

PALAEOMAGNETIC EVIDENCE FOR THE AGE OF THE LAPSTONE MONOCLINE, NSW

PW SCHMIDT, MA LACKIE & JC ANDERSON

SCHMIDT, P.W., LACKIE, M.A. & ANDERSON, J.C., 1995: Palaeomagnetic evidence for the age of the Lapstone Monocline, NSW. *Australian Coal Geology*, 10, 14-19.

Estimates of the age of the Lapstone Monocline range from Triassic to Cretaceous/Tertiary. Magnetic overprints, which are ubiquitous throughout the Permo-Triassic Sydney Basin sediments and the Jurassic breccia diatremes, have been deflected by movement on the monocline. From other palaeomagnetic investigations the age of the magnetic overprinting is thought to be ~90Ma, which is supported by fission-track ages of apatites and K-Ar ages on illites. This indicates that most of the movement on the Lapstone Monocline occurred after ~90Ma.

PW SCHMIDT, CSIRO Exploration and Mining, North Ryde, 2113
MA LACKIE, School of Earth Sciences, Macquarie University, 2109
JC ANDERSON, Kembla Coal and Coke, Wollongong, NSW, 2500

The Lapstone Monocline runs north-south for over 100km to the west of Sydney and forms an escarpment adjacent to the Blue Mountains plateau about 1000m ASL (Figure 1). Branagan & Pedram (1990) have described the form of the structure in some detail. They use the name "Lapstone Structural Complex" to include in it related folds and faults, such as the Nepean Fault at the southern end of the monocline.

Estimates of the age of the monocline, based on a variety of evidence, range from Triassic to Cretaceous/Tertiary. David (1897) considered undifferentiated gravels that drape, and appear to pre-date the monocline, to be Cretaceous or possibly Tertiary in age. This would seem to indicate a late Cretaceous or younger age, at least for the main phase of the folding. However, there is also evidence that the structure was active during the Triassic sedimentation since sequences thin significantly to the west of the monocline.

Moreover, as Pickett & Bishop (1992) observe, there is over 490m difference in elevation of the uppermost strata, the Wianamatta Shale, across the monocline, indicating that whilst some movement may have occurred during deposition, a major phase of movement continued after deposition. Pickett & Bishop (1992) suggest, from the lack of evidence of faulting in a diatreme outcropping at Nortons Basin, that major movement had ceased by the Early Jurassic.

This study presents palaeomagnetic evidence that suggests that the major tilting of the Hawkesbury Sandstone along the Lapstone Monocline occurred after a period of pervasive magnetic overprinting throughout the Sydney Basin, which is thought to be ~90Ma in age (i.e. Mid-Cretaceous; Schmidt & Embleton, 1981).

OVERPRINT MAGNETISATIONS IN ROCKS OF THE SYDNEY BASIN

Evidence for overprinting in the Sydney Basin has been found in rocks that are stratigraphically older than the Early Tertiary (Table 1). These rocks are either partially or completely remagnetised, while rocks of Early Tertiary or younger ages (mainly basaltic rocks) are not affected (Schmidt & Embleton, 1981; Schmidt, 1982). The direction of the overprint remagnetisation is very consistent and, on the basis of palaeomagnetic measurements from dated rock units, corresponds to the mid-Cretaceous direction for the Sydney Basin. This magnetisation has been used by the coal industry to orient fractures and cleat directions in bore core (Schmidt & Anderson, 1990, Lackie & Schmidt, 1992a and b).

The magnetisation history of any particular rock unit depends not only on the thermal conditions to which it has been subjected, but also on lithology and diagenesis. Thus, coarse grained permeable sandstones of the Hawkesbury Sandstone carry a late Tertiary remanence dating from late Tertiary weathering associated with the breakdown of siderite and the formation of haematite and maghaemite. It is noteworthy that these weathering magnetisations are roughly divided between normal and reversed polarity, with little bias to the present "normal" polarity (Hunt, 1985). This indicates quite a long history of weathering (>>1Ma) and the ability of these rocks to retain such a record. However, some less permeable rocks are not so prone to Tertiary weathering and carry more ancient remanences. These include many igneous rocks including diatreme breccias, and finer grained sediments.

