Pre- and post-folding magnetizations from the early Devonian Snowy River Volcanics and Buchan Caves Limestone, Victoria

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Summary. Multicomponent magnetizations of the Snowy River Volcanics have been resolved into pre-folding (dec. = 340.1°, inc. = -59.2°) and post-folding (dec. = 10.5°, inc. = -72.3°) elements. The former is attributed to initial cooling of the volcanics while the latter is probably related to the waning stages of the deformational episode which was presumably accompanied by cooling. We argue that the pole position from the pre-folding magnetizations (lat. = 74.3°S, long. = 222.7°E) represents the Australian palaeopole for the early Devonian. A reassessment of other Australian pole positions determined from rocks of about this age suggests that remagnetization during the Carboniferous may be common.

Interpretation of the pole path prior to the Devonian is equivocal and awaits further study. The post-folding magnetizations from the volcanics are similar in stability and direction to those from the Buchan Caves Limestone (dec. = 27.8°, inc. = -75.6°), which appears to be completely remagnetized. The age of this remagnetizing event appears to be mid-Carboniferous if our interpretation of the pole path for this time is correct. It is noted that a much unappreciated attribute of the fold test lies with identifying not just the relative age of magnetization, but also the palaeohorizontal. Only when the palaeohorizontal is established can the calculation of a palaeopole be justified.

Key words: palaeomagnetism, terranes, fold belts, overprints

1 Introduction

The majority of palaeomagnetic pole positions used to construct the Palaeozoic apparent polar wander path (APWP) for Gondwana have been derived from Australian rock formations, and based primarily on these results there are three distinct interpretations...

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(McElhinny & Embleton 1974; Embleton et al. 1974; Schmidt & Morris 1977; Morel & Irving 1978). Using more recently acquired results from Australian rocks, with updated structural information and new age constraints for some rock units previously studied, Goleby (1980) provides a fourth interpretation of the Gondwana Palaeozoic APWP. There is a clear need for a concerted effort to examine critically the available information and supplement those results that withstand such scrutiny with further results that can be shown to be reliable. Reliability factors are all too lacking in many palaeomagnetic investigations and while definitive tests such as the contact test are often reported as positive, they rarely resemble the full contact test as originally described by Everitt & Clegg (1962). This is presumably because the contact test is inherently difficult to implement. For instance, the concurrence of magnetization directions from an intrusive rock with those from its baked contact is not sufficient proof of original magnetization dating from cooling of the intrusion. It does not rule out the synchronous remagnetization of both the intrusion and the host rock at some later time. Further information is required from the host rock at various distances from the contact to investigate the thermal effects of the intrusion on the host rock and to assess the originality of magnetizations present within the intrusion. It is rare that rock outcrop permits the required spread of sampling and generally it is far easier to implement the fold test (Graham 1949). Of itself, a positive contact test does not identify the palaeohorizontal, and therefore does not necessarily justify the calculation of a palaeomagnetic pole position. Granted, the full contact test when fully executed can prove the originality of magnetization, but without further evidence for the palaeohorizontal the use of magnetizations to infer palaeopole positions may not be valid.

In terranes where the remagnetization of rock units is widespread, the opportunity to sample specifically with a fold test in mind is often readily available. In this study we have sampled folded early Devonian rock formations from the Lachlan Fold Belt (LFB) of southeastern Australia to redress, in part, the shortcomings of the existing results.

2 Geological setting

The Snowy River Volcanics consist of fine grained and porphyritic rhyodacites and minor andesite, rhyolite and dacite with interbedded sediments (Ringwood 1955). The volcanics are thought to be of early Devonian age since they unconformably overlie late Silurian sedimentary rock and are in turn overlain by the early Devonian Buchan Caves Limestone. The Bindi Orogenic phase was responsible for deformation of the Snowy River Volcanics, while the later Tabberabberan Orogeny affected both the volcanics and the overlying limestone, causing gentle to moderate folding along meridional axes (Talent 1965). In places these units outcrop adjacent to relatively undisturbed late Devonian non-marine strata.

