RE-EVALUATING THE SEISMIC HAZARD POTENTIAL OF THE NORTHERN LAPSTONE STRUCTURAL COMPLEX

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1. INTRODUCTION

Faults of the Lapstone Structural Complex (LSC - Mauger *et al*., 1984) underlie 100 km, and perhaps as much as 160 km, of the eastern range front of the Blue Mountains west of Sydney (e.g. Branagan, 1969; Branagan & Pedram, 1990). More than a dozen major faults and monoclinal flexures have been mapped (**Fig. 1** shows a subset). Of the flexures, the Lapstone Monocline is the most prominent, accounting for more than three quarters of the deformation across the complex at its northern end near the Colo River (e.g. Branagan & Pedram, 1990). While these structures have been known for more than 100 years (e.g. David 1896, 1902) very little is known about their sub-surface geometry and faulting history, particularly in the Cenozoic (last 65 million years). The latter uncertainty stems in a large part from a paucity of readily dateable Cenozoic units unequivocally associated with faulting (e.g. Wellman & McDougall, 1974; Bishop *et al*., 1982; Rawson, 1990; Pickett & Bishop, 1992).

Over the last several decades, a significant concentration of earthquake hypocentres occurred to the west of the LSC at depths of up to 15 km (Gibson, in press). This observation has been used to suggest that the surface expression of the LSC reflects displacement across an active low angle reverse fault. The fault is thought to be emergent at the surface south of Penrith, and underlies the Lapstone Monocline to the north of Penrith (IGNS, 1999). Displacement across the complex increases from south to north, with approximately 400 m of uplift evident in the Mountain Lagoon region. The youngest geological unit apparently deformed by faults of the LSC is the 18.8 Ma Green Scrub Basalt (Wellman & McDougall, 1974) which has a linear eastern margin defined by the Kurrajong Fault (Crook, 1957; Branagan & Pedram, 1990; **Fig. 1**).

A recent study of seismic hazard in the Sydney Basin identified the LSC as a potential source for large and damaging earthquakes, and estimated the average return period for M_W >7.0 events to be 15-30 ka based upon the above structural framework and field relationships (IGNS, 1999). This study examines the assumptions upon which these calculations of seismic hazard are based in the light of recent advances in our understanding of the rates of landscape processes in the Blue Mountains, and re-evaluates key landscape features associated with the major faults between the Colo River and Grose River. Specifically, the question of whether there is landscape evidence to support a 15-30ka return period for large earthquakes is examined.

2. AGE OF THE LAPSTONE STRUCTURAL COMPLEX

A fundamental barrier to assessing the seismic hazard that the Lapstone Structural Complex poses to Greater Sydney is timing of movement on the constituent faults. As mentioned previously, IGNS (1999) base their recurrence calculations on the apparent truncation of the 18.8 Ma Green Scrub Basalt by the Kurrajong Fault.

