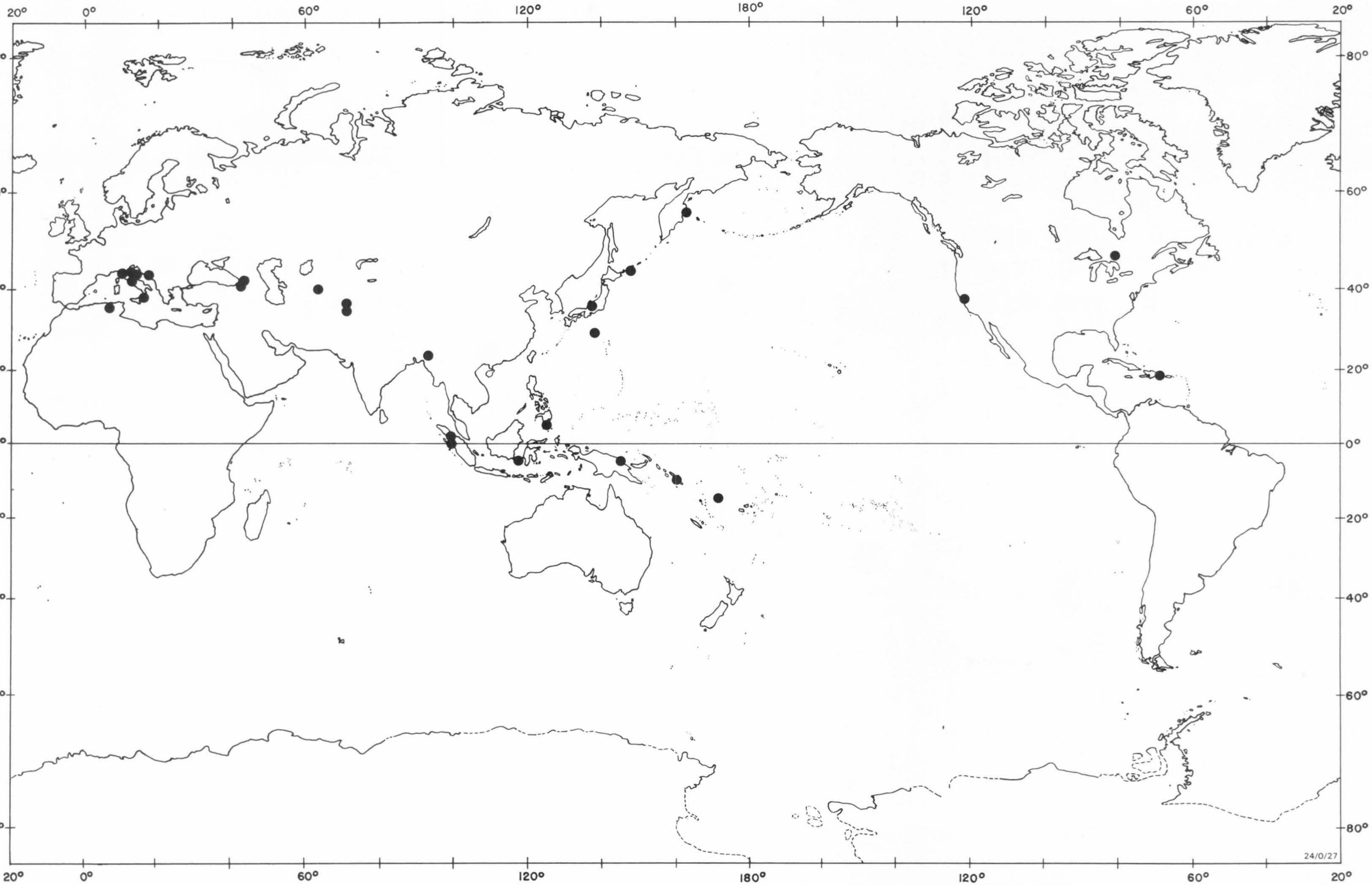


Fig. 16. Principal World earthquakes, 1984

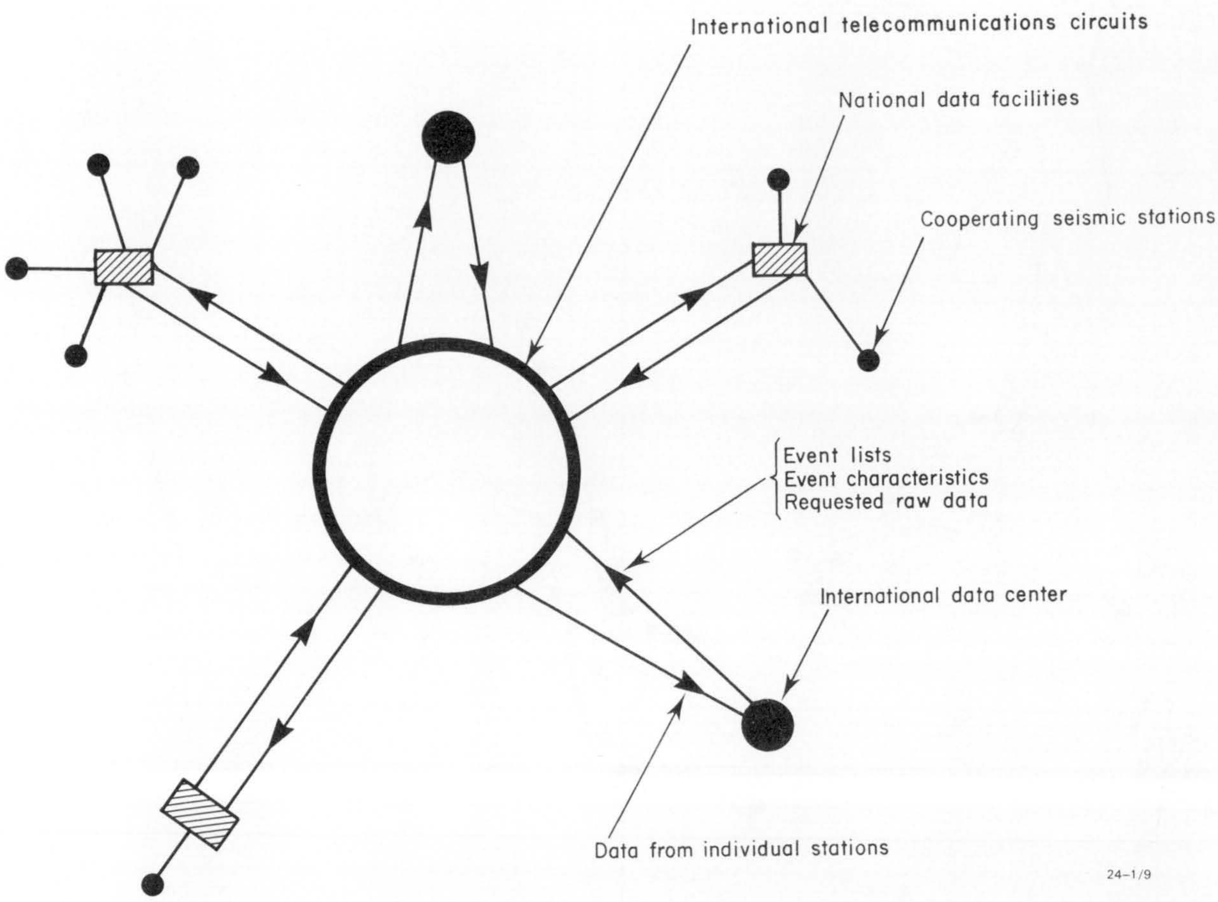


Fig. 17. International seismic data exchange network

building or engineered structure, such as a dam or tower, to record its response during an earthquake, or set up at temporary field sites wherever the seismicity is currently active.

