A palaeoseismological investigation of the Cadell Fault Zone, Victoria, Australia

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ABSTRACT: The Cadell Fault zone is at the northern end of the Silurian to Devonian aged Heathcote Line that trends 200 km north-south across Victoria to the NSW border. Significant rejuvenation of the Cadell Fault in the late Quaternary caused major drainage modifications and realignment of the Murray River.

Large future earthquakes on the Cadell Fault Zone put nearby urban centres including Echuca, Deniliquin, and Bendigo at risk. In addition, the drainage patterns of both the Goulburn and Murray Rivers could again change, significantly affecting productive farming land.

The Echuca South Fault scarp is a small secondary fault within a bend in the main fault structure. It is about 10 km west of the main fault zone, and is 12 km long with up to a few metres of vertical offset. Following an e-m survey across the Echuca South scarp during April 2002 we excavated a trench across its southern end to determine its late Quaternary palaeoseismic history.

The relief at the trench site was less than two metres, and the fault plane was not unequivocally and clearly exposed in the trench. However, ages of trench wall deposits place important constraints on the timing of faulting.

Further investigation will help us select trench sites along the main segment of the Cadell scarp north of Echuca for excavation in early 2005.

1 INTRODUCTION

Most seismic hazard maps rely on the assumption that future large earthquakes will occur in the same regions as historical events. However, some recent surface faulting earthquakes in Australia have occurred in essentially aseismic areas considered to have a low seismic hazard. The 1986 Marryat Creek and 1988 Tennant Creek earthquakes are good examples.

It is becoming increasingly apparent that active faults in stable continental regions display a long-term behaviour of surface rupturing that is charaterised by episodes of activity separated by quiescent intervals in the order of tens of thousands of years (Crone et al. 1997). The hazard posed by a single fault on a human time scale is therefore small. However, if other potentially seismogenic faults are present in a region, then the hazard is proportionally larger. Assessment of earthquake hazard therefore needs to be based on comprehensive geologic data that include the number and distribution of potentially seismogenic faults, and on better knowledge of patterns in the long-term behaviour of intraplate faults in Australia.

The long return period between major events means that most faults in eastern Australia are not easily located. The scarp retreats by erosion, and the original surface ruptures are hidden by deposition. The actual location of the rupture may be uncertain by tens or hundreds of metres, or even by kilometres.

To begin to address this problem a small number of palaeoseismological investigations have been conducted in Australia. Most of these investigations have been conducted in central or western Australia, with only two locations in eastern Australia; Lake Edgar Fault in Tasmania (McCue and others, 1996, Van Dissen and others, 1997) and the Lucas Heights Fault. Given the population concentration on the eastern seaboard, it seemed timely to begin to quantify the seismic risk posed by surface rupturing faults in this area.

Early in 2002 a brief field survey was conducted in Victoria to identify possible trenching sites for a study of the history of earthquakes on a potentially active fault. The survey investigated possible sites along the Cadell Fault Zone. The Echuca South Fault was identified and trenched.

2 SETTING

The Cadell Fault Zone is at the northern end of the Heathcote Line trending north-south across Victoria, which is thought to have originated in the Devonian Period of the Paleozoic era 400 to 345 Mya. The Cadell Fault (refer to Figure 1) is one of a number of similar tending faults that have a similar tectonic history.

