Palaeoseismic investigation of a recently identified Quaternary fault in Western Australia: the Dumbleyung Fault

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Introduction

Analyses of high resolution Digital Elevation Models (DEM) have led to the discovery of various linear scarps in the southwest of Western Australia, which are apparently related to large surface breaking earthquakes (Clark, 2005). Given the present lack of understanding of palaeoseismicity of this region, investigation of these features will significantly contribute to a better understanding of the seismic hazard.

Detailed analyses of one of these recently recognized scarps, the Dumbleyung Scarp, located 230 km southeast of Perth (Figure 1), revealed this feature to be a prominent and well preserved fault scarp. Field reconnaissance and analyses of DEM, aerial photographs and the associated drainage network indicated the likelihood of significant recent tectonic deformation. Consequently, the Dumbleyung Scarp was selected for detailed palaeoseismological investigations, the preliminary results of which are presented here.

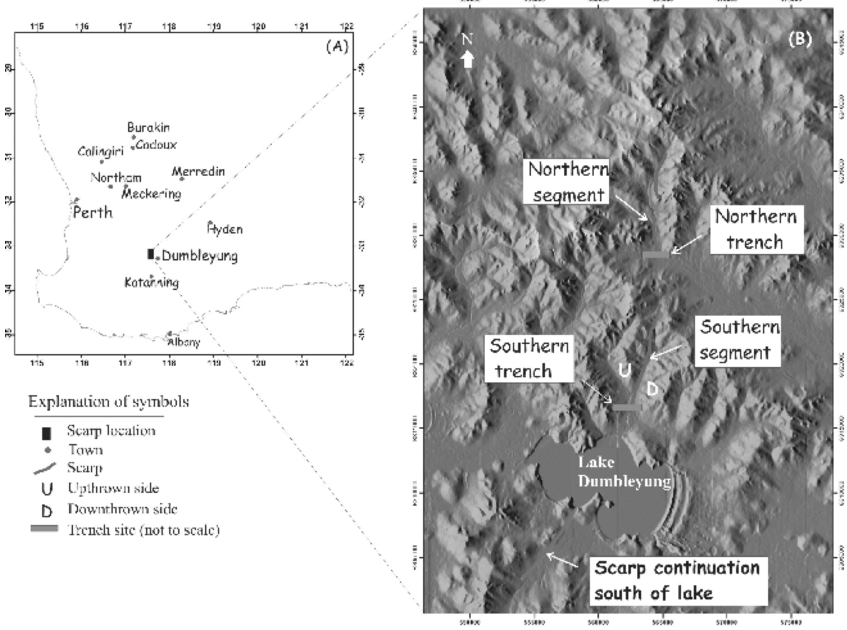

Figure 1. Location of the Dumbleyung Scarp. (A) Location of the scarp in the southwest of Western Australia. (B) Northern and southern segments and location of trenches across the scarp for palaeoseismological investigations

Dumbleyung scarp characteristics

The Dumbleyung Scarp lies within the 'Wheat Belt' of the southwest of Western Australia, on the Western Gneiss Terrain of the Archaean Yilgarn Craton (Gee et al., 1981). Its surrounding area is variably covered by lateritic soils and duricrust formed during the Late Cretaceous and Tertiary (Chin and Brakel, 1986). Regolith materials also include alluvium, colluvium, and reworked sandplain deposits.

The scarp lies within the South West Seismic Zone, SWSZ, (Doyle, 1971). The available seismic record (http://www.ga.gov.au/oracle/quake/quake.online.jsp), indicates that the scarp lies in an area where little instrumental or historical earthquake activity has been recorded (Figure 2).