Fifteen accelerograms were recorded during the year: two on an analogue SMA-1 recorder at 'Hillcrest' near Dalton, NSW and the rest in Victoria on PIT's digital accelerographs (Table 4). The recordings were made over the magnitude range of ML 0.7 to 4.3 and a distance range of 4 to 133 km with peak accelerations in the range 0.8 to 2500 $mm.s^{-2}$. The analogue recordings are particularly interesting, not just because of the high accelerations, but because they demonstrate that earlier accelerograms recorded on the same instrument at 'Hillcrest' (Smith & McEwin, 1980), did not trigger in time to record the peak ground motion. They caught just the tail of the coda. This is made clear in the second SMA-1 recording (Fig. 14), where the accelerograph was triggered and still recording when another aftershock occurred. Both P and S phases of the second aftershock can be seen clearly in Figure 14 but only the coda of the first aftershock that actually triggered the SMA-1 can be seen. Recording commenced too late to detect the maximum of either the P or S phases.

The digital accelerogram of Figure 15, recorded at PIT in Melbourne from the Cape Liptrap earthquake of 20 October, also shows the P and S phases which are characteristic of local earthquakes recorded on standard seismograms. Table 4 lists details of accelerographs installed in Australia during 1984, and Table 5, the parameters read from the accelerograms and the causative earthquakes.

No accelerograms were recorded in Tasmania, South Australia, or Western Australia during 1984.

(KEVIN McCUE, GARY GIBSON, & VAUGHAN WESSON)

PRINCIPAL WORLD EARTHQUAKES, 1984

Table 6 lists all earthquakes of magnitude 7.0 or greater, and damaging earthquakes of lesser magnitude, that occurred throughout the world in 1984. Figure 16 shows the locations of these earthquakes and the numbers of casualties.

Worldwide deaths in 1984 numbered about 73, compared with 2300 and 3300 in 1983 and 1982 respectively. The most disastrous earthquake was that of 18 September, in Turkey, but although 75000 homes were destroyed, only three people were killed. Earthquakes in Japan on 13 September and in the India-Bangladesh border region on 30 December killed 24 and 20 people respectively. The largest earthquake occurred on 7 February in the Solomon Islands region. It had a surface wave magnitude of 7.7 and resulted in some damage and landslides on southern Guadalcanal. It was felt throughout the Solomon Islands. These data are based on 'Earthquake Data Reports' published by the United States Geological Survey and the SEAN Bulletin of the Smithsonian Institution (SEAN, 1984).

(PETER GREGSON & KEVIN McCUE)

MONITORING OF NUCLEAR EXPLOSIONS

In 1983 the Department of Foreign Affairs, in consultation with the Department of Resources & Energy, proposed a new program to be conducted by the BMR , for the seismic monitoring of underground nuclear explosions. The new program was approved by Cabinet in July 1984, and funds were allocated in the 1984 Budget for the establishment over a three-year period of facilities to provide an independent national monitoring capability, and later a data analysis centre for international co-operative monitoring (McGregor & Denham, 1985). Although the newly formed nuclear monitoring group existed from only mid-August in 1984, this chapter gives the strategy adopted and implemented, and a summary of earlier work which led to the introduction of the program.

Background

Adequate verification is the cornerstone of any treaty, and under a Comprehensive Test Ban Treaty

(CTBT) which would ban all nuclear tests for all time in all environments, seismological techniques are expected to play a major part. In 1976 the then Conference of the Committee on Disarmament adopted a Swedish proposal to form an *Ad Hoc* Group of Scientific Experts (GSE) to consider international co-operative measures to detect seismic events. Mr P.M. McGregor (BMR) was the Australian delegate to the GSE from 1977 to 1985. Details of the GSE's work are contained in four reports (CD/558, 1978; CD/43, 1979; CD/448, 1984; CD/720, 1986). In brief, the GSE proposed and designed procedures for an 'international seismic data exchange' (ISDE, Fig. 17), which would comprise:

- a global network of 50 or more seismograph stations with improved equipment and upgraded procedures for extracting data
- an international exchange of these data over the World Meteorological Organisation's (WMO) Global Telecommunication System (GTS)
- processing of the data at special international data centres (IDCs) for use by participating States

The proposals on IDCs foresaw that at least one of the three should be situated in the southern hemisphere; by analogy with the WMO, and because one of the main GTS telecommunications hubs was located at Melbourne, Australia was suggested as the site for that IDC.

The data would be at two levels: Level I, basic parameters of seismic signals, to be reported for every event with minimum delay; and Level II, detailed records of waveforms to be provided in response to requests for additional information.

The GSE has conducted several experiments aimed at practical testing of features of the proposed ISDE. These experiments were:

- 1980, 6 October - 28 November: a trial exchange of level I data over the WMO/GTS, proposed and organised by Australia; 14 countries took part and it showed that much more detailed preparation and liaison with the WMO was needed than had been expected.
- 1980, 1-15 October: the 'common database' experiment initiated by Sweden; more than 20 countries provided Level I and Level II data to an experimental IDC in Stockholm. The object was to gain experience in IDC procedures and assess the value of Level II data in event-definition.
- 1981, 2 November - 11 December: a second GTS trial exchange, also organised by Australia, using more detailed procedures and with improved liaison with the WMO. Twenty-one countries took part, and the objectives included determination of error-rates, and transit-times of messages.
- 1982, 1 October - 7 November: a 5-countries test initiated by Sweden and USA, which used very large volumes of synthetic Level I data to determine the capacity of the GTS and to test IDC procedures for analysing data and distributing bulletins. Australia acted as a sender of southern hemisphere data; experimental IDCs were operated in Stockholm and Washington.
- 1984, 15 October - 14 December: a large scale experiment termed the GSE Technical Test (GSETT) 1984 which tested most of the main features of the ISDE. Details of GSETT and the Australian contribution are given below.

In addition to the GSE-sponsored experiments, national workshops were conducted by Sweden and the Federal Republic of Germany. The Swedish workshop was held in July 1979 to demonstrate the sort of facilities which might be needed at an IDC; in their report on the workshop, the Australian delegates (A. Behm, Department of Foreign Affairs; P.M. McGregor, BMR) recommended that '..Departments begin consideration of the development and establishment of an appropriate seismic data centre in Australia.'

The second workshop was held in July 1980 at the Graefenberg Observatory, Erlangen, FRG and its theme was the procedures for extracting Level I parameters at a digital broad-band station. The Graefenberg Observatory was then the most modern seismic array, and the workshop gave an excellent introduction to the equipment, procedures, and resources needed to provide an effective national monitoring service.

Establishment of nuclear monitoring program

Cabinet Decision 3996 of 31 July 1984 called for the establishment of a national capacity to monitor underground nuclear explosions; and after that, facilities for a GSE-type international data centre. Funding provided in the August budget was based on estimates made a year earlier; those estimates had been derived from information in the first report of the GSE and from discussions with experts from the experimental IDCs at Stockholm and Washington. In order to obtain more detailed advice, a consultant, Ms Ann Kerr of the US Defense Advanced Research Projects Agency (DARPA) visited BMR in September; the overall strategy adopted for the initial three-year period is based on her report (Kerr, 1984).

National monitoring capability (NMC)

As BMR is the Australian co-operating agency in the Joint Geological & Geophysical Research Station (JGGRS) at Alice Springs, and has operated a conventional seismograph station there since 1970, the first stage of the NMC would be to acquire the ASP array data. Planning allowed for the subsequent acquisition of signals from other digital high-quality stations at Charters Towers (CTA), Warramunga (WRA) and a station in Western Australia.

Given the limit of three years to establish both the NMC and an IDC it was clear that the basic requirements could be achieved only through the use of systems already developed, particularly in respect to software.

WMO/GTS data transmission experiment

In October 1984 an experiment on the global communication of seismic data, using the WMO's GTS was organised, on behalf of the GSE by BMR. Thirty-one member States participated in the experiment and nearly 4000 messages were exchanged in the two month period from 14 October through 14 December. Australian stations at Alice Springs, Charters Towers, Narrogin, and Mawson (Antarctica) participated in the experiment.

In general the results showed that the GTS could cope with the data rates required for transmitting parameter data but in some parts of the world (e.g. Africa and parts of South America) the capacity of the system was poor.

Nuclear explosions in 1984

Table 7 lists the 58 underground nuclear explosions detected throughout the world during 1984. The USSR detonated 29, USA 17, France, 8 and China and the UK 2 each. There is no evidence to suggest that any of these explosions exceeded the Threshold Test Ban Treaty limit of 150 kilotonnes.

