Location estimation for the Newcastle earthquake*

B. L. N. Kennett
Research School of Earth Sciences, Australian National University
Canberra ACT 2600

The magnitude 5.5 earthquake which devastated the central area of Newcastle in December 1989 proved to be difficult to locate because of the limited number and awkward distribution of seismic stations in eastern Australia. The event lies very close to the coast so that a large azimuthal sector is not covered by any propagation paths to stations within 1500 km. The distribution of available stations within 800 km of the event (Figure 1). There is a concentration of stations south of Sydney in the network operated by the Research School of Earth Sciences, ANU supplemented by stations Dalton (DAL) and Canberra (CNB) operated by the Australian Seismological Centre and stations Jenolan (JNL), Werombi (WER) and Avon (AVO) run by the (Sydney) Water Board. There are no close stations to the north or east. The geometry of the available stations limits the accuracy with which the location of the event can be estimated. The available observations are just the arrival times of different types of seismic waves, from these the origin time of the earthquake has to be found as well as the position of the earthquake focus in latitude, longitude and depth. The resolution in the north-south direction is expected to be better than in the east-west direction. The absence of any close station makes depth determination difficult.

Immediately after the event occurred the data from the ANU and (Sydney) Water Board stations together with Armidale (COO) and Cobar (CMS) were used to determine an approximate location using the algorithm of Sambridge & Kennett (1976). This process was complicated by the size of the event, seismic records at the stations were saturated for several minutes and so only the onset time could be determined and no later S wave arrivals could be read. This estimate of the epicentre of the event is marked as CAN in Figure 2.

The Australian Seismological Centre (then Bureau of Mineral Resources, currently Australian Geological Survey Organisation) also made an initial location estimate which was subsequently refined using readings from all the stations shown in Figure 1. This estimate is indicated in Figure 2 as BMR and lies at a depth of 11.5 km. The suggested location is close to the position of a small subsequent event (magnitude 2.8) determined from a network of portable instruments emplaced in the Newcastle area after the major event (indicated as *aft* i n Figure 2). The difference between the two estimates (BMR, CAN) for the major event arises from the adoption of different models for the propagation characteristics of the seismic waves and also different calculation procedures. The difference also represents the intrinsic limitations of working with sparse data in an unfavourable network geometry and is just a little larger than the estimated error in each location (around 10 km in horizontal position).

Because the earthquake was of substantial size, it was recorded across Australia and on more than 90 seismic stations in the global network. Such data from distant stations can also be used to estimate a location, but once again the geometry is unhelpful. All Australian stations lie to the west and the coverage to the east by global stations is very poor. This results in a tendency for the estimated hypocentre to be dragged to the west. This is illustrated in Figure 2 by the inclusion of the epicentre published by the International Seismological Centre (U.K) using the full global data set. The horizontal

* Ed. - Prof Kennett was unable to attend the meeting. Vaughan Wesson (RMIT, Bundoora) presented an alternative paper and solution. He used the same data but different non-linear inversion methods and crustal models to derive a best estimate of the epicentre at (32.97 °S, 151.60 °E), 2 km S of aft, Fig 1.

position is close to the BMR solution but the depth is much shallower at 4 km. The time separation of the main arrival and energy reflected from the surface near the event for seismic waves passing though the earth's core to European stations would favour a source depth of at least 10 km.

In order to try to place improved constraints on the location of the main Newcastle event, a range of different sets of arrival times were used with a common location procedure. The nonlinear grid search method of Kennett (1992) was employed with the iasp91 travel time tables of Kennett & Engdahl (1991). The location procedure uses a grid in 4-dimensions (space and time) which is progressively reduced in size until the location is defined within specified tolerances (1 km in latitude, longitude and depth; 0.15 sec in origin time). A centre point for the initial grid has to be specified and the search for the best fit between estimated and observed travel times is carried out over a zone 2° across in latitude and longitude, 50 km in depth and 12 sec in time. The measure of data fit employed is based on an L1 norm which is very robust and so the location estimate is not dominated by stations where the error in arrival time is larger then usual.

The various location estimates in Figure 2 were generated using the hypocentres from the 3 different agencies (ISC, BMR, CAN) with different data sets. The first part of each label indicates the data set employed (glo - global data, aus - all Australian stations, loc, lob - regional data) the second the reference point for the location procedures. The two sets of regional data reflect slightly different choices of stations so that the effect of network bias could be assessed. The hypocentres are also displayed in table 1.

The locations using distant stations lie to the west with shallow depths which are incompatible with the independent information from seismic waveforms. However, most of the revised location estimates based on the regional observations lie in a restricted zone near the coast which is smaller than the likely errors in the location procedure. The three estimates (lob-bmr, loc-bmr, loc-can) have a comparable fit to data which are significantly better than those for the reference solutions. The source depths lie between 8.8 km and 11.6 km which would fit with the depth phase information at distant stations. This group of solutions can therefore be regarded as the best available estimate for the location of the main Newcastle earthquake.

