Bureau of Mineral Resources,
Geology & Geophysics

RECORD

RECORD NO. 1990/36

HYPOCENTRE RELOCATIONS USING DATA FROM TEMPORARY SEISMOGRAPH STATIONS AT BURAKIN AND WYALKATCHEM, WESTERN AUSTRALIA

by

V. F. DENT

RECORD NO. 1990/36

HYPOCENTRE RELOCATIONS USING DATA FROM TEMPORARY SEISMOGRAPH STATIONS AT BURAKIN AND WYALKATCHEM, WESTERN AUSTRALIA

by

V. F. DENT

CONTENTS

HYPOCENTRE RELOCATIONS USING DATA FROM TEMPORARY SEISMOGRAPH STATIONS AT BURAKIN AND WYALKATCHEM, WESTERN AUSTRALIA

SUMMARY

Temporary seismograph stations were operated near Cadoux W.A. after a large (ML 6.2) earthquake on 2 June,1979, and near Wyalkatchem W.A., after an ML 4.3 event near there on 6 January 1988. The earthquake near Wyalkatchem was the largest of a series of events at this locality which continued over a period of 15 months. Arrival times recorded by these stations are tabulated here. They have been used to relocate some of the 1979 Cadoux aftershocks using the Phillip Institute of Technology EQLOCL earthquake location program. The effect of the relocations has been to move the epicentres from east of the fault complex, to west of it. This result is similar to the distribution of some accurately located 1983 earthquakes, and is consistant with the mapped fault dip. Relocations using data from the Wyalkatchem station have not resulted in a significant change in hypocentral parameters.

Consistent large residuals for NWAO S phases from Cadoux events indicate that the first S arrival is not SN, and is more likely to be SG.

INTRODUCTION

A temporary seismograph station was operated near Burakin, 30 km north of Cadoux (Figure 1), between June and August, 1979, after the large earthquake of 2 June 1979, and another near Wyalkatchem, January to March 1988, after a number of events were felt there during 1987 and early 1988. Another field station (MOR) operated near Meckering for 20 months (July 1978 to March 1980). This report records data collected by these stations which are important because they can significantly reduce the uncertainty in the origin times and focal depths of the earthquakes. Earthquakes with near station data are preferred for use in the MODEL inversion program (Wesson & Gibson, 1985) which was used by Dent (1989) to produce the WA2 crustal model. Data provided by these temporary stations will prove useful for future updates of this crustal model.

The coordinates of these temporary stations are shown in Table 1.

The major foreshocks and aftershocks (ML > 3.4) of the Cadoux earthquake which occurred during 1979 are shown in Table 2. This table indicates that the frequency of aftershocks had significantly declined within seven days of the main event.

The fracture zone formed during the Cadoux earthquake extended for approximately 15 km in a north-south direction, and has been presented in detail by Lewis et al., (1981). Their mapping indicated that the largest single section of the fault (the Robb fault, Figure 2) was a thrust fault dipping to the west.

It might be expected that aftershocks recorded by the station BKN, being relatively close in time to the formation of the fractures, would be distributed along that 15 km length. The local seismograph network (BKN to the north, MOR, MUN and NWAO to the south) is such that the location of after-shocks can be fairly well contrained in a north-south direction. East-west control is poorer, the only relevant station being KLG, 450 km to the east.

PART A) THE TEMPORARY STATION AT BURAKIN, 1979

This station operated near Burakin, 30 km north of Cadoux, (Figure 1) between 21 June and 02 August, 1979 (Gregson, 1980). It was moved from its pevious location near Meckering to better record aftershocks following the large (ML 6.2) earthquake which occurred just south of Cadoux on 2 June 1979. The station MOR, which was installed near Meckering in July 1978, continued operating through the life-span of the Burakin (BKN) station. Both of these recorders were Sprengnether MEQ 800's, and recorded at 120 mm/minute, which was twice the normal operating speed of permanent seismic stations in the West Australian seismic network.

Because of its proximity to the active zone, the station BKN was operated at reduced gain. It recorded 11 events, which are listed in Table 3. Their locations and magnitudes (ML) as indicated in the BMR earthquake data catalogue are also shown.

The arrival time data for these earthquakes at all stations are summarised in Table 4.

BMR EARTHQUAKE DATA CATALOGUE LOCATIONS

The BMR earthquake data catalogue lists locations for all Southwest Seismic Zone earthquakes of magnitude (ML) > 2.0. Earthquakes which occurred in 1979 were located using the stations MUN (Mundaring), KLG (Kalgoorlie) and MEK (Meekatharra). Because only events of magnitude ML 3.0 or more were satisfactorily recorded at these stations, only these events were located in 1979. Smaller events (ML 2.0 - ML 2.9) were given generalised locations only, based on S-P times at Mundaring.

Many of the events were recorded at NWAO (Narrogin, Figure 1). Shear (S) waves are generally clearly seen, and can be easily scaled. P waves have smaller amplitudes, and are harder to accurately scale, except for the larger events. The NWAO arrival time data were generally not used.

Using the arrival time data presented in Table 4, the events in Table 3 of ML < 3.0 can now be located, and the larger events relocated, using this additional data.

EFFECT OF RELOCATIONS ON EARTHQUAKE DISTRIBUTION

The catalogue locations for the four ML > 3 events recorded at BKN show two of them (22/6, 1953, ML 3.4 and 25/6, 1140, ML 3.3) as having occurred at 30.84 S and 117.08 E - i.e., just south of the Robb Fault. The other two (27/6, 0158, ML 3.0 and 16/7, 2350, ML 3.1) were located on the eastern side of the Robb Fault (30.80, 117.17 & 30.75, 117.19).

The earthquakes have been relocated using the Phillip Institute of Technology (PIT) EQLOCL earthquake location program, and the new data from BKN and MOR (Table 4) has been incorporated. The earth model used for the relocations was WA2 (Dent, 1989). The new locations are given in Table 3, and plotted on Figure 2.

Relocation with the EQLOCL program and using additional data from BKN and MOR has not significantly moved the locations for the two events south of the Robb fault (i.e., the locations are within 5 km of the original ones).

However, relocation of the other two events has resulted in quite considerable movements. The new locations are on the NW side of the fault complex, approximately 10 km from their original locations.

