Bureau of Mineral Resources, Geology & Geophysics

RECORD

RECORD 1990/44

RECENT INTRAPLATE SEISMICITY STUDIES SYMPOSIUM
PERTH, WESTERN AUSTRALIA
SEPTEMBER 1990

compiled by

Peter J. Gregson

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PREFACE

This record is a compilation of abstracts of papers presented at a symposium held at the Bureau of Mineral Resources, Perth from 5-7 September 1990. The symposium was entitled "Recent Intraplate Seismicity Studies", and was co-sponsored by the Specialist Group on Solid Earth Geophysics of the Geological Society of Australia and the Bureau of Mineral Resources. The abstracts in the Record are in the same order as in the symposium program at the beginning of the Record.

A list of participants and excursion notes are at the end of the Record.

SYMPOSIUM 5 - 7 SEPTEMBER 1990

RECENT INTRAPLATE SEISMICITY STUDIES

WEDNESDAY 5 SEPTEMBER

09.00	Late registrations	
10.00	Morning tea	
10.20	Dr D. Denham:	Welcome and introductory remarks.
	Session:	**Seismicity Studies.** (Chair D. Denham)
10.30	D. Denham:	Comparative Models and Risks for Inter- and Intra-Plate Earthquakes.
10.55	A. Crone:	Late Quaternary Tectonism and Intraplate Seismicity in the Central Interior of the United States.
11.20	D. Love & S. Greenhalgh:	Seismic Risk in South Australia.
11.45	P. Gregson:	Seismicity of Western Australia - An Overview
12.10	R. Cuthbertson	Seismicity studies in Queensland
12.30	Lunch	
	Session:	Newcastle Earthquake (Chair I. Everingham)
13.45	K. McCue:	Newcastle Earthquake and the Seismicity of Eastern Australia
14.10	G. Gibson:	Newcastle Earthquake Aftershocks and its Implications
14.35	I. Mumme:	Synthetic Accelerograms - Newcastle
15.00	L. Drake & I. Mumme:	Seismic Ground Motion in Sydney.
15.25	Afternoon tea	
	Session:	Meckering and Quantification (Chair: P. Gregson)
15.45	E. Paull & B. Gaull	Duration Magnitude
16.10	V. Dent:	The ML5.5 Meckering Earthquake of 17 Jan 1990 and its Foreshocks and Aftershocks
16.35	J. Lewis	Meckering Revisited
17.00	Video	Meckering Earthquake 1968
19.30		Symposium Dinner

THURSDAY 6 SEPTEMBER 1990

EXCURSION TO MECKERING

08.15 Depart Perth

09.10 Depart Mundaring

10.30 Site 1 - Kelly's farm
Morning tea
Stress site borehole, accelerograph site.

Site - McKenzie farm
Well preserved section of fault scarp.

Site 3 - Great Eastern Highway
Section of fault scarp trenched.

Site 4 - Snooke's farm
Examples of damage. Homestead built in 1904.

13.00 Lunch - Meckering sporting club.

14.00 Site 5 - Townsite gazebo
Display set up by local tourist committee includes section of damaged railway line and Mundaring - Kalgoorlie water pipe.

14.20 Depart for Mundaring.

15.30 Mundaring observatory
Afternoon tea and inspection of facilities and displays.

Poster Session

M. Machette & Others — Paleoseismology of the Wasatch Fault Zone, USA.

M. Michael-Leiba — Canberra Earthquake Risk

17.00 Depart for Perth.

17.45 Arrive Perth.

Booklet "Meckering Earthquake - October 14, 1968", prepared by Meckering Agricultural Society.

FRIDAY 7 SEPTEMBER

	Session:	**Microzonation** (Chair: K. McCue)
09.00	H. Kagami, H. Taniguchi & B. Gaull:	A Study on the Microzonation of the Perth Basin, Western Australia, through Microtremor Measurements. A pilot survey and its preliminary analysis.
09.25	B. Gaull: & Others	Preliminary results of the Microzonation of the Perth Basin in the region of the Perth Metropolitan Area
10.00	S. Hattori:	Microzoning of Tsukuba Area - data base by means of ground survey and its utilization.
10.25	Morning tea	
	Session	**Tennant Creek and Tasmania** (Chair: L. Drake)
10.45	J.R. Bowman, J. Dewey & N. Peters:	Recent Results from Tennant Creek.
11.10	E. Bouniot & Others	Tennant Creek Foreshock Sequence
11.35	J.R.Bowman & Others	Paleoseismologic Studies in Australia "Hot Out of the Dirt" (Preliminary results).
12.00	M. Michael-Leiba:	The West Tasman Sea Earthquake Zone.
12.25	Lunch	
	Session:	**Crustal Structure and Prediction** (Chair: M. Michael-Leiba)
13.35	V. Dent:	A Crustal Model for South-east Western Australia
14.05	R. Bowman & B. Kennett:	The Effects of Crustal Velocity Gradients on the Propagation of Lg Waves in the North Australia Craton.
14.30	V. Dent:	Deviations from Jefferys-Bullen Travel Times for Australian Earthquakes
14.55	M. Gladwin & Others	A Medium Term Precursor for the Loma Prieta, California, ML=7.1 Earthquake?
15.20	Afternoon tea	
	Session:	**Instrumentation** (Chair: G. Gibson)
15.40	B. Page & B. Gaull	History of Strong Motion Recording in Western Australia.
16.05	V. Wesson:	Developments in the Application of Seismic Digital Recorders
17.00		**Australian Standards Association Meeting - Australian Earthquake Risk Map.**

COMPARATIVE MODELS AND RISKS FOR INTER AND INTRA-PLATE EARTHQUAKES

DENHAM David

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This presentation aims to compare and contrast the models and risks for inter and intra-plate earthquakes. At plate boundaries we know where and why earthquakes occur and are very close to being able to anticipate when and how large future earthquakes will be. The Pacific rim is used as an example to show how well the models apply. One particular feature of the Pacific rim is that it can experience giant earthquakes (M 8) in areas of high population density. and hence the potential risks are very large.

In the intra-plate situation, such as in Australia, there is no model that adequately describes earthquake occurrences. However, it is evident that while giant earthquakes do not occur, the continent experiences significant levels of seismicity. Large (M-7) earthquakes occur from time-to-time, and the spatial and temporal distributions of earthquakes do not exhibit well defined patterns.

We now know that Australian earthquakes are caused by compressive stresses that, because they usually occur within the upper 20 km of the crust, they can cause surface faulting. Since 1967 five earthquakes have been unequivocally associated with surface faulting and there is ample evidence of similar recent pre-historic surface faults.

The seismicity levels are comparatively low in Australia and therefore the risks are not as great as at plate margins. However, because of the unpredictable time/space/magnitude relationships it is urgued that large areas of the continent are exposed to risks that demand appropriate action in terms of building regulations.

LATE QUATERNARY TECTONISM AND INTRAPLATE SEISMICITY IN THE CENTRAL INTERIOR OF THE UNITED STATES

CRONE, ANTHONY J.
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The evidence of significant late Quaternary tectonism in the central U.S. is present in only two areas: (1) the New Madrid seismic zone (NMSZ) in the central Mississippi River Valley, and (2) the Meers fault in southwestern Oklahoma. Late Quaternary tectonism in both areas has reactivated ancient faults that are associated with aulacogens, which formed in late Proterozoic or Early Paleozoic time when a major episode of extension affected the southern margin of the North American craton.

The New Madrid seismic zone is the most seismically active area in central and eastern United States. Between December 1811 and February 1812, four major earthquakes (M ~8) struck the sparsely populated region, caused widespread liquefaction, and were felt throughout a large part of eastern North America. A recurrence of earthquakes of magnitude ~7 or greater could potentially cause damage in a 650,000-km^2 area and cause about $50 billion (U.S.) in damage.

Most of the modern seismicity in the NMSZ is associated with Reelfoot rift, a northeasterly striking graben approximately 70 km wide and at least 250 km long. Seismic-reflection data indicate about 7 km of structural relief on crystalline basement between the deepest parts of the rift and the adjacent flanks. The seismicity is concentrated in three principle zones: (1) on the south, a narrow, linear, 120-km-long northeasterly trending zone that is coincident with the axis of the rift; (2) in the center, a 70-km-long, north-northwesterly trending zone of diffuse seismicity that extends from the rift axis to the northwest margin of the rift; and (3) on the north, a 45-km-long linear, northeasterly trending zone that is oblique to the northwest margin. Earthquake focal mechanisms show that the slip along the axial zone and the northwest margin is primarily right-lateral strike-slip. Focal mechanisms and geomorphic data show that the central cross-rift zone is being compressed and locally uplifted. Seismic-reflection profiles show that the earthquakes in the 120-km-long axial trend coincide with the Blytheville arch, a subsurface uplift of pre-Cretaceous age that was formerly a deep structural trough. The relations between earthquakes and specific faults or structural features is less clear in the other seismic zones.

The recurrence time for large earthquakes like the 1811-12 events is difficult to determine because surface ruptures that are unequivocally related to movement on deep-seated faults are rare. The only geologic data on earthquake recurrence is from a trench across the only prominent fault scarp in the NMSZ. The faults and liquefaction features exposed in this trench provide evidence of two large earthquakes that predate the 1811-12 events during the past 2,000 years, which implies a recurrence interval of about 700 years. However, this scarp is only 11 km long, therefore, it is unlikely that the fault associated with the scarp could generate earthquakes of M 7 or greater.

The rarity of surface faulting in the NMSZ means that recurrence information must be obtained from other kinds of geologic evidence. The New Madrid region is very susceptible to earthquake-induced liquefaction; the 1811-12 earthquakes produced extensive liquefaction in an area of more than 4000 km^2. Finding and dating evidence of prehistoric liquefaction may be the most promising way to get better information on the recurrence of large earthquakes in the NMSZ.

The only known late Quaternary fault scarp in the central U.S. is a linear, 26-km-long, 5-m-high scarp on the Meers fault. The fault strikes N. 60° W. and is part of the Wichita Frontal fault system, which separates the Wichita uplift on the southwest from the Anadarko basin on the northeast. The location and orientation of the Wichita Frontal fault system are controlled by crustal-penetrating faults that formed during the development of the Southern Oklahoma aulacogen, a west-northwest-trending rift of Early to Middle Cambrian age. The bimodal plutonic and volcanic rocks exposed in the Wichita uplift are structurally inverted and originally occupied the floor of the rift.

In contrast to the NMSZ, the region around the Meers fault is aseismic. As a result, although the fault was originally mapped nearly 50 years ago, the geomorphic evidence of youthful movement was only recognized about 7 years ago. The most recent surface rupture on the fault occurred about 1,200 years ago, but limited geologic evidence indicates a long-term recurrence interval on the order of 100,000 years or more. Holocene surface rupturing on the fault produced 2-3 m of vertical slip and 3-5 m of left-lateral slip.

A much better understanding of the long-term and short-term behavior of seismogenic intraplate faults in continental interiors is needed to improve seismic-hazard assessments in the central U.S. For example, if earthquakes on faults in continental interiors tend to cluster in time, then hazard assessments that are based on uniform recurrence intervals and long-term slip rates could be misleading. Paleoseismic studies can help characterize the behavior of these seismogenic intraplate faults but, worldwide, only eight historical earthquakes in continental interiors have produced surface ruptures. Five of the eight earthquakes occurred in Australia, thus, paleoseismic studies of historical and prehistorical fault scarps in Australia present unique opportunities to understand the behavior of seismically hazardous intraplate faults.

EARTHQUAKE RISK IN SOUTH AUSTRALIA

R.M. McDOUGALL Flinders University of South Australia
S.A. GREENHALGH Flinders University of South Australia
D.N. LOVE South Australian Department of Mines and Energy
C. SINADINOVSKI Flinders University of South Australia

A seismic risk assessment has been undertaken for South Australia using the seismic moment method. Risk is depicted as contours of expected return period for various intensities, and for various sites, as curves of the probability of exceedence of various intensities at various periods.

Two attenuation functions were used, derived from analysis of Australian and South Australian earthquakes. Magnitudes for instrumentally recorded earthquakes were calculated according to the relationship by Greenhalgh and Singh (1986), and for historic earthquakes according to the isoseismal relationships of Greenhalgh et al (1989). A maximum likelihood statistical technique was applied to over 100 years of data in the catalogue to estimate the recurrence parameters. Far northern and western areas of the State were excluded from the recurrence analysis.

For the cities of Adelaide, Port Augusta and Mount Gambier, which are the major population centres of South Australia, the seismic risk classification is Zone 1, using the current Standards Association of Australia Earthquake Building Code. This is in broad agreement with previous risk studies in South Australia.

SEISMICITY OF WESTERN AUSTRALIA - AN OVERVIEW

GREGSON Peter

(Bureau of Mineral Resources, Mundaring Geophysical Observatory)

The first significant report on the seismicity of Western Australia, based on information available to mid 1963 was prepared by Everingham (1968). Following the 1968 Meckering earthquake Everingham and Gregson (1969) prepared a map showing regions of seismicity. An update was made by McCue (1973). The most recent map of earthquake source zones (Fig. 1) was published by Gaull and others (1990).

This paper briefly outlines the features of each of the 10 zones and discusses in detail the features and variations in seismic patterns in the South-West Seismic Zone - SWSZ (zones 1 and 2).

Three series of earthquakes have resulted in the majority of the seismicity in the regions of Norseman (zone 6), Rowley Shoals (zone 11) and the eastern end of the Canning Basin (zone 10A). Scattered activity occurs in the off-shore zones 3 and 4 which run parallel to the 200m and 5000m isobathsrespectively. An earthquake of magnitude ML = 7.4 which occurred in zone 3 in 1906 is probably the largest recorded earthquake in the Australian Region. Some of the activity in the Kalgoorlie region (zone 7) is probably induced by mining. However it is important considering the population and mining activity.

The SWSZ is one of the most active in Australia. Prior to the Meckering earthquake, activity was low. Instrumental and historic records indicate that there were no large earthquakes in at least the previous 120 years. Three large earthquakes have occurred in the zone in the last 22 years. The level of activity (ML > 4) indicates a fivefold increase since 1968 compared to the period prior to 1968.