The loc, lob cluster of epicentre estimates lies further from the epicentre of the small later shock than the original location suggested by the Australian Seismological Centre, but could still be compatible with the events occurring on a common fault plane.

References

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Kennett B.L.N. & Engdahl E.R. (1991) Travel times for global earthquake location and phase identification. *Geophys. J. Int.*, 105, 429-465.

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Table 1. Location estimates for Newcastle event: 27 Dec 1989 at 23:26 (UTC)

	longitude [deg]	*latitude [deg]*	*depth [km]*	*origin time [sec]*
base estimates				
CAN (loc)	151.736	-33.035	22.0	57.43
BMR (lob)	151.602	-32.946	11.5	57.80
ISC (glo)	151.560	-32.940	4.0	56.00
nonlinear grid search				
lob-bmr	151.690	-32.982	8.8	58.12
loc-bmr	151.716	-33.002	11.4	58.20
loc-can	151.707	-33.000	11.6	58.27
loc-isc	151.772	-33.029	18.0	58.68
aus-bmr	151.531	-32.961	7.6	58.95
aus-isc	151.512	-32.960	1.6	58.45
glo-bmr	151.560	-32.980	4.1	58.34
later event				
aft	151.620	-32.952	13.6	

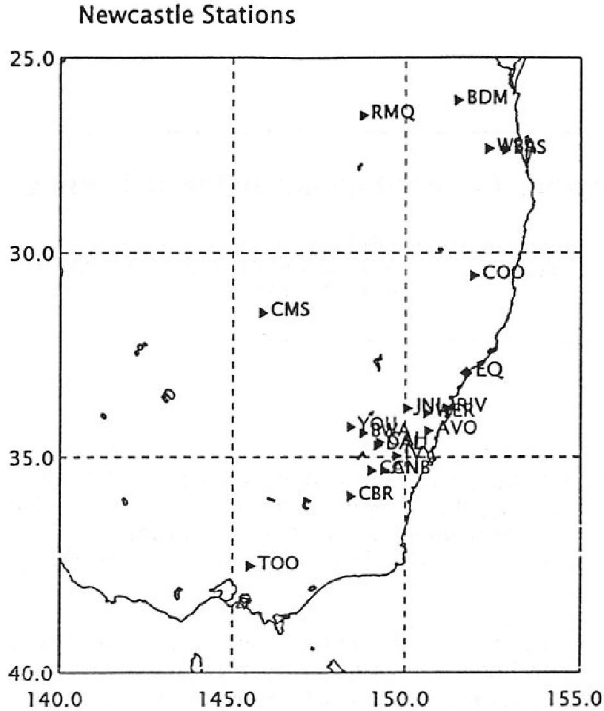

Fig 1. Seismic stations in eastern Australia for which P wave readings are available for the main Newcastle event indicated by EQ

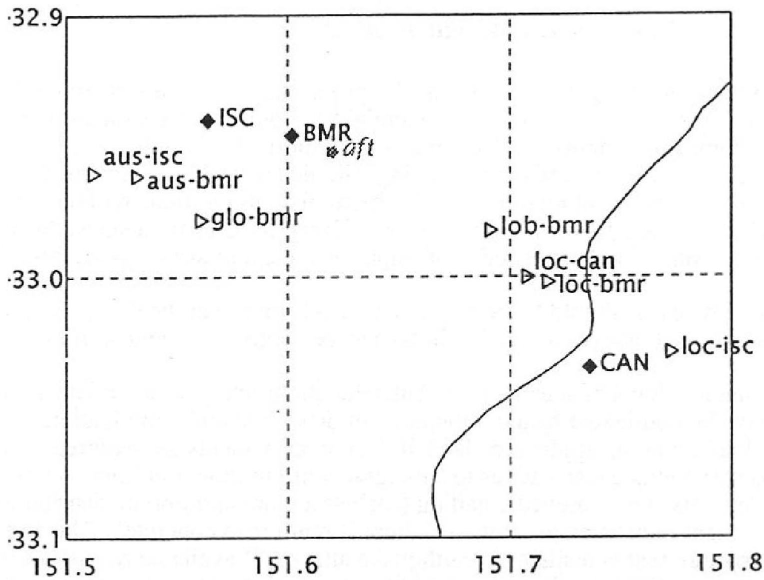

Fig 2. Relative locations of the epicentral estimates for the main Newcastle event. The reference locations (BMR, CAN, ISC) are indicated as well as the locations determined using a nonlinear search procedure with different data selections and reference locations. The depths associated with each location are displayed in Table 1.