(PETER McGREGOR & DAVID DENHAM)

TABLE 1. AUSTRALIAN REGION EARTHQUAKES, 1984 *: HYPOCENTRAL PARAMETERS

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N**
MUN	1 3	0318 29.0	26.320	126.850	10	3.2	3
MUN	1 8	1153 3.0	24.670	115.700	10	3.2	3
BMR	1 9	0829 29.4	26.170	130.920	0	3.7	6
BMR	1 11	1048 39.2	26.880	138.720	0	3.7	9
CAN	1 15	0632 46.5	33.690	148.640	16	3.2	11
CAN	1 20	1527 20.7	34.820	149.170	13	3.7	11
BMR	1 24	1441 35.1	22.040	129.760	0	4.0	6
PIT	1 27	1612 17.3	40.160	155.019	36	3.6	21
PIT	2 3	0429 7.5	40.203	149.337	8	3.2	17
MUN	2 3	1502 43.0	34.370	119.570	10	3.3	7
BMR	2 6	1443 6.8	35.448	147.408	7	3.5	20
CAN	2 8	1956 29.4	34.910	149.290	12	3.0	13
BMR	2 8	2250 32.0	11.400	134.800	15	4.1	4
MUN	2 21	0559 15.0	31.820	122.720	10	3.7	10
MUN	2 21	0559 51.0	31.820	122.720	10	4.2	10
CAN	2 28	1659 17.0	35.600	148.640	33	3.2	13
MUN	3 2	0501 57.0	17.660	122.420	10	4.1	5
CAN	3 5	1447 12.9	36.410	149.260	18	3.0	13
BMR	3 12	0524 15.0	11.800	133.200	0	3.1	3
CAN	3 14	0453 21.5	34.690	149.290	14	3.0	14
MUN	3 16	0346 6.0	14.950	123.380	37	5.2	10
ADE	3 17	0423 4.4	33.287	139.158	10	3.0	10
MUN	3 23	1938 14.0	21.290	125.520	19	4.0	8
MUN	3 24	0735 46.6	25.420	122.430	10	3.2	5
MUN	3 28	1453 33.7	30.720	117.080	10	4.2	9
MUN	3 28	1652 33.8	16.650	120.290	37	4.0	6
MUN	3 30	1015 26.0	27.140	124.550	10	3.3	8
TAU	4 10	0046 7.7	40.620	154.100	0	3.4	5
MUN	4 11	1354 21.0	15.480	119.340	10	4.3	8
BMR	4 12	2046 42.2	21.470	129.990	18	3.8	5
CAN	4 15	0410 37.6	33.570	148.830	19	3.0	13
MUN	4 17	0326 52.0	29.200	113.940	10	3.2	7
BMR	4 18	1220 10.0	21.260	132.190	0	3.0	4
MUN	4 23	1359 47.8	21.120	126.040	10	3.3	4
BMR	4 24	0911 22.0	12.400	135.600	0	3.2	1
MUN	5 17	0412 0.5	21.370	123.060	15	3.6	7
MUN	5 17	2021 19.6	27.780	115.840	30	3.0	5
MUN	5 20	0247 51.0	37.480	111.800	10	3.0	4
MUN	5 22	1852 20.0	24.630	110.740	37	3.8	10
BMR	5 27	0453 3.2	30.471	138.429	10	3.3	8
MUN	6 2	1536 36.0	22.750	113.380	10	3.4	6
BMR	6 3	0325 0.4	30.450	138.490	0	3.4	5
BMR	6 4	1948 23.4	34.760	149.220	3	3.3	17
MUN	6 7	2254 51.0	36.450	122.590	10	3.0	6
MUN	6 10	1559 25.9	32.230	117.370	10	3.0	6

* Only earthquakes of magnitude 3.0 or more are listed.

** Number of stations used to determine hypocentres.

\# Codes denote contributors listed in the text, page iii

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N**
BMR	6 11	1321 38.6	26.180	122.780	0	4.2	13
MUN	6 11	1331 0.0	26.280	122.510	10	3.3	2
MUN	6 12	1957 7.0	23.970	112.420	10	3.0	2
MUN	6 29	0204 54.4	32.230	117.410	10	3.4	7
MUN	6 30	1245 14.0	20.000	116.320	10	4.5	9
MUN	7 3	0155 43.0	20.020	116.380	37	4.1	8
BMR	7 7	0439 1.7	28.160	126.710	33	4.5	18
MUN	7 15	1120 17.6	18.610	113.250	10	3.4	3
CAN	7 19	2225 32.8	34.820	149.190	0	3.1	14
CAN	7 20	2156 20.2	32.520	151.370	21	3.9	9
BMR	7 25	1156 25.0	21.000	129.700	0	3.0	3
CAN	7 26	0840 32.7	34.830	149.190	15	3.4	14
CAN	7 28	0518 33.6	35.100	148.900	10	3.4	13
BMR	7 29	1806 43.1	36.170	144.100	33	3.1	9
MUN	8 6	1732 6.0	36.700	123.700	37	4.4	12
BMR	8 7	2051 12.6	15.550	127.320	0	3.5	6
BMR	8 7	2136 21.0	23.300	130.300	0	3.0	3
BMR	8 7	2325 34.0	23.150	130.100	0	3.5	3
BMR	8 8	0349 18.0	23.200	130.200	0	3.2	3
BMR	8 8	0357 7.0	23.200	130.150	0	3.8	3
MUN	8 8	1524 58.1	19.610	119.340	10	3.0	3
CAN	8 8	2016 19.3	34.790	149.200	16	3.5	12
BMR	8 9	0630 12.9	34.799	149.170	7	4.3	25
CAN	8 9	0636 29.6	34.820	149.150	0	3.3	12
CAN	8 9	0638 12.0	34.830	149.190	0	3.2	14
CAN	8 9	0641 25.2	34.820	149.180	0	3.1	13
CAN	8 9	0644 4.1	34.810	149.180	0	3.1	11
CAN	8 9	0747 10.9	34.830	149.190	15	3.2	14
CAN	8 9	0837 34.6	34.810	149.200	0	3.2	14
CAN	8 9	1001 21.9	34.820	149.190	14	3.9	14
CAN	8 9	1033 38.7	34.830	149.190	16	3.8	13
CAN	8 9	1037 17.2	34.810	149.120	10	3.3	14
CAN	8 9	1143 49.5	34.800	149.180	16	3.0	12
CAN	8 9	1401 27.8	34.820	149.190	14	3.8	13
CAN	8 9	1522 46.5	34.800	149.170	14	3.3	14
CAN	8 9	1535 55.8	34.830	149.200	15	3.2	13
CAN	8 10	0128 34.3	34.820	149.180	0	3.2	13
CAN	8 10	0129 55.8	34.820	149.190	0	3.7	12
CAN	8 10	0146 16.9	34.810	149.220	0	3.2	13
CAN	8 12	0128 39.8	34.830	149.190	16	3.0	12
CAN	8 12	1110 23.3	34.800	149.170	0	3.0	11
CAN	8 12	1256 17.0	34.810	149.190	15	3.3	13
CAN	8 13	0331 55.7	34.810	149.170	0	3.4	12
BMR	8 13	2237 20.0	23.150	130.100	0	3.3	2
BMR	8 13	2239 18.0	23.200	130.200	0	3.1	2
MUN	8 18	1407 58.0	22.000	126.490	19	3.2	6
MUN	8 19	2036 7.0	22.080	126.510	10	3.0	5
TAU	8 26	0723 27.8	37.730	148.970	0	3.4	5
PIT	8 26	0723 46.9	39.153	142.389	17	3.7	35
MUN	9 1	2255 50.0	27.140	113.320	10	3.0	5
BMR	9 8	0437 55.0	23.150	130.100	0	3.3	3
BMR	9 8	0451 0.0	23.200	130.200	0	3.0	2