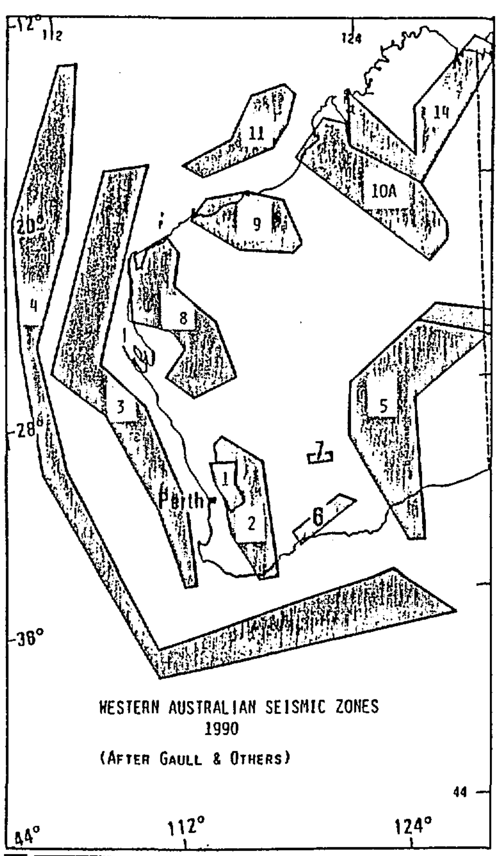
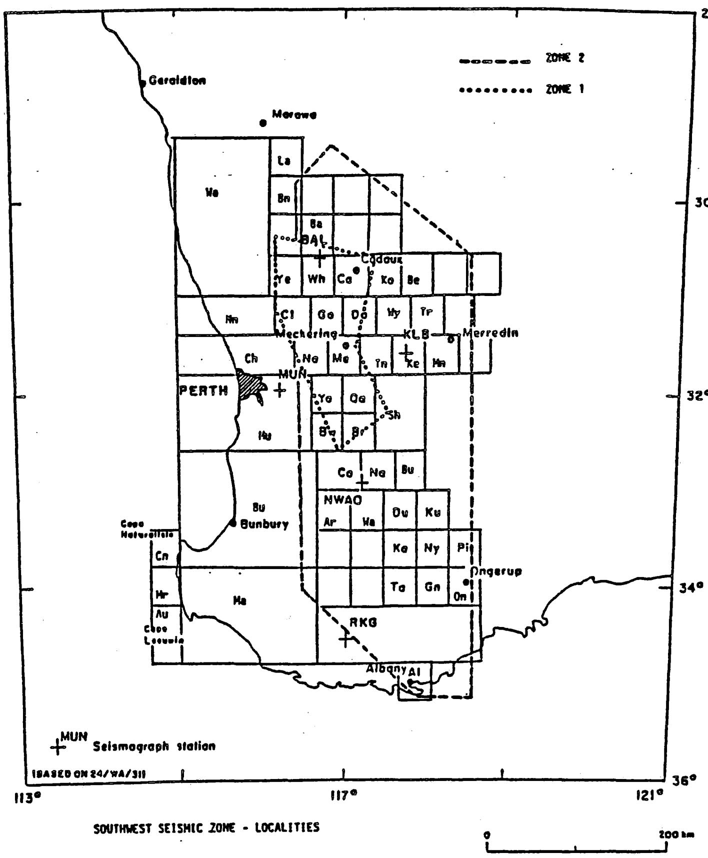


Fig. 1 Earthquake Source Zones

The SWSZ has been divided into areas about 40 km square (Fig. 2). Typically six patterns of activity occur. Strain release curves (Fig. 3) show vastly different patterns of activity following the two large earthquakes at Meckering (ML = 6.9) and Cadoux (ML = 6.2). The activity in the Meckering (Me) area decreased rapidly, whereas moderately sized earthquakes in the order of ML = 5 occurred over several years in the Cadoux (Ca) area.

Moderate sized earthquakes in the Brookton (Br) area are generally followed by numerous aftershocks compared with Meckering where few aftershocks occur. Dumbleyung (Du) is typical of areas of minor activity occurring frequently with occasional earthquakes in the order of magnitude 3. By comparison Pingrup (Pi) is an area of minor activity with the



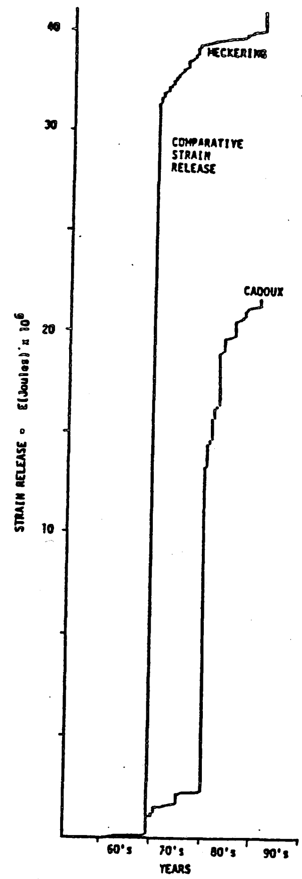


Fig. 2 South-West Seismic Zone Localities

Fig. 3 Strain Release Curves

tendency for it to occur in small bursts about every five years. Several areas such as Goomalling (Go) have experienced little activity in the last 30 years. Goomalling is an area adjacent to areas of high activity and also has high stress values. Some areas such as Arthur (Ar) exhibit a swarm pattern. In 1966 a series with over 50 earthquakes in the magnitude range of 2 to 4 occurred within a week.

Albany (Al) on the south coast doesn't fit into any of the above patterns Fourteen earthquakes were recorded over a two week period in 1977 including a magnitude 4.5 and 4.0. Only one minor earthquake has occurred since, in 1982.

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NEWCASTLE AND THE SEISMICITY OF EASTERN AUSTRALIA

Kevin McCue

Introduction By February 1990, Newcastle was well along the track to recovery following the 28 December 1989 earthquake there. Damaged buildings considered dangerous had been demolished or repaired and the cordoned-off Central Business District reopened for business. For the first time in an Australian earthquake, a number of people were killed, 13 according to the coronial inquiry report; it caused economic losses of about $1.5 billion, comparable to Cyclone Tracey, previously the most destructive natural disaster in Australia's recent history; and it demonstrated a lesson well learned overseas that the greatest contribution to seismic risk is not from the infrequent large or great earthquake but the more frequent moderate sized one.

Earthquake risk at Newcastle An extreme value plot of intensities for the combined set of infrequent but high intensities and recent well documented intensities (Table 1) resulted in an estimate of seismic risk which would place Newcastle well and truly in zone 2 in the current earthquake risk map of the Australian Building Code (AS2121—1979). It is likely that local soil conditions could account for the high intensities but even taking this into account, a zone 1 rating appears to be warranted for Newcastle.

Seismicity of Eastern Australia Plate tectonics provides a convenient model for zoning countries along plate boundaries with some confidence, and even for making sensible predictions based on the longetivity and length of seismic gaps. The best of current intraplate seismicity models could not have predicted the 1988 Tennant Creek NT earthquake series nor the 1986 Marryat Creek earthquakes. Both occurred in areas zoned 0 on the 1979 risk map.

A new Hazard Map of Australia based on recently published earthquake risk maps (Gaull, Michael-Leiba and Rynn, 1990) shows a series of bullseyes within the smoothed contours. The risk generally decreases from west to east across Australia.

The results of a type 1 extreme value analysis give the tabulated return periods for relevant magnitudes in Table 2. An earthquake of the size of that at Newcastle has an average return period of 10 years and the once-per-year earthquake has a magnitude of 4.5. The mapped epicentres are spread over a very large area but even so the risk is not negligable.

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Table 1 Earthquakes experienced at Newcastle, 1830 - 1989

Date	Epicentre Lat°S	Long°E	Place	Distance km	Magnitude ML	Maximum Intensity
1829 09 01	?	?	?	?	?	› III
1837 08 02	?	?	?	?	?	IV-V
1841 01 27	?	?	?	?	?	› III
1842 10 28	?	?	?	?	?	› III
1868 06 18	33.0	151.5	Maitland	25	5.3	V-VI
1916 06 11	?	?	?	?	?	III (?)
1919 08 15	33.5	150.7	Kurrajong	115	4.6	IV-V
1925 12 18	33.0	151.6	Booleroo	15	5.0	VI-VII
1949 07 18	?	?	?	?	?	IV (?)
1961 05 21	34.50	150.50	Picton	210	5.6	III
1973 03 09	34.17	150.32	Burragorang	195	5.6	IV
1981 11 15	34.25	150.90	Appin	170	4.4	III
1986 02 20	33.33	150.60	Upper Colo	115	4.0	II
1987 06 24	33.45	150.16	Lithgow	160	4.3	III
1989 12 28	32.95	151.61	Booleroo	15	5.6	VIII

Table 2 Seismicity of eastern Australia, 1880 - 1990

Magnitude	Return Period (years)
4.5	1
5.6	10
6.0	25
6.8	100

Acknowledgment David Palfreyman, Cynthia Hunter and the Riverview newspaper clippings book were the sources for information on early Newcastle earthquakes.

SEISMIC GROUND MOTION IN SYDNEY

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The occurrence of the earthquake near Newcastle on 27 December 1989 (Denham and McCue, 1990) with its accompanying loss of life and property damage has stimulated interest in the ground motion at Riverview Observatory in the Sydney suburb of Lane Cove from two earlier earthquakes of similar epicentral distance and magnitude.

The Robertson-Bowral earthquake of 21 May 1961 was distant 100 km from Riverview and appears to have been of magnitude 5.5 (Cleary and Doyle, 1962; Cooney, 1962; Denham, 1976; 1979; Doyle et al., 1968; Drake 1974; International Union of Geodesy and Geophysics, 1967). This earthquake was well recorded on the Mainka horizontal seismographs at Riverview and the two traces have been Fourier analysed (Mumme and McLaughlin, 1983). Although the Wood-Anderson magnitude of the earthquake suggests that the dominant energy at Riverview was at a period of 1.5 s, Fourier analysis shows considerable energy in the seismograms right up to the Nyquist frequency (10 Hz).

The earthquake in Burragorang Valley on 9 March 1973 appears also to have been of magnitude 5.5. Although the epicentral distance to Riverview was less (87 km) than for the Robertson-Bowral earthquake (100 km) and although the earthquake in Burragorang Valley appears smaller on the N-S component of the Mainka seismograph (Drake, 1985) than the Robertson-Bowral earthquake, the region of Intensity VI for the earthquake in Burragorang Valley (70 km across) is larger than for the Robertson-Bowral earthquake (50 km across). The depth of the earthquake in Burragorang Valley was approximately 24 km (International Seismological Centre, 1975; Denham, 1976); that of the Robertson-Bowral earthquake was 19 km (Cleary and Doyle, 1962; Doyle et al., 1968). Again Fourier analysis of the N-S Mainka seismogram shows energy up to the Nyquist frequency (Mumme and McLaughlin, 1983).

The comparatively large region of Intensity VI for the earthquake near Newcastle of 27 December 1989 (220 km across) suggests that its magnitude may have been greater than 5.6. Its depth was 12 km (Denham and McCue, 1990). The dominant period of the waves of this earthquake recorded at Riverview Observatory (distant 107 km) appears to be less than 1s.

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A DURATION-BASED MAGNITUDE SCALE FOR WESTERN AUSTRALIAN EARTHQUAKES

Edward P. Paull & Brian A. Gaull

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It is practical to derive a duration-based magnitude scale where analogue recorders with limited dynamic range are deployed, as amplitude-based estimates using them are generally limited to magnitude 3 or less, for events closer than about 200 km. In this study this was achieved by using a data base consisting of about 500 readings of the parameters ML, R, i and t representing the Richter magnitude, hypocentral distance (in km), recording station identifier (i = 1-9) and coda duration (in seconds) respectively. Magnitudes ranged between 2.0 and 6.9, and distances between 40 and 2100 km. The magnitudes for most events were derived using Gaull and Gregson's (in prep) amplitude scale.

The adopted relation which describes the duration-based magnitude scale ML(t), in Western Australia is given by:

$$ML(t) = 0.50 \log t + 0.0026\, t + 0.001\, R + D(i)$$

where D(i) is a constant correction term for seismograph i.

In his summary of research on earthquake magnitude, Bath (1981) explains the phenomenon of the earthquake coda as due to wave scattering and back scattering at crustal irregularities. He suggested that the coda could be used to measure the magnitude of earthquakes and gave a general form for relations which had been developed in the literature:

$$ML(t) = a \log t + b (\log t)^2 + c\Delta + dh + e$$

where ML(t) is the duration-based magnitude scale for an earthquake of depth h km and which registered a coda of t seconds at a station of epicentral distance Δ km. The constants a, b, c, d and e are regression coefficients which are determined uniquely for each seismograph. According to Bath the second and the fourth terms can be dropped from this empirical relation without significant loss in accuracy. Various formulae of this type in use at that time were presented in his paper.

It was found however that ML(t) was not linear in log t but increased with increasing duration, necessitating the introduction of the term proportional to t. This gave a better fit than using a $(\log t)^2$ term.

Included in the data were the 1968 ML 6.9 Meckering earthquake, the 1979 ML 6.2 Cadoux earthquake, the 1970 ML 5.8 Calingiri earthquake plus two ML 5.5 events, one at Meckering and one at Cadoux. The magnitude 6.9 and 6.2 earthquakes generated low frequency waves of period 8-10 seconds whose duration lasted about 3 times that of the waves of period around 1 second. These were not used for determining duration as they were not observed for events of ML < 6 or on seismographs whose filters effectively removed them.

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FORESHOCKS AND AFTERSHOCKS OF THE 17 JAN 1990 MECKERING EARTHQUAKE

V. F. Dent

(Bureau of Mineral Resources, Mundaring Geophysical Observatory)

An ML 5.5 earthquake occurred in the Meckering area (Figure 1) on 17/1/90, and was felt widely in south-west Western Australia. Other than the ML 6.9 event on 14 Oct 1968, there has been only one larger Meckering event, an ML 5.7 event 24 hours after the ML 6.9 event.

A preliminary location using P wave arrivals from the permanent regional seismograph network placed the epicentre approximately 9 km south of Meckering. Three aftershocks of ML 2.0 were recorded by the Mundaring Observatory in the following 10 hours, and four more events of ML > 1.8 occurred over the next 5 weeks (Table 1).

Two digital seismographs were deployed in the epicentral zone within 24 hours of the earthquake. They reoccupied sites which have been used in the past for strong motion instruments. One site (MEK), was approximately 7 km south of Meckering, and close to the anticipated epicentral zone. The other (RIC), was approximately 2km north of Meckering. Unfortunately, the station RIC was initially set up with no pre-event memory, and missed the P arrivals of the 3 events which triggered it in the first week. It was only triggered by one event in the last two weeks of its operation.

The station MEK however operated exceptionally well, and was triggered by 41 small after-shocks over the 3 weeks it operated. The highest density (12 events) occured in the first 12 hours of recording (Figure 2). The largest aftershock had a magnitude (ML) of 2.3. Most however had a magnitude less than ML 1.0.

The digital seismograph allowed determination of S-P times with high precision. The MEK S-P times ranged between 0.4 to 0.8 secs. (median value 0.6) although one event (ML 2.3 on Feb 01) had an S-P of 1.2 secs (Figure 3).

The digital data collected have assisted in the relocation of three events and allowed one new event to be located. Most significantly, they have given realistic depth control to the locations. The depths determined are in the range 4-6 km, with an accuracy of approximately +/- 2 km. The January epicentres are congregated near the main event, but, when other 1990 events are considered there is a definite north-east trend in the distribution of epicentres.

Compared to some other recent large Australian earthquakes e.g. the Meckering (1968), Cadoux (1979) and Tennant Creek events, the number of aftershocks was small. The aftershock sequence has similarities to that of the MB 5.2 event at Sharpsburg, Kentucky, in 1980 (Herrmann & others, 1982), described by Bowman et al (1990) as "a non-productive aftershock sequence". It may also be similar to the Ayers Rock (May 1989) "temporally isolated" earthquake (Bowman & others, 1990).

There were no foreshocks recorded by seismographs at KLB and MUN. Normally, this would be taken to mean that there was no precursory activity. However, some Meckering residents reported feeling tremors over a period of a couple of days, three weeks before the ML 5.5 event. These events must have been small (ML < 0.5) as they were not recorded by KLB or MUN seismographs.

Meckering earthquakes of magnitude ML > 2.9 which occurred since January 1980 are shown on Figure 1, together with all events since Jan 1989. This figure shows that the 17 Jan 1990 event and most of its located aftershocks are much closer to the surface fault scarp than other significant events of the last 10 years.

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Herrmann, R.B., Langston, C.A., & Zollweg, J.E. (1982). The Sharpsburg, Kentucky earthquake of 27 July, 1980. Bull. Seism. Soc. Am., 72, 1219-1239.

