REVIEW OF STRUCTURE AND BASEMENT CONTROL OF THE LAPSTONE STRUCTURAL COMPLEX, SYDNEY BASIN, EASTERN NEW SOUTH WALES

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ABSTRACT
In the western Sydney Basin, the Lapstone Structural Complex is a major north-trending association of monoclines and faults that forms the frontal ridge of the Blue Mountains Plateau. At Kurrajong Heights, the Lapstone Structural Complex is dominated by an east-facing monocline with a gently dipping central limb containing several different homoclinal segments. At the Hawkesbury Lookout section, strata are steeply dipping to near vertical along the main east-facing monocline. The Lapstone Structural Complex has been related to either steep east-dipping extensional faulting or to moderate to steep west-dipping contraction faults. Strike-slip displacement may also have played a role in its development. The Hawkesbury Lookout section is interpreted in the subsurface as a moderately west-dipping thrust fault. The historical development of the Lapstone Structural Complex has been difficult to resolve although palaeomagnetic data from the southern part are indicative of Late Cretaceous to Cenozoic deformation. Neotectonic activity may also have occurred along the structure. Basement to the Sydney Basin is the eastern Lachlan Fold Belt, which includes moderately west-dipping faults that may have been reactivated as thrust faults in the present-day stress regime. These structures provide a potential analogue for a basement-controlled fault that has generated the Lapstone Structural Complex.

INTRODUCTION
This account presents a brief review of the Lapstone Structural Complex in the western Sydney Basin (Figure 1). Two cross sections are shown for Kurrajong Heights and Hawkesbury Lookout and these complement the structural outline of the Lapstone Structural Complex given by Branagan and Pedram (1990, 1997). The Lapstone Structural Complex is a significant feature but its understanding has been limited by various contradictory data on its historical development and also by its overall classification as one of contractional, extensional and/or strike-slip association. Additionally, it has been considered controlled by an underlying basement structure and this is considered herein with reference to potentially active faults in the Lachlan Fold Belt to the west and southwest of the Sydney Basin.

BACKGROUND
The Lapstone Structural Complex is an association of east-facing monoclines, high-angle faults, and fracture zones to the west of Sydney (Branagan & Pedram 1990, 1997). Its development was considered syndepositional during the Permian and Triassic periods by Pickett and Bishop (1992) as units thicken immediately to the east of the complex (see also seismic interpretation in Australian Oil & Gas Corporation Ltd 1966). An upper limit to tilting associated with monocline development was based on the cross-cutting Jurassic Nortons Basin diatreme near Wallacia which is apparently undeformed (Pickett & Bishop