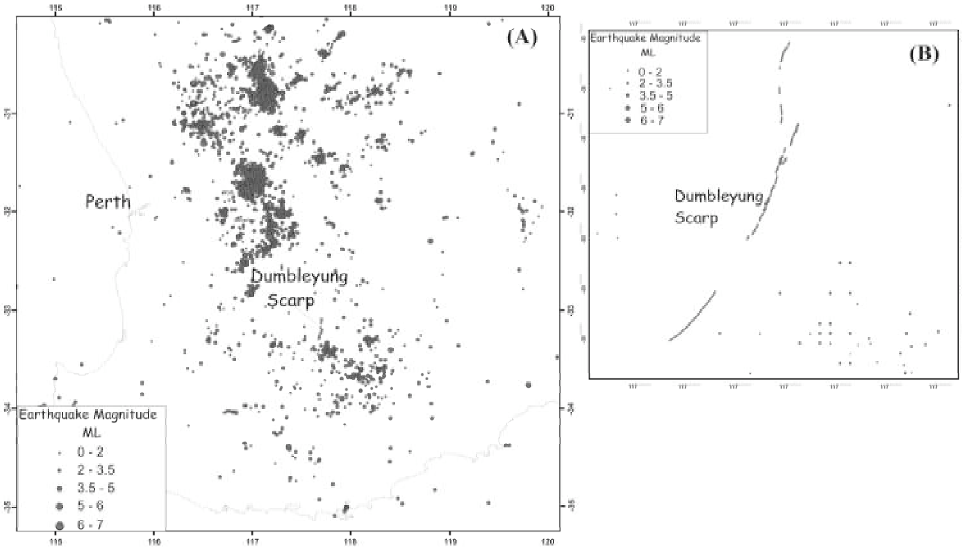

Figure 2. (A) Dumbleyung Scarp location with respect to the SWSZ. (B) Earthquake events recorded close to the scarp.

The Dumbleyung Scarp consists of two segments (Figure 1B). For both segments, uplift occurs in the western side of the fault. The southern segment strikes N20ºE and appears to continue to the south of Lake Dumbleyung, reaching ~24 km in length. The maximum height of this segment is 3 m. The northern segment strikes NS and has a length of approximately 12 km attaining a maximum height of 5 m.

Palaeoseismological investigations of the Dumbleyung Fault scarp: evidence of palaeoearthquakes

Two trenches were excavated across the scarp (Figure 1B) in order to obtain information about the earthquake history of the Dumbleyung Fault. Both trenches revealed that the Dumbleyung Scarp formed as a result of thrust faulting. In the southern trench, an east-facing fault propagation fold in alluvial deposits was exposed. Minor structures within the main zone of deformation in this trench indicate that the fold relates to reverse displacement on a buried west-dipping thrust fault. The northern trench also exposed reverse faulting but of significantly greater amplitude than in the southern trench. Further details of the northern trench are given below.

Northern trench

A trench 27 m long, 4 m deep and 3 m wide was excavated across the northern segment of the Dumbleyung Scarp (Figure 3). The scarp reaches 4 m in height at this site and is developed in a suite of alluvial deposits and younger colluvium. The trench exposed significant deformation largely accommodated by drag-folding and associated disruption of stratigraphic units within a main deformation zone up to 1.5 m wide and dipping 20 to 30º to the west (Figure 3A and 3B). Four discrete reverse faults (F2 to F5, Figure 3) were recognised proximal to the main zone of deformation and a fifth discrete fault (F1 in Figure 3A and 3D) was identified to the eastern margin of the trench, away from the main zone of deformation, apparently displacing sediments of the footwall.

The alluvial units exposed in the hanging wall (west side) of this trench could not be correlated to those exposed in the footwall (east side), indicating significant displacement along the main deformation zone (Figure 3A). The colluvial apron that overlies the main deformation zone (Units 16 and 17, Figure 3) has derived from the scarp that was formed after fault rupturing along the main deformation zone. This colluvial apron may prove to be datable using luminescence techniques and should provide an approximate age of the seismic event that caused the uplift that preceded the formation of the colluvial units.

The eastern end of the trench, on the footwall, Unit 13, (between vertical grid lines 18 and 21, Figure 3A), appears to be controlled by deformation related to F1; Unit 13 thickens across the projection of the F1 fault plane which may correspond to the manifestation of a propagation fold related to F1. Thickening of Unit 13 across F1 suggests that displacement across this fault immediately preceded deposition of the unit. Unfortunately, the superposition of channel Unit 15 (Figure 3) has masked the area where this thickening occurs making it difficult to establish unequivocally if the thickening of Unit 13 reflects relief generation subsequent to another earthquake event. The extent of Unit 13 to the west, close to the main zone of deformation, suggests that relief may have also been generated by displacement across this zone during the event along F1. As Unit 16 colluvium overlies Unit 13, which contains a well-developed palaeosol (Figure 3), it is inferred that Unit 13 was at the ground surface prior to the seismic event that produced the colluvial Unit 16 in the main deformation zone.

