Paleoliquefaction studies in Australia to constrain earthquake hazard estimates

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ABSTRACT: Australia has a low rate of modern seismicity compared to plate margin regions, and a short historical record of earthquakes. These factors combined manifest as significant uncertainty in the Australian earthquake hazard map. One approach to address the problem of sparse historic seismicity in intraplate regions like Australia is to use paleoliquefaction studies to constrain the occurrence of prehistoric earthquakes. Liquefaction was observed following large historic earthquakes in South Australia and Victoria, and numerous 'sand blows' were observed following the 1968 Meckering earthquake in Western Australia. It is therefore likely that prehistoric earthquakes in these areas would have also induced liquefaction. Liquefaction deposits might also be anticipated in other areas which are geologically prone to liquefaction, but have not experienced an historical earthquake. Four areas were investigated for paleoliquefaction: (1) southeastern South Australia, the site of pronounced liquefaction associated with a large (Ms 6.5) 1897 earthquake; (2) Meckering the site of the 1968 Ms 6.8 earthquake in the South West Seismic Zone; (3) the Perth region, a major urban centre situated in a large sedimentary basin west of the South West Seismic Zone, and (4) the Goulburn river near the Cadell fault in Victoria, whose banks consist of poorly consolidated fluvial sediments and lie near a large fault which experienced slip in the Quaternary. In this paper we discuss why we have chosen these sites as having high potential for paleoliquefaction studies, and present some results from preliminary surveys at the four target areas.

INTRODUCTION

Australia has a low rate of modern seismicity and a short historical record of earthquakes. Both of these factors combined make it difficult to construct an earthquake hazard map for Australia in which we can have complete confidence. The current hazard map is based exclusively on historical and instrumentally recorded seismicity. It is an open question whether this is a valid characterisation of seismicity over the long term. One approach to address this problem is to use paleoliquefaction studies to constrain the occurrence of prehistoric earthquakes. Liquefaction has been observed following large historic earthquakes in Australia (Fig. 1), but no specific studies have been made to investigate these areas. We present the preliminary results of a survey aimed at assessing the potential for liquefaction deposits in Australia to contribute to the next generation of seismic hazard maps.
PALAEOLIQUEFACTION STUDY AREAS

In 1897, liquefaction was observed during a large (Ms 6.5) earthquake near Beachport, southeastern South Australia. In 1968, numerous ‘sand blows’ were observed following the Ms 6.8 earthquake at Meckering in Western Australia. It is likely, therefore, that prehistoric earthquakes in these areas would have also induced liquefaction. Liquefaction deposits might also be anticipated in other areas which are geologically prone to liquefaction, but have no record of large historical earthquakes. Based on this historical evidence, and the potential for paleoliquefaction during pre-historic earthquakes, four areas were chosen for investigation. These areas were: (1) southeastern South Australia near Beachport; (2) the Meckering area, in the South West Seismic Zone of Western Australia; (3) the Perth region, a major urban centre situated in a large sedimentary basin west of the South West Seismic Zone; and (4) the Goulburn River in Victoria, whose banks consist of poorly consolidated fluvial sediments near the Cadell fault, a large fault scarp which developed in the Quaternary.

Study Area 1: 1897 Beachport Earthquake Epicentral Area, South Australia

Pronounced liquefaction was reported from the epicentral area of the Ms 6.5 1897 Beachport earthquake (Figs 1,2; Dodwell, 1910; Howchin, 1918). The physiography of the Beachport region is a series of north-south trending ~30 m high by ~2 km wide Pleistocene beach ridges separated by ~3 km wide Pleistocene lagoons (Fig. 2). The near surface stratigraphy consists of a thin soil (<1 m) overlying limestone that is ~1 m thick beneath the Pleistocene lagoons and ~30 m thick beneath the Pleistocene beach ridges. This geology is particularly evident along the banks of extensive drainage ditches that cross the landscape from west to east in the Beachport region.
A 70 m length of one such drainage ditch Drain M (37.295 S, 140.252 E) bisected a sand deposit, possibly relating to a north-south trending channel inset into the limestone. A 15 m portion of the 3 m high ditch wall was excavated and logged (Fig. 3). The bank exposed, in ascending order, a sand (unit 1), sandy clay to clayey sand (unit 2), mottled clayey sand (unit 3), limestone and hematite rubble zone interpreted to be a paleosol (unit 4), fluvial sand (unit 5), modern soil (unit 6), as well as one large sand dike and a number of small sand dikes. One charcoal and four OSL samples were collected from the profile for dating. Additionally, the units and large dike were sampled for sediment grain size analyses. These dates and grain size analyses should allow us to determine the origin of the dike. However, based on the field observations presented above, we tentatively interpret the dike to be a paleoliquefaction feature related to a pre-1897 earthquake event.
Study Area 2: 1968 Meckering Earthquake Epicentral Area

The 1968 Meckering earthquake, (Ms 6.8, Fig. 4) is the largest earthquake known to have occurred in the area of high seismicity east of Perth known as the South West Seismic Zone (Fig. 1). The Meckering earthquake was associated with surface rupture (Fig. 4), producing a scarp up to 2.5 m high and 37 km long, and it induced liquefaction near the town of Meckering (Everingham, 1968; Gordon and Lewis, 1980; Gregson, 1990).