DATA# SOURCE	DATE mo dy	TIME(UT) hrmn sec	LAT° S	LONG° E	DEPTH (km)	MAGNITUDE	N**
MUN	9 10	0154 22.0	20.090	123.250	10	3.3	7
MUN	9 10	0751 18.0	31.590	123.550	10	3.3	6
BMR	9 12	2102 12.6	22.040	126.540	0	4.4	13
MUN	9 13	1948 22.0	26.460	111.310	10	3.1	3
MUN	9 15	1002 40.0	22.050	126.550	10	3.7	10
BMR	9 15	1623 44.1	26.050	130.860	0	3.6	6
CAN	9 16	2129 8.9	36.420	150.240	17	3.0	11
CAN	9 22	0911 31.9	34.810	149.170	0	3.0	12
MUN	9 23	2102 0.0	21.910	126.480	10	3.2	6
PDE	9 27	1924 3.3	12.490	118.654	33	4.2	10
MUN	9 29	2137 20.0	30.680	117.090	10	3.0	4
MUN	9 30	1819 6.0	28.300	120.690	10	3.2	9
MUN	10 1	1547 44.0	18.760	126.830	10	3.6	4
BMR	10 14	0047 2.5	26.740	137.330	0	3.6	6
MUN	10 16	1357 2.0	10.350	131.630	10	3.3	3
PIT	10 20	0516 21.2	38.972	145.899	14	4.3	47
PIT	10 22	0004 30.5	38.948	145.917	15	3.5	36
MUN	10 27	1846 24.0	23.560	114.300	10	3.0	4
GSQ	10 30	0629 48.2	26.313	151.965	6	3.9	14
CAN	11 1	0154 1.9	34.790	149.160	16	3.5	11
CAN	11 1	0249 4.8	34.800	149.180	13	3.2	12
CAN	11 1	0440 20.6	34.800	149.190	0	3.0	13
MUN	11 3	2006 43.0	11.660	124.880	10	3.9	4
CAN	11 4	1424 45.5	34.790	149.180	16	3.5	13
CAN	11 6	0818 29.6	34.790	149.210	9	3.1	13
CAN	11 7	1819 56.8	34.790	149.180	14	3.7	13
CAN	11 11	0007 27.9	34.800	149.190	15	3.3	14
MUN	11 18	2119 27.0	17.670	122.890	37	3.4	6
MUN	11 21	0428 8.0	21.390	112.390	33	3.3	5
GSQ	11 24	2248 1.8	24.698	150.703	30	3.7	22
GSQ	11 24	2250 19.3	24.569	150.665	18	3.5	13
CAN	11 28	1724 7.0	34.780	149.180	15	3.2	13
CAN	12 4	1317 54.6	34.770	149.180	12	3.1	14
CAN	12 4	1318 56.0	34.750	149.180	0	3.0	6
MUN	12 7	1600 23.0	18.630	123.250	10	3.2	5
MUN	12 13	1648 13.0	26.250	124.910	10	3.2	5
MUN	12 15	1050 32.0	23.550	129.460	10	3.0	4
MUN	12 28	2148 51.0	19.270	125.810	10	3.5	6
MUN	12 28	2153 5.6	23.780	114.590	10	3.2	4

TABLE 2. AUSTRALIAN SEISMOGRAPH STATIONS, 1984

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
QUEENSLAND						
AWMQ	MT GOLEGUMMA	24.046	151.316	125	GSQ	1
BDMQ	BOONDOOMA DAM	26.112	151.444	320	GSQ	1
BFCQ	GLENDON CROSSING	20.614	147.161	160	GSQ	1
BFRQ	GLENROY	20.549	147.105	160	GSQ	1
BMGQ	MT GRAHAM	20.614	147.061	160	GSQ	1
BRS	MT NEBO BRISBANE	27.392	152.775	525	QLD	5
BSL	BRUSLEE	20.275	147.299	185	GSQ	1
DLB	DALBEG	20.151	147.264	70	GSQ	1
DNG	DOONGARA	20.555	146.475	280	GSQ	1
CTAO	CHARTERS TOWERS	20.088	146.255	357	QLD	2;4
ISQ	MOUNT ISA	20.715	139.553	500	BMR	1
MCP	Mt COOPER	20.552	146.806	300	GSQ	1
MHP	Mt HOPE	21.396	146.802	200	GSQ	1
RMQ	ROMA	26.489	148.755	360	BMR	1
UKA	UKALUNDA	20.899	147.127	200	GSQ	1
WBA	BUARABA	27.353	152.308	100	GSQ	1
WMB	MT BRISBANE	27.115	152.550	160	GSQ	1
WPL	PLAINLAND	27.606	152.417	160	GSQ	1
WPM	PINE MOUNTAIN	27.536	152.735	35	GSQ	1
WRC	REEDY CREEK	27.187	152.663	190	GSQ	1
WTG	TOOGOOLAWAH	27.146	152.333	130	GSQ	1
WTR	THALLON ROAD	27.528	152.465	100	GSQ	1
WWH	WIVENHOE HILL	27.370	152.587	190	GSQ	1
NORTHERN TERRITORY						
ASPA	ALICE SPRINGS	23.667	133.901	600	BMR	3
MTN	MANTON	12.847	131.130	80	BMR	1
WRA	WARRAMUNGA ARRAY	19.944	134.353	366	CAN	3
WESTERN AUSTRALIA						
BAL	BALLIDU	30.607	116.707	300	MUN	1
KLB	KELLERBERRIN	31.578	117.760	300	MUN	1
KLG	KALGOORLIE	30.783	121.458	360	MUN	1
KNA	KUNUNURRA	15.750	128.767	150	PWD/MUN	1
MBL	MARBLE BAR	21.160	119.833	200	MUN	1
MEK	MEEKATHARRA	26.613	118.545	520	MUN	1
MRWA	MORAWA	29.218	115.996	300	MUN	1
MUN	MUNDARING	31.978	116.208	253	MUN	2
NAU	NANUTARRA	22.544	115.500	80	MUN	1
NWAO	NARROGIN	32.927	117.233	265	MUN	4
WBN	WARBURTON	26.140	126.578	457	MUN	1
RKG	ROCKY GULLY	34.570	117.010	300	MUN	1
NEW SOUTH WALES AND AUSTRALIAN CAPITAL TERRITORY						
AVO	AVON	34.376	150.615	532	CAN	1
BWA	BOOROWA	34.425	148.751	656	CAN	1
CAH	CASTLE HILL	34.647	149.242	700	CAN	1
CAN	CANBERRA (ANU)	35.321	148.999	650	CAN	1
CBR	CABRAMURRA	35.943	148.393	1537	CAN	1
CMS	COBAR	31.487	145.828	225	BMR	1

TABLE 2 (cont.)

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
CNB	CANBERRA (BMR)	35.314	149.362	855	BMR	1
COO	COONEY	30.578	151.892	650	BMR	1
IVY	INVERALOCHY	34.972	149.718	770	CAN	1
JNL	JENOLAN	33.826	150.017	829	CAN	1
KHA	KHANCOBAN	36.214	148.129	435	CAN	1
LER	LERIDA	34.934	149.364	940	CAN	1
MEG	MEANGORA	35.101	150.037	712	CAN	1
RIV	RIVERVIEW	33.829	151.159	21	RIV	2
SBR	SOUTH BLACK RANGE	35.425	149.533	1265	CAN	1
STK	STEPHENS CREEK	31.882	141.592	213	BMR	1
TAO	TALBINGO	35.596	148.290	570	CAN	1
WAM	WAMBROOK	36.193	148.883	1290	CAN	1
WER	WEROMBI	33.950	150.580	226	CAN	1
YOU	YOUNG	34.278	148.382	503	CAN	1
SOUTH AUSTRALIA						
ADE	ADELAIDE	34.967	138.713	655	ADE	2
CLV	CLEVE	33.691	136.495	238	ADE	1
EDO	ENDILLOE	32.322	138.048	300	ADE	1
HTT	HALLETT	33.430	138.921	708	ADE	1
HWK	HAWKSNEST	29.958	135.203	180	ADE	1
MGR	MT GAMBIER	37.728	140.571	190	ADE	1
NBK	NECTAR BROOK	32.701	137.983	180	ADE	1
PNA	PARTACOONA	32.006	138.165	180	ADE	1
RPA	ROOPENA	32.725	137.403	95	ADE	1
UMB	UMBERATANA	30.240	139.128	610	ADE	1
WKA	WILLALOOKA	36.417	140.321	40	ADE	1
WRG	WOOMERA	31.105	136.763	168	ADE	1
VICTORIA						
ABE	ABERFELDY	37.719	146.389	549	PIT	1
BFD	BELLFIELD	37.177	142.545	235	BMR	1
BUC	BUCRABANYULE	36.238	143.498	210	PIT	1
DRT	DARTMOUTH	36.590	147.493	950	CAN	1
GVL	GREENVALE	37.619	144.901	188	PIT	1
HOP	MOUNT HOPE	35.995	144.207	300	PIT	1
JEN	JEERALANG JUNCTION	38.351	146.420	330	PIT	1
KGD	KANGAROO GROUND	37.699	145.269	80	PIT	1
LIL	LILYDALE	37.694	145.342	80	PIT	1
MAL	MARSHALL SPUR	37.749	146.292	1076	PIT	1
MEM	MERRIMU	37.637	144.497	160	PIT	1
MIC	MOUNT ERICA	37.944	146.359	805	PIT	1
PAT	PLANE TRACK	37.857	146.456	771	PIT	1
PEG	PEGLEG	36.985	144.091	340	PIT	1
PNH	PANTON HILL	37.635	145.271	180	PIT	1
RUS	RUSHWORTH	36.662	144.947	145	PIT	1
TOM	THOMSON	37.810	146.348	941	PIT	1
TOO	TOOLANGI	37.572	145.490	604	BMR	5
TASMANIA						
MOO	MOORLANDS	42.442	146.190	325	TAU	1
SAV	SAVANNAH	41.721	147.189	180	TAU	1