The movements for the 8 smaller events (ML < 3.0) relocated are also considerable. However, it should be remembered that the catalogue locations for these events were estimates only. These events have also been moved to the west side of the fault complex.

This pattern of aftershocks on the western side of the Fault zone is in agreement with a set of small but accurately located earthquakes which were recorded by a dense network of temporary seismographs in 1983 (Dent & Gregson, 1986; Dent, 1988).

DISUSSION OF NARROGIN (NWAO) DATA

Additional data pertaining to N-S control comes from NWAO Shear wave times. The S phases at NWAO are generally of relatively high amplitude, and their onset times are relatively easy to scale compared to the P wave arrivals, which are generally emergent.

For earthquakes in the Cadoux region (approximately 230 km north of NWAO), the first S wave arrival at NWAO should be the SN. However, the NWAO S times are consistantly late by about 3 seconds, and they are closer to the expected SG arrival time (approximately one second after the observed arrivals). This suggests that the S waves observed are in fact SG waves. The residuals for these alternatives are tablulated in Table 5. White (1969) noted that, in South Australia, SN arrivals for local earthquakes were often not identified on the regional seismograph network, and this seems to be true in Western Australia also.

To support these observations, the NWAO S times for two well-located Cadoux events (7/3/87 & 11/11/89) are included in Table 5. A copy of the NWAO seismogram for the 1987 event is shown in Figure 3. The parameters of these events are better constrained because there were more permanent seismographs operational when they occurred.

SURFACE WAVES

Surface waves were sometimes observed on BKN, MOR and NWAO seismograms. These wave are recognised by their late arrivals, relatively high period (up to 1 second), and relatively high amplitudes. Phases which could be scaled with reasonable confidence are shown in Table 6.

The velocities calculated for these phases range from 2.9 km/sec to 3.1 km/sec. This range is acceptable considering the difficulty in scaling the emergent phase onsets.

Two of the arrivals noted in Table 6 however have apparent velocities of 3.3 km/sec. These phases were not typical surface waves in that they were of shorter duration than normal and their period was about 0.3 sec. As 3.3 km/sec is not an unusual velocity for shear waves near the earth's surface for other Australian crustal models, it is possible that these phases are arrivals from a crustal layer not represented in current models for this region.

CONCLUSIONS

The additional data from the temporary stations has helped to improve locations for 11 Cadoux aftershocks. It indicates that only 2 of the locations were reasonably accurate, and large shifts have occurred in the other 9 estimates. The new set of locations shows a distribution on the west side of the fault complex. This distribution is more consistent with the concept of a westerly dipping fault plane. The significant shifts in most of the estimated locations suggests that not much reliance can be put on Cadoux locations for this period, and probably up until the installation of the permanent stations at Ballidu and Kellerberrin in 1981. Shear wave residuals at NWAO suggest that the first S phase arrivals are probably SG and not SN.

PART B) THE TEMPORARY STATION AT WYALKATCHEM, 1988

INTRODUCTION

A magnitude ML 4.3 event ocurred near Wyalkatchem on 6 January 1988, and was felt in the area at an intensity of MM V. It was the eighth event of ML > 2.9 to have occurred in almost the same spot since 2/3/87, and was also the largest. This earthquake series is different from that in the previous section in that the largest event in the series occurred towards the end of the sequence.

The catalogue locations, computed by the Mundaring Observatory, for these events are listed in Table 7. Four of these events were relocated by Dent (1989) in the course of producing and testing the WA2 crustal model,and these locations are also shown in Table 7. The MGO locations for these events have indicated that they are shallow (5km depth or less). The locations in Dent (1989) support this conclusion (see Table 7), although the ML 4.3 event was originally located at 10 km depth. Relocation of this event using improved NWAO digital data indicates that it too is shallow.

Besides these 8 larger events, there were also 33 smaller events (ML 2.0-2.9) in the same time period. The last event (ML 2.0) ocurred on 7 July, 1988.

The closest permanent seismograph to these events was at Kellerberrin (KLB) 50 km to the south-east. After the ML 4.3 earthquake of 6/1/1988, it was decided to temporarily move the MEQ800 near Cadoux (WA4), to the epicentral area in order to better define the epicentral region.

STATION DETAILS

Because of the sparse population of the area, there were not many places suitable for setting up the seismograph close to the assumed epicentre. The requirements were - good housing for the instrument, mains power, reliable operators, and preferably a nearby outcrop of basement rock on which to site the seismometer.

A suitable site was found, and the station was installed at the site (Figure 4), on 14 January 1988. Time checks of the seismograph's internal clock against the ABC radio time signal standard were usually conducted daily by the operator.

The station operated for approximately 6 weeks, and was closed on 2 March 1988 (Table 1).

ARRIVAL TIME DATA RECORDED BY THE TEMPORARY STATION

Arrival times for earthquakes of ML > 1.0 recorded by the Wyalkatchem seismograph (WYAL) are listed in Table 8. These arrival times have been adjusted to allow for drift in the MEQ's internal clock. Time checks on this clock are shown in the appendix. Earthquakes of ML < 1.0 were recorded, but were not detected by surrounding seismographs belonging to the permanent network. The larger events in this category are listed in Table 8, but to the hour and minute only.

Because the seismograph at WYAL recorded at 60mm/min, the data cannot be scaled as accurately as the data from the 1979 temporary stations. There are also other factors, such as poorer clock rate, and slight variations in drum rotation speed, which lower the accuracy of WYAL arrival times. When used in the EQLOCL location program, the WYAL data has been given a low weight (+/- 0.3 secs).

EARTHQUAKES RECORDED BY THE TEMPORARY STATION

A). Events of ML > 1.9

During its six weeks of operation, the station WYAL recorded six events of ML > 2.0, which were also located by the MGO in the course of its routine observatory procedures. The magnitudes were determined from the periods and amplitudes of recordings on the permanent seismograph network.

Three of these events (19 January, 0857, 29 January at 0330 and 11 February at 1252) came from the vicinity of the ML 4.3 event of 6 January - i.e. approximately 7 km north-west of the temporary station.

