Pokolbin Inliers - a restraining bend positive flower: Implications for timing of the Hunter-Bowen Orogeny

E.C. Willey

University of Southern Queensland
Address: 35, Mina Street, Rangeville, Toowoomba, Queensland, Australia
Email: willey@usq.edu.au

Keywords: Carboniferous, Permian, Lochinvar Anticline, flower structure, Hunter-Bowen Orogeny

Introduction

Inliers of pre-Permian rocks and the overlying strata outcropping west of Cessnock, NSW (Fig. 1), provide a remarkable opportunity to study the latest Carboniferous to earliest Triassic strata. This is a result of the thin, immature soil cover and the dissection of the area, particularly in the larger inlier - the Mount View-Mount Bright inlier (MVMBI) - in the south (see Fig.s 1 and 2).

Stratigraphic units in the area range from shallow marine, coal-bearing freshwater sediments, distinctive conglomeratic units and periglacial sediments to acid, intermediate and basic volcanics. This diverse, accessible geology and the added challenge of the faulting, makes it an ideal undergraduate mapping area. Over many years (1971-1993), student excursions have allowed opportunity to create and test field models and thus refine the geological interpretation presented here. Additional fieldwork was also undertaken.

Stratigraphy (Fig. 2)

The oldest unit is the Mount View Range Granodiorite (Brakel 1972); strata present belong to the Carboniferous upper Kuttung Group, the Permian Dalwood Group, Greta Coal Measures, Maitland Group and Singleton Coal Measures and the Triassic Narrabeen Group.

KUTTUNG GROUP. Browne and Walkom (1911) interpreted a non-conformity between the granodiorite and the Mt Bright Rhyolitic Ignimbrite Member (of Brakel 1972); this cannot be sustained as the latter rests on trachytic tuffs interpreted as the top of the Flying Fox Trachyte Member (of Brakel 1972) (Willey 1991). The granodiorite is faulted against other exposed units in the area (Willey 1991).

The Vineyard Lookout Volcanic Agglomerate Member of Brakel (1972) was correlated with the Mt Johnstone Formation (Willey 1991). The overlying Matthews Gap Dacitic Tuff Member, Flying Fox Trachyte Member and Mt Bright Rhyolitic Ignimbrite Member (of Brakel 1972) were grouped and correlated with the Paterson Volcanics (Willey 1991). This is supported by radiometric dating by Gulson *et al.* (1990), who also correlated the Matthews Gap Dacite (Member) with the Paterson Volcanics.

KUTTUNG GROUP to DALWOOD GROUP TRANSITION. The Seaham Formation and the basal Dalwood Group overlie the three volcanic members of the Paterson Volcanics (Brakel 1972 and reference therein). Brakel (1972) noted the difficulties that early authors (David 1907, Browne and Walkom 1911, Walkom 1913) had in reaching consensus on the succession in this interval; Osborne (1949) remarked on complexities of the Pokolbin area when discussing this part of the sequence. This interval commences with the periglacial Seaham Fm (Units I and II, Willey 1991) and ends with the 'Bimbadeen Basalt' (Unit VI, Willey 1991). These difficulties have arisen from failure to identify faults cutting the sequence; and Units I-VI (of Willey 1991) provide a framework for fault identification in the central part of the MVMBI.

Unit I comprises 2 to 5 (and up to 30) metres of monomictic, poorly sorted breccias, conglomerates and arenites derived mostly from the underlying volcanic rock. Unit II is 70-80 metres of red and purple mudstones and shales, with siltstones and sandstones and thin conglomerates; fine-grained lithologies are commonly varved and contain dropped pebbles; west of Jerusalem Rock (at AMG378634) 20 m of basic tuff occurs in this unit. These two units belong to the Seaham Fm at the top of the Kuttung Group. Units III and IV are conglomeratic units with interbedded sandstones; they are 50-65 m and 60-80 m thick respectively. While similar in lithology, their provenances are very different. Unit III contains rounded to subangular clasts of intermediate, trachytic and basic volcanics of a typically dark purply-brown colour. Unit IV has well-rounded pebbles of quartzite, quartz-feldspar porphyries, volcanics and hyperbyssals, with pale brown quartz-rich to arkosic sandstones and matrix. Unit V produces no exposures, and its outcrop contrasts with those of the Units IV and VI with brown soils and float of clasts from Units IV and III and of distinctive trachyte flow-tuff clasts only found in Unit II.