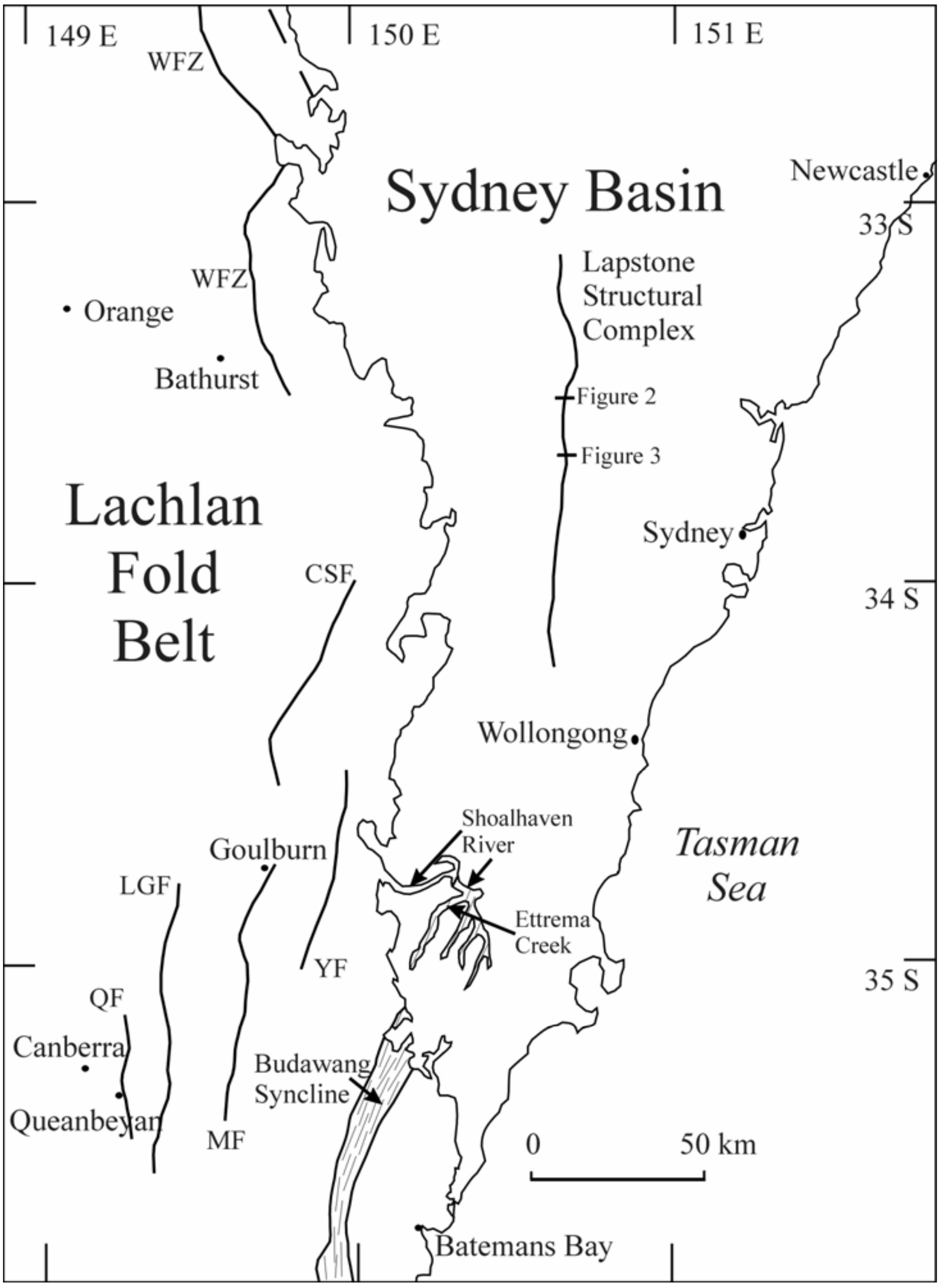

Figure 1 Sydney Basin and major structures in the adjoining Lachlan Fold Belt (after Scheibner 1997). Lapstone Structural Complex is marked along with locations of Figures 2 and 3. Faults in Lachlan Fold Belt: CSF = fault on western margin of Cockbundoon Syncline, LGF = Lake George Fault, QF = Queanbeyan Fault, MF = Mulwaree Fault, YF = Yarralaw Fault, WFZ = Wiagdon Fault Zone.

1992). Palaeomagnetic data indicate that tilting associated with the Lapstone Structural Complex affected the mid-Cretaceous overprint magnetisation at Tahmoor and that therefore much of the deformation post-dated the mid Cretaceous (Schmidt *et al.* 1995). A lack of tilting of Miocene magnetisation was determined for the monocline at Lapstone (Bishop *et al.* 1979). These constraints are consistent with an Early Tertiary age for the Lapstone Structural Complex suggested by Branagan and Pedram (1990) and supported by studies of the subbasalt topography and modelling in the Blue Mountains (van der Beek *et al.* 2001). Numerous earthquakes have occurred and indicate that the Lapstone Structural Complex may still be active (Brown & Gibson 2004). Neotectonic deformation in southeastern Australia is now recognised as being more prominent than previously considered (Sandiford 2003).

STRUCTURE OF THE LAPSTONE MONOCLINE

The Lapstone Structural Complex varies along its length with monocline(s), high-angle faults and minor structures such as thrusts, minor folds, tectonic breccias and joints (Branagan & Pedram 1990, 1997). An east-facing monocline is well developed along much of the complex as at Kurrajong Heights where the central, gentle limb of the monocline consists of several segments with different dips to the east (Figure 2). Much steeper dips on the monocline occur below the Hawkesbury Lookout. Here, strata west of the monocline are flat and gradually increase in dip up to *ca* 15º to the east before crossing a fault onto the steeply dipping near vertical central limb (Figure 3, Branagan & Pedram 1990, figure 7).