TABLE 2 (cont.)

CODE	NAME	LAT° S	LONG° E	ELEV. (m)	OP.*	TYPE**
SFF	SHEFFIELD	41.337	146.307	213	TAU	1
SPK	SCOTTS PEAK	43.038	146.275	425	TAU	1
STG	STRATHGORDON	42.751	146.053	350	TAU	1
SVR	SAVAGE RIVER	41.489	145.211	360	TAU	1
TAU	TASMANIA UNIV.	42.910	147.321	132	TAU	2
TRR	TARRALEAH	42.304	146.450	579	TAU	1
MCQ	MACQUARIE ISLAND	54.498	158.957	14	BMR	1
ANTARCTICA						
MAW	MAWSON	67.607	62.872	15	BMR	5

* Operator; refers to contributors listed on page iii.

** Type of seismograph

1. Short period (vertical and/or horizontal)
2. World Wide Standard Seismograph Station
3. Seismic Array
4. Seismological Research Observatory
5. Long and short period seismographs

TABLE 3. FOCAL MECHANISM OF THE 1984 OOLONG, NSW, EARTHQUAKE

Solution 1

	Azimuth	dip
P-axis	097	28
T-axis	333	47
B-axis	206	31

Double couples	A	B
Strike	032	320
Dip	83	32
Slip	58	21

Solution 2

	Azimuth	dip
P-axis	274	03
T-axis	166	73
B-axis	005	10

Double couples	A	B
Strike	020	346
Dip	50	45
Slip	117	117

TABLE 4. AUSTRALIAN ACCELEROGRAPHS, 1984

	LAT° S	LONG° E	ELEV.(m)	FOUNDATION	TYPE	OWNER
New South Wales						
Oolong	34.773	149.163	600	Firm soil/ granite	SMA-1	BMR
Mt Mundoonen	34.830	149.043	817		SMA-1	BMR
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	600	Dam wall	SMA-1	WRC
Hume Weir	36.110	147.043	329	Downstream bank	SMA-1	WRC
Hume Weir	36.110	147.043	600	Left hand abutment	SMA-1	WRC
AAEC	34.053	150.978	80	Reactor basement	SMA-1	AAEC
South Australia						
Kangaroo Ck Dam	34.87	138.78	244	Slates/schists	MO2	EWSSA
Little Para Dam	34.75	138.72	102	Dolomite		EWSSA
Modbury Hospital	34.83	138.70	50	Marl & clay	MO2	PWDSA
Admin. Centre	34.925	138.608	50	Alluvium	MO2	PWDSA
Tasmania						
Gordon Dam	42.71	145.97	350	Quartzite	MO2	HEC
Western Australia						
Meckering						
Kelly's	31.694	116.982	200	Alluvium/ granite	MO2	BMR
Morrell's	31.659	117.089	220	Alluvium/ granite	MO2	BMR
Cadoux	30.696	117.161	300	Granite	MO2	BMR
Mundaring Weir	31.967	116.169	250	Concrete wall	SMA-1	PWDWA
Ord River Dam	16.113	128.738	120	Rockfill	MO2	PWDWA
Perth						
Telecom	31.953	115.850	10	Basement	SMA-1	TEL
Exchange	31.953	115.850	40	Middle floor	SMA-1	TEL
Building	31.953	115.850	70	Top floor	SMA-1	TEL
Victoria						
Jeeralong (JNA)	38.351	146.419	330	Mesozoic sediments	PIT	PIT
Plane Track (PTA)	37.357	146.357	771	Palaeozoic sediments	PIT	PIT
Dartmouth Dam	36.570	147.580	520	Dam crest	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	520	Hoist house	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	360	Downstream bank	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	420	Downstream face	SMA-1	RWCV
Dartmouth Dam	36.570	147.580	360	Access tunnel	SMA-1	RWCV
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO
Animal Health Lab	38.15	144.39	10		SMA-1	CSIRO

OWNER KEY

AAEC = Australian Atomic Energy Commission
BMR = Bureau of Mineral Resources, Canberra or Mundaring
EWSSA = Engineering & Water Supply Department, South Australia
HEC = Hydroelectric Commission, Tasmania
PIT = Phillip Institute of Technology
PWDSA = Public Works Department, South Australia
PWDWA = Public Works Department, Western Australia
TEL = Telecom (Perth)
WRC = Water Resources Commission, NSW
RWCV = Rural Water Commission, Victoria

TABLE 5. ACCELEROGRAM DATA, 1984

YR MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
84 01 14	0658	37.55	146.74	2.4	PTA	45.8/42.4	PZ	0.04	1.05
							PN	0.04	1.05
							PE	0.03	1.39
							SZ	0.05	1.61
							SN	0.04	2.24
							SE	0.05	2.10
84 03 05	0906	38.21	146.48	1.5	JNA	22.9/16.5	PZ	0.05	0.53
							PN	0.04	0.36
							PE	0.04	0.66
							SZ	0.08	1.34
							SN	0.07	1.11
							SE	0.06	0.76
84 04 02	1333	37.71	146.43	1.8	PTA	22.3/16.6	PZ	0.03	4.48
							PN	0.03	5.45
							PE	0.03	6.46
							SZ	0.04	3.33
							SN	0.04	4.90
							SE	0.06	5.03
84 05 22	0955	38.00	146.42	1.5	PTA	22.3/16.5	PZ	0.04	0.45
							PN	0.05	0.64
							PE	0.03	0.68
							SZ	0.06	0.81
							SN	0.05	0.89
							SE	0.06	0.92
84 06 05	0656	37.94	146.50	1.3	PTA	20.0/10.3	PZ	0.04	2.17
							PN	0.03	1.90
							PE	0.03	2.42
							SZ	0.04	1.94
							SN	0.04	2.36
							SE	0.06	2.55
84 07 10	2212	38.45	146.18	2.7	JNA	29.1/23.5	PZ	0.04	2.51
							PN	0.05	2.68
							PE	0.06	1.68
							SZ	0.09	3.20
							SN	0.08	4.71
							SE	0.08	5.05
84 08 09	0630	34.81	149.17	4.3	OOL	3.0/5.0	SZ	0.04	1068.2
							SN	0.07	2175.6
							SE	0.05	2989.0
84 09 08	1001	34.82	149.13	3.3	OOL	3.0/5.0	SZ	0.06	778.0
							SN	0.06	1497.0
							SE	0.05	1279.0