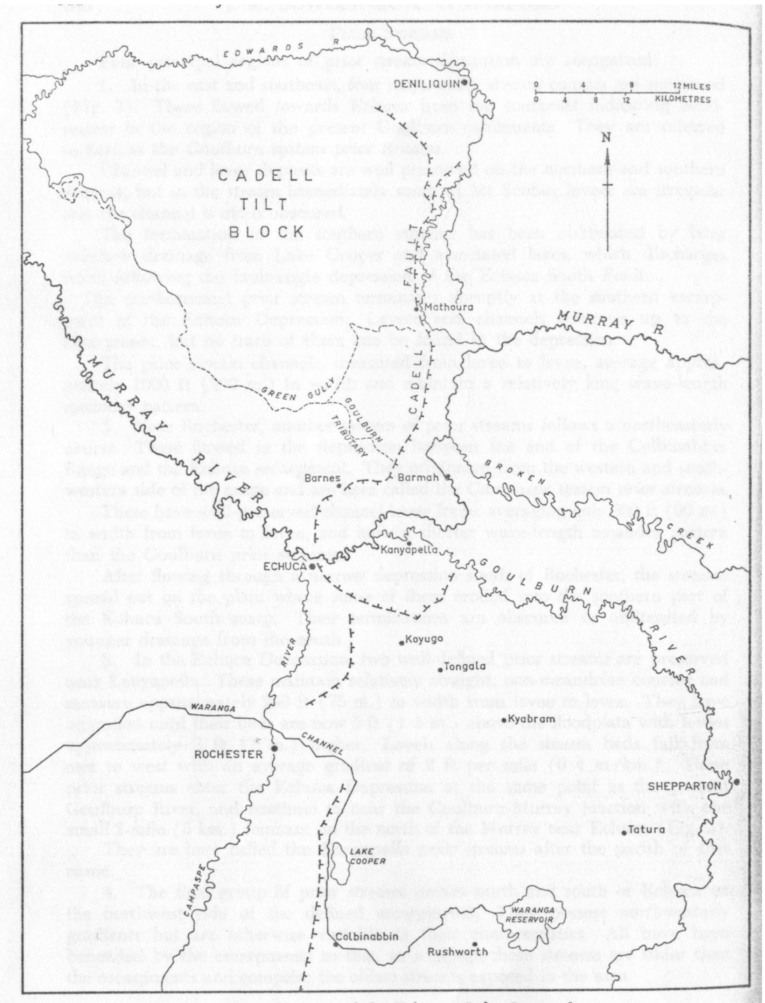

Figure 1 – Locality Map of the Area (Originally published by Bowler and Harford 1966)

The Cadell Fault Zone is a spectacular example of earthquake disturbed drainage. During the Early Holocene the course of the Murray River, one of the major rivers in southeastern Australia, was unable to maintain its course due to the rising Cadell Tilt Block (Bowler and Harford 1966). Eventually the Murray River flow was divided in two, with one branch forced south towards Echuca, and the other, called the Edwards River, passing around the tilt block to the north near Deniliquin. The Murray River's course was further disrupted by subsequent movements creating the Echuca Depression, which later was drained by erosion from the combined flow of the Murray and Goulburn Rivers (Twidale and Campbell 1993).

The Echuca South Fault scarp is a small secondary thrust fault within a bend in the main Cadell Fault-

Mt Ida Fault structure. It is about 10 km west of the main fault zone, and is 12 km long. Its northern limit is 10 km southeast of Echuca. From this point it strikes to the south, before turning southwest then disappearing near Rochester, conforming with the geometry of the main structure as presented by magnetic anomaly map (figure 2). The thrust fault is downthrown to the east and at places has escarpments reaching 6 m (Bowler and Harford 1966).

The Echuca Fault ruptures Quaternary sediments, and any evidence of older movement would be deeply buried. It is possible that the movement was associated with the stronger activity on the Cadell Fault to the north, over the past 100,000 years.