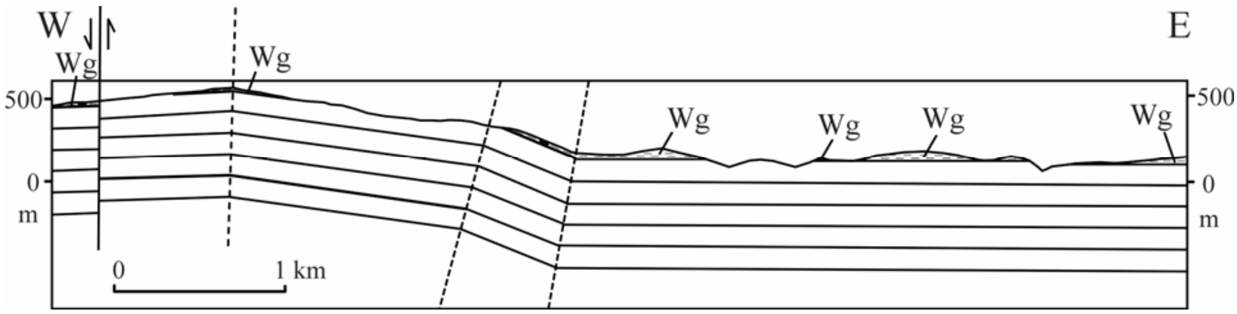

Figure 2 West to east cross section through the Lapstone Structural Complex at Kurrajong Heights. Wg = Wianamatta Group (underlying units not labelled). Vertical scale = horizontal scale. Cross section is constrained by the contact between the Wianamatta Group and the underlying Hawkesbury Sandstone as shown on the Penrith 1:100 000 Geological Sheet (Clarke & Jones 1991).

Interpretation

Monoclines, such as those of the Colorado Plateau, have been attributed to contractional deformation along thrust faults at depth (Bump & Davis 2003). But they are also related to deformation in rock strata overlying steeply dipping extensional faults in underlying basement (Withjack & Callaway 2000). Herbert (1989) noted from seismic data that high-angle reverse faults were associated with the Lapstone Structural Complex but that the en echelon geometry of these faults implies a strike-slip component. The cross sections shown above have been constructed from surface dip and stratigraphic data following Suppe's (1985) kink-band method. Available seismic data have not been used in their construction. The gentle nature of the monocline at Kurrajong Heights is difficult to interpret and could be related to either a contractional or extensional regime. For the Hawkesbury Lookout section, the zone of ductile deformation in the central limb of the monocline implies that a moderately west-dipping thrust fault occurs at depth with approximately 500 m of net slip. This thrust fault dips 50° to the west, some 20° less steep than the main high-angle reverse fault recognised by Herbert (1989) from seismic data to the south of Yellow Rock Lookout (~3 km south of Hawkesbury Lookout). Dips of reverse faults in other sections shown in Herbert (1989) are of the order of

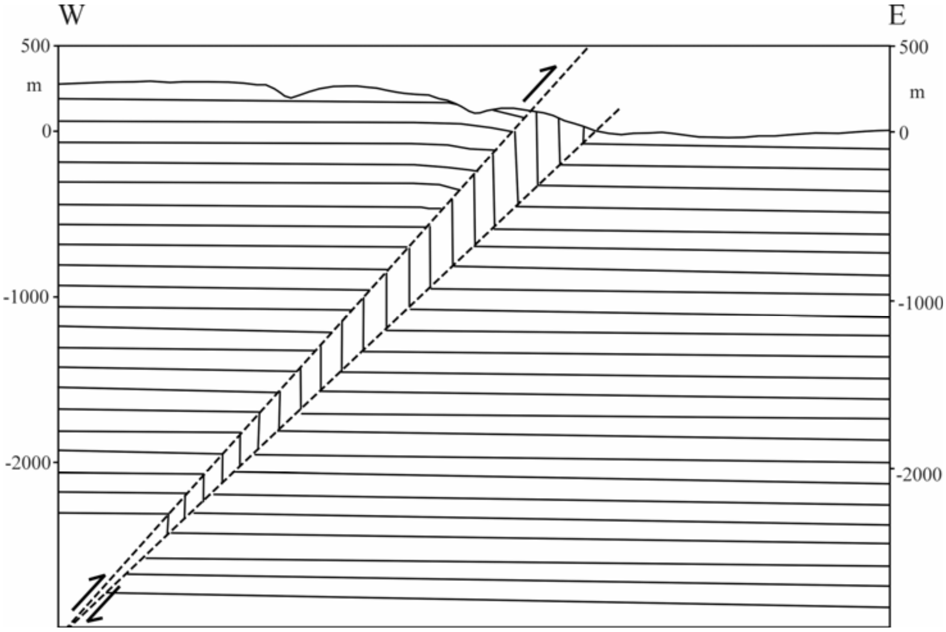

Figure 3 West to east cross section through the Lapstone Structural Complex at the Hawkesbury Lookout (note that stratigraphy is omitted but the surface exposure is in the Hawkesbury Sandstone). Vertical scale = horizontal scale.