Three backhoe trenches were excavated at sites where liquefaction features (sand blows) were reported to have occurred following the 1968 earthquake. In all three trenches we found thin sandy soils developed in a loose, grey sand horizon. The sand overlies a silty palaeosol and is connected below to what appeared to be sand-filled vent structures (Fig. 5). These cross-cut weathered and partially indurated fluvial deposits.

![Figure 4](image-url)  
Figure 4  Plan view and photograph of the 37 km long and up to 2.5 m high Meckering fault scarp.

Older sandy deposits with a similar morphology were also found in one of the trenches (Fig. 5). These structures underly the silty palaeosol beneath the grey sand and consist of tubes of vertically stratified brown sand which connect to an overlying brown sand horizon. The brown sand horizon also overlies a silty layer interpreted to be a palaeosol. We favour the interpretation that liquefied sand vented through zones of weakness in the sediments left by tree roots, forming the sandfilled vent structures and related sand blows seen in the trenches. We therefore contend that the trenches provide evidence for two liquefaction events in the Meckering region. As the "liquefaction" deposits occur in sediments of the Mortlock River floodplain, which owes its existence to the prehistoric damming of the Mortlock by the Meckering Fault, this work implies a minimum of three large earthquakes have occurred in the Meckering region.

Reconnaissance along the nearby Mortlock and Avon rivers failed to find evidence for liquefaction deposits related to the Meckering or prior earthquakes.
Study Area 3: The Swan and Canning Rivers near Perth

The Swan and Canning Rivers were selected for reconnaissance because of their proximity to Perth. Although there has been very little seismicity recorded in the Perth Basin, it lies within 100-150 km of several historic fault scarps, and abuts against the 1000 km long Darling Fault scarp (Playford et al., 1976). The Darling Fault is presently aseismic and its last major episode of movement is thought to have been in the Eocene.

We found no liquefaction features in the Holocene deposits of either river, ostensibly due to near-universal poor exposure. We did, however, find unusual features that might be related to earthquake induced liquefaction in Pleistocene deposits exposed on the Swan near Courtney Island (Fig. 6). The size of the features suggests that they might be related to movement on the Darling Fault. Samples for dating were obtained.
Study Area 4: The Goulburn and Murray River near the Cadell Fault, NSW/Victoria border

No historic events of sufficient magnitude to produce liquefaction have been experienced in the eastern states of Australia (Fig. 1). However, the area is of great interest as the greater proportion of Australia's population lives on the eastern seaboard. The Cadell fault is considered a likely source of earthquake shaking for possible paleo-liquefaction along the Goulburn and Murray River flood plains. The Cadell scarp is 37 km long, over 10 m high in places (Figs 7,8), and has a down-to-the-east displacement (Bowler and Harford, 1966). Thrust displacement on the Cadell fault is thought to have diverted the course of the Murray, possibly as little as 4,000 years ago. Canoe trips were made along portions of the Goulburn and Murray rivers upstream of Echuca to seek evidence of paleoliquefaction. Most of the bank sediment in these rivers is sandy and clayey silt. The very few sand lenses present are commonly indurated with iron oxide. No sand dikes were found anywhere along the 64 km of the Goulburn and Murray rivers floated.

Figure 7 The Murray and Goulburn Rivers where they are diverted by the Cadell Fault

Figure 8 Aerial view of the 10 m high Cadell scarp looking NW. Barmah forest formed where the Murray River ponded, before diverting.
CONCLUSIONS

Perhaps the most promising and exciting of the field areas is the Meckering epicentral area. Dating of the liquefaction deposits identified in the Mortlock River floodplain, together with dating the basal sediments of the floodplain, has the potential to provide the first estimates of recurrence for large earthquakes in this area. This data will have direct implications for the assessment of seismic hazard for nearby Perth. The deposit identified in the Swan River also has the potential to add to the picture of large earthquake occurrence proximal to Perth. Our preliminary assessment of the Drain M sand dike near Beachport, South Australia, is that it is a paleoliquefaction dike. Ongoing research seeks to determine the age of the dike. We believe that the liquefaction site exposes the intersection of a natural N-S drainage and Drain M. The study of aerial photographs may confirm this interpretation and reveal additional intersections where more liquefaction deposits, potentially of different generations, may be found. No evidence of paleoliquefaction was found in cut banks of the Goulburn and Murray rivers upon canoeing 64 km of these rivers. In view of the almost complete dominance of silt over sand in the floodplain deposits, and that the area is likely to have experienced strong ground motion relating to movement on the Cadell Fault, we believe that these sediments are not prone to liquefaction.

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REFERENCES:


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