TABLE 1 MECKERING EARTHQUAKES, ML > 1.1, JAN & FEB, 1990

DATE	ORIGIN TIME		ML	EASTING	NORTH	DEPTH	REMARKS
17 Jan	0638	08.2	5.5	498.8	6491.9	5.0	relocated using DOW S-P
17 Jan	1104		1.4				not located
17 Jan	0741	16.5	2.0	498.5	6492.4	5.1	relocated with NWAO P deferred
17 Jan	1539	30.0	2.0	499.9	6492.2	5.	MGO location
17 Jan	1652	09.2	2.0	498.0	6492.3	3.4	MGO location
18 Jan	0247		1.7				not located
18 Jan	0408	06.5	1.9	501.9	6496.1	5.6	new location, using MEK S-P
18 Jan	0557		1.5				not located
18 Jan	1237		1.6				not located
18 Jan	1619		1.2				not located
19 Jan	0223	01.1	2.3	497.8	6492.7	3.8	relocation, using MEK S-P
25 Jan	0547	51.0	1.6	498.0	6493.2	4.2	relocation, using MEK S-P
31 Jan	0032		1.3				not located
01 Feb	0711	55.2	2.3	504.4	6498.6	6.3	relocation using MEK S-P
06 Feb	1426		1.2				not located
07 Feb	1447		1.2				not located
25 Feb	1600	10.6	2.1	503.1	6501.0	9.5	MGO location

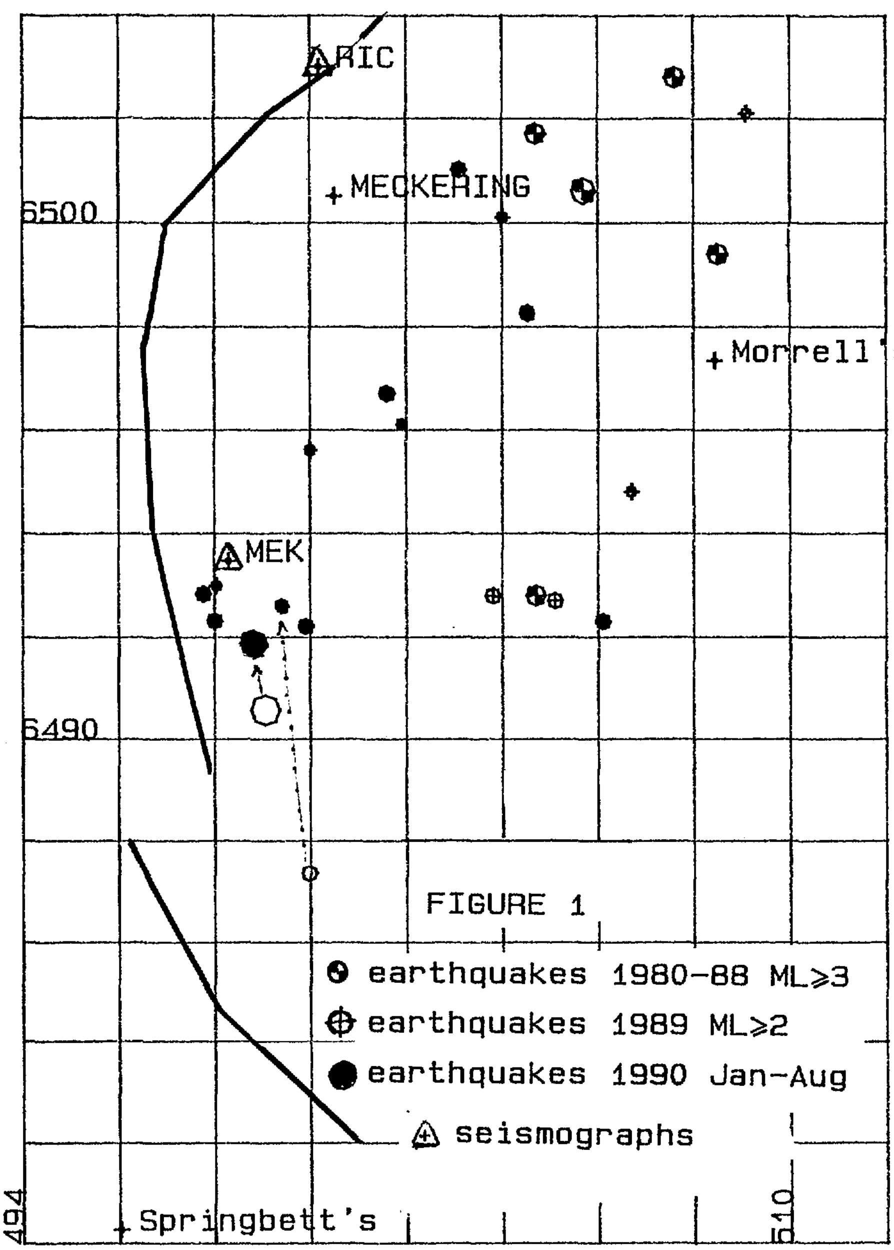


FIGURE 1

FIGURE 2

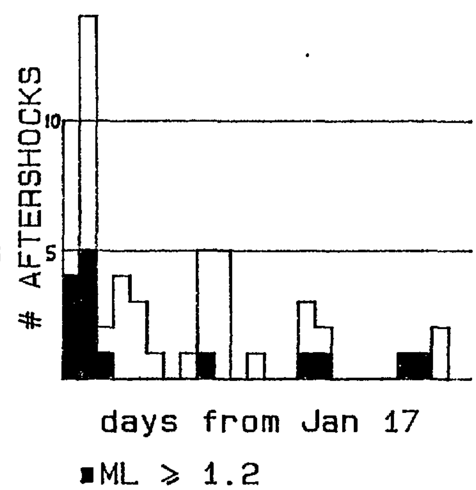
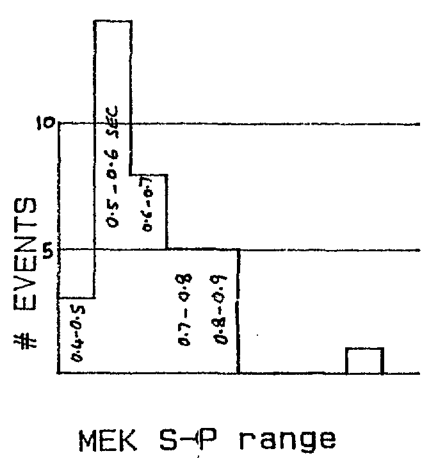


FIGURE 3



MECKERING REVISITED

LEWIS John

(Geological Survey of Western Australia)

The following is taken from the GSWA Bulletin 126 by Gordon, F.R & Lewis, J.D.

Chapter 1. This bulletin reports the results of a study of the Meckering Earthquake of 14th October 1968, and the smaller Calingiri Earthquake of 11th March 1970. The Meckering Earthquake was one of the largest recorded in Australia, and the first to cause surface faulting. The earthquake was felt throughout the southern half of Western Australia, and resulted in considerable property damage.

Meckering is situated near the western margin of the Archaean Yilgarn Block. The regional geology of the district (Plate 1) consists of a series of granite plutons with a general north-northwest foliation, remnants of older gneiss, and younger dolerite dykes. The area mapped lies on the western edge of a downwarped zone of gneisses which outline the main seismic zone of Western Australia. No correlation between geology and faulting was found.

Chapter 2. Meckering is a small agricultural township about 130 km east of Perth, and lies astride all the main communications to the eastern states of Australia and the water supply pipeline to Kalgoorlie.

The earthquake damaged or destroyed most houses in the town, but there were only 17 injuries and no deaths. Only timber houses withstood the shaking, but the degree of damage was also controlled by the foundation material and orientation of the structure with respect to the shaking. Masonry houses built on alluvial sand suffered most damage.

The Eastern Goldfields Water Supply pipeline, the Great Eastern Highway, the transcontinental railway, and telephone lines were all disrupted at the fault scarp. Many minor roads and bridges, and the electricity supply to houses and farms were also damaged. The pipeline was also fractured, in the week following the earthquake, at points where it crossed developing tension fractures. Two reinforced concrete grain storage silos suffered only minor damage.

The fault scarp dammed several tributaries of the Mortlock River, but the main stream was less affected as it ran parallel to the fault throughout part of its length. Flooding was minimized by regrading the stream beds, but more subtle changes in the landscape may take many years to manifest themselves.

Chapter 3. The Meckering Earthquake was felt over an area 700 km in radius and caused damage in many towns, particularly Northam, York and Perth, Significant damage was confined to the area within the MM VI isoseismal.

In Perth the intensity was commonly MM V and damage consisted mainly of cracked walls and plaster. Isolated higher intensities of MM VI were a reflection of poor foundation geology. Damage in areas of unconsolidated sands and clays was greater than in areas underlain by coastal limestone.

The isoseismal map for the Meckering Earthquake shows that shaking was more easily propagated to the east than to the west. The shape of the isoseismals can be correlated with the structure and geology of the region.

Chapter 4. Several minor tremors have been felt in the Meckering district since 1900, but for a number of years before 1968 the area had been seismically quiet. Foreshocks to the main event were felt on 31st August, 29th September, and 3rd October 1968.

Seismic data for the main event are:

Time: 14 October 1968, at 02 58 50.9 hrs U.T.

Location: Lat. 31°36′S Long. 117°0′E, 2.5 km N.E. of Meckering.

Magnitude: M_L 6.9, M_S 6.8, m_b 6.0.

Depth: 7±5 km.

At Meckering, the initial strong motion was a near vertical impulse, followed by two periods of east-west shaking. From observations of displaced monuments a radial pattern of movement is inferred.

The pattern of aftershock epicentres suggests they were associated with an extension of the Meckering Fault and a radial fault. Strain release curves also suggest radial fracturing.

Chapter 5. Three major faults were produced by the earthquake. The largest, the Meckering Fault (Plate 2) was an arcuate dextral thrust fracture 37 km long, with several dextral offsets in the fault trace. The Splinter Fault, a 9 km long dextral thrust fault, was parallel to and 1.5 km northwest of the northern section of the Meckering Fault. The Burges Fault Complex (Plate 3), showed a dominant dextral strike-slip movement, and was a radial fault which caused a 1.6 km dextral offset to the trace of the Meckering Fault.

The maximum displacement of the Meckering Fault was 2 m vertical, 1.5 m dextral slip and 2.4 m heave, measured at the centre of the arc. Displacements decreased both north and south. The fault plane was exposed at several points and its dip varied from 28° to 55°, with an average of 43°. A cadastral survey at ten stations showed a calculated dip of 36°-49°, averaging 42°. The same survey showed a net slip varying regularly from less that 1 m near the ends of the fault trace to 3.08 m at the centre. Slickensides were observed at only three points.

The morphology of the fault scarp was related to the nature and thickness of the soil cover and a variety of simple structures was found (Fig. 41). Generally the fault consisted of a single thrust fracture, but in some areas there were a number of associated fault planes which gave rise to a variety of fracture patterns.

The Splinter Fault was similar in every way to the Meckering Fault, but displacements were only about a quarter of those on the main fault and the fault plane appeared to dip at less than 30°.

The Burges Fault consisted of a number of parallel fractures, often showing different styles of movement on each branch. The dominant movement was a dextral strike slip of up to 1.5 m. The principal fault plane dipped 80° to the south, and showed reverse uplift of 1 m. Slickensides indicated that movement took place in two stages, first the dextral strike-slip, followed by nearly vertical reverse displacement.

The Burges Fault Complex also contains a number of minor branch faults, including the Anterior and Posterior Faults at its eastern end, and the Robinson Fault at the western end. A consideration of the displacement on all the faults in the complex suggests that the Burges Fault is a major independent fault, not parasitic on the Meckering Fault. Together, the Burges, Robinson and Posterior Faults form a radial fault to the arcuate Meckering Fault.

Other dextral offsets in the trace of the Meckering Fault are not associated with radial faulting. The complex fracture pattern at one such offset, near Wilson Street, northwest of Meckering, is fully described (Plate 4).

The Sudholz Fault, a radial fault 4 km long, was adjacent to a small sinistral offset in the Meckering Fault trace and appeared to be a sinistral normal fault of small displacement.

Reverse and thrust faults from New Zealand, California, Japan, Mongolia and Alaska are described from the literature and compared with the Meckering Fault.

Chapter 6. In addition to the major faults, a number of secondary faults were associated with the Meckering Fault, some possibly resulting from elastic creep in the weeks following the earthquake. The Chordal Fault, so named because it formed a chord to part of the arcuate Meckering Fault, was traced for 13 km. The fault was dextral normal, with up to 23 cm strike-slip displacement and 15 cm normal displacement. The fault appeared to develop over a period of six weeks following the earthquake.

In the segment isolated between the Chordal and Meckering Faults there were a number of large tension fractures up to 3 km long. One fracture, which disrupted a pipeline and the concrete floor of a grain silo, probably formed during an aftershock on the day following the principal earthquake.

The Backscarp Zone was a depressed linear zone about 4 km wide, joining the two ends of the Meckering Fault. It marked the eastern limit of faulting, and of the mobile block. Numerous small tension fractures were found within the zone, probably compensating, in part, for the compression observed at the Meckering Fault.

The only new fracture found in fresh rock was the Koolbunine Fault, about 100 m long and with a sinistral displacement of about 0.5 cm. Periodic observation showed that the fracture doubled in length over a period of two years.

Chapter 7. Seismic shaking caused a number of small slumps and clastic extrusions, but no major landslides.

Slumps were common in areas of high water table and occurred as isolated circular structures. Linear slumps were found on steep slopes or as apparent extensions of faulting.
Clastic extrusions were found in the salt flats of the Mortlock River. Water flowed for several hours after the earthquake, depositing low mounds of sand and silt.

Chapter 8. Several lines of evidence suggest that the Meckering Fault was a reactivated feature. At one point compact iron-stained fault breccia was found and in some areas the fault was associated with small quartz reefs and stringers. The fault was also associated with soil containing quartz fragments, and by following such indicators extensions of small faults could be located.

Geomorphological features also suggested a long history for the Meckering Fault. Northeast of Meckering the Mortlock River changes abruptly from wide salt flats to a narrow channel where it is crossed by the Sudholz Fault. The river then follows an arcuate course, parallel to the Meckering Fault. The fault itself does not traverse any fresh rock outcrop, but to the east, on the uplifted block, a line of small granite domes is exposed, while to the west there are wide sandplains.

Chapter 9. Geodetic measurements were made on a line crossing the earthquake affected area and compared with earlier measurements. Over the whole of a 115 km section there was no change, but certain sections showed an increase or decrease in length. Between Karrabein and Cunderdin the apparent increase in distance beteen 1958 and November 1969 was 9.5 cm. Other measurements, however, taken in mid 1968 and September 1969 showed a decrease of 23.2 cm. These conflicting results can be rationalised by assuming a slow dextral movement of 32.7 cm between 1958 and 1968, followed by a sinistral movement of 23.2 cm at the time of the earthquake.

Third order levelling profiles showed that levels were depressed up to 7.6 cm to the west of the overthrust block, and that the maximum elevation of about 1.6 m was reached about 2 km east of the fault. From this point elevations decreased until a further depressed area, the Backscarp Zone, was reached about 13 km east of the Meckering Fault. Levelling anomalies were not found south of the faulted area but there were indications of ground distortion extending northwest from the Meckering area.

Contouring of uplift on the mobile block of the Meckering Fault shows that it was uplifted and tilted to the east.

Chapter 10. The mobile block associated with the Meckering Fault is a segment of a saucer shaped body. Fault movement appeared to be a constant dextral strike-slip of 0.5 m, combined with a thrust movement varying from zero at the ends of the fault to a maximum of about 2 m at the centre of the arc. The model proposed to explain these features involves the straining of a superficial circular cap of rock by sinistral movement on an underlying shear zone. The essential points of this model have been confirmed by focal mechanism studies.

Chapter 11. The Calingiri Earthquake of 11th March 1970 had a magnitude of 6 and its epicentre was located 77 km northwest of Meckering. A small thrust fault scarp was formed, similar to the Meckering Fault. Only minor damage was caused and outside the epicentral area the damage from the Meckering Earthquake was often greater than that from the local event.

PALEOSEISMOLOGY OF THE WASATCH FAULT ZONE, U.S.A.