Faults F2 to F4 appear to terminate against the base of colluvial Unit 16, and consequently may relate to the main deformation event at the main deformation zone. In contrast, F5 appears to displace colluvium relating to the main deformation event (Unit 16-16′), and therefore may reflect a later, more recent seismic event (MRE). Once luminescence dates become available it may be possible to establish if the base of Unit 16 has indeed been displaced by faulting along F5. The combined evidence suggests the possibility of three discrete seismic events. The oldest event along F1 (and probably also along the main deformation zone) is represented by Unit 13. A second penultimate event (PE) at the main zone of deformation may be indicated by colluvial Units 16 and 17, and as already noted, the possibility of a third event (MRE) is associated with F5 which appears to displace colluvial Unit 16 resulting from the PE .

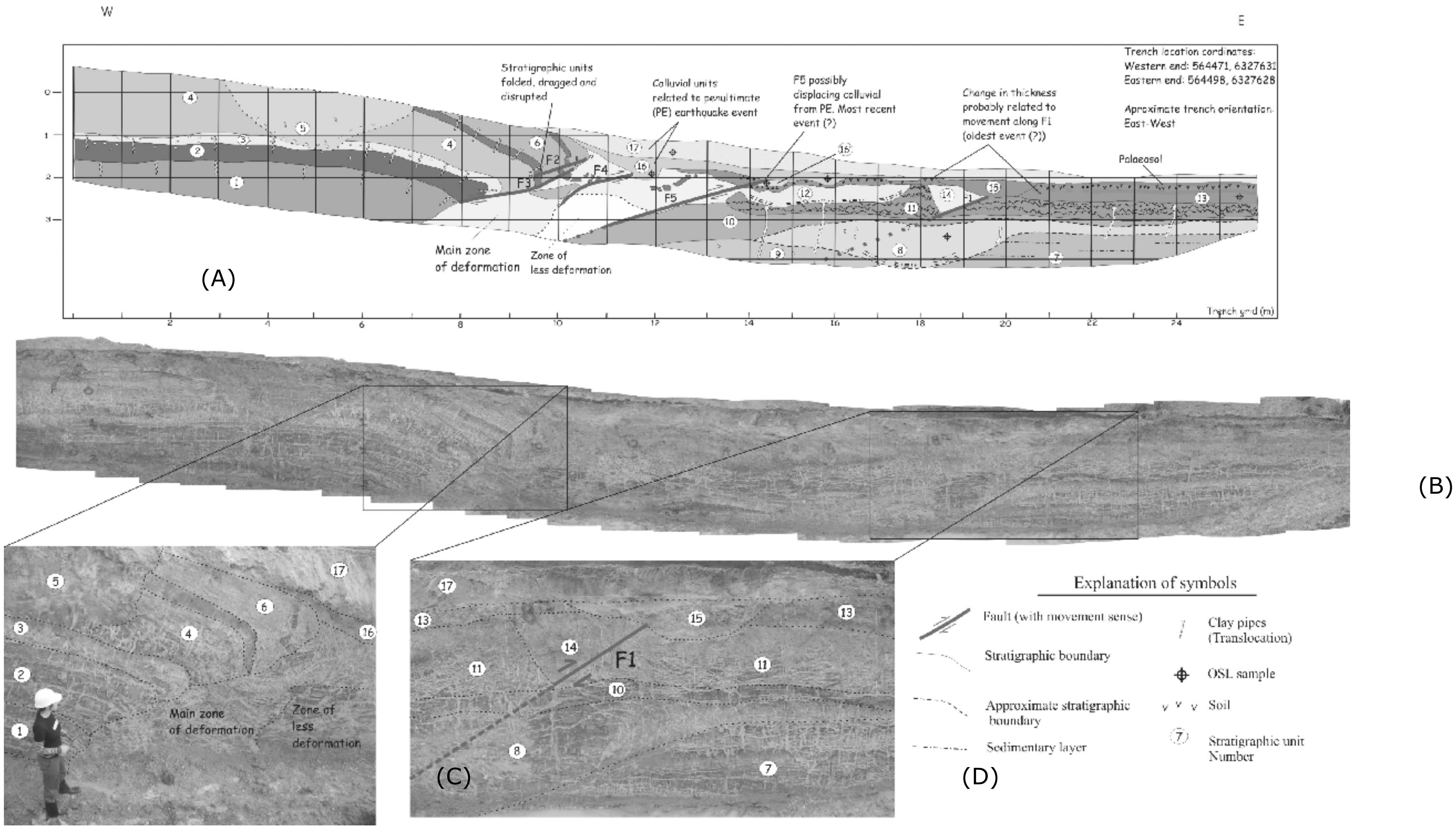

Figure 3. Dumbleyung Scarp Northern trench. (A) Log of the northern trench across the scarp illustrating the different stratigraphic units and their stratigraphic relationships. The main zone of deformation and the faults exposed in the trench are also illustrated. (B) Photographic mosaic of the northern trench. (C) Detail of the main zone of deformation and (D) Detail of fault F1 and Units 11, 13, 14, 15 and 17. Note that Unit 13 thickens in the footwall of F1.

Discussion and conclusions

The Dumbleyung scarp is the surface expression of thrust faulting. The scarp consists of a southern and a northern segment, which together reach 36 km in length. Each segment has different characteristics including strike, vertical displacement and amount of near surface deformation. Luminescence dating results may establish if the northern and southern scarps have ruptured simultaneously during the same earthquake event.

The preliminary evidence presented here suggests the possibility of three earthquake events exposed in the northern trench. However, only one event has been confirmed at this stage (PE), pending the results of the luminescence dating. As indicated above, the three events appear to be represented by the three colluvial deposits inferred (Units 13, 16 & 17). Unit 13 appears to be associated with the relief caused by movement along F1 but its continuation to the west, until the main zone of deformation, suggests that deformation also took place at this zone during this event. A soil profile developed in the upper parts of Unit 13, suggests significant time between its deposition and the deposition of the overlying colluvial units 16, & 17 that formed after a second event (PE). The PE appears to be associated with a large amount of relief generation across the main zone of deformation, and with the significant folding of strata in the hanging wall. Fault F5 appears to displace colluvial Units 13 and 16 and is interpreted as having formed during a more recent seismic event (MRE).