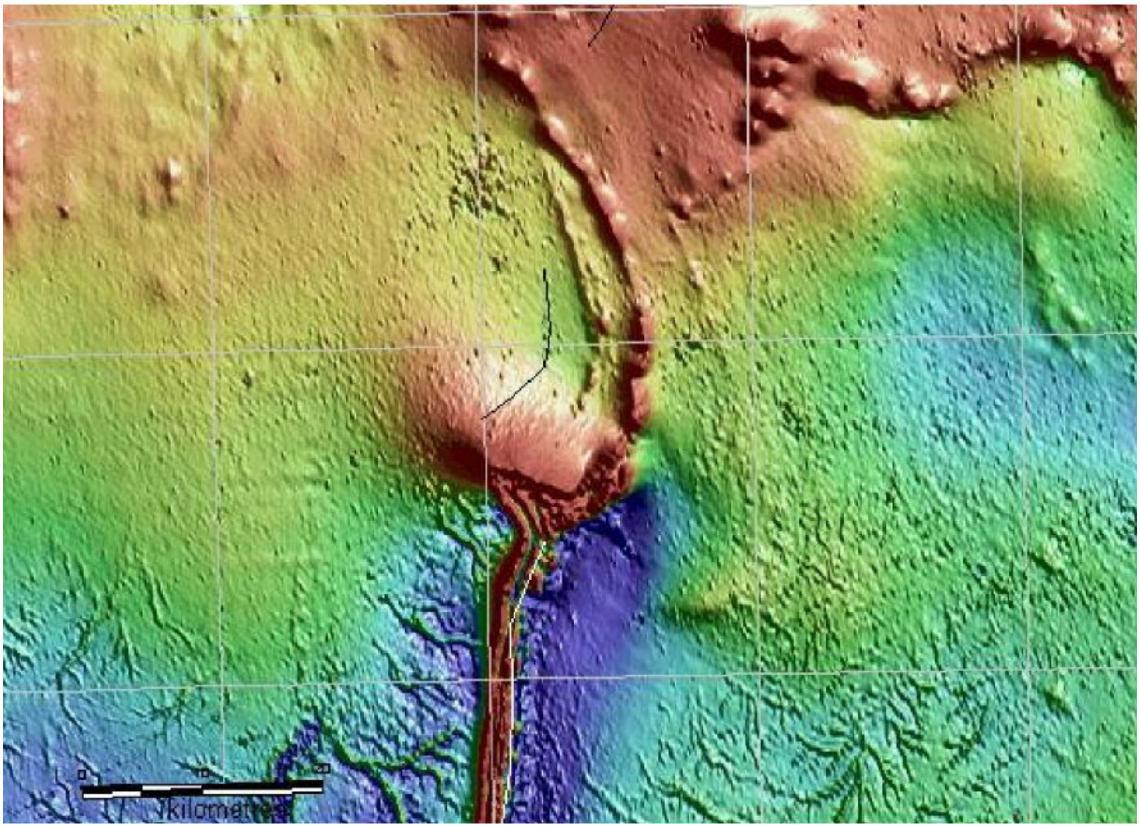

Figure 2: The Echuca South Fault is a small secondary fault about 10 km west of the main fault structure.

The site chosen for trenching was located just south of the bend in the Echuca South Fault, at the location suggested by Bowler. Prior field surveys had indicated a promising topography, with a clearly defined scarp up to two metres high in this area.

The choice was strengthened by an E-M Survey over the proposed area (Figure 3). Six traverses were made over the scarp and all showed a decrease in conductivity while passing from the upthrown block to the downthrown, with the inflexion in the conductivity plot within metres of the scarp. The EM data does not necessarily relate to the faulting, and may be simply a result of topography leading to higher salinity in the upthrown block. Since the bedrock is at a depth of many tens of metres, and the expected fault slip is only a couple of metres, this severely limits the ability of geophysical methods to detect the offset in bedrock.