Fine grained rocks of the Narrabeen Group (Late Permian to Early Triassic) from the rock platform at Coal Cliff and from the drift at the Tahmoor Colliery (Figure 1) are magnetised uniformly in

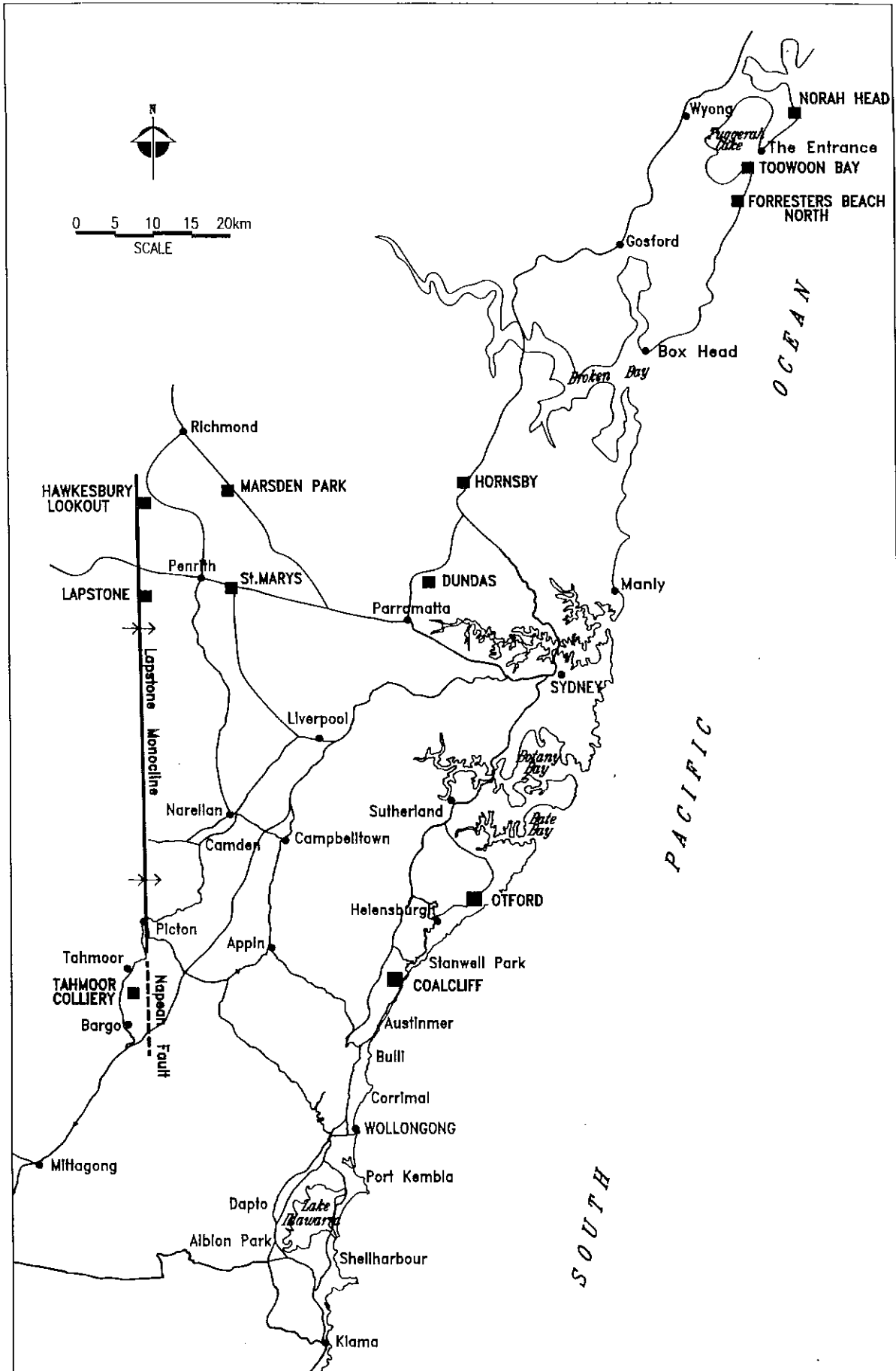


Figure 1. Locality map showing the Lapstone Monocline and site locations (closed squares) discussed in the text.

Table 1. Stratigraphic Column.

Age	Stratigraphy	Tectonic/Depositional Event	
Late Tertiary	undifferentiated gravels and volcanics	fluvial deposition and volcanism	
Mid-Cretaceous (~90Ma)		coal measures reach maximum level of coalification main uplift of Blue Mountains overprint palaeomagnetic directions set in Sydney Basin rocks	
Jurassic	breccia diatremes	intrusive (and extrusive?) volcanism — continued sedimentation but later eroded	
Triassic	Wianamatta Group	Sydney	
	Hawkesbury Sandstone		
	Narrabeen Group	red claystones	Basin
Permian	Illawarra Coal Measures	Bulli Coal	sedimentation
	Gerringong Volcanics		extrusive (and intrusive?) volcanism

a direction similar to the overprints established in younger rock units, such as the overlying Triassic red beds and the Jurassic diatremes (Figures 2 and 3). In only a few samples of the Narrabeen Group is there any relict of an older magnetisation, and this is only shown up after high alternating field demagnetisation (>600 Oersted) and because the relict magnetisation has reversed polarity. It is not possible to recognise unequivocally older magnetisations of normal polarity in the Narrabeen Group.