Relocations for these events using the EQLOCL program and the WA2 model are shown in Table 9 and plotted on Figure 4. The relocations of the Wyalkatchem earthquakes are close to the original MGO locations (i.e., within 2 km. The quoted error for MGO locations of accuracy "A" is +/- 5 km). The depths computed by the EQLOCL program are shallow, in agreement with the MGO locations. However, because the uncertainties in the WYAL times are relatively high (+/- 0.3 seconds), they have not contributed greatly to constraining the focal depths.

Because of their high amplitudes, and physical proximity to P wave arrivals, the S wave arrivals of the larger Wyalkatchem events could not be scaled. However, using the smaller aftershocks as a guide, the S-P interval is estimated to be between 0.5 and 1.0 seconds. This is consistant with an epicentre about 6 km distant. It also constrains the earthquake to a shallow focal depth (< 10 km). If the arrivals could have been scaled with greater precision (to about +/- 0.1 seconds) then the distances to the earthquake foci could have been determined with far more confidence.

Two of the other 3 earthquakes in this category came from near Cadoux. The event at 2149 on 4 February (ML 2.7) occurred approximately 4 km east of Cadoux, while the other (1234 hrs on 21 February, ML 2.5) was about 18 km south of Cadoux. The relocations of these earthquakes, using WYAL data, (Table 9) has not resulted in any significant change in their estimated hypocentral parameters.

The other event in this category was an ML 2.0 event, which occurred south of Meckering at 1533 on 28 January. Again, relocation of this event has not caused any significant change in its estimated location.

B) Events ML 1.4 - 1.9

This group basically includes all locateable events of ML less than 2.0 (ie, recorded by at least three seismic stations, including WYAL). These small events are not normally located by the Mundaring Observatory. There are two such events in Table 8. These came from 5 km SE of Meckering (8 February 0849, ML 1.9) and 17 km SW of Cadoux (15 February 0638, ML 1.4). There were no Wyalkatchem aftershocks in the ML 1.4 - 1.9 range recorded by the WYAL seismograph.

With the addition of WYAL data, the above earthquakes all have arrivals at at least 3 seismographs, and their epicentres are therefore fairly reliable (+/- 10 km). However, since the nearest seismographs were more than 30 km distant in all cases, there is not much confidence in the depth determinations.

C). Events of ML < 1.4

This group includes events too small to be located - ie, too small to be recorded by other seismic stations (the closest being KLB, 50 km to the south-east). 13 of the larger events in this catagory (zero to peak amplitude on the WYAL seismograms of > 20 mm) are shown in Table 8. On the basis of their S-P times, they are probably from the same location as the larger Wyalkatchem events - ie, approximately 7 km northwest of the WYAL temporary seismograph.

Magnitudes of events in this range cannot be accurately determined, because the portable instrument was not calibrated. However, some magnitudes have been obtained from examination of recordings at KLB.

DISCUSSION

The locations computed by the EQLOCL program are similar to the MGO locations (which were derived graphically, and used the WA1 model). The MGO assigned the same locations to all the events, and the EQLOCL solutions are minor variations (less than the accuracy of the solutions) about this point.

It might be expected that the earthquake series at Wyalkatchem would show a migration of epicentres with time, to show activity along a presumed fault. However, within the accuracy which can be obtained from the present data, no linearity or possible trends can be observed from the locations in Table 7. These events seem to represent an epicentral zone of relatively small dimensions. In this respect, it is similar to an earthquake series which occurred south of Cadoux in 1982. Relocation of the better recorded events by Dent (1990) has moved a fairly scattered set of epicentres into a more confined zone. These locations are shown in Appendix 2.

SHEAR WAVE AND SURFACE WAVE ARRIVALS

The first S wave arrivals at Rocky Gully (RKG), which is 380 km south of Wyalkatchem, should be SN, and were generally scaled as such. However, with the advent of the EQLOCL program, it became evident that these arrivals were far too late (approximately 10 seconds) to be SN, and were probably SG. These phases show a very good fit with SG, using the WA2 model velocity of 3.62 km/s Residuals for some of the earthquakes which have been relocated using EQLOCL are listed in Table 10.

As with the Cadoux events discussed in Part A, surface wave arrivals can often be observed at Narrogin (NWAO) and Mundaring (MUN) for Wyalkatchem earthquakes. Two representative arrivals have been included in Table 6. The velocities computed from these arrivals (3.11 and 3.13 km/s) are consistent with those computed from the Cadoux events. For very small earthquakes, surface waves are sometimes the only phases observed on some seismographs, and so using these velocities may assist in the location of such events.

CONCLUSIONS

The temporary station at Wyalkatchem recorded three earthquakes of ML > 1.9, from a series of 41 events of ML > 1.9, lasting over 16 months. Adding WYAL data to the location process has significantly reduced the uncertainties in the estimated hypocentral parameters, without changing them significantly. The poor time control on the field recorder has limited the usefulness of the readings. On RKG seismograms, the SN wave for Wyalkatchem events is not easily dist- inguished, and the S wave scaled there fits the expected SG time, with a velocity of 3.62 km/s.

ACKNOWLEDGEMENTS

The operators of the seismographs (F. Morrell at Meckering, P. Trenorden at Wyalkatchem) are to be acknowledged for their cooperation, and care of the seismographs. The Cadoux fault (Figure 2) was digitised by Howard Stagg, from the map in Lewis et al., 1981. I would also like to thank Kevin McCue for his helpful criticisms of my reports.

REFERENCES

DENT V. F., & GREGSON, P. J., 1986 - Cadoux Microearthquake Survey 1983. Bureau of Mineral Resources Australia, Record 1986/22.

DENT, V. F., 1988 - The Distribution of Cadoux Aftershocks - Additional data from temporary stations near Cadoux, 1983. Bureau of Mineral Resources Australia, Record 1988/51.

DENT, V. F., 1989 - Computer generated crustal models for the South-west Seismic Zone, Western Australia. Bureau of Mineral Resources Australia, Record 1989/43.

DENT, V. F., 1990 - Accurately located earthquakes near Cadoux, W.A. - in (Abst.) Geol. Soc. of Aust. 10th Congress

GREGSON, P.J., 1980 Mundaring Geophysical Observatory Annual report 1979. Bureau of Mineral Resources Australia, Record 1980/51.

LEWIS, J.D., DAETWYLER, N. A., & MONCREIFF, J.S., 1981 - The Cadoux earthquake, 2 June 1979. Geological Survey of Western Australia, Report 11.