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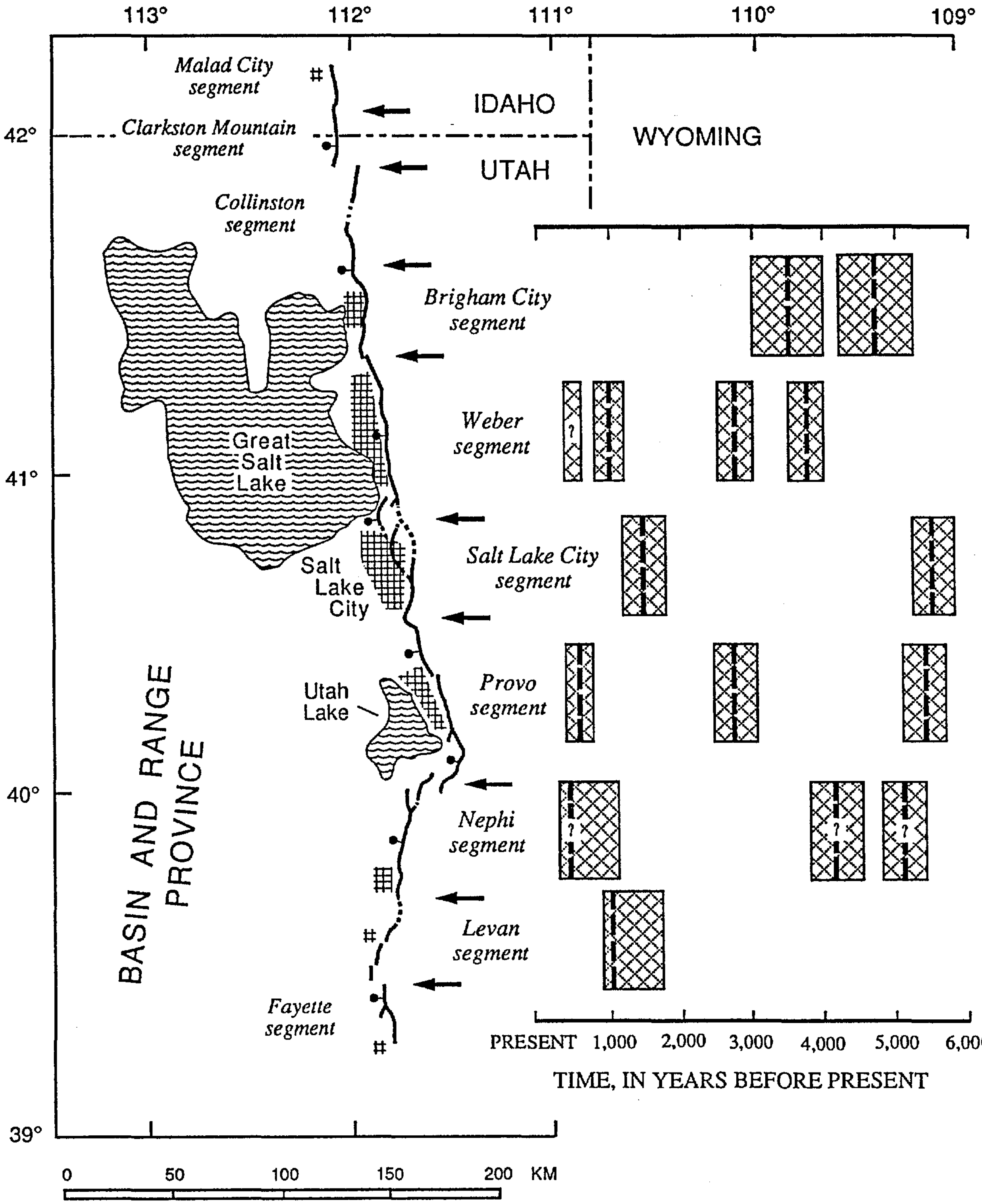
The Wasatch fault zone extends 343 km from southern Idaho to central Utah and forms the eastern boundary of the Basin and Range province–a region of pervasive Cenozoic extension and block faulting. The Wasatch is the longest continuous, active normal fault in the United States; it underlies an urban corridor of 1.6 million persons (80 percent of Utah's population) who live along the Wasatch Front. As such, the fault zone constitutes the largest earthquake risk in the interior of the Western United States. During the past 6 years, the USGS has been involved in geologic mapping at 1:50,000 scale, Quaternary stratigraphic studies, and detailed investigations of about 20 trenches along the Wasatch fault zone. In addition, university, state, and private scientists have conducted studies that contribute to a large data base of paleoseismic information.

Collectively, these studies have helped us identify 10 discrete segments of the Wasatch fault zone (see figure). The fault zone has (1) five active, medial segments with Holocene slip rates of 1-2 mm/yr, recurrence intervals of 2,000-4,000 yr, and average lengths of about 50 km, and (2) five less active, distal segments with mostly pre-Holocene surface ruptures, late Quaternary slip rates of <0.5 mm/yr, recurrence intervals of ≥10,000 yr, and average lengths of about 20 km. Surface-faulting events on each of the medial segments of the Wasatch fault zone formed 2- to 4-m-high scarps repeatedly during the Holocene; latest Pleistocene (14-15 ka) deposits commonly have scarps as much as 15-20 m high. The medial segments are about twice as long as those proposed for other range-bounding late Quaternary normal faults in the region.

The paleoseismological record for the past 6,000 years indicates that a major (M≥7) surface-rupturing earthquake has occurred along one of the medial segments of the Wasatch fault zone about every 400 years, on average. However, between about 400 and 1,500 years ago, the fault zone experienced 6 major surface-rupturing events, an average of one event every 220 years, or about twice as often as expected from the 6,000-year record. This pattern of temporal clustering (a period of accelerated earthquake occurrence) is similar to that of the central Nevada-eastern California Seismic Belt in the western part of the Basin and Range province, where 11 earthquakes of M>6.5 have occurred since 1860. Although the time scale of the clustering is different–130 years versus 1,100 years–we consider the central Nevada-eastern California Seismic Belt to be a modern analog for movement on the Wasatch fault zone during the past 1,500 years.

The sparse record of modern seismicity for the Wasatch fault zone is typical of intraplate fault zones. During the past 105 years, the two largest earthquakes that can be placed on the Wasatch fault zone are estimated at M 5; in general the fault zone's earthquake catalog is dominated by earthquakes of M<3. We have been unable to show that any surface-rupturing events occurred during the past 400 years, a time period which is twice the average intracluster recurrence interval and equal to the average Holocene recurrence interval. In addition, the Brigham City segment (the northernmost medial segment) has not ruptured in the past 3,400 years–a period that is about three times longer than its average recurrence interval during the early and middle Holocene. Thus, although the seismological record is one of relative quiescence, the paleoseismological record suggests that a major earthquake associated with tens of kilometers of surface rupture and several meters of normal dip slip should be expected in the future along the Wasatch fault zone.



Map of the Wasatch fault zone in Utah and southern Idaho showing segment names (italics) and times of faulting (hachured boxes) on the Holocene segments during the past 6,000 years. Solid arrows show proposed segment boundaries.

A Study on Microzonation of Perth Basin, Western Australia, Through Microtremor Measurements. -A pilot survey and its preliminary analysis.-

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Hitoshi TANIGUTCHI (The Research Institute of Regional Problems, Japan) and
Brian A. Gaull (Mundaring Geophysical Observatory, BMR)

Seismic microzonation is the fundamental stage in a regional earthquake disaster mitigation programs especially in an urbanized area and microtremors have been utilized as a capable experimental method to make a seismic microzoning maps. In Perth Basin, Western Australia, we got an opportunity to start a seismic microzonation project and this time we carried out a pilot measurement across the basin.

Perth is the capital city of Western Australia State and the metropolitan area spreads on a flat plain called Perth Basin bounded by the Indian Ocean and east side mountains (Figure 1). This area is close to one of the most active seismic zone in Australia, where the Meckering Earthquake of M=6.9 was occurred in 1968 and much bigger earthquake occurrence has been anticipated. This is the reason that a microzonation of the metropolitan area is required.

As for the first step of this project, a pilot measurement of microtremors was carried out in January 1990. Two observation lines were set up. One is 25 km length traversing the basin east to west to grasp general trend and the other one is 3 km crossing downtown area north to south to clarify local geological conditions (Figure 1). A reference point was set up on the outcrop site of the permanent seismic station of Mundaring Observatory. Two kinds of observation systems were used in order to cover wide period range. One is an analogue type for long-period microtremors with 5 second pickup which was brought from Japan and the other one is a digital Kelunji Seismograph with 1 second pickup for usual micro earthquake measurements. Field observations were carried out point by point with the above two systems and daily measurements were started and ended at the reference point. It took four days to do in the whole points.

In this paper, main discussions are focused on the results obtained by the long-period seismometer. Digitization were performed with 50Hz sampling rate for each 40.96 second record and a Fourier spectrum was calculated. Figure 2 shows typical spectra of horizontal component. In the spectrum on the reference baserock site has sharp peak in the

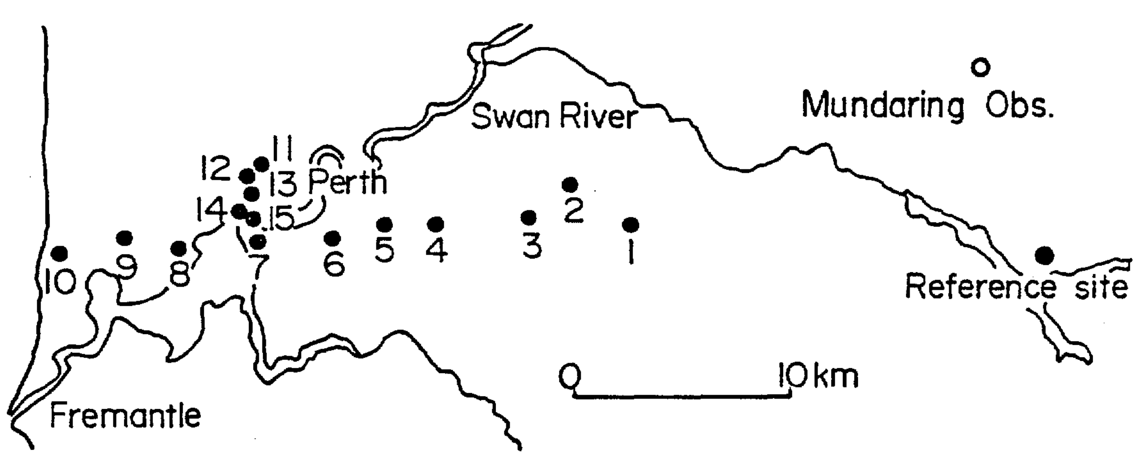

Fig.1. Location of observation sites.

frequency range of 0.2 Hz. This peak is also seen in the all sites and only a spectrum amplitude level is increasing in the sites of deposit. This common predominant peak is considered to be microseisms caused by ocean waves. In the spectrum at site #15 has another peak in the frequency range of 1 to 2 Hz (Figure 2) which is also seen in the spectrum at sites #13 and #14. These sites are set up on the thick alluvium deposit along the Swan River and these peaks might be reflecting the existing of surface soft layer. Figure 3 shows a spatial change of peak spectrum amplitude in the frequency of 0.2 Hz along the observation line from the reference site #R to the Indian Ocean side site #10. The spectrum amplitudes are several times larger than that of the reference site. This relation of an amplification on deposit sites has been pointed out in our previous fields in Japan and US, where the thickness of deep deposit have been estimated through the microtremors amplitude ratio of deposit to baserock site.

This time results suggest an applicability of microtremors measurements to microzoning problems in spite of a partial measurement and a rough analysis. This also encourages us to continue further cooperative investigations. The next step field measurements is going on schedule.

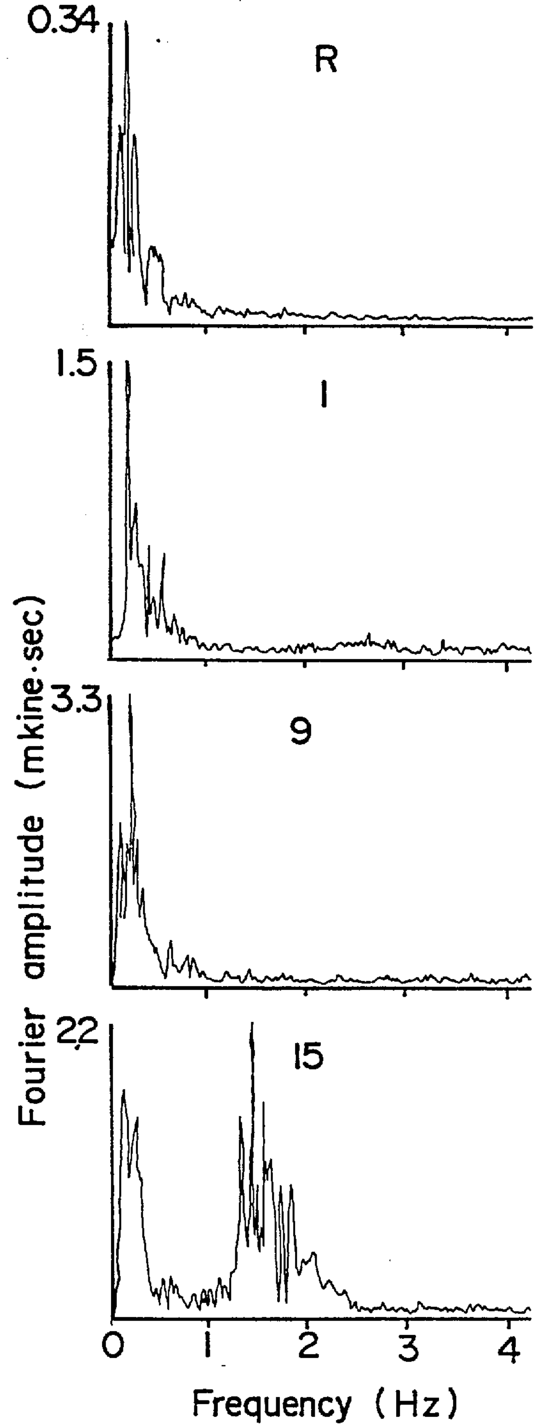

Fig. 2. Fourier spectra.
#R (Reference site)
#1 (east side)
#9 (west side)
#15 (downtown Perth)

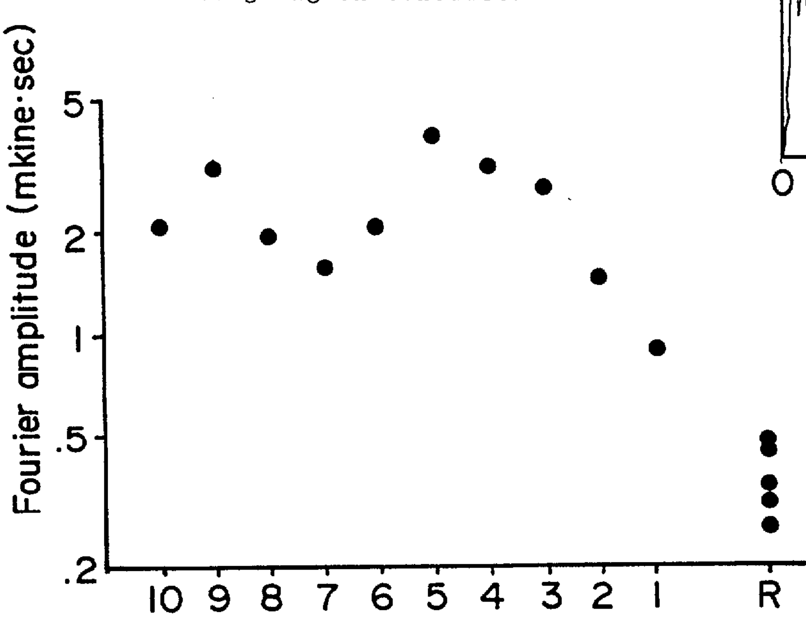

Fig. 3. A spatial change of peak spectrum amplitude in 0.2Hz along the observation line.

PRELIMINARY RESULTS OF THE MICROZONATION OF THE PERTH METROPOLITAN AREA USING MICROTREMOR SPECTRAL RATIOS

Brian Gaull+, Hiroshi Kagami*, Hitoshi Taniguchi**, Peter Gregson+, Geoffrey Woad+, and Barry Page+.