The rock units which best display partial remagnetisation are the Milton Monzonite, the Hornsby Breccia and the red claystones of the Narrabeen Group. Palaeomagnetism of the Hornsby Breccia samples display two well separated components after step-wise thermal demagnetisation (Schmidt & Embleton, 1981). Red claystone samples from the Patonga Claystone near The Entrance (Figure 1) typically reveal steep normal components overprinting original Early Triassic magnetisations. Embleton & McDonnell (1980) have shown that the Early Triassic magnetisations may be either of normal or reversed polarity. As they did not publish stereo projections of directions of the components, stereonet are reproduced here for comparison (Figure 2). The overprint components from the Patonga Claystone are identical to those found in the Narrabeen Group at Tahmoor and Coalcliff, and in the breccia pipes at Hornsby, Dundas, Marsden Park and St Marys. Details of results from the breccia pipe localities are reported in Schmidt & Embleton (1981) and Schmidt (1982). Clearly the overprint event had a wide-

spread effect on magnetisations of Sydney Basin rocks. The mean directions of the overprint are listed in Table 2.

RESULTS FROM LAPSTONE MONOCLINE AND TAHMOOR 600 PANEL MONOCLINE

The amplitude of the Lapstone Monocline decreases to the south where it merges with the Nepean Fault. The fault cuts across the eastern portion of the Tahmoor mining lease and is an effective barrier to mining. The Nepean Fault generally strikes NNW but over the 10km interval from Picton to the southern edge of the Tahmoor lease it shows some minor local changes in direction, or lateral off-sets. Seismic lines show that the fault zone is about 500m wide with a down-throw of a few tens of metres to the east. The boundaries of the fault zone have been taken as the limits of good quality seismic reflections from the Bulli coal. The boundaries are not sharp and it is possible that smaller scale faulting occurs alongside the main fault.

A number of seismic lines that cross the fault zone north of Tahmoor have been interpreted to show high angle reverse faulting dipping down to the west (Herbert, 1989). In detail there appears to be a complex system of reverse faults and subordinate normal faults with individual fault planes dipping either to the east or west.

In plan, individual faults are laterally discontinuous and are arranged in an *en echelon* pattern. Herbert (1989) further concludes that the Nepean