Unit VI – the 'Bimbadeen Basalt' and the only basic volcanic unit in the area - is 35-80m thick. It rests unconformably on an eroded surface, which cuts down to Unit I and truncates faults already present in the underlying rocks and not reactivated during later movements. At AMG383629, this unconformity is marked, and were it not for recent erosion, Unit VI would rest on the Mt Bright Rhyolitic Ignimbrite Member of Jerusalem Rock. Given the pre-Unit VI faulting events, Unit V is interpreted as a sag pond deposit associated with the faulting. Osborne (1949) suggested a possible unconformable relation between Kuttung and Dalwood strata at Pokolbin, but presented no evidence. Browne and Walkom (1911) interpreted the basalt as intrusive. This is unnecessary; also, David (1907) said that the (Bimbadeen) basalts at the Mt View Lookout are *contemporaneous,* emphasising their interbedded nature.

Correlating Units I to VI with the standard Hunter Valley succession presents difficulties. Units I and II clearly belong to the Seaham Formation, as perhaps does also Unit III, which seems to comprise a conglomeratic phase from a similar source to Unit II. Brakel (1972) was also uncertain about the stratigraphy of strata placed in Units IV and VI (of Willey 1991), yet wrote: "the polymictic conglomerate, basalt, and an overlying lens of tuff containing *Eurydesma cordata* may be correlatable with the Lochinvar and Allandale Formations, while succeeding sandstones are probably correlatable with the Rutherford and Farley Formations." This sequence is identified at AMG373643, where 9 m of marine Rutherford Fm with 0.80m of conglomerate rest on fresh basalt (Willey 1991); nearby the basalt overlies Unit IV conglomerates. Unit VI (Bimbadeen Basalt) could be best correlated with the basalts of Lochinvar Formation, thus making allocating Unit IV to the Allandale Fm impossible. So the placement of Unit IV and VI remains uncertain.

UPPER DALWOOD GROUP. The upper Dalwood units -Rutherford Formation and Farley Formation - are thinner in the MVMBI. The Rutherford Fm is most markedly so; it is 30-40 m thick at the Mount View Lookout, and in the centre of MVMBI, it thins to 10 m or less; east of the Mount View (Paxton) Fault, it thickens to 180+ m; Osborne (1949) reported a composite section of 356m. The Farley Fm is 120 m thick in Cedar Creek (AMG370639), and over 200 m east of Mt View Fault.

A useful marker horizon -the Ravensfield Sandstone Member (base of the Farley Fm)- is a feature-former separating outcrop of the Rutherford and Farley formations across the area. Just east of the Mt View Fault, its massive, well-sorted and crossbedded nature changes, developing characteristics typically present through-out its outcrop west of the fault. Here, it comprises 6 m of bioturbated, fossiliferous, poorly sorted arenites and mudstones with tuffaceous pebbles; David (1907) described these elsewhere as local occurrences in the member. Regardless, it still consistently lies between the strata of the Rutherford and Farley formations.

GRETA COAL MEASURES. All four units are seen in Cedar Creek (AMG368638 to AMG364637). Here the thickness of Neath Sandstone (40 m), Kurri Kurri Conglomerate (35 m), Kitchener Formation (5 m) and Paxton Formation (15 m) compare with their developments elsewhere -18+, 43, 5 and 42 m respectively. Coal is absent as observed in a borrow pit at AMG367638, exposing the uppermost Kurri Kurri Conglomerate, Kitchener Fm and most of the Paxton Fm.

MAITLAND GROUP. The Cessnock Sandstone Member is the base of both the group and the Branxton Formation. This distinctive member is a useful marker bed easily traced around the southern and southwestern outcrop of the MVMBI, but is faulted out in the northwest. The monotonous lower Branxton Fm makes it difficult to establish how much of the sequence is preserved. In Cedar Creek 250 m of lower Branxton Fm occurs, with no hint of coarsening suggesting condensation. The upper part of the Branxton was *either* never deposited here *or* if deposited was later removed by erosion. The Muree Sandstone Member (top of the Branxton Fm) is absent west of the MVMBI and southwest of Cessnock; it emerges from beneath the Narrabeen Group 4-5 km south of Ellalong, and then trends ENE to Bow Wow Gorge and north of Mulbring.