WESSON, V. C., & GIBSON, G. M., 1985 - Lithospheric Modelling in Victoria using non-linear least squares. - in (Abstr.) Victorian Lithosphere Symposium (Ed. A. H. M. VanderBerg), Melbourne.

WHITE, R. E., 1969 - Seismic Phases Recorded in South Australia and their Relation to Crustal Structure. Geophys. J. R. astr. Soc., 17,249-261.

TABLES

TABLE 1
LOCATIONS AND OPERATIONAL PERIODS OF TEMPORARY STATIONS

CODE	LAT S	LONG E	ELEV m	OPERATIONAL PERIOD	
MOR	31.659	117.089	300	5 JULY 78 -	22 MAR 80
BKN	30.494	117.127	300	21 JUNE 79 -	2 AUG 79
WYAL	31.236	117.561	300	14 JAN 88 -	2 MAR 88

TABLE 2
EARTHQUAKES NEAR CADOUX, 1979 (ML > 3.4)

DATE	ORIGIN T. U.T.	CATALOGUE	LOCN	DEP km	ML
1979- 3-13	0729 40.4	30.832	117.174	6.0	3.9
1979- 3-14	2345 45.2	30.839	117.170	6.0	3.7
1979- 6- 1	2154 1.1	30.812	117.177	6.0	5.2
1979- 6- 2	0134 54.1	30.830	117.165	6.0	3.8
1979- 6- 2	0947 59.3	30.827	117.179	6.0	6.2
1979- 6- 2	1104 57.2	30.774	117.200	6.0	4.1
1979- 6- 2	1147 51.9	30.756	117.206	6.0	3.8
1979- 6- 2	1708 53.3	30.814	117.184	6.0	3.7
1979- 6- 3	0745 33.2	30.773	117.188	6.0	5.3
1979- 6- 3	0745 34.5	30.770	117.170	10.0	5.3
1979- 6- 3	2054 11.7	30.771	117.143	6.0	3.5
1979- 6- 6	1736 51.4	30.711	117.191	6.0	3.5
1979- 6- 7	0645 14.7	30.800	117.179	6.0	5.5
1979- 6- 7	2233 29.2	30.724	117.196	6.0	4.0
1979- 6-10	1824 51.1	30.769	117.213	6.0	4.3
1979- 6-14	2131 41.5	30.843	117.130	6.0	3.5
1979- 6-18	0503 48.0	30.825	117.246	6.0	3.9
1979-10-11	0404 9.9	30.757	117.146	6.0	4.8
1979-12-17	0954 2.5	30.942	117.240	6.0	3.9

TABLE 3
EVENTS RECORDED BY THE BURAKIN SEISMOGRAPH (BKN)

DATE 1979	ORIGIN T. U.T.	ML	CATALOGUE LOCN		DEP KM	NEW LOCATION		DEP KM	LOCN FROM CADOUX
22 JUN	0728 26.1	2.4	117.15	30.85	0	117.171	30.750	5	5 KM NE
22 JUN	1953 47.9	3.4	117.08	30.84	23	117.085	30.848	3.3	11 KM SW
24 JUN	0028 53.6	2.5	117.15	30.85	0	117.154	30.747	5	
25 JUN	1116 18.7	2.7	117.15	30.85	0	117.118	30.861	5 N	11 KM S
25 JUN	1140 50.5	3.3	117.08	30.84	15	117.091	30.853	5 N	10 KM S
27 JUN	0158 50.1	3.0	117.17	30.80	5	117.101	30.700	5 N	9 KM N
5 JUL	1101 34.0	2.4	117.15	30.85	0	117.098	30.808	3.1	5 KM SW
16 JUL	2350 35.2	3.1	117.19	30.75	3	117.111	30.693	5	
17 JUL	1827 51.1	2.5	117.15	30.85	0	117.009	30.802	1 C	12 KM W
22 JUL	1514 58.4	2.7	117.15	30.85	0	117.08	30.83	5 N	7 KM SW
26 JUL	0755 47.2	2.9	117.15	30.85	0	117.096	30.685	1 C	10 KM N

TABLE 4

ARRIVAL TIMES FOR EVENTS RECORDED BY BKN

DATE 1979	TIME U.T.	ML	BKN	MOR	MUN	NWAO	KLG
22 JUN	0728	2.4	S-P 3.3	S-P 11.5	52.0		
					71.2	91.6	
22 JUN	1953	3.4		62.7	72.0	81.7	P 104.5
			S-P 4.5	S-P 10.2	89.1	110.8	PG 115.6
							S 146.0
							SG 163.0
25 JUN	1116	2.7	S-P 4.5	33.0	43.0	52.4	
					60.0	81.3	
25 JUN	1140	3.3	56.6	65.2	74.4	84.0	P 107.0
			S-P 4.5	S-P 10.0	91.9	113.0	PG 118.0
							S 149.0
							SG 165.0
27 JUN	0158	3.0		67.6	76.2	86.0	
			S-P 2.5		95.4	117.0	
05 JUL	1101	2.4		50.0	58.7		
			S-P 4.0	61.0	77.0	98.3	
16 JUL	2350	3.1		52.8	61.3	71.3	P 90.8
			S-P 2.5	S-P 12.0	81.0	102.5	
17 JUL	1827	2.5		66.5	75.4		
			S-P 4.2	S-P 11.0	92.9	114.4	
22 JUL	1514	2.7		74.0	82.7		
			S-P 4.0	S-P 10.5	100.7	122.1	
26 JUL	0755						
		2.9	S-P 2.25	S-P 12.0	92.9	114.9	