Magnetic Overprint Directions in Sediments

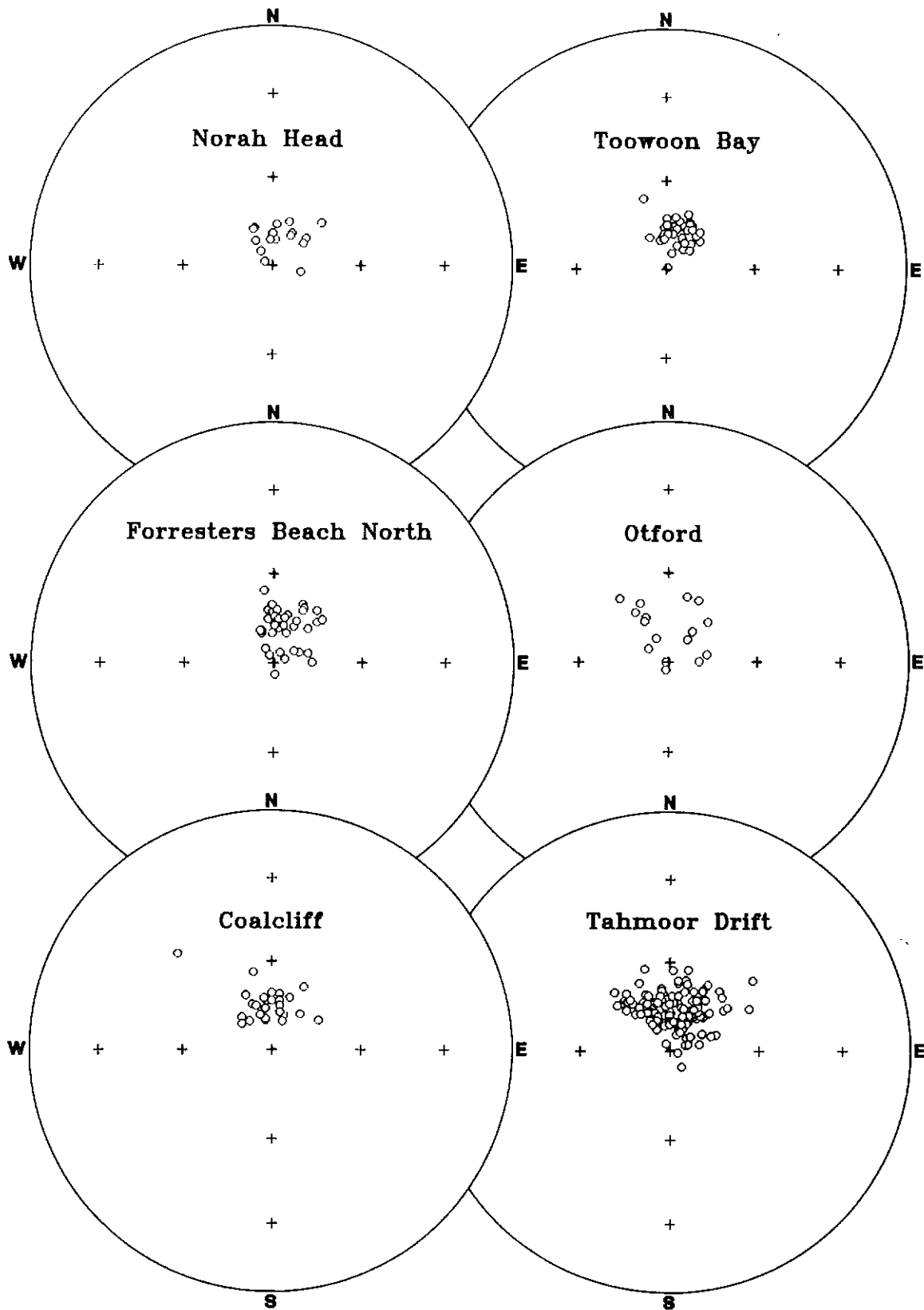


Figure 2. Upper hemisphere equal-area stereonet of magnetic overprint directions in Narrabeen Group sediments throughout the Sydney Basin. Sediments sampled at Norah Head, Toowoon Bay, Forresters Beach (North) and Otford are red claystones, while the sediments at Coalcliff and Tahmoor are drab coloured shales and sandstones.