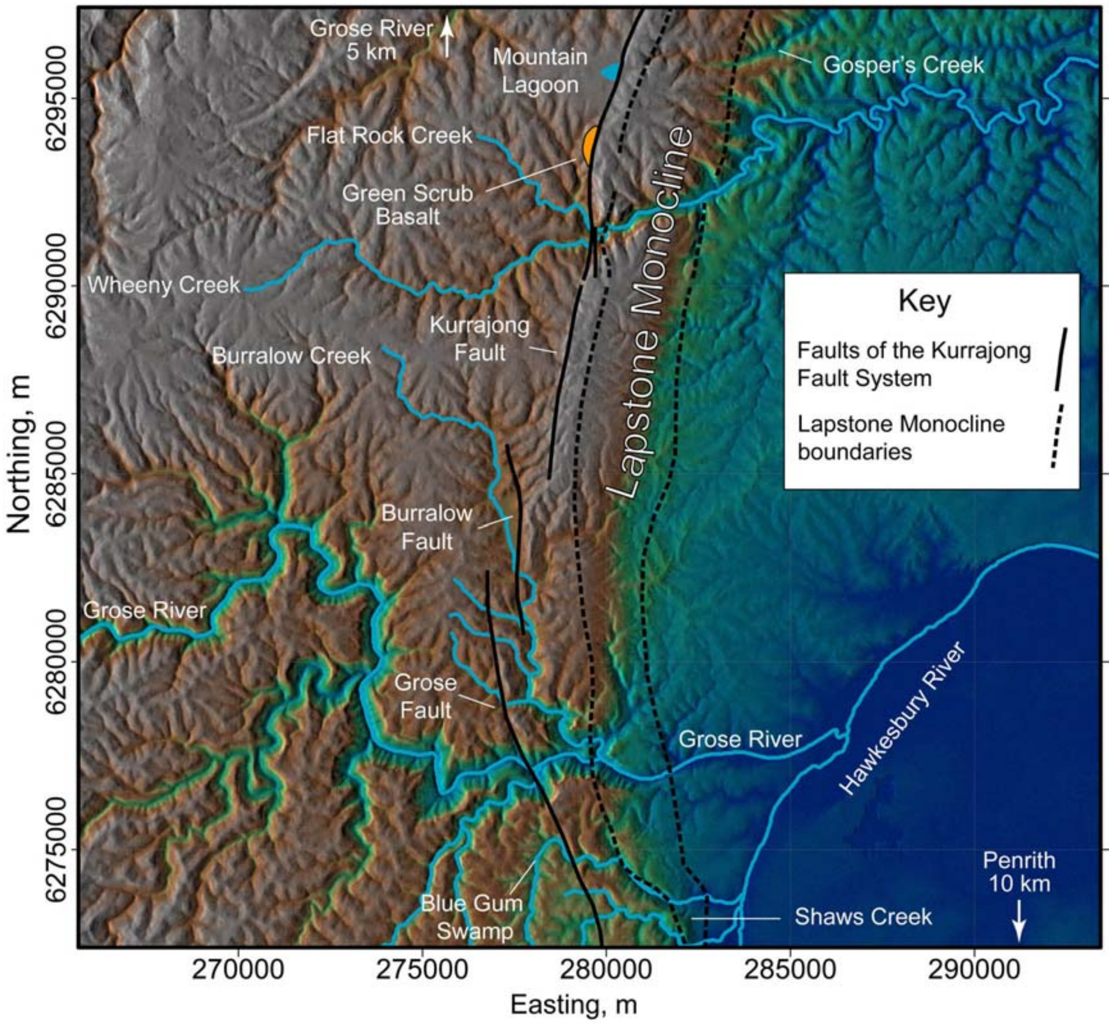

Figure 1 The northern Lapstone Structural Complex showing the position of key streams, and the major faults and flexures. Graticule in the GDA94/MGA56 system. Background image is a 25 m resolution digital elevation model from the NSW Lands Department. Deep blues are several tens of metres in elevation and less, greys are greater than 600m in elevation.

However, the flow might just as plausibly have been emplaced against a pre-existing fault scarp. Field relations at the outcrop are equivocal (e.g. Rawson, 1990; John Pickett, verbal communication 2007; this study). An alternative view argues that fold development was largely complete by the Early Jurassic (185 –200 Ma) (Pickett & Bishop, 1992). These authors cite thickening of Sydney Basin lithologic units across the Lapstone Monocline as evidence for a largely syn-sedimentary origin for the LSC. According to this hypothesis, the landscape we see today is largely the result of erosional exhumation of a pre-existing structure. However, palaeomagnetic data require that most folding post-dates the mid-Cretaceous (*ca.* 90 Ma - Schmidt *et al.*, 1995), and was complete by 8±5 Ma (Bishop *et al.*, 1982 with age recalculated by Pillans, 2003). The cessation of folding might relate either to the termination of major deformation, or to a time when faults underlying folds broke through to the surface and subsequent deformation proceeded by slip on discrete fault planes.