55–65° mainly to the west. From this we may infer that contractional faulting was responsible for the Lapstone Structural Complex but the excessive dips in contrast to most thrust faults in undeformed strata (i.e. <35°, following Anderson's classification of faults) are anomalous unless these structures have a listric geometry. The dips of reverse faults portrayed by Herbert (1989) could be accounted for by reactivation of west-dipping normal faults but this is clearly inconsistent with any inferred normal faults associated with deposition and/or Mesozoic rifting as these would be east-dipping. It is considered that strike-slip movement could have played only a local role in structural development of the Lapstone Structural Complex.

BASEMENT CONTROL

It has been suggested that the Lapstone Structural Complex was controlled by reactivation of the western margin of the Budawang Syncline (the Eden-Comerong-Yalwal Rift) in the underlying Lachlan Fold Belt especially where this was intersected by elements of the east-trending Lachlan Lineament (Branagan & Pedram 1990). The structure of the Budawang Syncline exposed at the Shoalhaven River and Ettrema Creek has been described by Cooper (1992). The western margin of the Budawang Syncline is locally faulted and other faults occur within it although no evidence has been found indicating reactivation of these faults in the present-day stress field. West of the Sydney Basin, faults are west dipping and include structures such as the Wiagdon Fault Zone, Mulwaree Fault, and Yarralaw Fault (Fergusson & VandenBerg 1990). The Lake George Fault, northeast of Canberra, has spectacular topographic expression and has been related to Tertiary normal faulting (Abell 1991). It is associated with a thin (up to 165 m) late Tertiary succession in Lake George that indicates development of the depression east of the fault in the last ~10 Ma (Abell 1989). Most other faults in the region show little sign of Tertiary reactivation although some have limited topographic expression with subdued fault scarps consistent with some local neotectonic activity. A pre-existing west-dipping thrust in the basement under the western Sydney Basin, perhaps analogous to the Lake George Fault further west, may have controlled development of the Lapstone Structural Complex. This structure would have been reactivated in the Late Neogene east-west contractional regime that has affected southeastern Australia (Sandiford 2003; Brown & Gibson 2004).

DISCUSSION AND FUTURE DIRECTIONS

Earthquake activity in southeastern Australia is concentrated in a broad zone between Sydney and Melbourne in the southeastern highlands as well as in other regions such as the Mt Lofty and Flinders Ranges (Brown & Gibson 2004). Seismicity has been related to a contractional regime reflecting east-west convergence across the Australian-Pacific plate boundary in the South Island of New Zealand that has developed in the Late Neogene (Sandiford 2003). Slip rates along faults in southeast Australia are low (metres per million years, Brown & Gibson 2004) and it is therefore not surprising that neotectonic faulting remains difficult to establish. Many earthquakes cannot be tied to source faults. Given the clear topographic expression of the Lapstone Structural Complex, and faults such as the Lake George Fault, these structures may be at least partly related to the Late Neogene contractional tectonic setting. Suggestions of an extensional origin for both these structures need to be critically re-evaluated. A Late Neogene age for the Lapstone Structural Complex is apparently contradicted by untilted Miocene magnetisation at Lapstone (Bishop *et al.* 1979) but it does provide a plausible explanation for the problematic Rickabys Creek Gravel at Glenbrook and elsewhere (cf. Pickett & Bishop 1992).

Given the great antiquity of much of the landscape in eastern Australia, the lack of evidence for notable tectonic events in the latest Cretaceous to latest Palaeogene and recent evidence of Late Neogene deformation and uplift in southeastern Australia (Sandiford 2003), it is important to re-evaluate the role of reactivation and neotectonic activity on structures such as the Lake George Fault, Mulwaree Fault and Lapstone Structural Complex. The present-day seismicity of southeastern Australia indicates that thrust faulting is active and therefore west-dipping structures with potential evidence for neotectonic activity should be carefully examined. More cross sections drawn to depth incorporating seismic and borehole data are needed to determine if these structural geometries are viable.

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