The volcanics and the limestone were sampled in a synclinal structure around Buchan, Victoria (Fig. 1). Generally, outcrop is good although steep terrain, associated with the volcanics, limited suitable sites to the sporadic outcrops that were clearly in situ and where structural attitudes were evident. The limestones were widely accessible and were sampled in two sections with contrasting structural attitudes. The fold axis of the synclinal structure is approximately N–S with shallow dips near the centre and steeper dips near the edge of the limbs (Fig. 1).

3 Methods

Routine procedures (Collinson, Creer & Runcorn 1967), including the use of a sun compass, were followed in the collection and preparation of orientated rock specimens, nominally
Devonian magnetization of the Snowy River Volcanics

25 mm in diameter and 22 mm high. Magnetic remanence measurements were performed on a DIGICO fluxgate spinner magnetometer for the volcanics and a three-axis CTF cryogenic magnetometer for the limestones. This latter instrument is housed inside three concentric \( \mu \)-metal cylinders to shield the sensor region during initial cool-down. To give greater control over the field, the magnetometer is placed inside a set of three orthogonal 4 m square Helmholtz coils, which also enable the field to be contained within workable limits, \( \pm 500 \) nT (\( \gamma \)), at the magnetometer head. Specimens are transported in \( \mu \)-metal canisters from demagnetizer stations to the magnetometers ensuring that specimens are not exposed to magnetic fields unnecessarily. Similarly, the DIGICO magnetometer head is placed inside a Helmholtz coil to reduce strong fields associated with the end effects of the magnetometer \( \mu \)-metal shield (Schmidt 1976).

Demagnetization of specimens was achieved using a three-axis tumbling alternating field (AF) demagnetizer similar to that described by Roy, Reynolds & Sanders (1973), a Schonstedt GSD-1 non-tumbling AF demagnetizer, and an automatic furnace installed within a 10-coil Helmholtz set with feedback to maintain a quasi-zero magnetic field.
A feature of this furnace is its ability to heat and cool batches simultaneously. The furnace is off-centre such that on completion of a heating cycle, the furnace is raised and the batch of specimens rotates into the centre of the coil set while another batch rotates under the furnace ready for heating. Specimens are thus heated in low-

Figure 2. Orthogonal projections (Zijderveld 1967) of in situ magnetization vectors during thermal demagnetization of samples of Snowy River Volcanics. The temperature (°C) steps following initial measurement of NRM were 200, 300, 400, 500, 530, 540, 550 and 570. Open (closed) symbols refer to the vertical (horizontal) plane. Note that different projections have been used depending on the spread of data points.
Devonian magnetization of the Snowy River Volcanics

fields, ~20 nT (γ), and cooled in quasi-zero field, <5 nT (γ). The heating and cooling cycles are microprocessor controlled enabling three batches of up to 50 specimens each to be heated and cooled (for pre-set temperatures and times) with no operator attendance. Susceptibility versus temperature determinations were performed on the transformer bridge described by Ridley & Brown (1980).

Data acquired from the CTF cryogenic magnetometer are processed and stored on a computer/disc system enabling fast retrieval and transmission to a Tektronix graphics system for further processing and visual display. The final mode allows a variety of analytical tools to be applied to the data, including principal component analysis (PCA, Kirschvink 1980) and linearity spectrum analysis (LSA, Schmidt 1982). Linear segments selected for statistical analysis have been accepted only if they possess a precision parameter arbitrarily chosen to be greater than 100, and these have been combined according to the methods described by McFadden & Schmidt (1986). The estimated precision parameter (k) is related to the maximum angular deviation (MAD, Kirschvink 1980), by the following expression

\[ k = \frac{(m - 1)}{\tan^2(MAD)}, \]

where m is the number of observations.