Magnetic Overprint Directions in Breccia Diatremes

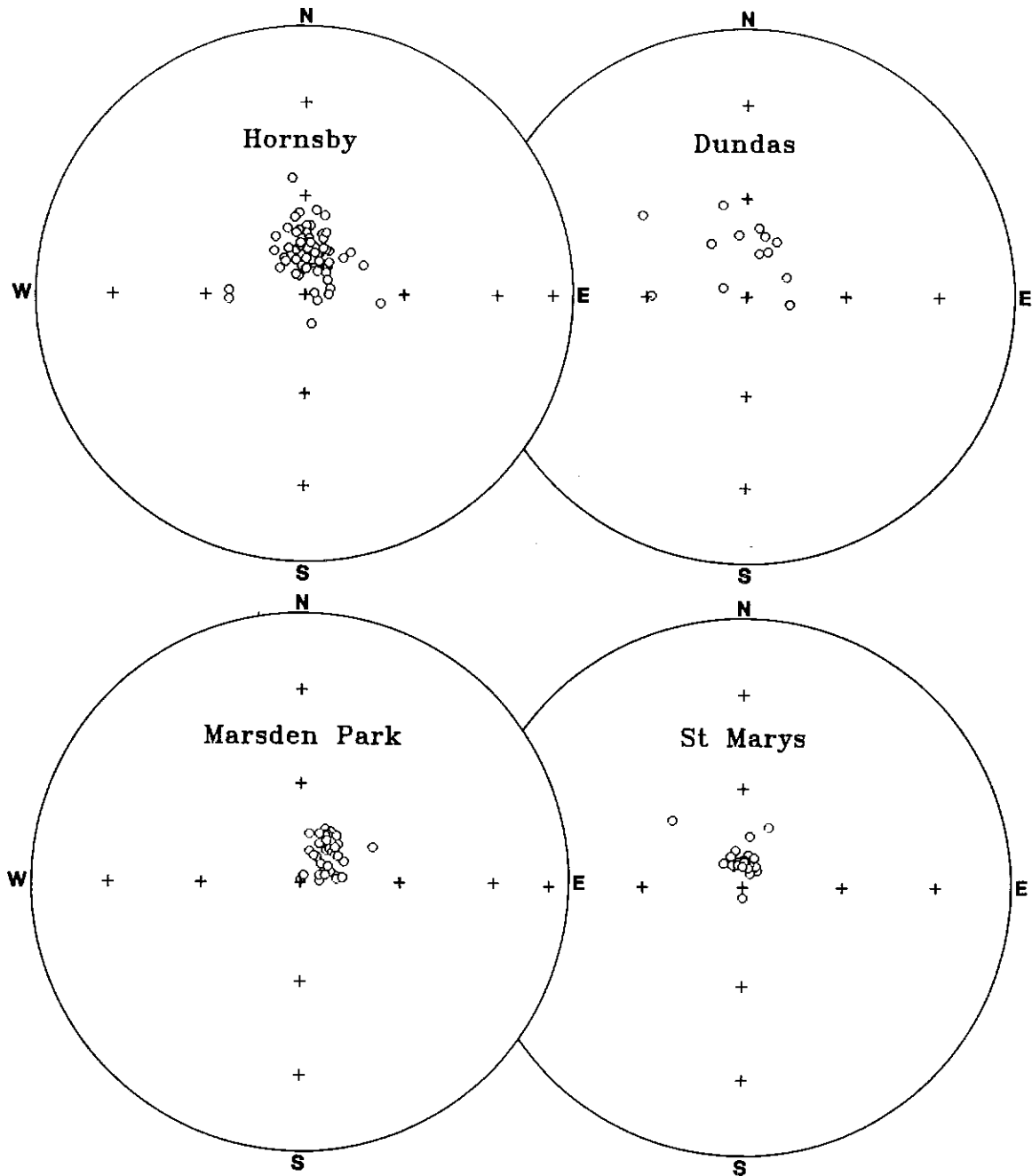


Figure 3. Upper hemisphere equal-area stereonets of magnetic overprint directions in breccia diatremes throughout the Sydney Basin.

Table 2. Mean Directions of Sydney Basin Overprint Magnetisations.

Locality	N	Dec(°)	Inc(°)	k	α_{95} (°)
Norah Hd	16	17.0	-80.3	94.1	3.8
Toowoona	36	6.4	-74.8	183	1.8
ForesterN	36	17.9	-77.5	83.9	2.6
Otford	16	0.8	-79.1	41.4	5.8
Coalcliff	26	355.2	-74.4	60.9	3.7
Tahmoor	131	6.0	-76.4	60.6	1.6
Hornsby	70	5.5	-77.5	65.3	2.1
Dundas	13	349.7	-75.7	22.9	8.8
Marsden	36	43.5	-78.0	165	1.9
St Marys	24	358.1	-81.8	133	2.6

N: number of samples, Dec: declination, Inc: inclination, k: precision parameter, α_{95} : 95% confidence radius.

Fault generally has a compressive origin but with a degree of wrenching. This interpretation may be equally applicable in the Tahmoor lease, particularly at the stratigraphic level of the Bulli coal.

A monocline located near the southern boundary of the Tahmoor mining lease was first encountered in a mine roadway (600 Panel) driven to ventilate the southern end of a series of north-south oriented longwall blocks, and is referred to here as the 600 Panel Monocline.

The monocline represents the northern tip of the westernmost *en echelon* fault of the Nepean Fault zone. Its strike is NNW and bedding dips to the WSW by as much as 40° with an overall displacement of 5m. Figure 4 is a photo mosaic of the monocline looking towards the north-west. The monocline attenuates to the north. At an intersection 200m north of 600 Panel, the displacement is only 0.5m and further north it disappears altogether.

The 600 Panel Monocline is located 500m to the west of the Nepean Fault Zone. This proximity and the similarity in strike and tectonic style suggest that it is an integral part of the zone. There are other structures close to, and parallel with, the Nepean Fault Zone but the monocline is the largest in the Tahmoor Mine workings. In the immediate vicinity of the Nepean Fault Zone, faults parallel and antithetical to the Nepean Fault coupled with high lateral stress have resulted in severe mining problems (I. Stone, *personal communication*, 1993).

Table 3. Mean Directions from Lapstone Monocline.

	N	Dh(°)	Ih(°)	α_{95} (°)	Db(°)	Ib(°)	α_{95} (°)
1*	41	286.3	-66.6	3.9	68.4	-74.1	4.1
2	37	63.3	-56.5	4.3	352.4	-80.3	4.3
3	26	50.4	-46.0	5.5	334.9	-60.7	5.5
4	104	37.1	-67.2	7.8	16.9	-73.8	5.7

Key, 1 – 600 Panel (*variable dips), 2 – Lapstone, 3 – Hawkesbury Lookout, 4 – All data.

N: number of samples, D: declination, I: inclination, h: with respect to present horizontal, b: corrected for bedding, α_{95} : 95% confidence radius.

To investigate the effects of the monocline on the overprint directions samples were collected from 600 Panel (Figure 4). The samples were taken from basal Narrabeen Group sediments forming the roof of the Bulli Coal. Strata showing a variety of dips were sampled and directions of magnetisation were found to show concomitant amounts of deflection, when compared with the mean direction observed in flat-lying strata (cf. Figures 2 and 5).

Underground samples were oriented using a combination of magnetic compass and survey data but accuracy was affected by the presence of roof-straps and rib-mesh (clearly evident in Figure 4).