A bilateral project between the BMR (Australia) and various institutions in Japan to determine the likely response of the sediments near Perth to earthquake vibrations, officially commenced in August 1989 when the first author visited Japan. This was followed up with a visit by the two Japanese authors to Perth in January 1990. The results of this work will be discussed by Kagami and others in a companion paper at this symposium.

Since this visit, a systematic occupation of 50 more sites using 6 Kelunji seismographs, has been carried out by staff at the Mundaring Geophysical Observatory (MGO), as shown in Figure 1. Before deployment each seismometer was fitted with seismograph damping resistors and anti-aliasing filters. The 1-second, 3-component seismometers were sampled at 32 sps. Operational advantages introduced at this stage over the earlier sets of observations were:

1. The recordings were timed to trigger simultaneously and late at night when traffic induced vibrations were minimal. This meant that (at least at the long period end of the spectrum (>1s)) effects from temporal changes in source, were also minimised.

2. Direct comparison between one traverse and another was made possible by having the same reference point at MGO throughout the observations.

3. A north-south orientation for each of the 10 traverses occupied, was chosen so as to eliminate attenuation effects from any one traverse. The assumption here is that the source of the longer-period microtremors was the Indian Ocean.

4. Seismometers were buried to reduce wind effects.

5. Repeat observations were made at each site over 2 nights to check for consistency of spectra and also to allow averaging of them.

Hence in this manner, 100 seconds of microtremor recordings were obtained simultaneously at 4.00 a.m. L.T. at 5 sites, located along each of the traverses shown in Figure 1 as well as at the reference site. Site selection was based on a grid spacing of about 3 km and also on as diverse site geology as possible.

The spectra at each site were then compared using the following procedure:

1. Each file was transferred into the Webster (Spectrum computer) at MGO and the data plotted using the PIT software REPLAY.

2. The "quietest" 30s of each component of each record was selected and spectral analyses carried out using the Fourier transform and smoothing function in REPLAY. A file for each spectra was saved.

3. Spectral ratios were then computed and plotted for each component of each recording at each site using the corresponding reference site spectra for each ratio calculation.

It was fortuitous that on 8 May 1980 a ML4.5 earthquake centred near Cadoux triggered seismographs located at MUN and at KEW (Figure 1). These earthquake seismograms are compared in Figure 2. The spectral ratios from this event were then used to "calibrate" the spectral ratios obtained from the microtremor recordings from the same pair of sites (Figure 3) and a procedure for interpretation of the spectral ratios was developed as follows:

1. Determine the mean spectral ratios for both records for each component at each site.

2. Determine the mean curve of both horizontal components of the mean curves derived in (1).

3. Apply an attenuation factor of x 2 to ground periods less than 2 s.

4. Apply an additional attenuation factor of x 2 whenever "local" sources were observed, providing the frequency of this temporal source was still apparent through the rest of the recording. Otherwise any spike in the ratio plot owing to such a source was completely ignored.

It was found that when this procedure was applied the spectral ratios determined by microtremor recordings as described above compared reasonably well with those obtained from the earthquake recordings (Figure 4).

Spectral ratios at periods of 5, 2, 1, 0.5, 0.33 and 0.2 secs were interpolated from the spectral ratio plots, derived as above, for each of the above 50 sites. These results were then contoured (as shown in Figure 5) and the following conclusions were drawn:

1. Results in Kagami and others (this volume) compare favourably with those in this paper which is interesting considering their seismometer period was 5s.

2. Estimates of amplification of ground motion in the sediments in the Perth Basin varied between 2-10 times that observed on the hard rocks of Mundaring over all the periods of interest. This effect should be incorporated into earthquake risk estimates.

3. Contours at 5 seconds correlate reasonably well with gravity contours.

4. Other possible microtremor-contour correlations with geological contours were:
   at 2s, the intra Neocomian unconformity surface
   at 1s, the Leederville Formation
   at 0.5 and 0.33s the Kings Park and Osborne Formations.

5. It is thought that peak contours in the shorter period maps may correspond to alluvial deposits of various thickness.

6. Further field work is required to improve control on contours. Also further averaging of spectral ratios is required to reduce sampling error.

Footnotes: + From Bureau of Mineral Resources, MGO.
* From Hokkaido University, Japan.
** From The Research Institute of Regional Problems, Japan.

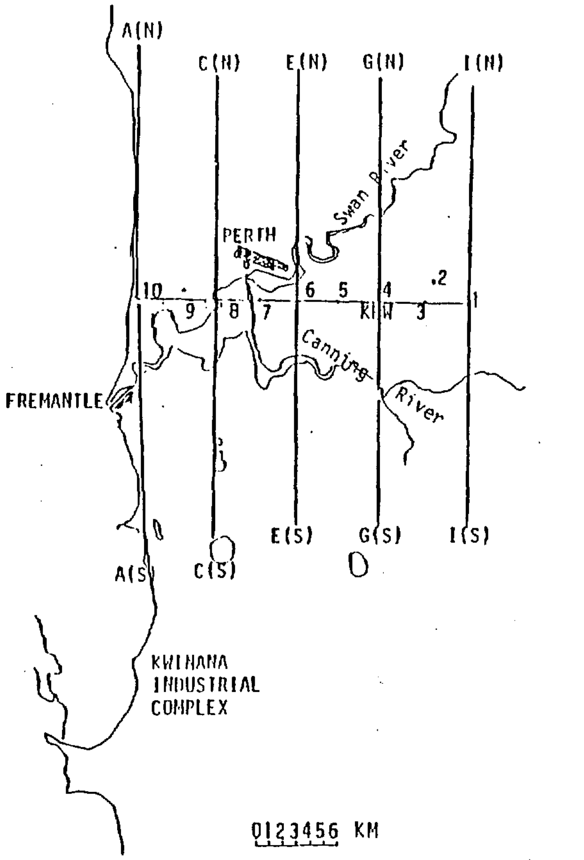

Figure 1: Sketch showing original sites occupied by Kagami et al (companion paper) as well as the 10 traverses used in this paper.

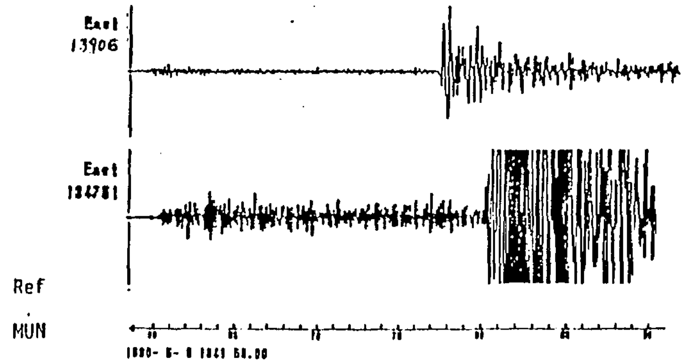

Figure 2: Recordings of the Cadoux earthquake of 8/5/90 (ML4.5) at MUN (top) and KEW (bottom).

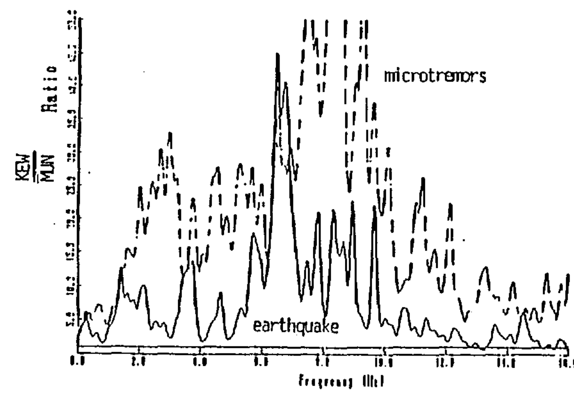

Figure 3: Spectral ratios from the earthquake of the 8/5/90 at MUN and KEW compared with those obtained from microtremors at the same sites.

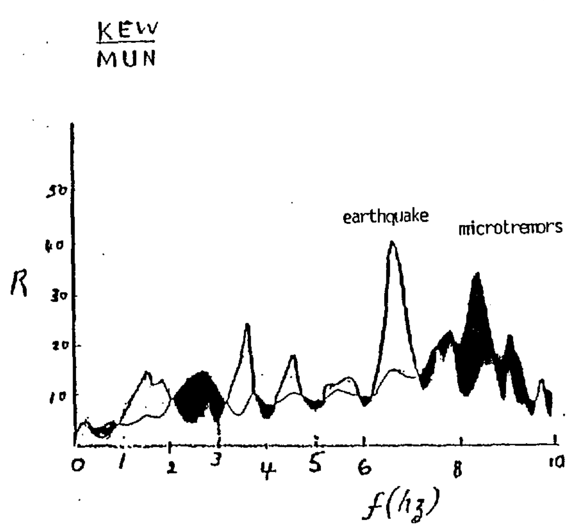

Figure 4: Comparison of mean spectral ratios of X and Y components of the earthquake of 8/5/90 at MUN and KEW with equivalent ratios determined from microtremors (See text for how this was done).

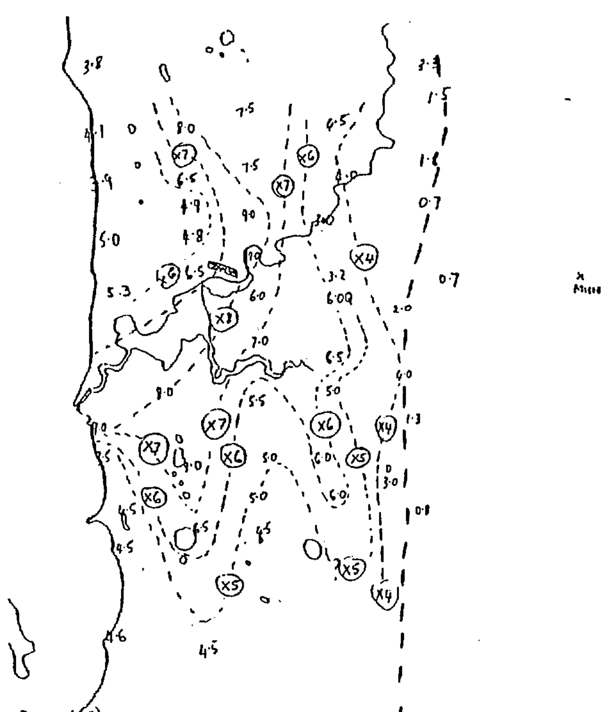

Figure 5: Example of results showing contours of spectral ratios at a ground period of 1 second.

Microzoning of Tsukuba Area—Data Base by means of Ground Survey and its Utilization—

Sadayuki Hattori

Muroran Institute of Technology

Data base by means of ground survey in Tsukuba area was prepared and analyses of microzoning on ground amplification were made.

Geological surveys through bore holes had been carried out at about 2600 sites of Tsukuba area, for about 1500 sites of which the following values were digitized; (1) depth of geological discontinuity, (2) N value, (3) depth where N value was measured, (4) class of medium, (5) age of medium, (6) coordinate of site and (7) level of site. In order to calculate amplification curve of ground, underground structures of S wave velocity (Vs) and density (ρ) are necessary for each site. It is possible, in general, to introduce empirical formulas proper to the area concerned, which give Vs and ρ of the ground from only geological data, through correlativity between results of seismic propecting and geological data, but there were not so many data of seismic prospecting as to be able to create such formulas in Tsukuba area. In this report, therefore, the formulas of Iida et al. were used.

Amplification curve for each site was calculated by Haskell's method, when soil was treated as visco-elastic media of Voigt type. Analyses were made for almost all of meshes (unit area) in the area of about 21km in latitude (35° 58'45"N-36° 10'00"N) and about 15km in longitude (140° 1'45"E-140° 11'45"E), when one unit area was 380m in longitude and 460m in latitude. Regional distributions of three predominant periods between 0.1 sec and 1.0 sec and corresponding peak amplitudes were obtained.

The underground structure of P wave velocity in the depth of less than 400m was determined by seismic prospecting which was carried out by the Geographical Survey Institute to investigate the ground condition in and around the bore hole for earthquake observation. On the basis of S wave velocity, which was estimated from the above P wave data, amplification curve of a little deep ground was obtained and predominant periods 2.5 sec and 1.3 sec were recognized.

Recent Results from Tennant Creek

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On 22 January 1988 three earthquakes of M_S 6.3-6.7 near Tennant Creek, Northern Territory produced 32 km of surface rupture on two thrust-fault main scarps. The surface deformation, seismicity history, aftershock distribution and focal mechanisms of these earthquakes have been described in previous papers. Here we report new results based on relocation of the 100 largest earthquakes of the sequence and from levelling surveys conducted in the fault zone after the main shocks.

All earthquakes that occurred in the Tennant Creek fault zone from 1987 to March 1989 and were large enough to be recorded by national and global networks are relocated using the method of joint hypocenter determination (JHD). Arrival times from the WRA array and portable stations are combined with the national and global network data in order to provide temporally uniform coverage of the fault zone and calibration of teleseismic station corrections. The JHD locations for the mainshocks are consistent with the interpretation of faulting that progressed from west to east. The spatial distribution of the largest aftershocks in 1988 and 1989 is similar to that observed for smaller aftershocks that were well located with only portable array data. The 1987 earthquake series occurred in a cluster in the gap between the two main scarps. This result is consistent with the locations of aftershocks of the largest 1987 shocks that were determined using data from WRA and three portable stations (Bouniot, in preparation).

Sixty-six 200-m long topographic profiles, which cross the fault scarps every 500 m, provide a clear picture of the sense of deformation associated with the Tennant Creek earthquakes. In particular, these profiles provide additional evidence for a reversal of the sense of thrusting between the east and west ends of the Lake Surprise scarp. Level data that were collected after the January, 1988 earthquakes are compared to data from surveys conducted in 1954 and 1972 and reveal clear evidence of extensive uplift over the headwall blocks of the thrust faults. Preliminary modelling of the co-seismic elevation change is consistent with faulting models derived from other observations. On the east and west ends of the fault zone, thrust faulting on south-dipping planes is implied by the level data. In the center part of the fault zone, near the western Lake Surprise fault, reverse faulting on a north to northwest dipping fault is required to match the geodetic signal observed north of Lake Surprise and along the western fence.

The pattern of 1987 sequence at Tennant Creek, NT

Emmanuel BOUNIOT, Trevor JONES, Kevin Mc CUE
ASC, BMR, CANBERRA

Between the 5th of January and the 9th of January 1987, four earthquakes of about the same size (ML 4.9 to ML 5.4) rocked the area southwest of Tennant Creek. The biggest event of this sequence occurred on 7th January at 20:01 UT (05:32 am local time) and reached ML 5.4. A search in the area by one of us (TJ) within a few days and during installation of a 3 station temporary seismographic network, failed to find any evidence of surface faulting. Three large (Ms>6.0) earthquakes within a 12 hour period on 22 January 1988 did rupture the surface and the relationship between these two sequences is investigated here.

The temporary stations were in place for two months during which 116 events were recorded and 50 of them have been accurately located to date (figure 1). All the epicentres have an accuracy of better than 2 km and the focal depths have been determined to better than about 3 km in general and never more than 5 km. Most of the epicentres were in the depth range 1 to 6 km with many of them near 3 km.

The epicentres are not distributed along the subsequent fault scarps formed during the 1988 mainshocks, but are in the gap between the Lake Surprise and Kunayungku scarps. A cross section (figure 2) shows that most of the foci are shallower than 10 km and have a south dipping trend which indicates that they are coincident with the Kunayungku fault surface defined by well located aftershocks of the 1988 sequence. Even though the Kunayungku scarp wasn't visible in 1987, this shows that this escarpment may have existed already and was active before the strong sequence of 1988. It thus appears likely that the rupture sequence during 1988 probably commenced with failure of the Kunayungku fault segment and subsequent easterly propagation of the rupture during the two next earthquakes.

The cumulative number of events (figure 3) shows that there is two main peaks of activity: first at the very beginning of the sequence in January and second in June.