4 Results

4.1 Snowy River Volcanics

Intensities of natural remanent magnetization (NRM) ranged from about 10 mAm\(^{-1}\) (x 10\(^{-6}\) emu cm\(^{-3}\)) to several hundred mAm\(^{-1}\). While both AF and thermal

![Figure 3](https://academic.oup.com/gji/article-abstract/91/1/155/594739)
demagnetization were used, the latter proved to be the more effective in resolving the magnetic components present. Representative orthogonal plots of thermal demagnetization of the volcanics are shown in Fig. 2. Two magnetic components are present in most samples with a northerly steep upward directed magnetization being removed by 300–400°C, leaving a single high temperature (up to 580°C) magnetization of various directions. Linearity spectra (Schmidt 1982) reflect this two-component nature with high values of linearity around 200–300°C followed by depressed values to 500°C and then high values up to 580°C (Fig. 3a, b and c). However, some sites displayed low linearity levels for all temperatures above 300°C (Fig. 3d). Single high temperature components failed to be resolved in samples from these sites, although the off-set of the extrapolation of the low-temperature component towards the origin implies the existence of such high-temperature components (Fig. 2a).

Fig. 4 displays low field susceptibility versus temperature behaviour for a rhyodacite sample possessing two well-resolved magnetizations [SV09A]. The curve is reversible on cooling and exhibits features indicative of the presence of optimum-sized magnetite grains capable of high-fidelity magnetic recording (Clark & Schmidt 1982). The isotropic point at around -150°C reveals multidomain magnetite while the slow increase in susceptibility with temperature reflects a continuum of unblocking up to just below the Curie temperature of magnetite (580°C). The unblocking temperature spectrum is dominated by unblocking at high temperatures (>550°C, e.g. Fig. 2d) indicating long relaxation times.

When the susceptibility versus temperature of a sample is monitored, any unblocking may be observed as an increase in induced magnetization. However, this may be obscured somewhat by the competing effect of the decay of spontaneous magnetization, particularly near the Curie temperature when the induced magnetization rapidly decreases. The increase in magnetization when grains unblock is not observed when remanence versus temperature is monitored because in (a), the step-wise mode, a sample is observed at room temperature and any remanence that unblocked on heating would have been re-blocked on cooling (albeit by then quasi-randomized or ‘demagnetized’), and in (b), the continuous mode, although the sample is observed at high temperature when some remanence may become unblocked, because no magnetizing field is applied any induced magnetization does not manifest itself. The relationship between unblocking, thermal decay of remanence and the thermal decay of spontaneous magnetization is discussed at length by Schmidt & Clark (1985).

Sample directions derived from LSA for high temperature ranges are plotted in Fig. 5(a), and site means are tabulated in Table 1 with respect to present horizontal and bedding

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**Figure 4.** Low-field susceptibility variation with temperature of a typical sample from site SV09.
Figure 5. Equal-angle projections of magnetization directions before (left hand side) and after (right hand side) unfolding for (a) high temperature components from the Snowy River Volcanics, (b) low temperature components from the Snowy River Volcanics, and (c) low temperature components from the Buchan Caves Limestone. Open (closed) symbols refer to the upper (lower) hemisphere.

planes. There is clearly an improvement in the grouping of high-temperature directions after tilt correction, i.e. with respect to bedding, and a deterioration in the grouping of low-temperature directions (Fig. 5b). The high-temperature directions are accordingly interpreted as being pre-folding while the low-temperature directions are post-folding (McFadden & Jones 1981). The deviation of the high-temperature directions from site SV01
Table 1. Summary of pre-folding magnetizations from the Snowy River Volcanics