Since underground orientations were not as accurate as can be achieved above ground, further samples were collected from recent roadworks at both Lapstone and the Hawkesbury Lookout, where major roads cross the Lapstone Monocline (Figure 1). The samples were all from grey shales near the top of the Hawkesbury Sandstone. The strata sampled at Lapstone are dipping 32° to the east, while the strata at Hawkesbury Lookout dip 50° to the east. Directions from these samples are plotted in Figure 5 and listed in Table 3.

It is clear from these data that the directions of remanence from sediments at Lapstone and Hawkesbury show a deflection which is consistent with the sense of dip at each locality. Some directions, particularly from Hawkesbury Lookout samples appear to be over-corrected which might imply magnetisation in some intermediate attitude, or some partial remagnetisation in the present geomagnetic field. These possibilities will require further sampling to test.

The point we wish to convey in this report is that the monocline has affected the directions of the overprint magnetisation by a considerable amount.

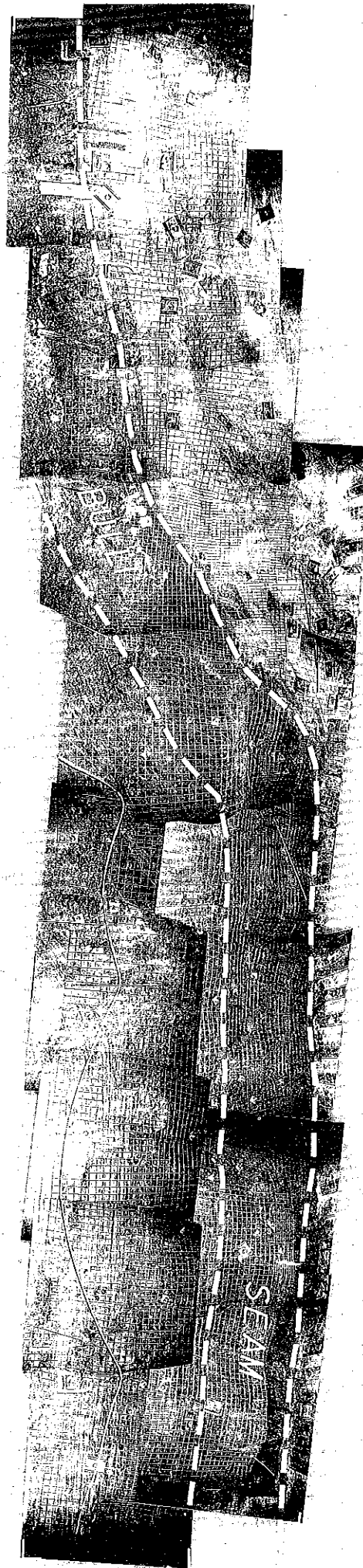


Figure 4. Photo mosaic of the underground 600 Panel Monocline at Tahmoor Colliery.