Northwest of the MVMBI, the Permian is represented only by fault-bound slivers of fossiliferous marine sandstones (Maitland Group) and the considerably reduced Singleton Coal Measures.

SINGLETON COAL MEASURES. In Cedar Creek, 250m of this group occur. Northwards, 150 m of strata have been bleached in a soil profile (the *somewhat cherty* rocks of David (1907)), and are overlain by unaltered Narrabeen Group. This suggests that after deposition of at least part of the Coal Measures, uplift and weathering (with limited erosion) occurred prior to further subsidence before the Triassic.

Structure (Fig. 3 and 4)

The complex geology of the central MBMVI results from the numerous thin distinctive stratigraphic units present, the topographic relief and naturally the faulting. This faulting resulted from movements along the Elderslie-Matthews Gap East Fault Zone in the north-west and the Mount View-Paxton Fault in the south-east - the Elderslie-Paxton Fault System (EPFS). Principal structural features (see Fig. 1 and 2) are:

a) the spindle-shaped central zone of MBMVI bounded by faults of the EPFS converging northwards into the Matthews Gap East-Elderslie Fault Zone and southwards into the Mount View-Paxton Fault;

b) the *en echelon* trend of these faults beyond the northern and southern ends of the central zone,

c) the up-throw of the central zone, best appreciated at the north and south ends of the central zone;

d) the braided faults within the central zone of MBMVI;

e) the older the unit is and the closer the unit is to the central zone, generally the greater is its dip;

f) the SE trending splay faults, part of a set of similar trending faults extending across the Lochinvar Anticline, and which have been encountered in mines (see *i.a.* Shepherd and Burston 1977);

g) the three stratigraphic breaks in the MBMVI - below Unit VI (Bimbadeen Basalt), between the lower Branxton Fm and the Singleton CM, and between the latter and the Narrabeen Group, and

h) the interpretation that the faults bounding the central spindle-shaped zone must meet at depth.

These features of the MBMVI are characteristics of restraining bend flowers (*e.g.* Echo Hills (Campagna and Aydin 1991) and Confidence Hills (Dooley and McClay 1996); see also Cunningham and Mann 2007). Modelling of transpressional regimes produces positive flowers and restraining bends which are characterised by central zones, which, given initially horizontal strata, generally show the oldest units in the core, with these units displaying the steepest dips (see sections of Wilcox *et al.* 1973). This mechanism also produces structures described in 1930 by Dorothy Hill as *fractured anticlines* within the Esk Trough.

Given this interpretation of the MBMVI, the movement on this system is dextral transpression, with the Drake's Hill and the Hungerford Hill inliers representing features of the splay faults (see (f) above) associated with this movement. Blayden (1978) proposed regional right lateral wrench faulting in the Sydney Basin, particularly during the deposition of the Upper Permian Singleton Coal Measures

There are no breaks in the Kuttung strata and units appear to maintain their thicknesses, so the unconformity below Unit VI (Bimbadeen Basalt) records the first transpressional movement along the EPFS. The marked thinning of the Rutherford Fm, the Ravensfield Sandstone Member facies change, and the thinning of the Farley Fm suggest that some residual uplift continued into the upper Dalwood.

During the deposition of the Greta CM and the lowermost Branxton Fm, no noticeable movement occurred. Movement recommenced, perhaps with greater effect, certainly before the deposition of the Singleton CM, and ceased during the earliest Triassic. During this time, movement was interrupted at least once, and was accompanied by uplift in the east of the EPFS, resulting in the Singleton CM being absent to the east.

The Lochinvar Anticline is horst-like (Rawlings and Moelle 1982) defined in the west by the EPFS and in the east by the Buchanan Monocline (Blayden 1970) with easterly dips of up to 65°, but decreasing southwards. The monoclinal nature indicates block faulting, with the "buckle" folds (Blayden 1970) suggesting an element of transpressional strike-slip. Blayden (1970) interpreted two periods of movement on the monocline - during Tomago Coal Measures times and following the Newcastle Coal Measures. This parallels the general activity of the EPFS in the west at this time. Carboniferous and basal Permian do not outcrop in the Buchanan Monocline, so tectonic movement at this time cannot be established.