YR MN DY	TIME	LAT° S	LONG° E	ML	LOC	H/E	COM	T(s)	ACC
84 10 20	0516	38.97	145.90	4.3	JNA	83.8/82.6	SZ	0.17	10.73
							SN	0.17	11.40
							SE	0.17	13.41
84 10 20	0516	38.97	145.90	4.3	PTA	133.8/133.0	PZ	0.10	1.57
							PN	0.13	1.83
							PE	0.17	2.66
							SZ	0.09	5.40
							SN	0.13	7.92
							SE	0.14	9.00
84 10 22	0004	38.95	145.92	3.5	PTA	130.7/129.9	SZ	0.11	2.62
							SN	0.13	3.65
							SE	0.17	3.54
84 10 31	0416	38.49	146.25	2.4	JNA	25.4/21.1	PZ	0.08	1.45
							PN	0.07	1.69
							PE	0.06	1.33
							SZ	0.14	2.71
							SN	0.08	2.91
							SE	0.13	4.18
84 10 31	0416	38.49	146.25	2.4	PTA	66.8/65.3	SZ	0.07	1.33
							SN	0.10	1.74
							SE	0.10	1.91
84 11 19	2124	38.42	146.38	1.8	JNA	19.15/8.4	PZ	0.05	0.81
							PN	0.05	0.69
							PE	0.04	0.63
							SZ	0.08	1.01
							SN	0.07	1.51
							SE	0.06	1.51
84 11 30	0036	37.94	146.44	0.7	PTA	15.1/9.2	PZ	0.03	0.94
							PN	0.03	0.72
							PE	0.03	1.02
							SZ	0.06	0.85
							SN	0.05	0.88
							SE	0.06	1.06

YR = YEAR, MN = MONTH, DY = DAY, TIME = UNIVERSAL TIME, ML = RICHTER MAGNITUDE, LOC = ACCELEROGRAPH LOCATION, H/E = HYPOCENTRAL/EPICENTRAL DISTANCE, COM = COMPONENT, T(s) = GROUND PERIOD IN SECONDS, ACC = PEAK GROUND ACCELERATION IN $mm.s^{-2}$.

TABLE 6. PRINCIPAL WORLD EARTHQUAKES, 1984

(Earthquakes of magnitude 7.0 or greater, or causing damage or fatalities.
PAS--Pasadena, BRK--Berkeley, PMR--Palmer, Alaska, PAL--Palisades, New York,
JMA--Japan Meterological Agency, TRI--Trieste, NEIS--US Geological Survey)*

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
8 Jan	15 24 13.5	Sulawesi	2.82 S	118.81 E	6.0 mb, 6.6 Ms 6.7 Ms(BRK)

Depth 33 km. Two people killed, 23 injured, and damage to buildings in the Mamuju area.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
1 Feb	14 22 07.4	Afghanistan	34.62 N	70.48 E	5.9 mb, 5.8 Ms

Depth 33 km. One person killed, 35 injured, and damage in the Jalalabad area. Felt (IV) in the Ishkashim-Khorog area, USSR. Felt also in northwestern Pakistan.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
7 Feb	21 33 21.4	Solomon Islands	10.01 S	160.47 E	6.6 mb, 7.5 Ms 7.5 Ms(BRK) 7.7 Ms(PAL) 7.3 Ms(PAS)

Depth 18km. Damage on southern Guadalcanal and some landslides reported. Felt throughout the Solomon Islands, (VI) at Honiara and (III) at Rabaul, New Britain.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
16 Feb	17 18 41.6	Hindu Kush region	36.43 N	70.83 E	6.0 mb

Depth 208 km. Four people killed, 13 injured, and considerable damage in the Chitral-Landi Kotal, Pakistan area. Felt in the areas of Faisalabad, Islamabad, Lahore and Rawalpindi, Pakistan. Minor damage (VI) in the Ishkashim-Khorog area and at Parkhar, USSR. Felt strongly in much of northwestern Afghanistan, Northern India, and (III) in the Samarkand-Frunze, USSR area.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
6 Mar	02 17 21.2	South of Honshu, Japan	29.38 N	138.94 E	6.2 mb 6.6 mb(BRK)

Depth 457 km. One person died from a heart attack in Yokohama and one person injured in the Tokyo area. Felt (IV JMA) on Honshu.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
19 Mar	20 28 38.2	Uzbek SSR	40.32 N	63.35 E	6.5 mb, 7.0 Ms 7.1 Ms(BRK)

Depth 26 km. At least 100 people injured and extensive damage (IX) in the Gazli area. Damage (VIII) at Dzhangeldy and (VII) in the Bukhara area. Felt (VI) at Samarkand, (V) at Dzhiak, and (IV) at Tashkent. Felt (VI) at Mary and (V) at Ashkhabad, Turkmeniya. Felt in large parts of Soviet Central Asia and at Mashhad, Iran.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
24 Mar	09 44 02.6	Kuril Islands	44.12 N	148.19 E	6.1 mb, 7.0 Ms 6.7 Ms(BRK)

Depth 44 km. Felt (V) at Yuzhno-Kurilsk and (IV) on Shikotan. Felt (II JMA) at Nemuro, Obihiro and Urakawa, Hokkaido, and at Hachinohe and Miyako, Honshu. Fourteen cm. tsunami at Nemuro, Hokkaido. Possible multiple event.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
27 Mar	20 06 33.2	Near north coast of Papua New Guinea	4.65 S	145.81 E	5.8 mb, 6.6 Ms 6.8 Ms(BRK)

* Based on USGS 'Earthquake Data Reports' and the SEAN bulletins.

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 28 km. Eleven people injured and many buildings destroyed (VIII) on Karkar. Minor ground fissures and two holes formed, 3-7 m in diameter and 2 m deep.					
22 Apr	17 39 23.1	Central Italy	43.62 N	10.19 E	4.3 mb
Depth 10 km. Three people died of heart attacks. Damage (VI) in the Livorno-Pisa area.					
24 Apr	21 15 19.0	Central California	37.32 N	121.70 W	5.7 mb, 6.1 Ms 6.2 ML(BRK)
Depth 8 km. Maximum intensity VII in the Morgan Hill area. Twenty-one people sustained minor injuries in the Morgan Hill-San Jose area. Damage from the earthquake estimated at 7.5 million dollars with the most damage occurring in the Jackson Oaks subdivision east of Morgan Hill. The earthquake was felt from Bakersfield to Sacramento and from San Fancisco to Reno. A magnitude 3.6 aftershock occurred approximately 5 minutes after the main shock.					
29 Apr	05 03 00.0	Central Italy	43.26 N	12.56 E	5.2 mb, 5.3 Ms
Depth 12km. Thirty-six people injured and extensive damage (VIII) in the Assisi-Gubbio-Perugia area. About 7,500 people homeless. Felt strongly in central Italy.					
7 May	17 49 41.6	Southern Italy	41.77 N	13.90 E	5.5 mb, 5.8 Ms 5.8 Ms(BRK) 6.0 ML(TRI)
Depth 10 km. Three people killed, at least 100 injured, and extensive damage (VIII) in the Abruzzo area. Felt throughout southern Italy.					
11 May	10 41 49.9	Southern Italy	41.83 N	13.96 E	5.2 mb, 5.2 Ms 5.4 ML(TRI)
Depth 13 km. Three people died from heart attacks, at least 63 injured, and damage (VIII) in the Abruzzo region. Felt at Rome and Naples.					
13 May	12 45 55.8	Adriatic Sea	42.98 N	17.73 E	5.1 mb, 5.1 Ms
Depth 10 km. One person killed from rockfalls in the Hercegovina region of Yugoslavia. Felt (VII) at Dubrovnik and (VI) at Titograd, Yugoslavia and (III) at Trieste, Italy.					
20 Jun	14 12 27.0	Ontario (OTT)	46.58 N	80.80 W	3.4 mbLg
Depth 1 km. Rockburst in the Falconbridge mine. Four miners killed.					
24 Jun	18 18 51.0	Dominican Republic Region	18.01 N	69.20 W	5.1 mb, 4.7 Ms
Depth 32 km. Five people killed in the Bayaguana area. Felt throughout eastern Dominican Republic.					
27 Aug	06 41 26.2	Northern Sumatera	1.76 N	99.08 E	5.1 mb, 5.2Ms
Depth 33 km. One hundred and twenty-three people injured; 350 homes and 65 government buildings damaged in the Taratung area. Felt at Kuala Lumpur and Pinang, Malaysia.					
13 Sep	23 48 49.9	Honshu, Japan	35.79 N	137.49 E	6.0 mb, 6.1 Ms 6.3 Ms(BRK)