The start of the sequence of earthquakes in the first few days of January is very sharp, and most of the energy is released (figure 4). The second concentration of events is characterised by an increase over April and May with a maximum of activity in the second week of June (figure 3). Two events of magnitude MD 4.4 and one MD 4.7 are responsible of the two last steps on the cumulative moment (figure 4) and indicate the end of the significant activity for 1987. Unfortunately the survey by the temporary stations cover the first three months of activity, so we cannot localise accurately the events of this second peak.

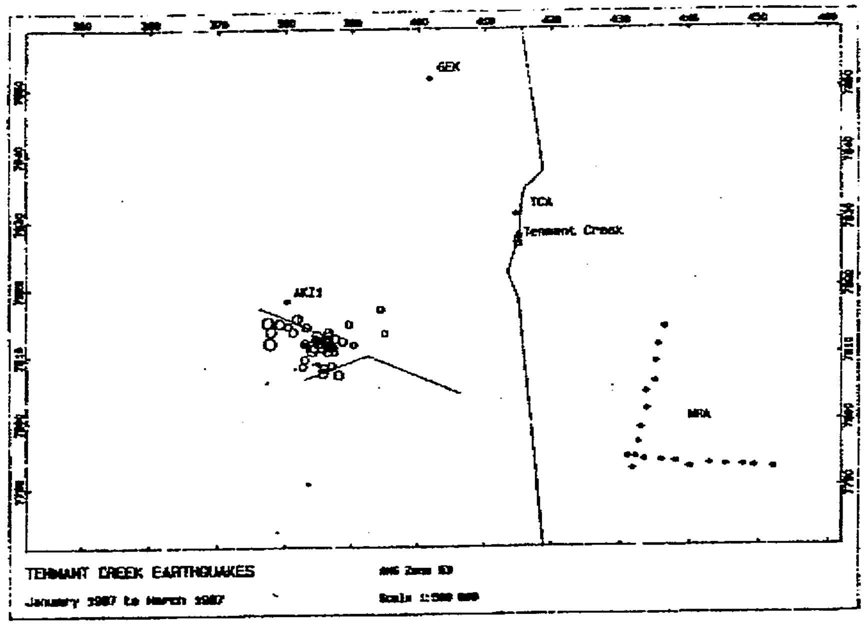
From the cumulative moment released (figure 4) we can deduce two things:

- The four first events released 82% of the total moment released ($3.8*10^{18}$ N.m) until the beginning of the 1988 sequence.

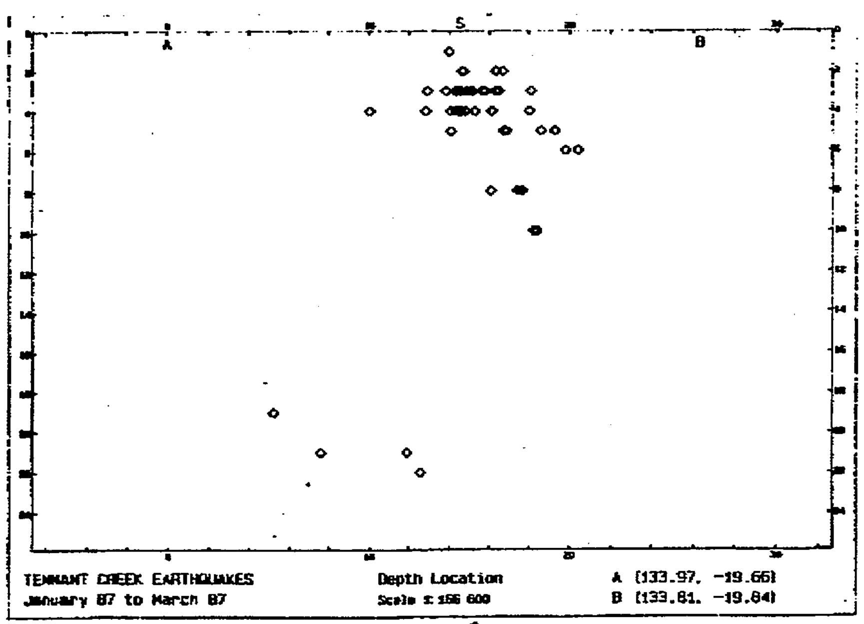
- The tail of the curve is asymptotic to the horizontal with no indication of the amazing sequence to follow.

Unfortunately the 1987 foreshock sequence has all attributes of a mainshock/aftershock sequence with no obvious warning of the three large earthquakes to follow.

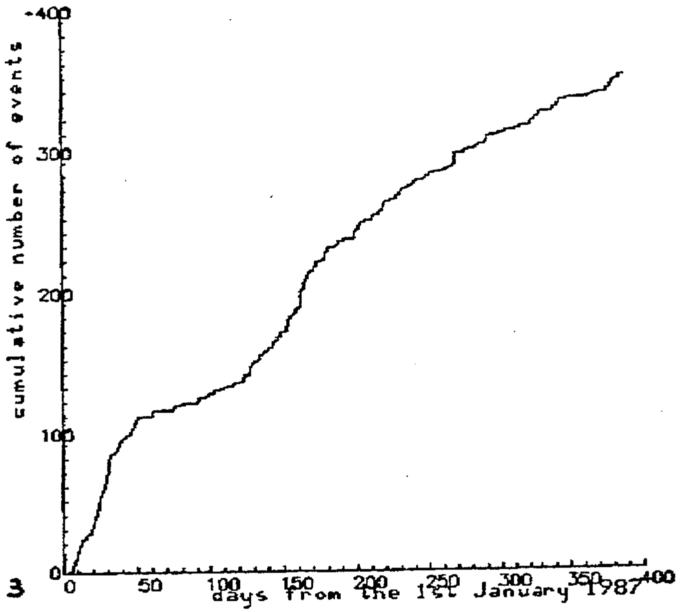
There are interesting gravity and magnetic anomalies in the epicentral area that modelling by one of us (EB) shows are associated with a very shallow intrusive body. This shallow body is likely to induce a stress concentration who have provided the energy for the 1987 and 1988 sequences.


GEX
TCA
Tennant Creek
AKI1
WRA
TENNANT CREEK EARTHQUAKES
January 1987 to March 1987

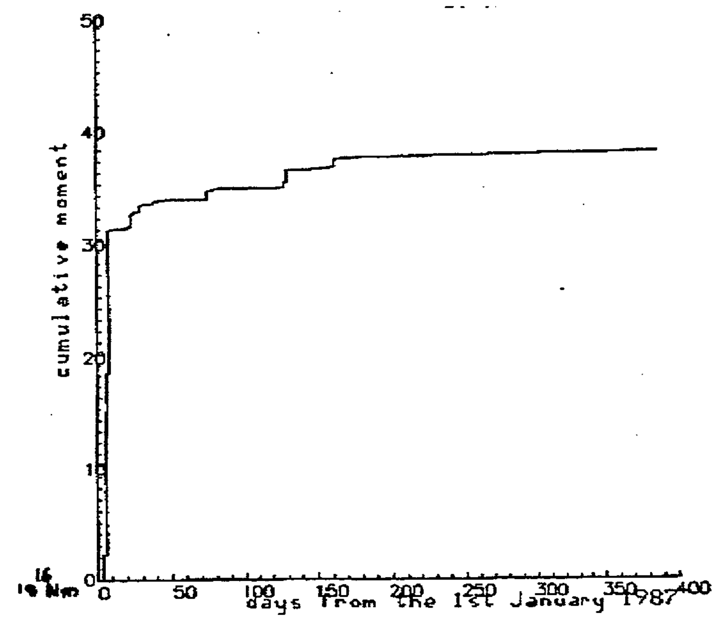
1


A
B
TENNANT CREEK EARTHQUAKES
January 87 to March 87
Depth Location
Scale 1:166 600
A (133.97, -19.66)
B (133.81, -19.84)

2


cumulative number of events
days from the 1st January 1987
0
50
100
150
200
250
300
350
400

3


cumulative moment
days from the 1st January 1987
10
20
30
40
50
0
50
100
150
200
250
300
350
400

4

PALEOSEISMOLOGIC STUDIES IN AUSTRALIA
"HOT OUT OF THE DIRT"

J.R. Bowman & Others

(Australian National University, School of Earth Sciences)

The authors have recently visited the fault scarp produced by the Tennant Creek earthquake of January 1988. Their presentation will be:

"HOT OUT OFF THE DIRT"

THE WEST TASMAN SEA EARTHQUAKE ZONE

MICHAEL-LEIBA Marion

(Bureau of Mineral Resources, Australian Seismological Centre)

The West Tasman Sea earthquake zone is situated near the edge of the continental shelf to the east of Flinders and Cape Barren Islands and northeastern Tasmania.

The earliest record of possible seismic activity in the zone was of an earthquake at 1330 UTC on 18 August 1844. This event was felt on Flinders, Goose and Cape Barren Islands, and if its epicentre were in the zone, it had an intensity-deduced Richter magnitude of 4.7.

No further events were reported until April 1883 when an extraordinary sequence of seismic activity commenced. An estimated 1701 earthquakes with intensity-deduced Richter magnitudes of at least 4.0 were felt in northeastern Tasmania and the islands off its coast during the period April 1883 - January 1902. Most of the events occurred during the first three years when the monthly seismic energy release generally exceeded 10^{12} Joules and five of the 1675 earthquakes during this period had intensity-deduced Richter magnitudes of 6.0 or more. This was followed by several years of relative quiescence then, in January 1892, the largest recorded event in eastern Australia took place. It had an intensity-deduced Richter magnitude of 6.9 and was followed by a magnitude 6.0 aftershock eight minutes later.

Activity was returned to a relatively low level following these earthquakes. Around 15 independent events with magnitude 4.0 or more have occurred since January 1892. Two of these had Richter magnitudes greater than 5.5. That of 28 December 1929 had ML 5.6 (RIV) and its intensity-deducted magnitude was the same. Both this earthquake, and the ML 5.7 (RIV) event of 14 September 1946 at 1948 UTC, caused minor damage in Launceston over 100 km distant. The latter event had an intensity-deduced Richter magnitude of 6.0 and was widely recorded at Seismograph stations around the world.

The seismic history of the West Tasman Sea Zone shows that large and potentially damaging earthquakes, which are difficult to predict on the basis of seismicity patterns, occur in the coastal areas of southeastern Australia.

A NEW CRUSTAL MODEL FOR SOUTH-EAST WESTERN AUSTRALIA

V.F. DENT
(Bureau of Mineral Resources, Mundaring Geophysical Observatory)

In March, 1989, two relatively large (ML 4.8 and ML 5.4) earthquakes occurred approximately 160 km southeast of Laverton, W.A. These earthquakes, and their aftershocks, showed clear secondary phases on some seismographs, arrival times for which did not fit closely any expected phase arrival times for the crustal model being used to locate the earthquakes (WA1). This model had a two-layer crust, and it seemed that the fit could be improved if a new layer was introduced.

The Phillip Institute of Technology (PIT) has a computer program "MODEL", written by Vaughan Wesson, which, given sufficient quality data, can simultaneously locate earthquakes, and compute an earth model from the data. Secondary phases are particularly useful for this program, provided they are correctly identified.

I have extracted from the MGO earthquake data catalog all earthquakes in the southeast Western Australian region, which I considered had a chance of being satisfactorily located. The data search started from October 1988, when a station was installed at Forrest, in the far south-east of Western Australia. Arrival times at FORR, WARB and COOL were necessary, otherwise constraint on the locations is unsatisfactory. Only 5 events satisfied the requirements and these are shown in Table 1. The prominent second arrivals were interpreted as PG and SG.

Besides an over-all lack of arrival time data, the inversion is severely limited due to the lack of close stations. Consequently depths to the crustal layers are poorly constrained. Also, for some earthquakes, the stations are up to 600 km distant, and the flat earth approximations used start to become invalid. For comparison, the PIT used over 500 arrivals from 21 earthquakes or blasts to compute its VIC5A crustal model.

The model produced by the inversion program ("Eastern Goldfields" or "EGF") is shown in Table 2. The program was instructed to produce a 3 layered crust. From the data provided, the boundaries for this new layer were found to be at 9 and 23 km below the surface. The P and S velocities are now significantly higher for this depth range than they were in the WA1 model, but significantly lower from there to the Moho.

The earthquakes were then relocated using the EQLOCL program, using the new model, and also the models WA1 and SA1A (the model used by SADME for South Australian earthquakes). Only stations closer than 700 km were used in these locations. The results are summarised in Table 3.

This table shows that the scaled arrival time data fits the Eastern Goldfields model significantly better than the other models. The slow top layer of the WA1 model does not fit the observed PG and SG velocities.

Another significant (ML 5.4) occurred in the southest WA region (50 km SE of Norseman) in July 1985. This earthquake was difficult to locate at the time, because there were no seismic stations, within 1000 km. to the east of the event. However, some aftershocks show PG and SG arrivals on stations to the north and west, which can be used with the EGF model, to get an improved location. One such event occurred in June 1987, and this has been relocated approximately 64 km southeast of Norseman. This confirms its original location using graphical techniques.

There is some evidence for another phase between the PN and PG arrivals. It is possible that the arrival is a reflection. White (1969) suggested that crustal reflections were commonly seen in South Australian events, but reflected phases are yet to be positively identified on WA seismograms.

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TABLE 1 EARTHQUAKES USED TO CONTRUCT AND TEST EGF MODEL (MGO DATA)

EV	DATE	O. TIME		LONG	LAT	DEP	ML	#PHA	SD	REMARKS
1	85-07-28	0739	47.3	122.22	-32.51	10	5.4	-	-	50 K SE OF NORSEMAN
2	87-06-14	1806	32.5	122.31	-32.59	5N	3.5	-	-	65 K SE OF NORSEMAN
3	89-03-03	0922	07.0	123.64	-29.59	5N	4.8	8	0.52	160 K SE OF LAVERTON
4	89-03-03	1326	41.7	123.65	-29.60	5N	5.4	11	0.48	160 K SE OF LAVERTON
5	89-04-17	0349	40.0	123.76	-28.75	5N	3.5	5	0.52	120 K EAST OF LAVERTON
6	89-08-10	1545	28.8	124.70	-29.95	5N	3.1	13	0.80	161 K NE OF ZANTHUS
7	89-10-12	0403	29.5	122.92	-27.69	5N	3.5	17	0.87	120 K NE OF LAVERTON