Conclusions

At least three pulses of dextral transpressional movements in the Lochinvar Anticline are interpreted:

a) at the Carboniferous-Permian boundary - only seen in the MBMVI restraining bend;

b) between the late Maitland Group and the upper Permian CM, and

c) during and/or immediately after the upper Permian CM.

These events agree with the chronology recognised by Collins (1991) - an early Permian event, followed by a complex series of pulses during the later Permian. However, the D2 and D4 sinistral rotation (Collins 1991) may only reflect deformation north of the Hunter Thrust, as it cannot be reconciled with the clearly dextral transpression in MBMVI (see also Blayden 1978). This contrasts with the Late Permian (265Ma) to Middle Triassic (230Ma) age for the Hunter-Bowen event in the northern New England Fold Belt (Holcombe *et al.* 1997), although basal Narrabeen isopachs suggest early Triassic activity (Herbert 1993).

Cedar and Flying Fox Creeks rise within the MBMVI, and flow westward through the dominant ridge of the Narrabeen Group; this suggests drainage pattern control by post-Permian activity on the EPFS. In August 1994, the Paxton (or Cessnock) earthquake suggests continued activity on the EPFS, with Ellalong Lagoon (just south of Paxton) being a sag pond generated by recent movement. Also, neotectonic movements on the EPFS are probably responsible for the immature soils and dissection of the MBMVI.

Acknowledgements

To students for finding exposure critical to the interpretation of faults. To Bruce Runnegar, for introducing the area to the author. To Bertie Brakel and Dick Evans for helpful comments and discussion. Local property owners for their generous hospitality.

References

Blayden, I.D. 1970. Buchanan Monocline and associated structures. *Abstracts, 5th Newcastle Symposium "Advances in the study of the Sydney Basin"*, page 18, Geology Dept, Newcastle Univ.

Blayden, I.D. 1978. Wrench faulting in the northern Sydney Basin. *Abstracts 12th Newcastle Symposium "Advances in the study of the Sydney Basin and the New England Fold Belt"*, pp. 17-18, Geology Dept, University of Newcastle.

Brakel, A.T. 1972. Geology of the Mt View District, Pokolbin, NSW. *Journal of the Royal Society of New South Wales,* **105**, 61-70.

Browne, W.R. and Walkom, A.B. 1911. The geology of the eruptive rocks and associated rocks of Pokolbin, NSW. *Journal of the Royal Society of New South Wales,* **45**, 379-408.

Campagna,D.J. and Aydin, Atilla 1991. Tertiary uplift and shortening in the Basin and Range: the Echo Hills, SE Nevada. *Geology* **19**, 485-488.

Collins, W.J. 1991. A reassessment of the 'Hunter-Bowen' Orogeny: Tectonic implications for the southern New England Fold Belt. *Australian Journal of Earth Sciences,* **38**, 409-423.

Cunnigham, W.D. and Mann, P. 2007. Introduction, *in* Cunningham, W.D. and Mann, P. Tectonics of strike-slip restraining and releasing bends. *Geological Society of London Special Publication,* **290**, 1-12.

David, T.W.E. 1907. The geology of the Hunter River Coal measures, NSW. *Memoirs of the Geological Survey of New South Wales*, number 4.

Dooley, T.P. and McClay, K.R. 1996. Strike-slip deformation in the Confidence Hills, southern Death Valley, eastern California, USA. *Journal of the Geological Society, London,* **153**, 375-387.

Gulson, B.L., Diessel, C.F.K., Mason, D.R. and Krogh, T.E. 1990. High precision ages from the northern Sydney Basin and their implication for the Permian time interval and sedimentation rates. *Australian Journal of Earth Sciences*, **37**, 459-469.

Herbert, C. 1993. Tectonics of the New England Orogen in the sequence stratigraphy of the Narrabeen Group of the Sydney basin. *In* Flood, P.G. and Aitchison, J.C. *NEO 1993 Conference*, 127-135. Dept of Geology and Geophysics, University of New England, Armidale, Australia.

Hill, Dorothy 1930. The development of the Esk Series between Esk and Linville. *Proceedings of the Royal Society of Queensland*, **41**, 28-48.