Date	Origin time(UT)	Region	Lat.	Long.	Magnitude
Depth 2 km. At least 24 people killed and severe damage and landslides (IV JMA) in the Otaki area. Felt (IV JMA) at Iida and Kofu, (III JMA) in the Tokyo-Yokohoma, Kyoto-Nagoya and Nagano-Toyama areas, (II JMA) at Tateyma, Utsunomiya and on Oshima, and (I JMA) at Ajiro, Mito, Aikawa and on Dogo.					
18 Sep	13 26 01.8	Turkey	40.89 N	42.22 E	5.3 mb, 6.4 Ms
Depth 10 km. Three people killed, 38 injured, and 75 000 houses destroyed or damaged in the Olur-Senkaya area.					
6 Oct	06 37 26.9	Algeria	36.01 N	6.72 E	4.7 mb
Depth 10 km. Many homes collapsed and many families evacuated in the Ain-el-Bordj-Oum-el-Bouahji area.					
18 Oct	09 46 18.4	Turkey	40.59 N	42.48 E	5.2 mb, 5.4 Ms
Depth 33 km. Three people killed, some injured, and damage in the Erzurum-Senkaya region.					
25 Oct	01 12 08.7	Southern Italy	38.69 N	16.03 E	4.4 mb
Depth 98 km. Twelve people injured and many houses destroyed.					
17 Nov	06 49 30.0	Northern Sumatera	0.19 N	98.04 E	6.2 mb, 7.2 Ms 7.4 Ms(BRK)
Depth 33 km. One person injured and two buildings damaged on Nias. Felt strongly at Tarutung. Felt in the Medan-Padang area.					
20 Nov	08 15 16.0	Mindanao Philippine Islands	5.21 N	125.25 E	6.6 mb 7.1 mb (NEIS)
Depth 202 km. Slight damage in the Davao area. Felt (IV RF) at Cayagan de Oro and Surigao del Sur, (II RF) at Zamboanga.					
23 Nov	04 46 06.4	Vanuatu Islands region	14.30 S	171.28 E	5.8 mb, 6.7 Ms 7.1 Ms(BRK)
Depth 33 km.					
28 Dec	10 37 53.7	Near east coast of Kamchatka	56.17 N	163.58 E	6.2 mb, 7.0 Ms
Depth 33 km.					
30 Dec	23 33 39.1	India Bangladesh border region	24.60 N	92.84 E	5.8 mb
Depth 33 km. At least 20 people killed, many injured, 10 000 homeless and extensive damage in southern Assam, India.					

TABLE 7. NUCLEAR EXPLOSIONS, 1984

DATE	TIME(UT)	MAGNITUDE mb	Ms	LAT		LONG		SITE*	REF#
01 31	1530 00.0	4.1		37.11	N	116.12	W	NTS	PDE
02 15	1700 00.1	5.0		37.22	N	116.18	W	NTS	PDE
02 19	357 03.5	5.9	4.7	49.86	N	78.81	E	EKaz	ISC
03 01	1745 00.0	5.9	4.4	37.07	N	116.05	W	NTS	PDE
03 07	239 06.4	5.7	4.1	50.00	N	78.99	E	EKaz	ISC
03 29	519 08.3	5.9	4.5	49.87	N	78.97	E	EKaz	ISC
03 31	1429 59.5	4.5		37.13	N	116.04	W	NTS	ISC
04 15	317 09.3	5.7	4.5	49.69	N	78.14	E	EKaz	ISC
04 25	109 03.7	6.0	4.8	49.91	N	78.91	E	EKaz	ISC
05 01	1904 59.1	5.4	4.3	37.11	N	116.03	W	NTS	ISC
05 02	1349 59.8			37.19	N	116.02	W	NTS	ISC
05 08	1726 00.0	5.3		21.80	S	139.40	W	Mur	NZ
05 12	1730 58.6	5.7	3.8	21.83	S	138.97	W	Mur	ISC
05 16	1559 58.9			37.09	N	115.97	W	NTS	ISC
05 26	313 12.5	6.1	5.8	49.93	N	79.03	E	EKaz	ISC
05 31	1303 59.2	5.8	4.3	37.13	N	116.05	W	NTS	ISC
06 12	1716 00.0	4.5		21.80	S	139.40	W	Mur	NZ
06 16	1743 58.5	5.3		21.85	S	139.00	W	Mur	ISC
06 20	1515 00.7	4.7		37.02	N	116.06	W	NTS	ISC
06 23	257 00.0			50	N	79	E	EKaz	FOA
07 12	1359 59.9	3.6		37.19	N	116.01	W	NTS	PDE
07 14	109 10.5	6.2	4.8	49.85	N	78.92	E	Kaz	ISC
07 21	259 57.2	5.4	4.6	51.37	N	53.28	E	USSR	ISC
07 21	304 57.1	5.3	4.3	51.38	N	53.29	E	USSR	ISC
07 21	309 57.2	5.4	4.5	51.38	N	53.28	E	USSR	ISC
07 25	1529 59.2	5.4		37.27	N	116.42	W	NTS	ISC
08 02	1459 59.7	4.6		37.01	N	116.03	W	NTS	ISC
08 11	1859 58.1	5.3		65.07	N	55.08	E	Ural	ISC
08 25	825 53.0			58.0	N	31.9	E	USSR	ISC
08 25	1859 58.7	5.3	3.7	61.88	N	72.10	E	USSR	ISC
08 27	559 58.3	4.7		67.77	N	33.0	E	USSR	ISC
08 28	259 57.5	4.4		60.82	N	57.1	E	Ural	ISC
08 28	304 55.6	4.4		60.69	N	57.5	E	Ural	ISC
08 30	1444 59.1	4.9		37.12	N	116.06	W	NTS	ISC
09 09	259 06.5	5.1		49.83	N	78.15	E	EKaz	ISC
09 13	1359 59.4	5.0	4.2	37.07	N	116.08	W	NTS	ISC
09 15	615 07.3	4.7		50.07	N	78.85	E	EKaz	ISC
09 17	2059 57.7	5.0		55.86	N	87.46	E	USSR	ISC
10 02	1813 59.2	4.2		37.08	N	116.00	W	NTS	ISC
10 03	559 57.9	5.4		41.54	N	88.67	E	LopN	ISC
10 18	457 06.0	4.5		49.80	N	78.16	E	EKaz	ISC
10 25	629 58.1	5.8	6.1	73.37	N	54.84	E	NovZ	ISC
10 27	150 10.7	6.2	4.8	49.92	N	78.83	E	EKaz	ISC
10 27	559 57.3	5.0	3.7	46.90	N	48.15	E	USSR	ISC
10 27	604 57.2	5.0	3.7	46.94	N	48.12	E	USSR	ISC
10 27	1716 00.7	4.5		21.5	S	139.1	W	Mur	ISC
11 02	2044 58.7	5.6		21.87	S	139.00	W	Mur	ISC
11 10	1639 59.8	4.4	3.2	36.99	N	116.06	W	NTS	ISC
11 23	355 05.1	4.7	4.6	49.90	N	78.11	E	EKaz	ISC

Table 7 (cont.)

DATE	TIME(UT)	MAGNITUDE mb	Ms	LAT		LONG		SITE*	REF#
12 01	1651 00.0	4.2		21.80	S	139.40	W	Mur	NZ
12 02	319 06.5	5.9	5.1	49.95	N	79.03	E	EKaz	ISC
12 06	1728 58.9	5.6		21.81	S	138.93	W	Mur	ISC
12 09	1939 59.3	5.5	4.3	37.28	N	116.50	W	NTS	ISC
12 15	1444 59.4	5.4		37.27	N	116.30	W	NTS	ISC
12 16	355 02.8	6.1	4.8	49.88	N	78.82	E	EKaz	ISC
12 19	600 02.8	4.7	4.2	41.62	N	88.22	E	LopN	ISC
12 20	1620 00.2			36.97	N	116.01	W	NTS	ISC
12 28	350 10.9	6.0	4.1	49.83	N	78.71	E	EKaz	ISC

* NTS = Nevada, USA; EKaz = East Kazakh, USSR; Mur = Muroroa, French Polynesia;
Lopn = Lop Nor, China.