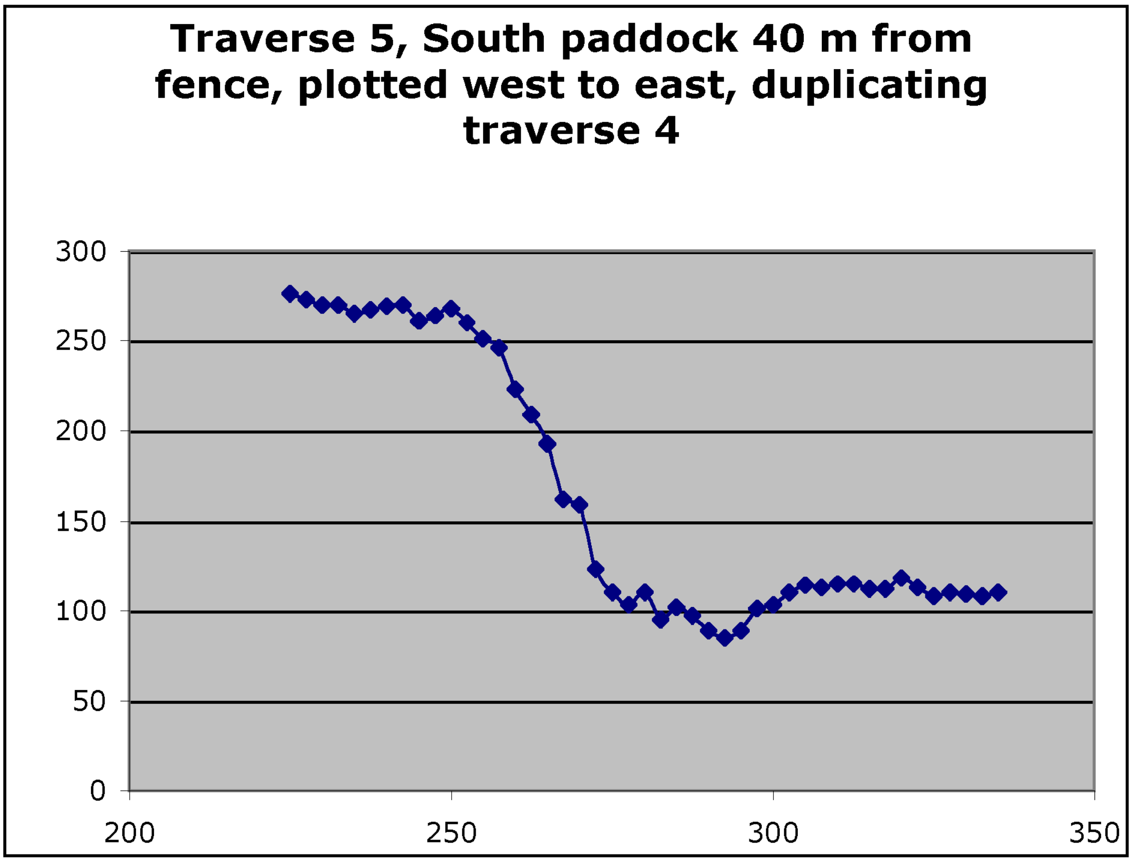

Figure 3: Conductivity in mho/m with distance in metres. The inflexion for all traverses was within metres of the current scarp.

3 TRENCH STRUCTURE AND STRATIGRAPHY

In March of 2002 a trench was excavated over the mapped location of the Echuca South Fault, just north of Rochester. The trench was 34 meters long and 3 to 5 m deep. The excavation exposed a number of alluvial deposits consistent with the fluvial history of the area. The trench deposits were mostly clays with various amounts of silt content, making the identification of the stratigraphic horizons difficult in places.

The dominate feature of the trench was a past stream channel, that extended to the full depth of the trench. The silty clay (shown in pink in Figure 4) cuts through the flat lying deposits creating the classic u shape of a prior stream.

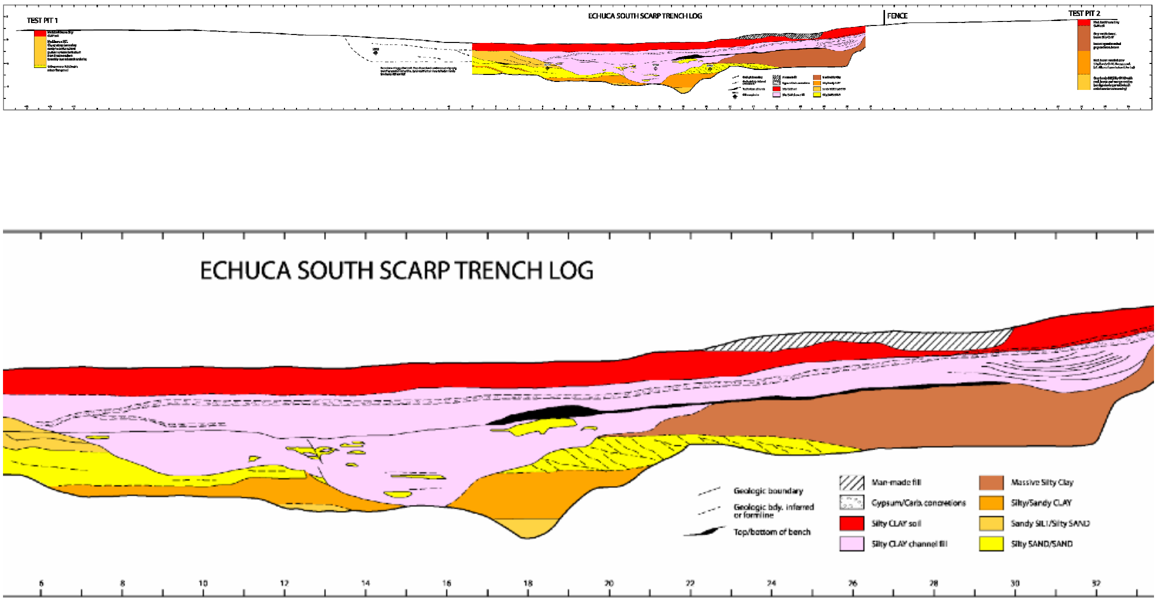

Figure 4: Extract of trench section.

What was not readily apparent in the trench walls was a fault scarp. There are a number of linear features that are consistent with the proposed fault orientation, particularly in the lower half of the exposed trench wall. Past experience in trenches cut across the Tennant Creek Fault Scarp showed little disturbance of the soils, with the fault expressed as a thin discontinuity (Personal Comms, Kevin McCue 2004).