Holcombe, R.J., Stephens, C.J., Fielding, C.R., Gust, D., Little, T.A., Sliwa, R., McPhie, J. and Ewart, A. 1997. Tectonic evolution of the northern New England Fold Belt: the Permian-Triassic Hunter-Bowen event. *In* Ashley, P.M. and Flood, P.G. (eds.) *Geological Society of Australia Special Publication*, **19**, 52-65.

Osborne, G.D. 1949. The stratigraphy of the Lower Marine Series of the Permian System in the Hunter Valley, NSW. *Proceedings of the Linnean Society of New South Wales*, **74**, 203-223.

Rawlings, C.D. and Moelle, K.H.R. 1982. The Lochinvar Anticline: not just an anticline. *Abstracts, 16th Newcastle Symposium "Advances in the study of the Sydney Basin"*, pp. 23-24, Dept of Geology, University of Newcastle.

Shepherd, J. and Burston, R.J. 1977. Maps of faulting and roof failure at Aberdare East Colliery, Cessnock, NSW. CSIRO Mineral Research Laboratories (Mineral Physics), Investigation Rep. 122.

Walkom, A.B. 1913. Stratigraphical geology of the Permo-Carboniferous System in the Maitland-Branxton district. *Proceedings of the Linnean Society of New South Wales*, **38**, 114-145.

Wilcox, R.E., Harding, T.P. and Seely, D.R. 1973. Basic wrench tectonics. *American Association of Petroleum Geologist Bulletin*, **57**, 74-96.

Willey, E.C. 1991. The geology of the Mount View-Mount Bright Inlier and adjacent rocks, Pokolbin, NSW. *In* Diessel, C.F.K. *25th Newcastle Symposium "Advances in the study of the Sydney Basin"*, pp.146-153, University of Newcastle, Dept of Geology Publication No. 413.