Magnetic Overprint Directions in Monocline Sediments

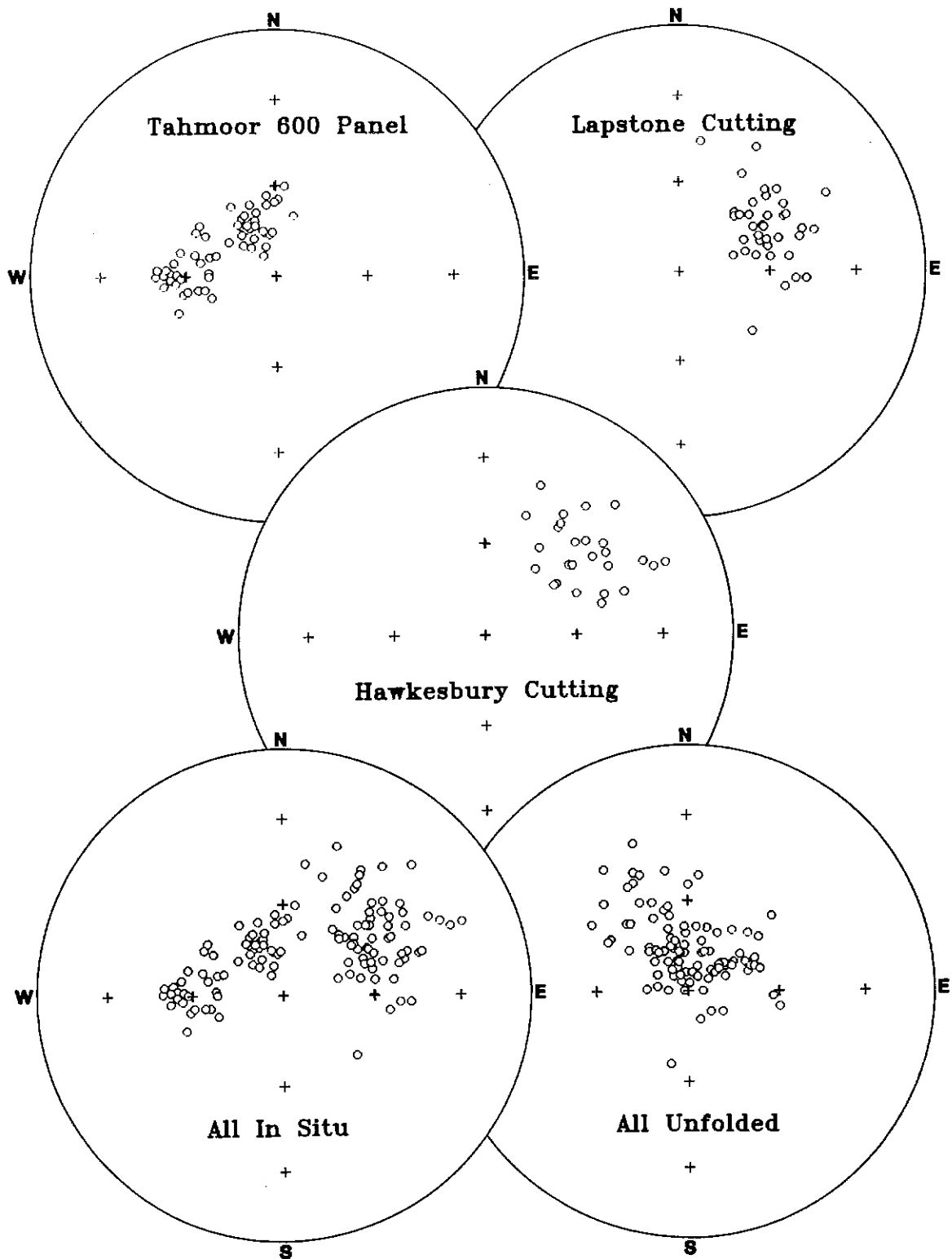


Figure 5. Upper hemisphere equal-area stereonet of magnetic overprint directions in Narrabeen Group (at Tahmoor) and Hawkesbury Sandstone (at Lapstone and Hawkesbury Lookout), showing in situ directions and tilt corrected directions. The main phase of tilting of the monocline appears to post-date the magnetization age which is about 90Ma.

DISCUSSION

There is now overwhelming evidence from a variety of techniques that the Sydney Basin has been subjected to low temperature metamorphism during the Mid-Cretaceous, particularly in the south-east. Evidence has been derived from palaeomagnetism (Schmidt & Embleton, 1981, Schmidt, 1982), fission-track dating (Morley & others, 1980), vitrinite reflectance (Middleton & Schmidt, 1982), fluid inclusion data and K/Ar dating (Bai & others, 1993). These last two avenues of research support the inference based on palaeomagnetic data that a thermal event occurred at about 90Ma involving uplift and supra-crustal cooling from elevated temperatures.

Fluid inclusions in quartz overgrowths in Narabeen Group samples from only a few hundred metres depth reveal minimum homogenisation temperatures of up to 100°C requiring some considerable overburden, may be coincident with an enhanced geothermal gradient. K/Ar dates of fine authigenic illite reveal a consistent eastward decrease towards the coast from 146Ma to 91Ma, closely paralleling iso-reflectance contours (P.J. Hamilton, *personal communication*, 1994). Modelling of vitrinite reflectance values indicates palaeotemperatures of 130°C to 180°C and requires burial depths of 1500m to 2100m in the mid-Jurassic (Bai & others, 1993).

This modelling is independent of that used by Middleton & Schmidt (1982) which arrived at similar conclusions. Overprinting, or complete remagnetisation, related to the Mid-Cretaceous thermal event have been recognised in many different rock-types throughout the Sydney Basin, including red, grey and green fine sandstones, siltstones, claystones, Permian and Early-Mid Jurassic igneous rocks, such as the Gerringong Volcanics, the Milton Monzonite and the breccia diatremes. In sedimentary strata or intruded igneous rocks that have not been tilted, the Cretaceous overprint magnetisations are consistently directed northward, albeit steeply upwards. This property has afforded the coal industry a valuable orientation tool.

The deflection of Cretaceous overprint directions by the Lapstone Monocline, and related structures, indicates that these tectonic structures post-date the Mid-Cretaceous, *viz.* ~90Ma. This in turn implies that the major movement along the Lapstone Monocline post-dates ~90Ma and was probably related to precursor events leading to rifting in the Tasman Sea.

Other models for the age of the Lapstone Monocline include those which support its early development (Early Mesozoic; Pickett & Bishop, 1992) and its later development (Cretaceous-Tertiary; David, 1897). The evidence tendered by Pickett & Bishop (1992) is contingent on the magnitude of the Glenbrook Fault at its southern extremity. If this fault actually peters out north of Nortons Basin then their observation, that the breccia out-

cropping there shows no signs of faulting, is of little consequence. The southern extremity of the Glenbrook Fault is not well defined as Pickett & Bishop (1992, page 22) clearly recognise.