TABLE 5

S WAVE RESIDUALS RECORDED AT NARROGIN

DATE	ML	ORIGIN T U.T.	ARRIVAL TIME	DISTANCE km	SG RES	SN RES
22 JUN 1979	2.4	0728 26.1	91.6	241	-1.2	+3.8
22 JUN 1979	3.4	1953 47.9	110.8	231	-1.1	+4.0
25 JUN 1979	2.7	1116 18.7	81.3	229	-0.7	+3.6
25 JUN 1979	3.3	1140 50.5	113.0	230	-1.9	+3.2
27 JUN 1979	3.0	0158 50.1	117.0	247	-1.5	+4.0
05 JLY 1979	2.4	1101 34.1	98.3	235	-0.8	+3.5
16 JLY 1979	3.1	2350 35.2	102.5	248	-1.2	+4.2
17 JLY 1979	2.5	1827 51.1	114.4	236	-2.1	+1.9
22 JLY 1979	2.7	1514 58.4	122.1	235	-1.0	+3.6
26 JLY 1979	2.9	0755 47.2	114.9	249	-1.4	+4.0
03 MAR 1987	4.5	0538 07.6	68.3	238	-2.4	+2.7
13 JAN 1989	3.0	1638 37.9	99.3	224	-0.5	
11 NOV 1989	3.6	1658 08.8	74.0	242	-1.7	+2.9

TABLE 6
VELOCITIES CALCULATED FROM SURFACE WAVE ARRIVALS

DATE	LOCATION	ORIGIN TIME	STN	ARRIVAL sec	TT sec	DIST km	VEL km/s
22 JUN 79	CADOUX	1953 49.7	BKN	61.5	13.6	39.1	2.88
25 JUN 79	CADOUX	1116 18.7	MOR	47.0	28.3	88.5	3.13
25 JUN 79	CADOUX	1140 50.5	BKN	64.5	14.0	40.0	2.86
05 JUL 79	CADOUX	1101 34.0	MOR	64.5	30.5	94.3	3.09
16 JUL 79	CADOUX	2350 35.2	NWAO	110.0	74.8	248.0	3.31
22 JUL 79	CADOUX	1514 58.4	MOR	88.5	30.1	93.5	3.11
26 JUL 79	CADOUX	0755 47.2	NWAO	122.0	74.8	249.0	3.33
03 MAR 87	WYALKATCHEM	1327 42.5	MUN	90.5	58.0	149.5	3.11
06 JAN 88	WYALKATCHEM	0342 08.0	NWAO	70.1	62.1	193.0	3.11
19 JAN 88	WYALKATCHEM	0857 44.4	KLB	61.5	17.1	50.0	2.92

TABLE 7
EARTHQUAKES NEAR WYALKATCHEM, ML > 2.4, 1987-1988

DATE	ORIGIN T.	ML	MGO LOCATION		DEPTH km	DENT (1989) LOCN		DEPTH
1987								
02 MAR	2222 13.2	3.1	31.22	117.49	2	31.200	117.499	2.5
02 MAR	2222 20.0	3.0	31.22	117.49	5			
11 JUN	1218 42.5	3.5	31.20	117.51	3	31.190	117.514	4.2
11 JUN	1219 43.1	3.2	31.20	117.51	3			
11 JUN	1711 53.0	3.2	31.21	117.51	3			
12 JUN	0300 12.8	2.6	31.21	117.49	1			
10 JLY	2232 54.2	2.6	31.22	117.47	1			
18 DEC	1755 48.5	3.4	31.20	117.51	3	31.201	117.496	5.5
19 DEC	0143 28.6	2.6	31.20	117.50	5			
21 DEC	2153 56.9	3.2	31.18	117.51	4			
28 DEC	2312 59.0	2.5	31.18	117.51	4			
1988								
05 JAN	2327 40.6	2.8	31.20	117.50	5			
06 JAN	0342 08.2	4.3	31.20	117.50	2	31.176	117.542	10.4
06 JAN	0355 11.8	2.9	31.20	117.50	5			
11 FEB	1252 39.3	2.6	31.20	117.51	5			
29 JUN	1922 02.9	2.8	31.20	117.49	5			

TABLE 8
ARRIVAL TIMES RECORDED BY WYAL SEISMOGRAPH

DATE	TIME U.T.	ML	P TIME secs	S-P secs	T.C. secs	AMPL mm	REMARKS
15 JAN	1041	0.8		1.2		14	
18 JAN	0348	< 1		(0.5)		24	
18 JAN	2327	< 1		(0.5)		37	
19 JAN	0857	2.0	43.9		+0.4		12 KM E OF WYALKATCHEM
21 JAN	1932	1.1		(0.5)		36	
25 JAN	0400	< 1		(0.5)		14	
26 JAN	1649	< 1		(0.5)		30	
28 JAN	0946	1.0		(0.5)		37	
28 JAN	1533	2.0	55.5	6.8	+1.3		12 KM SE OF MECKERING
29 JAN	0330	2.3	18.7		+1.3		12 KM E OF WYALKATCHEM
	0332	0.9		(0.5)		36	
03 FEB	0536	< 1		(0.5)		38	
04 FEB	0050	1.2	55.7	(0.5)		37	TWO EVENTS 3.6 SECS APART?
	2149	2.7	00.0	9			4 KM EAST OF CADOUX N24LTY
08 FEB	0849	1.9	55.9	6.5	+1.6		5 KM SE OF MECKERING
10 FEB	1412	0.6		0.6		25	
11 FEB	1252	2.6	33.2				13 KM EAST OF WYALKATCHEM
15 FEB	0638	1.4	47.8		+6.3		17 KM STH OF CADOUX
19 FEB	2155	< 1		(0.5)		35	
21 FEB	1234	2.5	11.3		+5.5		18 KM STH OF CADOUX NO CLEAR S
01 MAR	1920	< 1		(0.5)		19	

TABLE 9
EVENTS ML > 1.0 RECORDED BY WYAL TEMPORARY STATION, JAN-MAR 1988

DATE	ORIGIN TIME	ML	MGO LOCATION		DEPTH km	NEW LOCATION		DEPTH km	REMARKS
19 JAN	0857 43.8	2.0	31.20	117.50	5	31.176	117.490	1.8	WYALKATCHEM A/S
28 JAN	1533 44.7	2.0	31.72	117.07	3	31.704	117.065	4.4	9 KM SE MECKERING
29 JAN	0330 19.2	2.3	31.20	117.50	2	31.189	117.513	2.1	WYALKATCHEM A/S
04 FEB	0049 51.5	1.2	NOT LOCATED			31.140	117.271	5N	11K NW OF WYALK
04 FEB	2148 50.2	2.7	30.77	117.09	5	30.784	117.085	3.1	4KM E OF CADOUX
08 FEB	0849 46.7	1.9	NOT LOCATED			31.656	117.052	4.3	5K SE OF MECKER.
11 FEB	1252 39.3	2.6	31.20	117.51	5	31.207	117.504	2.6	WYALKATCHEM A/S
15 FEB	0638 36.6	1.4	NOT LOCATED			30.861	116.986	5N	17 K SW OF CADOUX
21 FEB	1234 09.3	2.5	30.93	117.14	2	30.937	117.137	0.6	18 K S OF CADOUX