A possible fault was on the south wall of the trench, dipping to the west from the 4 metre position near the surface to 9 metre position at the base of the trench. This is at the boundary between the sandy silt/silty sand (light orange) and silty sand/sand (medium orange) to the east, and the silty clay channel fill (pink) to the west. The "channel-fill" unit has a layer of gypsum concretions which dip more steeply to the east approaching the hypothesized fault, typical of surface sediments deformed at reverse faults, and more difficult to explain without tectonic deformation. On the north wall of the fault, a one to two millimeter thick layer of calcite (?) was co-planar with the hypothesized fault.

The section shows a massive silty clay (brown) beneath the channel fill in the west of the trench and in test pit 2 further to the west, but not in the east of the trench or in test pit 1 further to the east. This means that if no faulting occurred, then the massive clay lensed out within the few metres of trench containing the channel fill unit, or that if faulting occurred, the massive clay now underlies the sediments shown in the east of the trench.

Figure 4 shows the silty sand/sand unit (yellow) and slaty/sandy clay unit (deep orange) extending horizontally across the base of the trench. Unfortunately this exposure was limited due to trench flooding, but it is inconsistent with faulting at this location.

With this knowledge in mind, careful examination of all linear features in the trench was undertaken. Dating of soils within the channel fill and either side were also taken to help determine the depositional history of the area.

A simpler explanation of the features witnessed in the trench is that rather than exposing the fault scarp with very little disturbance, that the trench exposed a tectonic riser, produced by stream erosion into the fault scarp. The following three diagrams illustrate this idea.

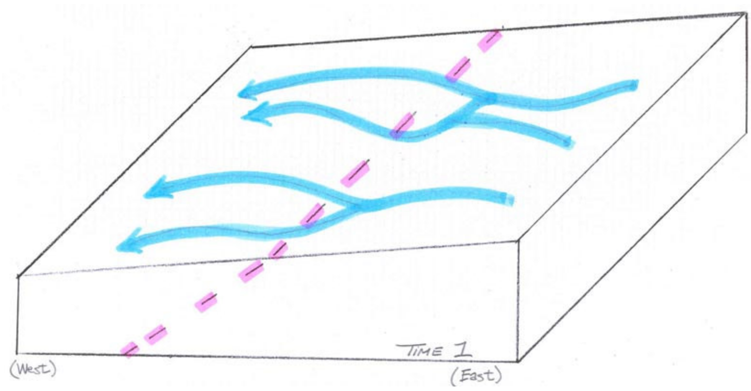

Figure 5: Time 1.

Time 1 – The Goulburn River flows east-west across the position of the Echuca South Fault. During this time, Early Holocene, the Goulburn River would have been in a period of significant aggregation (Butler 1960). The river would have formed a very wide flood plain, comprised of multiple, relatively shallow, braided stream channels. Movement began on the Cadell Fault Zone (upstream facing, vertical displacement) and movement on the Echuca South Fault began to impact on the flow of the Murray River.

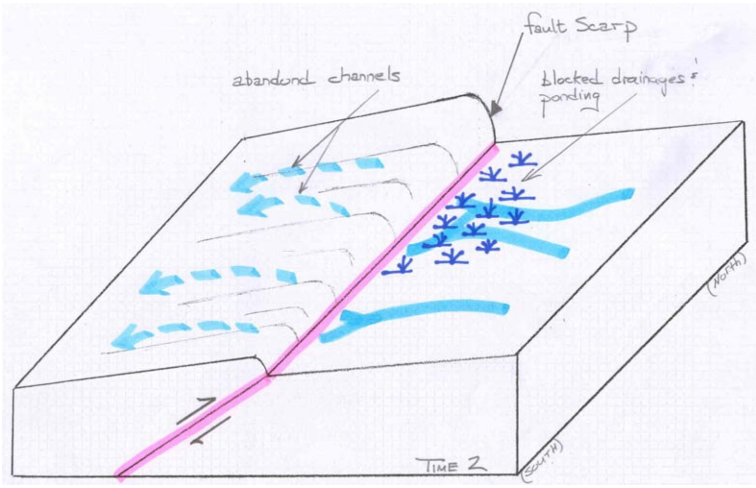

Figure 6: Time 2.

Time 2 – A large earthquake with significant surface rupture occurred on the Echuca South Fault. This event produced the 1 to 2 metre high north-south trending fault scarp that blocked the shallow, west-flowing, braided channels upstream of the fault and initiated ponding and lake formation on the down thrown side. On the up thrown block abandonment of the streams begins as the streams are cut off from their source by the fault scarp.

The southern end of the fault scarp is thought to have less displacement then the northern end, as this part of the fault scarp is eventually defeated by the streams, causing erosion and a cutting back of the fault scarp to form the tectonic riser we see today.