# PDE = Preliminary determination of epicentres
ISC = International Seismological Centre
NZ = Department of Scientific & Industrial Research, Wellington, NZ
FOA = National Defence Research Institute, Stockholm, Sweden

REFERENCES

ANDERSON, J.A. & WOOD, H.O., 1925 – Description and theory of the torsion seismometer. *Bulletin of the Seismological Society of America.*, **17**, 1-72.

BÅTH, M., 1981 – Earthquake magnitude - recent research and current trends. *Earth Science Reviews,* **17**, 315-398.

BMR, 1985 – Oolong earthquake series, August-December 1984. *BMR Research Newsletter* **2**, 10.

CD/558, 1978 – Report to the Conference of the Committee on Disarmament of the *Ad Hoc* Group of Scientific Experts to consider international co-operative measures to detect and identify seismic events.

CD/43, 1979 – Second report of the *Ad Hoc* Group of Scientific Experts to consider international co-operative measures to detect and identify seismic events.

CD/448, 1984 – Third report to the Conference on Disarmament of the *Ad Hoc* Group of Scientific Experts to consider international co-operative measures to detect and identify seismic events.

CD/720, 1986 – Fourth report to the Conference on Disarmament of the *Ad Hoc* Group of Scientific Experts to consider international co-operative measures to detect and identify seismic events.

CLARKE, Rev. W.B., 1869 – On the causes and phenomena of earthquakes, especially in relation to shocks felt in New South Wales, and in other provinces in Australasia. *Transactions of the Royal Society of New South Wales,* **2** , 51 - 86.

DENHAM, D., 1982 – Proceedings of the workshop on Australian Earthquake magnitude scales, BMR, Canberra, 21 May 1982. *Bureau of Mineral Resources, Australia, Record* 1982/29.

DENHAM, D., 1985 – The Tasman Sea earthquake of 25 November 1983 and stress in the Australian Plate. *Tectonophysics,* **111** , 329-338.

DENHAM, D., & Gregson, P.J., 1984 – Australian Seismological Report, 1980. *Bureau of Mineral Resources, Australia, Report* 252.

DENHAM, D., GREGSON, P.J., 1985 – Australian Seismological Report, 1981. *Bureau of Mineral Resources, Australia, Report* 259.

EIBY, G.A., 1966 – The Modified Mercalli scale of earthquake intensity and its use in New Zealand. *New Zealand Journal of Geology and Geophysics,* **9** , 122-129.

EVERINGHAM, I.B., McEWIN, A.J., & DENHAM, D., 1982 – Atlas of Isoseismal Maps of Australian Earthquakes. *Bureau of Mineral Resources, Australia, Bulletin* 214.

GREGSON, P.J., & DENHAM, D., 1986 – Australian Seismological Report, 1982. *Bureau of Mineral Resources, Australia, Report* 273.

GREGSON, P.J., & DENHAM, D., 1987 – Australian Seismological Report, 1983. *Bureau of Mineral Resources, Australia, Report* 280.

GREGSON, P.J., PAULL, E.P., DENT, V.F., WOAD, G., & PAGE, B.J., 1985 – Mundaring Geophysical Observatory, twenty-fifth year, 1983. *Bureau of Mineral Resources, Australia, Record* 1985/37.

GUTENBERG, B., 1945 – Amplitudes of P, PP and SS, and magnitudes of shallow earthquakes. *Bulletin of the Seismological Society of America,* **35**, 57-69.

HOWCHIN, W., 1918 – The Geography of South Australia. *Whitcombe & Tombs , Christchurch N.Z.*

KANAMORI, H., 1978 – Quantification of earthquakes. *Nature,* **271**, 411-414.

KERR, A.U., 1984 – Design and development of an Australian seismic data centre. *Defense Advanced Research Projects Agency.*

McCUE, K.F., 1978 – The value of historical records: the Warrnambool earthquake of July 1903. *Proceedings of the Royal Society of Victoria,* **90** (1&2), 245-250.

McCUE, K.F., 1980 – Magnitude of some early earthquakes in Southeastern Australia. *Search,* **11** (3), 78-80.

McGREGOR, P.M., & DENHAM, D., 1985 – Seismic verification of a test ban - Australian involvement. *Geological Society of Australia, Specialist Group on Solid-Earth Geophysics, Newsletter No.1*

McGREGOR, P.M., & RIPPER, I.D., 1976 – Notes on earthquake magnitude scales. *Bureau of Mineral Resources, Australia, Record* 1976/76.

RICHTER, C.F., 1958 – Elementary Seismology. *Freeman & Co., San Francisco.*

RYNN, J.M.W., 1986 – Queensland seismic risk study. *University of Queensland , Report* QSRS - **4**, 191 pp.

RYNN, J.M.W., DENHAM, D., GREENHALGH, S., JONES, T., GREGSON, P.J., McCUE, K.F. , & SMITH, R.S., 1987 – Atlas of isoseismal maps of Australian earthquakes. *Bureau of Mineral Resources, Australia, Bulletin* **222.**

SEAN, 1984 – *Scientific Event Alert Network Bulletin, Smithsonian Institution, Washington, DC.*

SMITH, R.S., & McEWIN, A.J., 1980 – Earthquake accelerograms and attenuation of seismic waves at Oolong, New South Wales. *BMR Journal of Australian Geology & Geophysics*, **4**(1), 63-67.

USGS, 1985 – *Earthquake Data Reports. United States Geological Survey, Washington, DC.*

WILLMORE, P.L., 1979 – Manual of Seismological Observatory Practice. *World Data Center for Solid Earth Geophysics, US Department of Commerce, Boulder, Colorado, USA., Report SE-20.*

APPENDIX

MODIFIED MERCALLI (MM) SCALE OF EARTHQUAKE INTENSITY

(after Eiby, 1966)

MM I — Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floors of buildings more than ten storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors, and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes, reservoirs, etc., may be set into seiche oscillation.

MM II — Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long-period effects listed under MM I may be more noticeable.

MM III — Felt indoors, but not identified as an earthquake by everyone. Vibrations may be likened to the passing of light traffic. It may be possible to estimate the duration, but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV — Generally noticed indoors, but not outside. Very light sleepers may be awakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frame of building are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock, and the shock can be felt by their occupants.

MM V — Generally felt outside, and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows crack. A few earthenware toilet fixtures crack. Hanging pictures move. Doors and shutters swing. Pendulum clocks stop, start, or change rate.

MM VI — Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows and crockery broken. Objects fall from shelves, and pictures from walls. Heavy furniture moves. Unstable furniture overturns. Small school bells ring. Trees and bushes shake, or are heard to rustle. Material may be dislodged from existing slips, talus slopes, or slides.

MM VII — General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls crack. Weak chimneys break, usually at the roof-line. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips, and caving-in of sand and gravel banks.

MM VIII — Alarm may approach panic. Steering of motor cars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers, and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles break. Frame houses not secured to the foundation may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shift off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alluviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well-built wooden buildings and bridges seriously damaged. Dams, dykes, and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes, and canals thrown up on the banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines. Great damage to underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of slight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

Categories of non-wooden construction

Masonry A Structures designed to resist lateral forces of about 0.1 g, such as those satisfying the New Zealand Model Building By-law, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality and the design and workmanship are good. Few buildings erected prior to 1935 can be regarded as Masonry A.

Masonry B Reinforced buildings of good workmanship and with sound mortar, but not designed in detail to resist lateral forces.

Masonry C Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners, but neither designed nor reinforced to resist lateral forces.

Masonry D Buildings with low standards of workmanship, poor mortar, or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

Windows Window breakage depends greatly upon the nature of the frame and its orientation with respect to the earthquake source. Windows cracked at MM V are usually either large display windows, or windows tightly fitted to metal frames.

Chimneys The 'weak chimneys' listed under MM VII are unreinforced domestic chimneys of brick, concrete block, or poured concrete.

Water tanks The 'domestic water tanks' listed under MM VII are of the cylindrical corrugated-iron type common in New Zealand rural areas. If these are only partly full, movement of the water may burst soldered and riveted seams. Hot-water cylinders constrained only by supply and delivery pipes may move sufficiently to break pipes at about the same intensity.

9 780644 088701

R 88/21458 Cat No 88 15616