TABLE 10

SG RESIDUALS AT ROCKY GULLY (RKG)

DATE	LOCATION	DISTANCE km	ORIGIN TIME U.T.	ARRIVAL	RESIDUAL
02 MAR 87	WYALKATCHEM	378	2222 13.2	117.5	0.39
11 JUN 87	WYALKATCHEM	379	1218 42.5	133.3	0.38
18 DEC 87	WYALKATCHEM	377	1755 49.5	153.0	-0.25
06 JAN 88	WYALKATCHEM	377	0342 08.2	114.0	2.04
19 JAN 88	WYALKATCHEM	377	0857 43.4	148.2	0.17
29 JAN 88	WYALKATCHEM	377	0330 19.0	124.0	0.69
11 FEB 88	WYALKATCHEM	376	1252 39.3	143.6	0.58
21 FEB 88	CADOUX	403	1234 09.0	120.5	0.11

APPENDIX 1

CLOCK ERROR DETERMINATIONS FOR WYAL SEISMOGRAPH

DATE	TIME	CORRN	COMMENTS
15 JAN	0800	+1.5	
17 JAN	0100	+0.5	
19 JAN	0100	+0.6	
20 JAN	0100	+0.7	
22 JAN	0100	+1.0	
23 JAN	0100	+0.6	
26 JAN	0100	+1.0	
29 JAN	0100	+1.2	
05 FEB	0900	+1.1	
08 FEB	0000	+1.6	
10 FEB	1100	+6.8	
11 FEB	1000	+6.8	UNCLEAR (DIRTY PEN)
16 FEB	0800	+6.7	
16 FEB	1200	+6.3	
17 FEB	1500	+5.8	UNCLEAR (DIRTY PEN)
20 FEB	1600	+5.7	UNCLEAR (DIRTY PEN)
22 FEB	1200	+5.8	
23 FEB	1200	+5.9	
25 FEB	1200	+5.8	
28 FEB	0900	+5.4	
02 MAR	0400	+5.6	

APPENDIX 2

RELOCATIONS OF EARTHQUAKES SOUTH OF CADOUX, 1982

DATE	TIME	ML	MGO LOCATION		DENT (1990) LOCN	
22 JAN	1802	3.8	117.11	30.93	117.148	30.919
24 JAN	0406	4.3	117.12	30.90		
25 JAN	2326	4.4	117.13	30.91		
06 FEB	1524	4.9	117.15	30.88	117.149	30.915
06 FEB	1530	4.6	117.10	30.87	117.137	30.893
07 FEB	1307	4.1	117.09	30.89		
08 FEB	0439	4.1	117.10	30.89	117.145	30.912
08 FEB	1611	3.9	117.11	30.88		
20 MAR	1004	3.7	117.12	30.88		
15 APR	1750	3.9	117.12	30.89		