Earthquake magnitude and implications for seismic hazard

The 36 km length of the Dumbleyung Scarp (assuming that the southern and northern segment ruptured together) physically limits the earthquake size that the structure can produce. Empirical equations relating displacement, rupture length and rupture area to earthquake magnitude (Bonilla, 1982, Shimazaki, 1986, Wells and Coppersmith, 1994, Stirling et al, 2002) indicate that a 36 km rupture length may be associated with an earthquake of magnitude Mw 6.9-7.2 and an average vertical displacement of around 2 m. In contrast, a rupture length of about 80 km may be expected for an earthquake large enough to produce 4m of uplift in a single event. A large event implies a large rupture area. However, information from the earthquake records in the southwest of Western Australia and the characteristics of the recent earthquake ruptures such as. Meckering, Cadoux and Calingiri (Gordon, 1971; Denham et al., 1979; Denham et al., 1980; Gordon et al., 1980; Lewis et al., 1981; Langston, 1987; Vogfjord and Landston, 1987); indicate that the seismogenic layer in the region is confined to the top of the crust. Seismic information shows that the seismogenic layer appears to have a maximum thickness of 20 km which in turn restricts the maximum earthquake magnitudes that can be produced in the region.

The height of the scarp (4m) at the northern trench location is therefore best explained as being the result of the whole length of scarp rupturing at least twice. This is consistent with the stratigraphic relationships exposed in the trench profile, which suggest at least one or most probably two major relief-generating earthquake events (oldest and PE), and a third event producing only modest relief (MRE). The smaller displacement across F5 (MRE) may be the result of movement along only the northern segment and not along the whole length of the fault.

Based on the above analysis, at least two events of magnitudes Mw 6.9-7.2 appear to be necessary to produce the scarp relief observed on the northern segment of the Dumbleyung Fault. The northern trench interpretation indicates that these events correspond to the oldest and penultimate events. The earthquake generation dates will help to establish a possible recurrence pattern for this fault, a parameter necessary for seismic hazard assessment.

Although the Dumbleyung Fault appears to be capable of producing earthquakes of Mw 6.9-7.2, the smaller amount of displacement observed along F5 suggest that the fault does not rupture characteristically and may generate earthquakes of lower magnitudes.

A Mw 6.9-7.2 earthquake produced by the Dumbleyung Fault would impact significantly on nearby towns such as Dumbleyung, Wagin and Katanning.

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