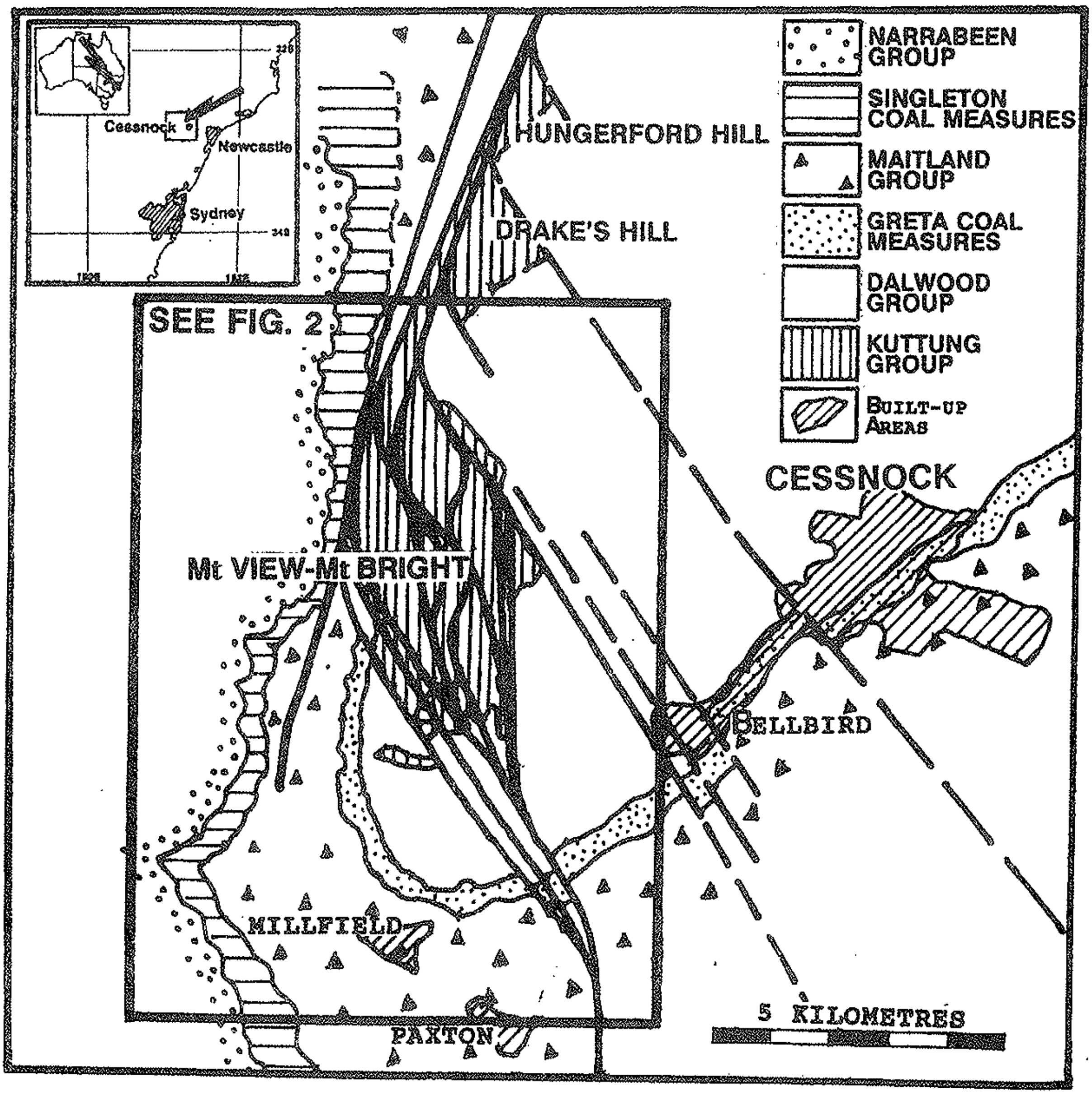

Fig. 1 Geology map of Cessnock region.