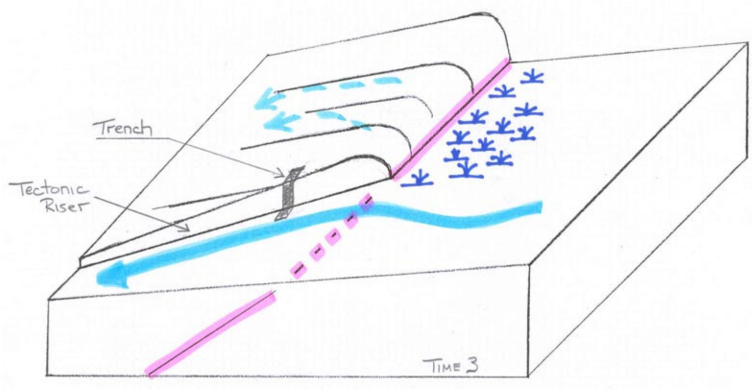

Figure 7: Time 3.

Time 3 – With continued ponding and aggradation upstream of the scarp, the fault scarp is defeated and drainage is once again established across it. Lateral migration of this drainage, and erosion along its channel banks, leads to the formation of a tectonic riser on the downstream, up-thrown side of the fault.

The obvious ambiguity with this model is that the fault would have to be oriented east-west. It would be simpler to presume that the streams had cut through the perhaps several distributed fault planes and removed any evidence of them in the top few metres of the trench, leaving only the in-filled stream channel. This would be more consistent with the e-m survey results and the fault trend previously identified on the ground and in air photos.

4 CONCLUSIONS

Determining the true nature of the feature trenched is difficult with only one trench and future trenching exercises must include multiple trenches to avoid ambiguity. Given the trench was shallow it is difficult to determine what the true nature of the feature was. If the feature trenched was a tectonic riser, the orientation of the fault would be more likely to be east-west, making it difficult for the fault to be active under the current northwest-southeast tectonic stress field in Southeastern Australia. However, if the angle of the tectonic riser was acutely shallow then it may still be feasible. Dating of samples taken from the trench wall, may help clarify the argument.

The difficulty of palaeoseismological investigations in Australia are the long intervals between movements on any particular fault. However, this very point makes it essential that trenching exercise continue despite the ambiguous conclusions to arise here. This sentiment is reinforced by efforts to find another suitable site for trenching along the same system. Additional field surveys have been conducted and detailed gravity surveys have been carried out on a potential new site. Additional trenching exercises coupled with the experience and knowledge gained during this venture will aid in understanding the nature of the faulting in this region and the potential impact it might have on earthquake hazard for Victoria.

5 ACKNOWLEDGEMENTS

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REFERENCES:

Bowler, J.M. & Harford, L. B. 1966. Quaternary Tectonics and the Evolution of the Riverine Plain Near Echuca, Victoria. *Geological Society of Australia*, Vol 13(2), 339-354.

Butler, B. E. 1960. Riverine Deposition During Arid Phases. *The Australia Journal of Science*, Vol 22, 451-452.

Crone A., Machette M. & Bowman J. 1997. The episodic nature of earthquake activity in stable continental regions revealed by paleoseismicity studies of Australian and North American Quaternary faults *Australian Journal of Earth Sciences*, Vol 44, 203-214

McCue, K.F., Boreham, B., Van Dissen, R., Gibson, G., Jensen, V., & McKavanagh, B., 1996 A Paleoseismology Case Study: the Lake Edgar Fault Scarp in Tasmania *Proceedings of the 13th AGC, Canberra, 19-23 February 1996, GSA Abstracts 41*, Geoscience for the Community.

Twidale, C. R. & Campbell, E. M. 1993. *Australian Landforms: Structure, Process and Time*. Department of Geology and Geophysics, University of Adelaide.

Van Dissen, R., McCue, K.F., Gibson, G., Jensen, V., Somerville, M., Boreham, B., McKavanagh, B., & Goede, A. 1997. The Lake Edgar Fault: Evidence for Repeated Quaternary Dispalcement on an Active Fault in Southwest Tasmania. *Proceedings of the Seminar 'Earthquakes in Australian Cities - can we ignore the risks?'* Australian Earthquake Engineering Society, Brisbane 2-3 Oct 1997.

Smith W.D. 1995. A development in the modeling of far-field intensities for New Zealand earthquakes. *Bulletin of the New Zealand Society for Earthquake Engineering*. Vol 28(3). 196-217.