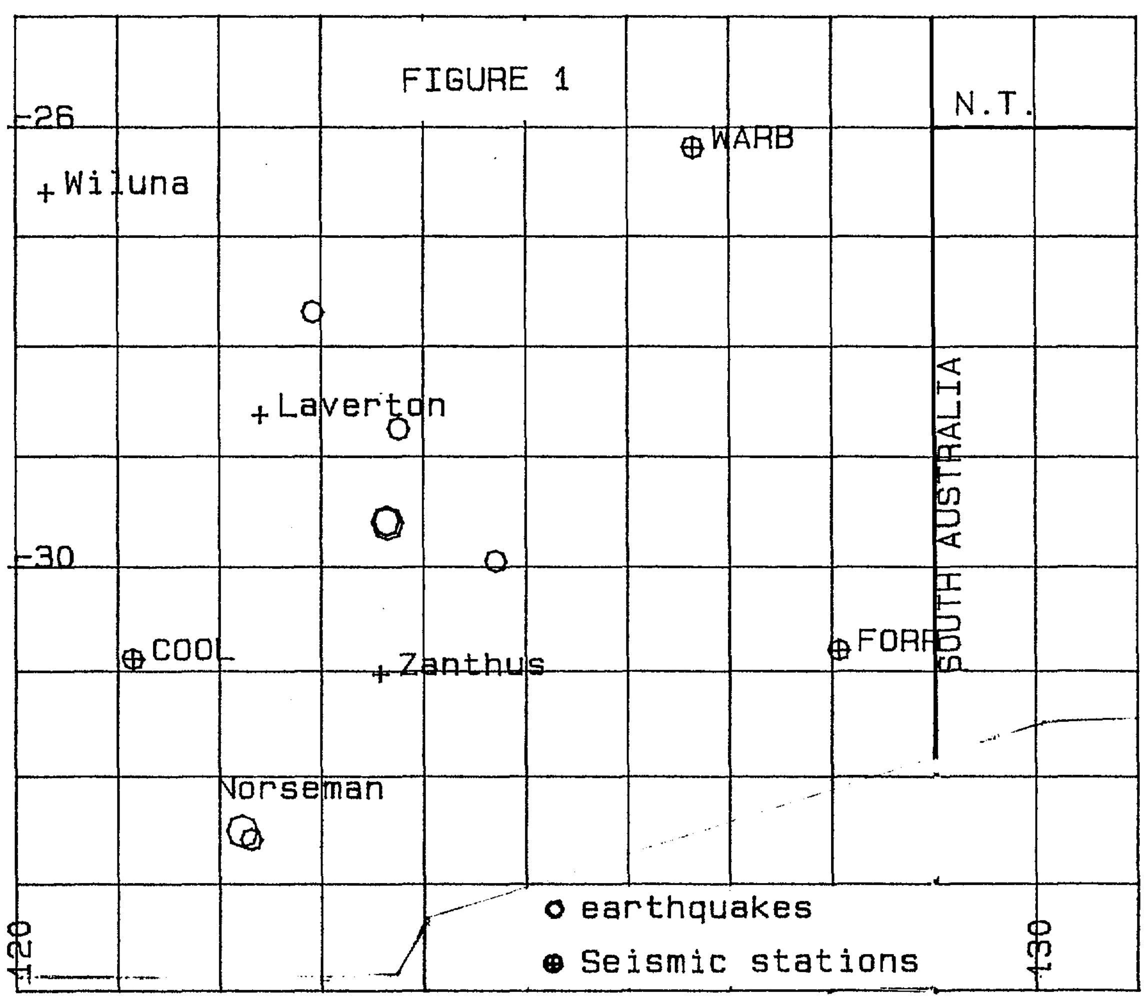
TABLE 2 CRUSTAL MODELS

EGF			WA1			SA1A		
DEP	P	S	DEP	P	S	DEP	P	S
0	5.94	3.36	0	6.13	3.61	0	6.23	3.58
9	6.37	3.70						
23	6.50	3.85	19	7.17	4.14			
36	8.16	4.66	37	8.11	4.61	38	8.05	4.60

TABLE 3 COMPARISON OF LOCATION QUALITY USING VARIOUS MODELS

EV	EGF			WA1		SA1A		REMARKS
	#PHA	DEP	SD	DEP	SD	DEP	SD	
2	8	9.4	.56	-5.9	.79	13.0	1.27	(not used in inversion)
3	10	9.6	.22	-9.4	.40	13.5	.47	
4	10	13.5	.17	-5.6	.35	16.0	.46	
5	7	16.2	.48	-3.6	.77	21.8	.67	
6	7	9.1	.68	-7.4	.92	15.9	.85	
7	8	18.9	.24	-6.9	.51	21.2	.40	

FIGURE 1



The Effects of Crustal Velocity Gradients on the Propagation of Lg Waves in the North Australia Craton

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Aftershocks of three large earthquakes near Tennant Creek in the Northern Territory of Australia provide a unique opportunity to study regional seismic phases in the North Australian craton. We report results from an analysis of velocity and attenuation of Lg waves recorded at an array of portable digital seismographs and the Alice Springs array. Three recorders were operated in the source zone to provide control on the epicenters, and seven formed a line between Tennant Creek and the Alice Springs array, which is 430 km to the south. Eleven earthquakes of sufficient size for analysis were recorded in a one week deployment two months following the mainshocks. The observed group velocity of 3.7 km/s for Lg waves is at the high end of the range usually observed. We estimate attenuation in discrete frequency bands by measuring the decay of amplitude as a function of distance from the source and assuming the common $r^{-5/6}$ relationship for geometrical spreading. However, this assumption leads to attenuation estimates that are abnormally high for a stable continental region and are inconsistent with the high frequency content of the data and with observations of M_L bias in the Australian shield. Some crustal models for northern Australia based on seismic refraction show a gradient zone between 47 and 55 km rather than a sharp Moho discontinuity. We investigate the effect of gradient zones on decay of Lg amplitudes using synthetic seismograms calculated with the wavenumber integral method. The modeling suggests that S-wave energy that would be trapped in a crustal wave guide with a sharp lower boundary leaks out in the presence of a gradient, and may explain the high apparent attenuation. Attenuation of Lg waves is observed to be frequency dependent, with Q increasing with frequency. Coda Q estimated for the same suite of earthquakes is higher for the same frequency band than the Lg Q estimates, supporting the hypothesis that the low Q observed for Lg is a structural effect.

DEVIATIONS FROM JEFFREYS-BULLEN TRAVEL TIMES FOR AUSTRALIAN EARTHQUAKES

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It has long been recognised that there are problems when the Jeffreys-Bullen (JB) travel-time tables are used for locating Australian earthquakes (e.g. Hales et. al., 1980). There is a need to quantify the deviation of observed arrivals from the expected time according to the JB tables, in order to compile more appropriate tables.

The EQLOCL earthquake location program (copyright of the Seismology Research Centre at the Philip Institute of Technology), which many Australian seismic groups now use, is very flexible regarding the models which can be used to locate earthquakes. Most agencies have their own local model, and the first arrivals are assumed to be Pn (Sn) up to a set distance, after which JB tables are invoked. Because of the non-fit of JB data, it has been neccessary for some agencies to introduce the tables at distances of > 2000 km, which effectively rules out their use altogether. The deviations presented here were derived by bringing the JB tables into effect from 400 km.

The seismic coverage of the Australian continent has steadily improved, and location accuracy has correspondingly improved. It is now possible to define the coordinates and origin times of most earthquakes with much more confidence than was possible in the 1970's. I have selected earthquakes from the Cadoux, Meckering, Wyalkatchem and Ballidu areas of W.A., two Tennant Ck. earthquakes (NT), and 5 east Australian earthquakes (Wonanngatta, 1982, Dalton, 1984, Nhill, 1987, Bunnaloo, 1988, and Newcastle, 1989) and assumed the focal parameters shown in Table 1.

Plots of the deviations from the JB times for these earthquakes, using the parameters in Table 1, are shown in Figures 1 to 4. The P wave deviations for Tennant Ck. earthquakes are shown in Fig.1, for West Australian earthquakes on Fig. 2, and for east Australian earthquakes on Fig. 3. A combined plot for S wave deviations is shown in Figure 4. On Fig. 1, I have also plotted deviations presented by Hales et al (1980) for the Ord River blasts (data from Denham et. al., 1972) and a large Lake McKay event in 1975. The Ord River data is in approximate agreement with data for the Tennant Creek events.

Figures 1 & 2 show clear deviation trends for P waves. Deviations steadily increase (become more negative) until about 16 degrees, and then start to decline again. These trends are similar to those trends exhibited by data from the Early Rise project, conducted in North America in 1966 (Iyer et. al., 1969). I believe the Lake McKay event has been mislocated, and if it is moved 20 km. to the west, and its depth changed to 5 km, its residuals are then in close agreement with other West Australian events.

The deviations for West Australian events are slightly greater than those for the Tennant Creek events. For the east Australian events however (Fig. 3), deviations are much less, and the trend is less distinct. Only the Nhill event (in Victoria, near the S.A. border), shows consistant negative residuals.

The residuals for the S waves (Fig. 4) show a similar trend to the P waves, but the size of the deviation is approximately double that of the P waves.

The data in figures 1-4 are for earthquakes which are both large and reasonably well constrained. I have examined 5 less-well located events from regions not represented by the above earthquakes (South Australia, and NW and SE West Australia), and the deviations for these events tend to confirm the trends exhibited by the events listed above.

The deviation plots suggest upper mantle velocities under Western Australia are slightly higher than under other Australian shield areas. They confirm other well documented conclusions that velocities under the east Australian orogenic areas are significantly lower.

Hales et. al., (1980), presented an earth model which they believed satisfactorily explained the deviations they observed. Whether or not their model is correct, it is reasonable to conclude that when locating earthquakes, the assumption that the first P & S arrivals after 400 km (approximately) have followed a Pn (or Sn) type path is generally invalid. In the absence of a believable earth model which can be incorporated into the EQLOCL program, it may be better to use new tables based on deviations such as demonstrated by these earthquakes.

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Hales. A.L., Muirhead, K.J., & Rynn, J.M.W. (1980). A compressional velocity distribution for the upper mantle. Tectonophysics, 63:309-348.

Iyer, H.M., Pakiser, L.C., Stuart, D.J., & Warren, D.H. (1969) Project Early Rise: Seismic Probing of the Upper Mantle Journ. Geophys. Res. 74 p 4409-4441

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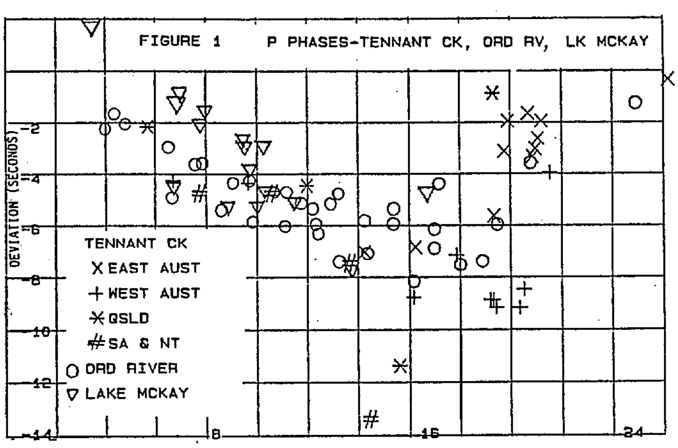
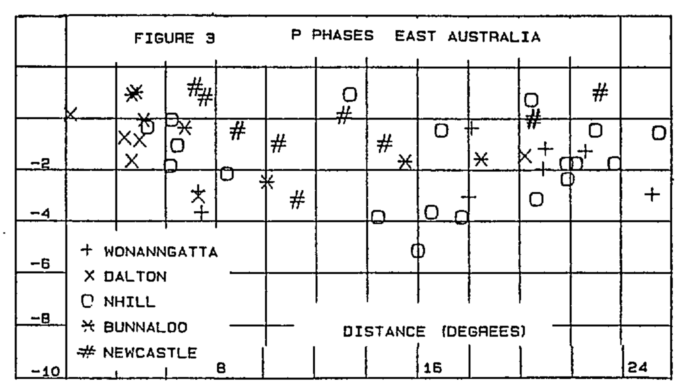
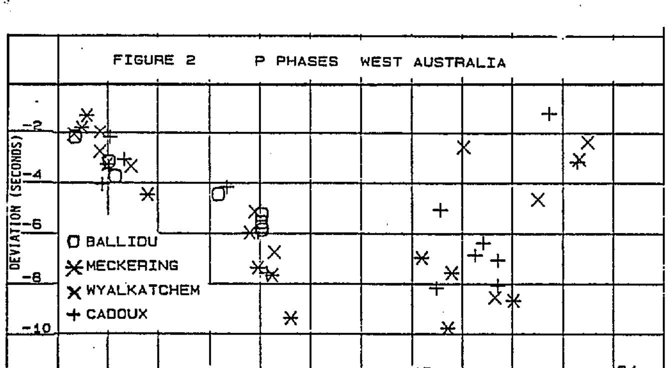
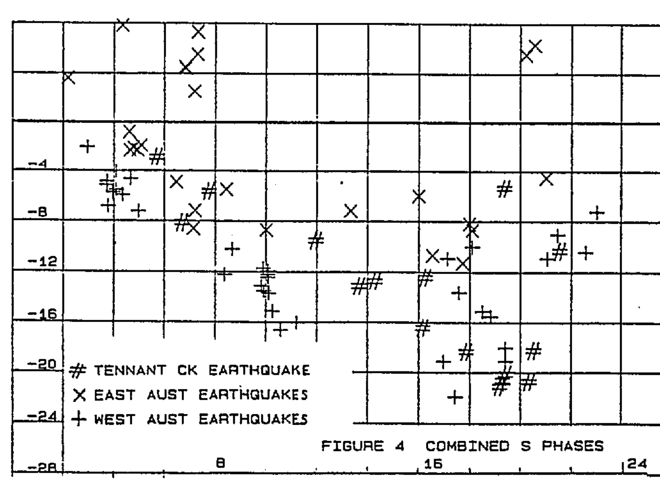
TABLE 1
PARAMETERS OF WELL-LOCATED EARTHQUAKES USED TO STUDY DEVIATIONS FROM JB TABLES

STATE	DATE	TIME	LONG	LAT	DEP	ML	STN	DIST	REGION
WA	1975-10-03	1151 09.2	126.554	-22.101	5	6.0	GLS	370	LAKE MCKAY (REVISED)
VIC	1982-11-21	1134 17.7	146.974	-37.219	17	5.5	TOO	137	WONANNGATTA
NSW	1984-08-09	0630 12.8	149.170	-34.810	5	4.3	CAH	19	DALTON
WA	1987-03-07	0538 07.4	117.094	-30.779	6.5	5.7	CAA	7	CADOUX
WA	1987-06-11	1218 42.2	117.517	-31.182	3.9	3.5	KLB	51	WYALKATCHEM
VIC	1987-12-22	1506 31.5	141.494	-36.138	17	4.9	WKA	110	NHILL
WA	1988-01-06	0342 08.0	117.502	-31.198	5.9	4.3	KLB	50	WYALKATCHEM
NT	1988-01-22	2054 05.6	134.084	-19.887	2.8	5.3	WR1	28	TENNANT CREEK
NT	1988-01-29	1019 34.4	133.956	-19.771	6.8	5.5	WB2	46	TENNANT CREEK
WA	1988-03-14	0748 24.4	116.799	-30.541	3.4	3.6	BAL	11	BALLIDU
NSW	1988-07-03	0823 10.7	144.496	-35.672	3.6	4.0	BFD	242	BUNNALOO
WA	1989-11-10	1658 08.8	117.133	-30.747	2.4	3.8	CAA	2	CADOUX
NSW	1989-12-27	2326 57.1	151.559	-32.905	12	5.5	RIV	109	NEWCASTLE
WA	1990-01-17	0638 08.1	116.990	-31.720	5.8	5.5	KLB	74	MECKERING
WA	1990-05-08	1840 56.6	117.098	-30.782	1.8	4.5	CAA	7	CADOUX









A MEDIUM TERM PRECURSOR FOR THE LOMA PRIETA, CALIFORNIA, ML=7.1 EARTHQUAKE ?

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AUSTRALIA.

ACTIVITIES IN CALIFORNIA

Detailed investigation of the long and short term strain data associated with the Loma Prieta earthquake (M=7.1) of October 17, 1989 has been carried out. This earthquake provided the first opportunity in California to observe the near field of a magnitude 7 earthquake with borehole tensor strainmeters. No short term (seconds to days) precursors were identified at the 1 nε level. The medium term data at the San Juan Bautista tensor strainmeter site, 30 km to the south of the epicentre, where the strain rate had been constant at the 20nε level since 1986, showed a clearly anomalous change in strain rate of approximately 200nε/year established in late 1988, a year before the event, in the fault parallel shear $\Gamma_1 = (e_{xx} - e_{yy})/2$. The areal and Γ_2 (e_{xy}) shear strain rates remained constant over this period. These data are shown in the accompanying figure, which contains areal strain and shear strains Γ_1 and Γ_2 in nanostrain. Two simple exponentials have been extracted from the data to account for grout cure (approximately 100 days time constant) and non elastic long term hole recovery (approximately 1000 days time constant).