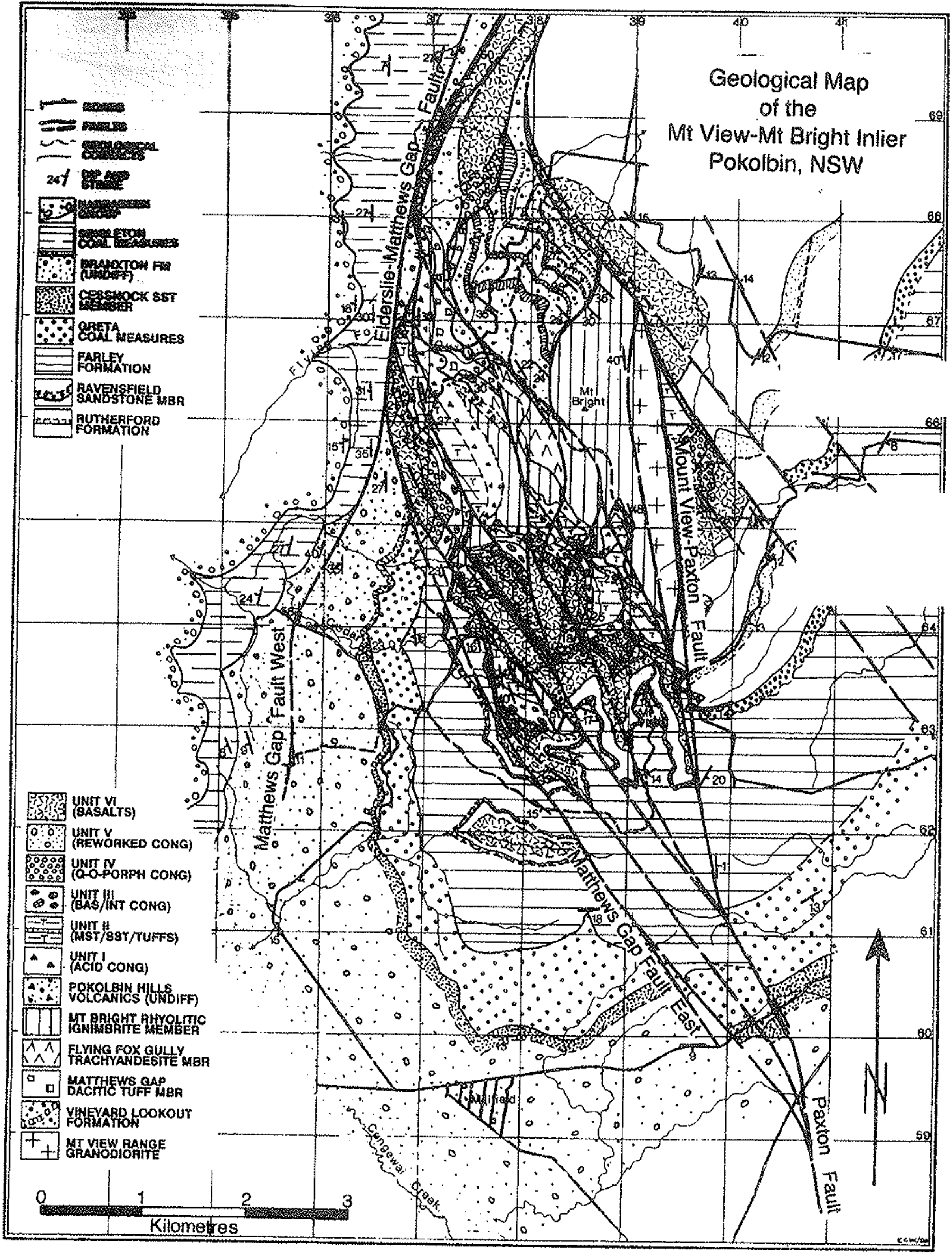

Fig. 2 Geology map of the Mt View-Mt Bright Inlier, Pokolbin, NSW.