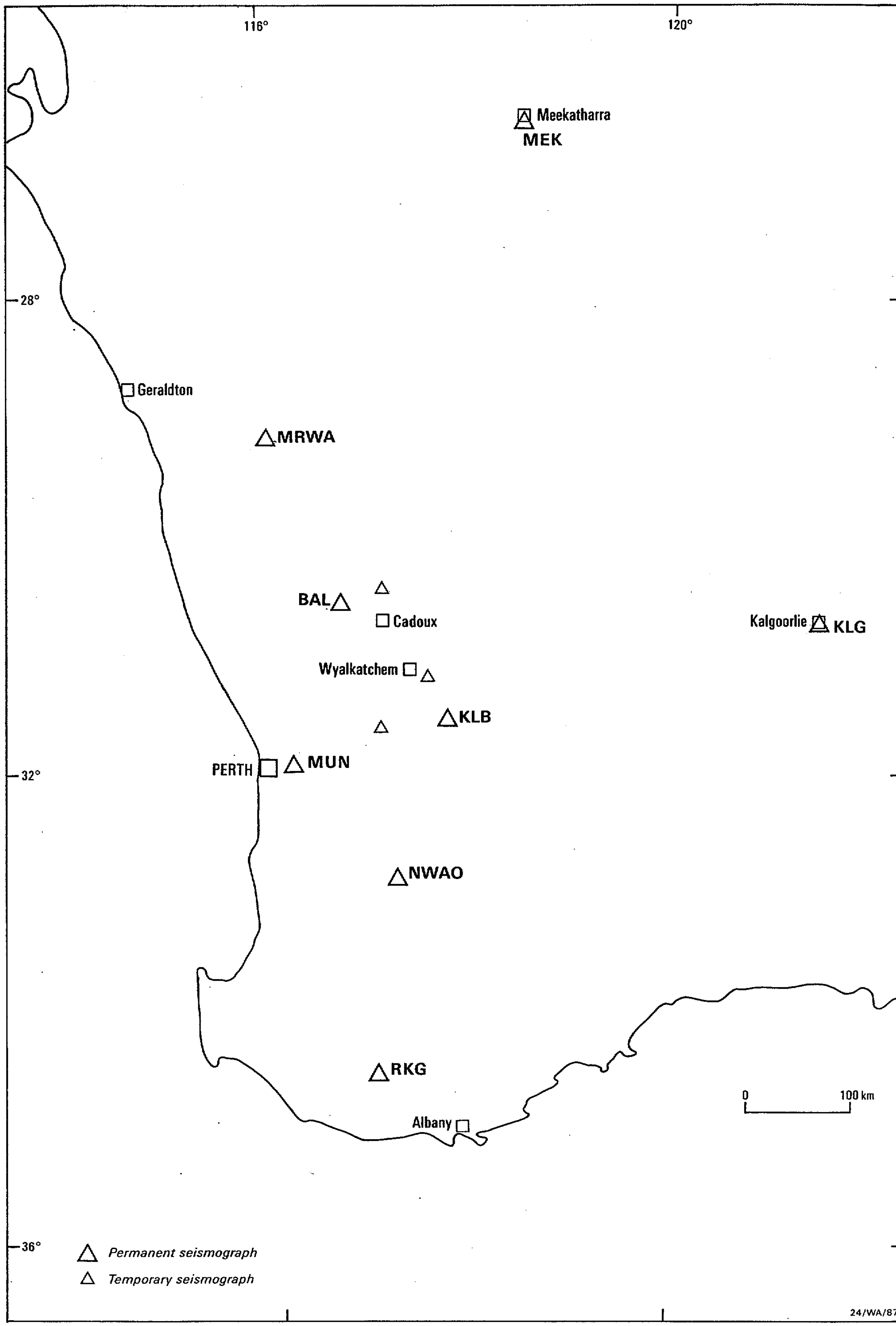

FIGURE 1 SOUTHWEST WESTERN AUSTRALIA LOCALITY MAP

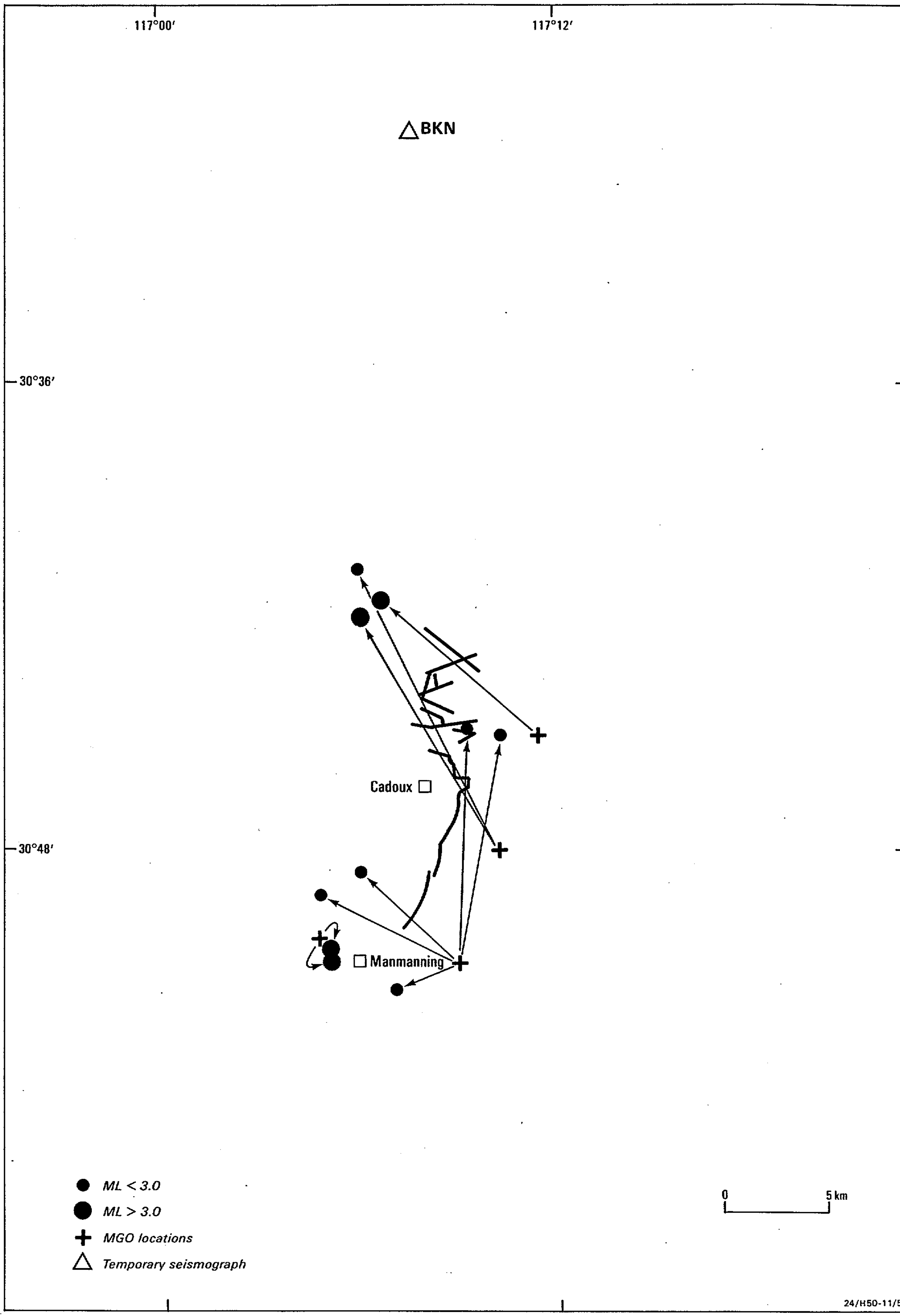

FIGURE 2 EARTHQUAKE LOCATIONS USING BURAKIN (BKN) SEISMOGRAPH