The palaeomagnetic evidence shows that although sedimentary units thin to the west of the Lapstone Monocline indicating that the structure was active during sedimentation, the major tilting along the monocline was at least as young as the mid-Cretaceous. An earlier palaeomagnetic study of Hawkesbury Sandstone folded by the monocline by Bishop & others (1982) concluded that movement had ceased before the Late Tertiary on the basis that weathered sandstones yielded palaeomagnetic pole positions consistent with an age of 15 ± 7 Ma irrespective of structural position. Movement may have ceased long before this time.

CONCLUSIONS

The deflection of palaeomagnetic overprint directions associated with a mid-Cretaceous thermal event indicates that major movement on the Lapstone Monocline post-dates ~90Ma. The palaeomagnetic evidence therefore strongly supports a Cretaceous-Tertiary development of the Lapstone Monocline.

ACKNOWLEDGEMENTS

The authors acknowledge funding by ACARP Project C1615 and helpful discussions with Ian Stone (KCC), and Joe Hamilton and Peter Eadington (both CSIRO Petroleum Resources) and David Titheridge (KCC) for comments and suggestions on an earlier version of the paper.

REFERENCES

- BAI, G.P., EADINGTON, P.J. & HAMILTON, P.J., 1993: Fluid history investigation of Permo-Triassic sandstones in the Sydney Basin. CSIRO Division of Exploration Geoscience, North Ryde, Restricted Report 417R.
- BISHOP, P., HUNT, P. & SCHMIDT, P.W., 1982: Limits to the age of the Lapstone monocline, NSW — a palaeomagnetic study. *Journal of the Geological Society of Australia*, **29**, 319–326.
- BRANAGAN, D.F. & PEDRAM, H., 1990: The Lapstone Structural Complex, New South Wales. *Australian Journal of Earth Sciences*, **37**, 23–36.
- DAVID, T.W.E., 1897: Anniversary address. Summary of our present knowledge of the structure and origin of the Blue Mountains of New South Wales. *Journal and Proceedings of the Royal Society of NSW Bulletin*, **30**, 33–69.
- EMBLETON, B.J.J. & MCDONNELL, K.L., 1980: Magnetostratigraphy in the Sydney Basin, Southeastern Australia. *Journal of Geomagnetism and Geoelectricity*, **32**(III), 1–10.

- HERBERT, C., 1989: The Lapstone Monocline-Nepean Fault — A high angle reverse fault system. *Twenty Third Newcastle Symposium*, Department of Geology, University of Newcastle, Newcastle, 179–186.
- HUNT, P.A., 1985: The mobility of silicon and iron in the near surface zone: a re-evaluation of the concept of duricrust in central and eastern New South Wales. Ph.D. thesis, School of Earth Sciences, Macquarie University, NSW.
- LACKIE, M.A. & SCHMIDT, P.W., 1992a: Some examples of drill core orientation using palaeomagnetism in the South Sydney Basin. CSIRO Division of Exploration Geoscience, North Ryde, Restricted Report 300R.
- LACKIE, M.A. & SCHMIDT, P.W., 1992b: Preliminary study of drillcore orientation using palaeomagnetism, German Creek Colliery. CSIRO Division of Exploration Geoscience, North Ryde, Restricted Report 345R.
- MIDDLETON, M.F. & SCHMIDT, P.W., 1982: Paleothermometry of the Sydney Basin. *Journal of Geophysical Research*, **87**, 5351–5359.
- MORLEY, M.E., GLEADOW, A.J.W., & LOVERING, J.F., 1980: Evolution of the Tasman rift: Apatite fission track dating from the southeastern Australian continental margin. *Proceedings of the Vth Gondwana Symposium*, 289–293.
- PICKETT, J.W. & BISHOP, P., 1992: Aspects of landscape evolution in the Lapstone Monocline area, New South Wales. *Australian Journal of Earth Sciences*, **39**, 21–28.
- SCHMIDT, P.W., 1992: Linearity spectrum analysis of multi-component magnetizations and its application to some igneous rocks from south-eastern Australia. *Geophysical Journal of the Royal Astronomical Society*, **70**, 647–665.
- SCHMIDT, P.W. & ANDERSON, J.C., 1990: Feasibility of using palaeomagnetism to orient drill core from the Tahmoor Colliery. CSIRO Division of Exploration Geoscience, North Ryde, Restricted Report 177R.
- SCHMIDT, P.W. & EMBLETON, B.J.J., 1981: Magnetic overprinting in southeastern Australia and the thermal history of its rifted margin. *Journal of Geophysical Research*, **86**, 3998–4008.