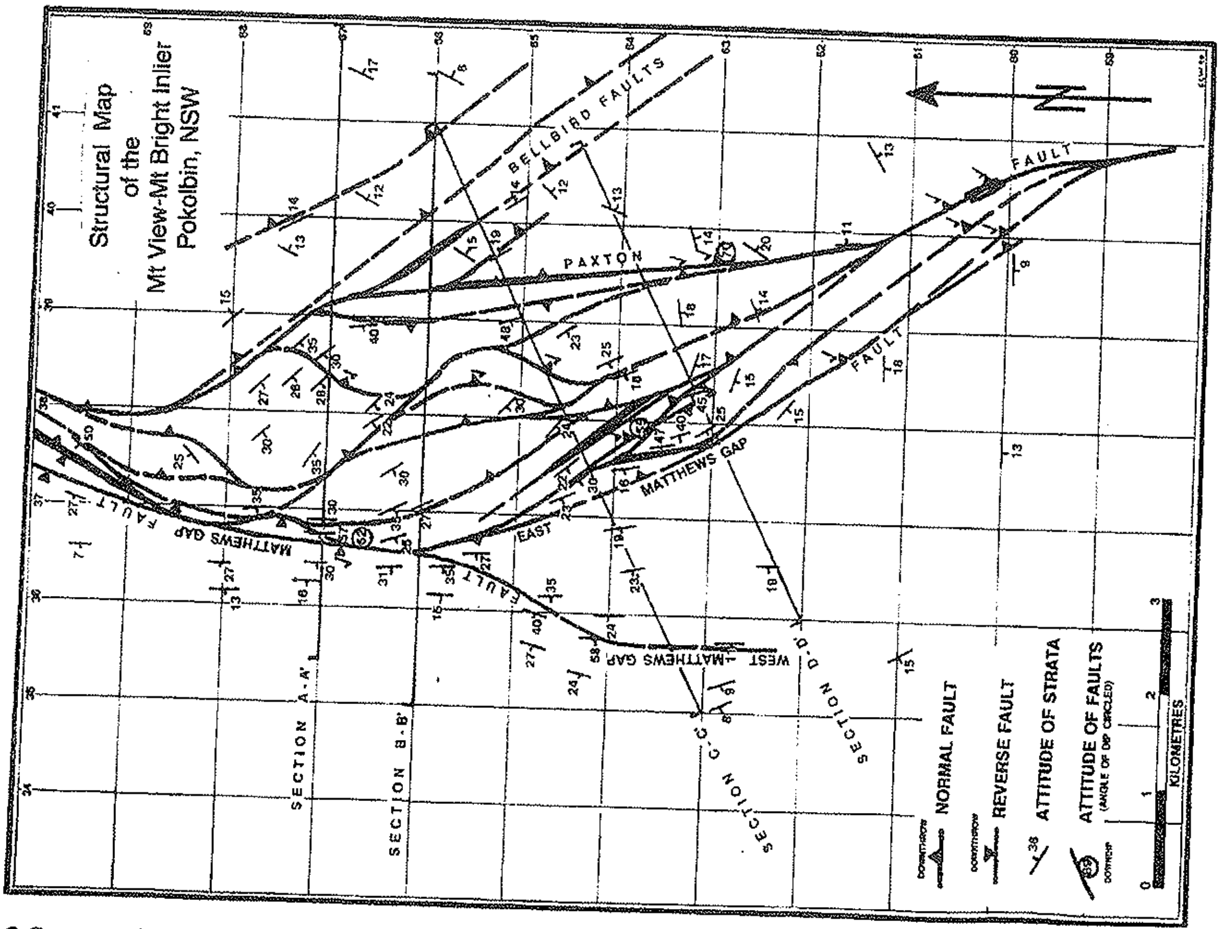

Fig. 3 Structural map of the Mt View-Mt Bright Inlier, Pokolbin, NSW.

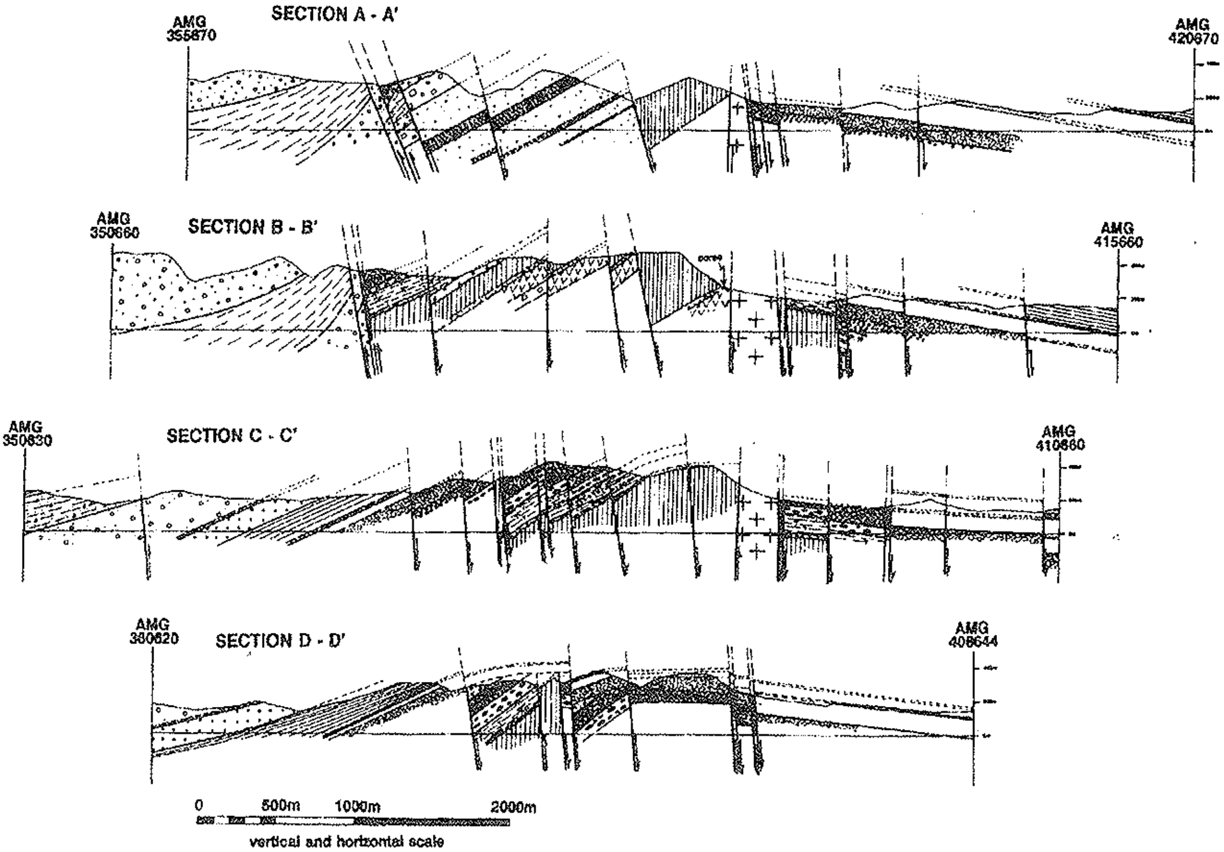

Fig. 4 Cross-sections. Refer to Fig. 3 for locations.