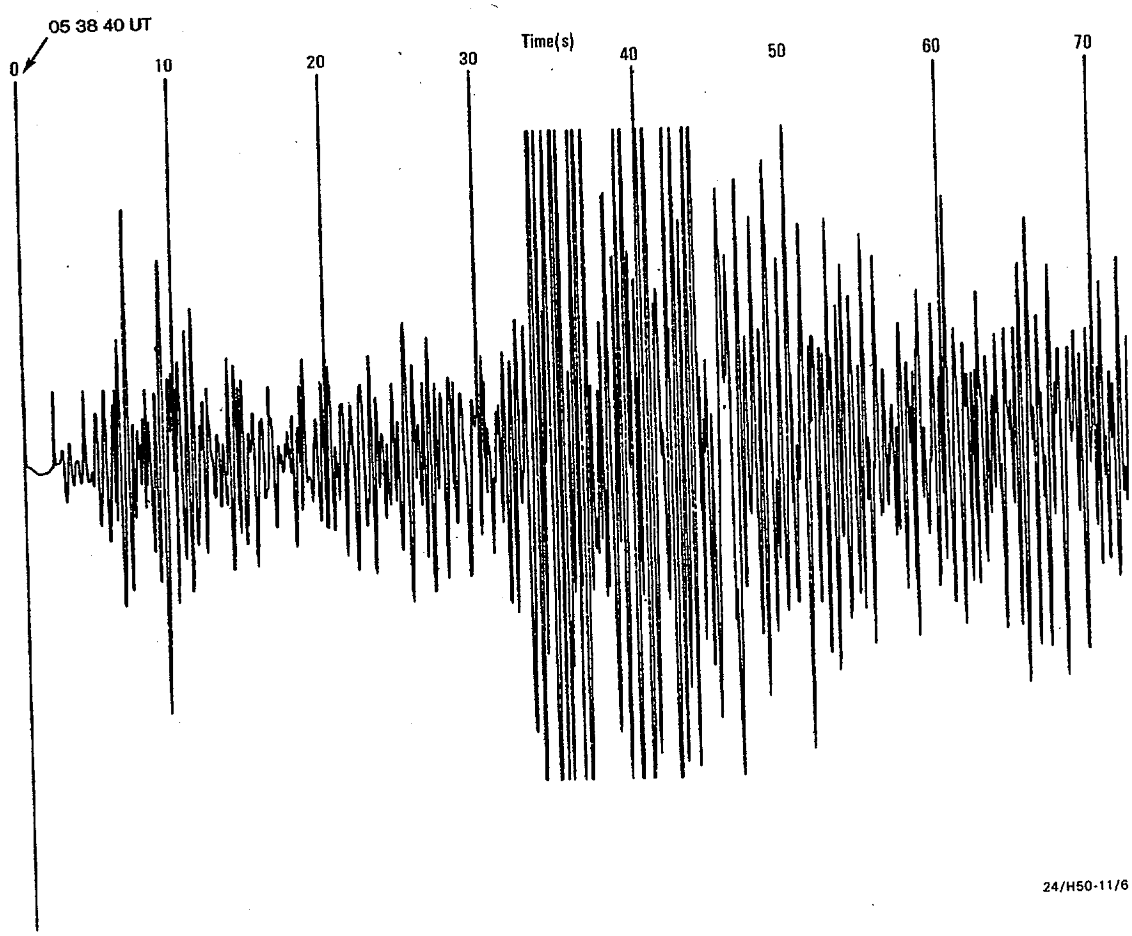

FIGURE 3 CADOUX EARTHQUAKE (7/3/87) RECORDED AT NARROGIN (NWAO)

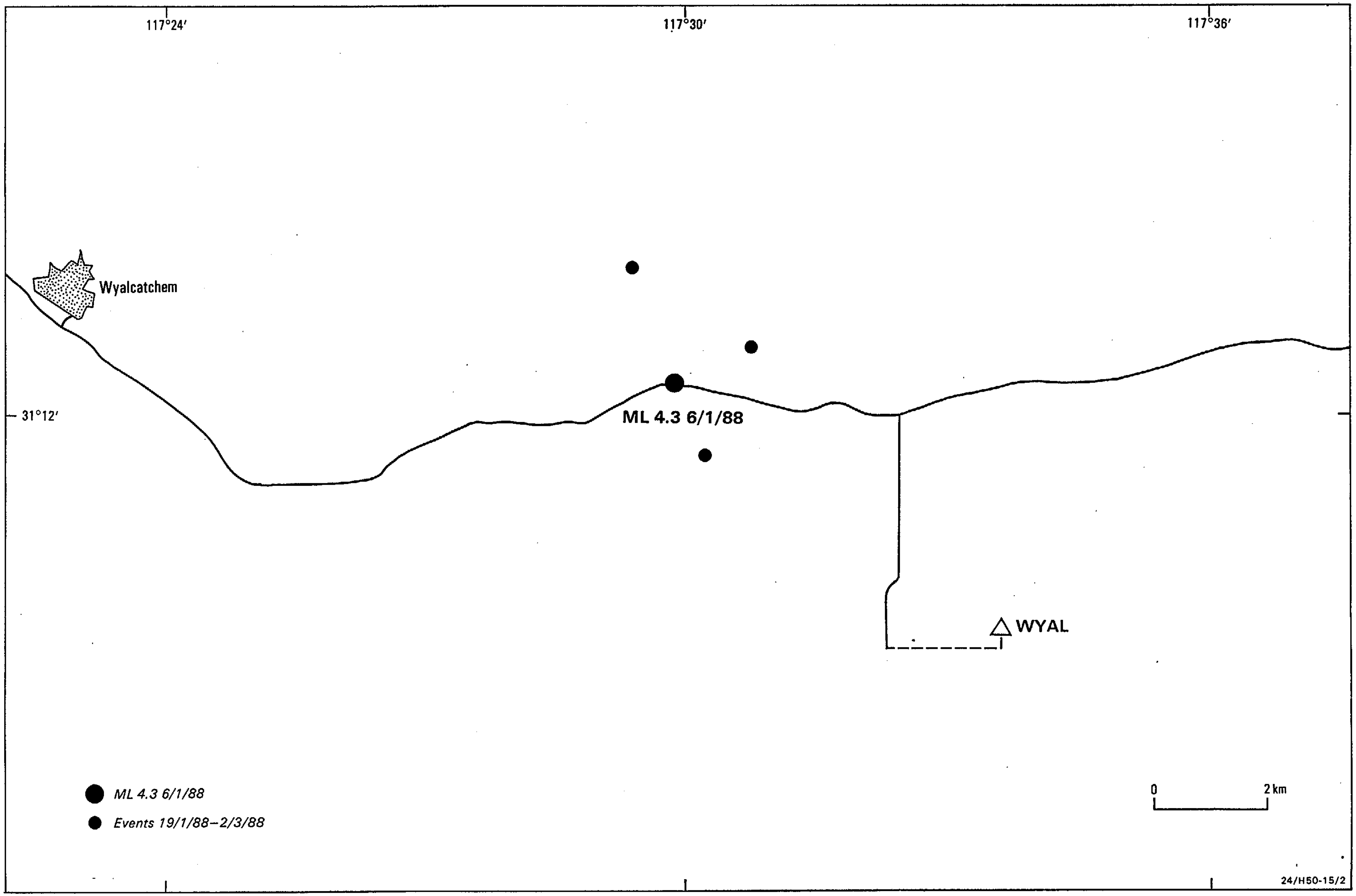

FIGURE 4 WYALKATCHEM EARTHQUAKES RECORDED BY WYAL SEISMOGRAPH