3. EVIDENCE FOR RECENT FAULTING: MOUNTAIN LAGOON AND ASSOCIATED STREAM PROFILES

Recent deformation in the form of slip along discrete fault planes is indicated by the presence of a number of lakes and swamps where easterly flowing streams cross the western faults of the northern LSC (e.g. Mountain Lagoon, Burralow Creek, Blue Gum Creek Swamp, Shaw's Creek, **Fig. 1**). The smallest of these features, Mountain Lagoon, occurs immediately west of the Kurrajong Fault scarp and captures drainage from a tiny catchment of less than 1 km^2 in the headwaters of Gosper's Creek. The size of the catchment is at odds with the Gosper's Creek valley profile east of the Kurrajong Fault, which is deeply incised slot canyon several tens of metres wide and 50-80 m deep (**Fig. 2**). This canyon testifies to a time of significant stream power, and must therefore have formed when the catchment area was much larger than today.

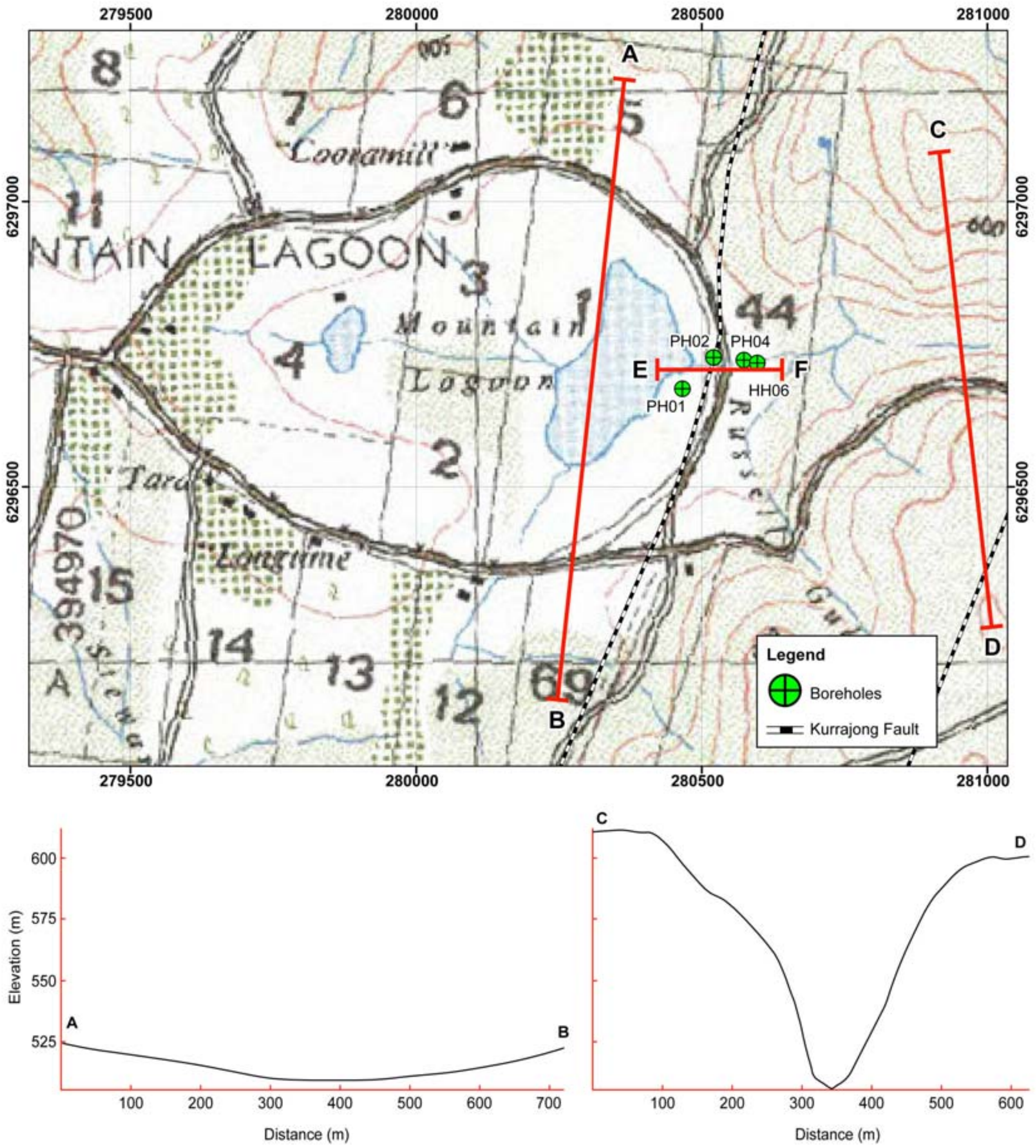

Figure 2 Topography of Mountain Lagoon with borehole locations and profile extents marked. Graticule is in metres in the GDA94/MGA56 system. Note that the entire catchment of the lagoon is defined by the ring road. Topographic valley profiles vary markedly between reaches upstream and downstream of the Kurrajong Fault. Fault location is pinned by the escarpment to the north and south of the lagoon and by drilling results east of the lagoon. Base map is 1:25 000 scale topography.

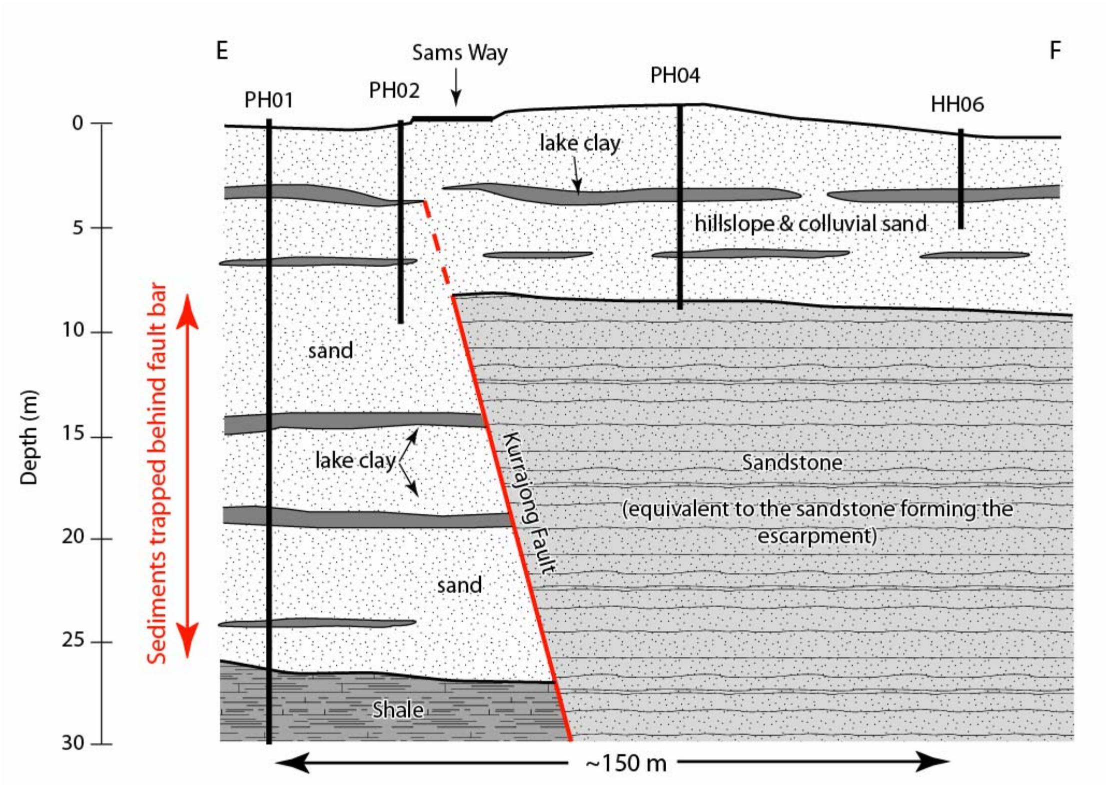

Figure 3 Schematic section through the Kurrajong Fault at Mountain Lagoon showing the gross architecture of the fault-angle basin and borehole locations. Section location is shown on Fig. 2.