This signal is compatible in sense of shear and order of magnitude with a change in strain rate of 300 nε/year implied from changes of line length of the Loma Prieta - Allison geodetic record. These observations seem to indicate a broad regional change of strain rate about one year before the event acting to increase the shear stress across the fault and the probability of failure. With such limited spacial sampling of the region it is impossible to model the tectonic processes occuring in the region and so determine whether there is a causal link useful for prediction between this observation and the Loma Prieta earthquake.

A recent presentation at a workshop in Morro Bay, California, developed the concept of an instrument cluster to provide a coherent observatory type data base for geodetic, seismic and borehole strain instruments for a region scaled appropriately for a magnitude 7+ event. Typically a cluster would cover an area of about 150 by 50 km, and include sites instrumented with borehole strain monitors, seismometers and accelerometers. The region of the Haywood fault near San Francisco would be a prime target for such an array, since the probability of a significant event in the area during the next 30 years has been increased by the occurrence of the Loma Prieta event. It can be demonstrated that for reasonable borehole strain coverage of such an area, a minimum of 25 sites would be necessary. The sites would be located not nearer than 5 km from the fault trace, and be operated at a precision of 0.1 nanostrain for frequencies below 10 Hz. This will provide useful co-seismic data for all events above M=4, and for larger events permit monitoring of longer period precursive strain fluctuations larger than 0.1% of the event. The strain cluster should be a 50-50 mix of dilatometers and tensor strain meters because of their complementary characteristics.

HISTORY OF STRONG MOTION RECORDING INSTRUMENTS IN W.A.

B.J. Page & B.A. Gaull

(Bureau of Mineral Resources, Mundaring Geophysical Observatory)

After a major earthquake of ML 6.9 hit the state of Western Australia at the country town of Meckering in October 1968 it was decided to install a network of strong motion instruments in the region. It was not until mid 1971 that the first instrument was actually installed and in the intervening period another strong quake of magnitude 6.0 was centred on the town of Calingiri to the north-west of Meckering.

From the data collected from these accelerographs, it was hoped to be able to predict the behavior of the ground during a large earthquake, and for the engineer to determine the response of his structures.

The first accelerographs deployed were the MO-2, which were manufactured in New Zealand. This produced a photographic record on 35mm film and was theoretically capable of storing some 7.2 metres of data. Each record being 47 seconds duration. The basic principle of operation was that a source of light projected a beam of light onto the surface of the triaxial accelerometers. The mirrors fixed to these transducers in turn projected four spots of light, suitably displaced, onto the film producing the accelerogram. Some experimentation at MGO to increase trigger sensitivity at higher frequencies was carried out, which resulted in the acquisition of our first accelerograms.

A second modification enabling time and date information to be displayed on the record was designed and produced in Canberra workshops by Black, 1986. This meant that event identification was no longer a problem.

The second type of strong motion instrument to appear onto the Western Australian scene was the KINEMETRICS SMA-1. Three were purchased on MGO's recommendation for use in Telecom's 18 story building in Perth central. A fourth is installed at the top centre of the Mundaring Weir which is owned by the West Australian Water Authority.

The progression to digital instruments was both desirable and inevitable. The acquisition of data in digital form had many advantages over analog data, for instance it was now possible to capture the p-wave data using the pre-event facility. The first digital system acquired was the A700 accelerograph and its associated Data Retrieval Unit (DRU-750) and PB-800 playback system, manufactured by TELEDYNE GEOTECH. A number of these instruments have been deployed on WAWA dam sites and in the active fault zone of Meckering and Cadoux.

The final change in instrumentation of the strong motion program was to occur in December 1988 when the KELUNJI, manufactured and designed by the Phillip Institute of Technology was introduced. Two units were installed - one in the Goomalling district and the other north of the township of Dowerin.

About 250 accelerograms have been obtained from the West Australian network providing a data base for preliminary attenuation studies such as Gaull, 1988, as well as for response spectra.

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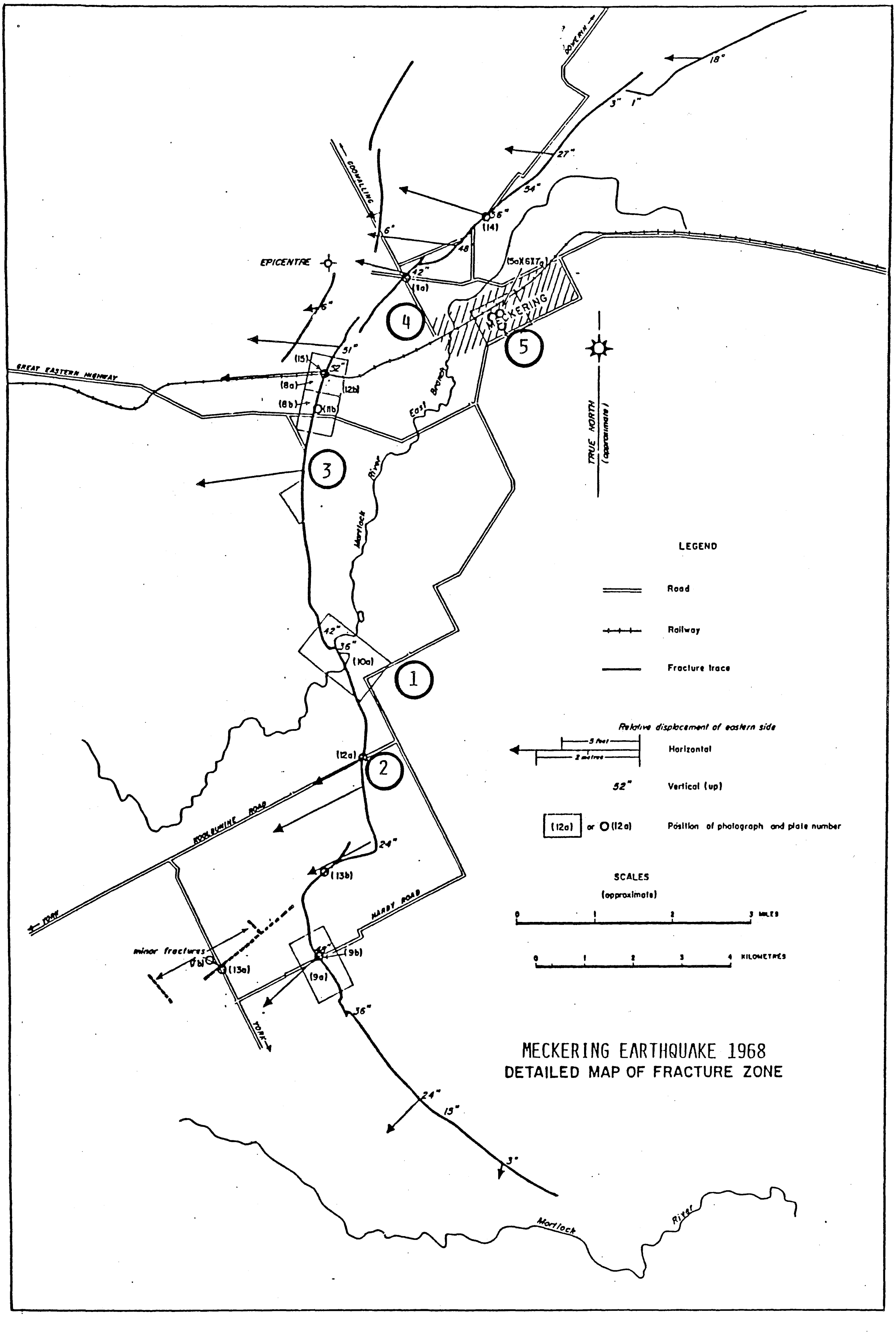
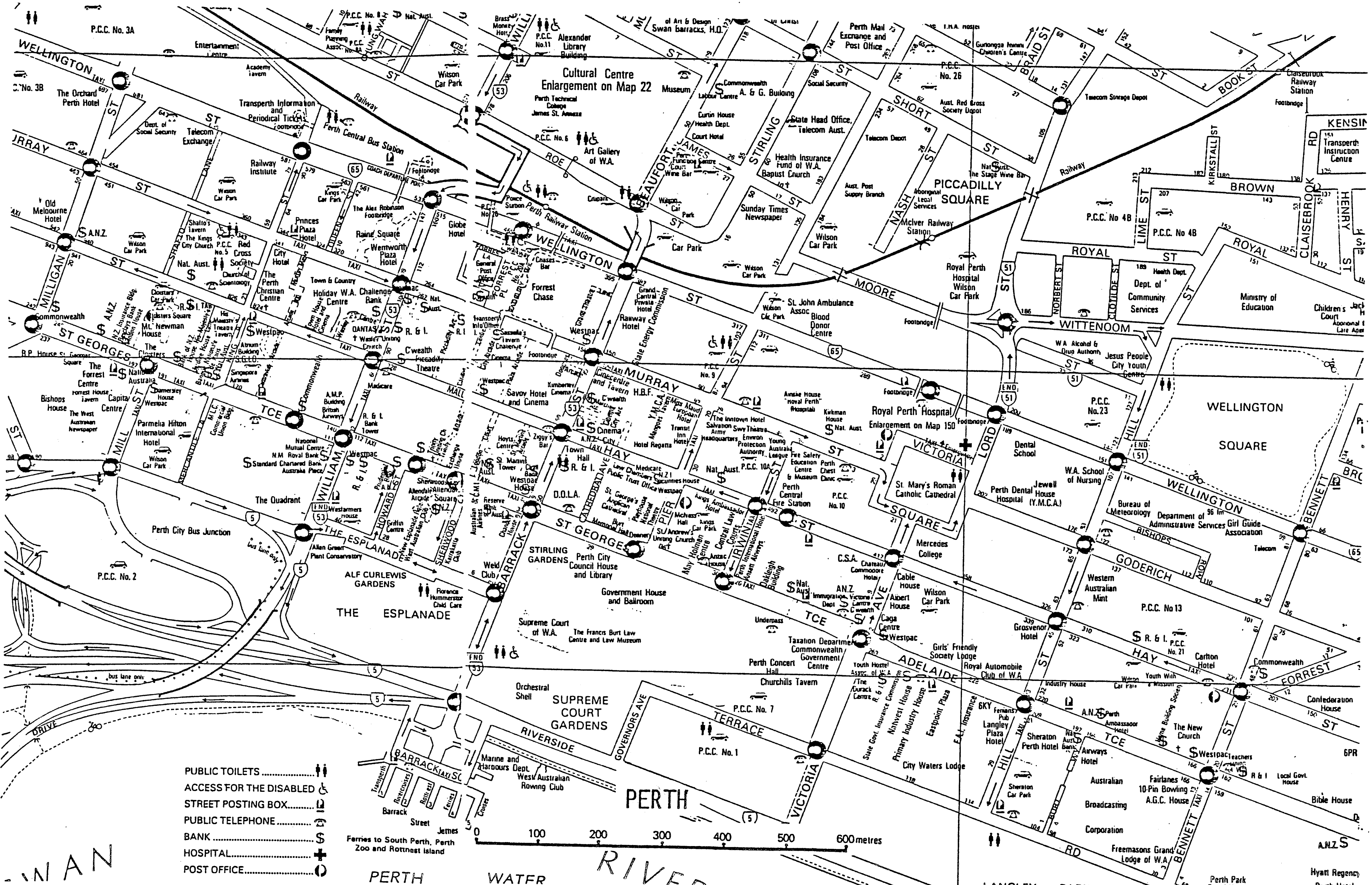

EPICENTRE
GREAT EASTERN HIGHWAY
COONDALLING
DOWERIN
MECKERING
TRUE NORTH (approximate)
East Branch
Mortlock River
GOOMALLING ROAD
YORK
HARDY ROAD
minor fractures
Mortlock River
LEGEND
Road
Railway
Fracture trace
Relative displacement of eastern side
5 feet
2 metres
Horizontal
52"
Vertical (up)
(12a) or O (12a)
Position of photograph and plate number
SCALES
(approximate)
0 1 2 3 MILES
0 1 2 3 4 KILOMETRES
MECKERING EARTHQUAKE 1968
DETAILED MAP OF FRACTURE ZONE



PUBLIC TOILETS
ACCESS FOR THE DISABLED
STREET POSTING BOX
PUBLIC TELEPHONE
BANK
HOSPITAL
POST OFFICE
0
100
200
300
400
500
600 metres
PERTH
PERTH
WATER
LANGLEY
PARK
WELLINGTON
ST
MURRAY
ST GEORGES
TCE
THE ESPLANADE
HAY
MILLIGAN
MILL
WILLIAM
BARRACK
PIER
IRWIN
VICTORIA
ADELAIDE
TERRACE
RIVERSIDE
GOVERNORS AVE
BARRACK
MOORE
ST
ROYAL
WITTENOOM
LORD
HILL
BENNETT
GODERICH
FORREST
JAMES
ROE
BEAUFORT
STIRLING
SHORT
BROWN
LIME
KIRKSTALL
CLAISEBROOK
NASH
BOOK
DRIVE
P.C.C. No. 3A
P.C.C. No. 2
P.C.C. No. 1
P.C.C. No. 7
P.C.C. No. 26
P.C.C. No 4B
P.C.C. No 13
P.C.C. No.23
Cultural Centre
Enlargement on Map 22
Museum
Art Gallery
of W.A.
Alexander
Library
Building
Perth Railway Station
Perth Central Bus Station
Transperth Information and Periodical Tickets
Entertainment Centre
The Orchard
Perth Hotel
Old
Melbourne
Hotel
Telecom
Exchange
Railway
Institute
Globe
Hotel
Raine Square
Wentworth
Plaza
Hotel
Princes
Plaza
Hotel
City
Hotel
Forrest
Chase
Railway
Hotel
State Energy Commission
St. John Ambulance
Assoc
Blood
Donor
Centre
Car Park
Perth Mail
Exchange and
Post Office
Commonwealth
A. & G. Building
State Head Office,
Telecom Aust.
Health Insurance
Fund of W.A.
Baptist Church
Sunday Times
Newspaper
Wilson
Car Park
PICCADILLY
SQUARE
McIver Railway
Station
Royal Perth
Hospital
Wilson
Car Park
Dept. of
Community
Services
Ministry of
Education
Children's
Court
Jesus People
City Youth
Centre
WELLINGTON
SQUARE
Royal Perth Hospital
Enlargement on Map 150
St. Mary's Roman
Catholic Cathedral
VICTORIA
SQUARE
Dental
School
Perth Dental
Hospital
Jewell
House
(Y.M.C.A.)
W.A. School
of Nursing
Bureau of
Meteorology
Department of
Administrative Services
Girl Guide
Association
Mercedes
College
Western
Australian
Mint
Grosvenor
Hotel
Carlton
Hotel
Commonwealth
Confederation
House
Royal Automobile
Club of W.A
Girls' Friendly
Society Lodge
Sheraton
Perth Hotel
The New
Church
Australian
Broadcasting
Corporation
Fairlanes
10-Pin Bowling
A.G.C. House
Freemasons Grand
Lodge of W.A.
Bible House
Perth Park
Royal Hotel
Hyatt Regency
Perth Hotel
City Waters Lodge
Churchills Tavern
Perth Concert
Hall
Taxation Department
Commonwealth
Government
Centre
Orchestral
Shell
SUPREME
COURT
GARDENS
Marine and
Harbours Dept.
West Australian
Rowing Club
Supreme Court
of W.A.
The Francis Burt Law
Centre and Law Museum
Government House
and Ballroom
STIRLING
GARDENS
Perth City
Council House
and Library
Weld
Club
ALF CURLEWIS
GARDENS
THE
ESPLANADE
Perth City Bus Junction
The Quadrant
Parmelia Hilton
International
Hotel
Bishops
House
Capita
Centre
The
Forrest
Centre
B.P. House
Holiday W.A.
Centre
Challenge
Bank
Savoy Hotel
and Cinema
Town
Hall
D.O.L.A.
Hotel Regatta
Perth
Central
Fire Station
C.S.A.
Cable
House
Wilson
Car Park
Albert
Facey
House
Ferries to South Perth, Perth
Zoo and Rottnest Island
Barrack
Street
Jetties