A drilling investigation of the eastern margin of the lagoon confirmed that the lagoon is the consequence of fault damming (**Fig. 3**). Fifteen metres of intercalated lake clays, alluvial fan sands and hillslope sandy sediments overlying shale bedrock are preserved behind a sandstone fault barrier corresponding to the location of the Kurrajong Fault inferred from the line of the escarpment to the north and south of the lagoon. This displacement is all that appears to have occurred across this section of the Kurrajong Fault since Gosper's Creek catchment was dissected to the point that the Creek had insufficient stream power to erode the sandstone bar.

We have no dating results from the sediments within the lagoon as yet. However, the displacement magnitude of the bedrock bar in Mountain Lagoon is consistent with the height of over-steepened sections in the channels of nearby Flat Rock Creek and Wheeny Creek where they cross the Kurrajong Fault (Kirkby, 2008). These over-steepened sections are presumably short lived in the landscape (i.e. less than a couple of million years at most), given the average landscape denudation rates of 21.5 ±7 m/Ma (Tomkins *et al.*, 2007). This suggests that the 15 m thick sedimentary record preserved in Mountain Lagoon reflects displacement across the Kurrajong Fault in only the last few million years.

4. DISCUSSION: A RE-EVALUATION OF THE SEISMIC HAZARD POSED BY THE LSC

Drilling in Mountain Lagoon reveals evidence for the most recent 15 m of vertical displacement across the Kurrajong Fault, which has a total offset of 130 m (e.g. Branagan & Pedram, 1990). While an ongoing dating program will constrain the timing of this most recent uplift, it is critical to note that 15 m is the total amount of uplift that has occurred since the catchment of Gosper's Creek was sufficiently large to generate enough stream power to erode through the sandstone fault bar. An indication of a minimum size for the palaeo-Gosper's Creek catchment, assuming similar climate, is given by the Burralow Creek catchment of today. Burralow Creek (**Fig. 1**) has a catchment area of approximately 40 km^2 (i.e. 40 times larger than Mountain Lagoon) yet it still shows evidence of partial fault-damming, with at least 6-7 m of sediment trapped behind a fault barrier corresponding to the Burralow Fault (Rawson, 1990). Given the current Gosper's Creek catchment size of <1 km^2, and landscape denudation rates of around 21.5 ±7 m/Ma (Tomkins *et al*., 2007), it must have been several million years or more since fluvial flow sufficiently energetic to remove the fault barrier has occurred.

The faults that form the western margin of the northern LSC (i.e. the Kurrajong, Burralow and Grose Faults) are arranged in an overlapping *en echelon* pattern and merge at depth (Herbert, 1989). Their total strike length is in the order of 30 km. If we assume that they ruptured simultaneously as the result of movement on the west-dipping master thrust (c.f. IGNS, 1999), then displacements of the order of 2 m might be expected per event (Wells & Coppersmith, 1994). The total displacement observed in Mountain Lagoon might therefore represent as few as about seven individual earthquake events. Over several million years this represents an average return period for large earthquake events in the order of several hundred thousand years or more. The existence of over-steepened sections of nearby creeks where they cross the Kurrajong Fault indicates that the majority of this uplift has occurred in more recent portion of the last couple of million years.

5. CONCLUSIONS

Based upon a structural model for the LSC involving a large west-dipping thrust fault beneath the Lapstone Monocline, a recent study of seismic hazard in the Sydney Basin identified the LSC as a potential source for large and damaging earthquakes, and estimated a recurrence for M_W >7.0 events at 15-30 ka (IGNS, 1999). However, our preliminary results from Mountain Lagoon indicate that only 15 m of fault displacement has occurred across the Kurrajong Fault in the last several million years or more. If this qualitative assessment is proven correct, then the average return period for large earthquakes along the Kurrajong Fault, and by implication the northern Lapstone Structural Complex, is actually in the order of hundreds of thousands of years or more.

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