<table>
<thead>
<tr>
<th>Site (DDA, Dip)</th>
<th>N</th>
<th>R</th>
<th>$D_H$</th>
<th>$I_H$</th>
<th>$D_B$</th>
<th>$I_B$</th>
<th>$\alpha_{ss}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV01 (240, 28)</td>
<td>9</td>
<td>8.869</td>
<td>270.8</td>
<td>-25.8</td>
<td>283.9</td>
<td>-48.4</td>
<td>6.6</td>
</tr>
<tr>
<td>SV07 (093, 53)</td>
<td>6</td>
<td>5.965</td>
<td>056.3</td>
<td>-39.9</td>
<td>345.8</td>
<td>-61.3</td>
<td>5.5</td>
</tr>
<tr>
<td>SV08 (093, 53)</td>
<td>5</td>
<td>4.967</td>
<td>051.1</td>
<td>-37.1</td>
<td>349.8</td>
<td>-56.8</td>
<td>7.0</td>
</tr>
<tr>
<td>SV09 (283, 45)</td>
<td>4</td>
<td>3.993</td>
<td>305.9</td>
<td>-18.8</td>
<td>326.5</td>
<td>-57.6</td>
<td>4.3</td>
</tr>
<tr>
<td>SV10 (283, 45)</td>
<td>5</td>
<td>4.998</td>
<td>307.2</td>
<td>-22.2</td>
<td>332.0</td>
<td>-59.8</td>
<td>1.7</td>
</tr>
<tr>
<td>SV11 (283, 45)</td>
<td>4</td>
<td>3.997</td>
<td>307.2</td>
<td>-21.8</td>
<td>331.5</td>
<td>-59.5</td>
<td>3.1</td>
</tr>
<tr>
<td>SV12/13 (273, 45)</td>
<td>4</td>
<td>3.993</td>
<td>310.1</td>
<td>-29.1</td>
<td>347.2</td>
<td>-56.8</td>
<td>4.5</td>
</tr>
<tr>
<td>SV14 (343, 26)</td>
<td>4</td>
<td>3.963</td>
<td>161.1</td>
<td>26.9</td>
<td>160.2</td>
<td>52.9</td>
<td>10.2</td>
</tr>
<tr>
<td>SV15 (343, 26)</td>
<td>3</td>
<td>2.939</td>
<td>189.9</td>
<td>45.1</td>
<td>214.4</td>
<td>65.9</td>
<td>21.8</td>
</tr>
<tr>
<td>SV19 (130, 50)</td>
<td>3</td>
<td>2.951</td>
<td>246.2</td>
<td>50.8</td>
<td>183.9</td>
<td>45.4</td>
<td>19.6</td>
</tr>
<tr>
<td>Mean</td>
<td>47</td>
<td></td>
<td>328.9</td>
<td></td>
<td>-44.0</td>
<td></td>
<td>-59.4</td>
</tr>
</tbody>
</table>

$R_H = 33.751$  
$R_B = 44.678$  
$R_H = 7.489$  
$R_B = 9.649$

Pole*  
lat. = 74.3° S, long. = 222.7° E (dp = 10.9°, dm = 14.5°)

* Based on the sample mean direction before tilt correction.

Abbreviations: DDA = down-dip azimuth, N = number of unit direction, R = resultant of N unit directions, D = declination, I = inclination (H = horizontal and B = bedding), $\alpha_{ss}$ = semi-angle of confidence cone (Fisher 1953).

(Table 1 and Fig. 5a) is most probably the result of our inability to restore exactly these directions to their pre-folding orientation although it is also reasonable to suppose that the directions may reflect secular variation of the geomagnetic field at the time of formation of the volcanics. It is not possible to decide which of the foregoing is responsible. The reversed

Table 2. Summary of overprint magnetizations from the Snowy River Volcanics

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>R</th>
<th>$D_H$ (°)</th>
<th>$I_H$ (°)</th>
<th>$\alpha_{ss}$ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SV02</td>
<td>3</td>
<td>2.926</td>
<td>316.8</td>
<td>-73.6</td>
<td>24.1</td>
</tr>
<tr>
<td>SV03</td>
<td>5</td>
<td>4.919</td>
<td>338.4</td>
<td>-71.7</td>
<td>11.0</td>
</tr>
<tr>
<td>SV04</td>
<td>4</td>
<td>3.964</td>
<td>353.0</td>
<td>-73.4</td>
<td>10.2</td>
</tr>
<tr>
<td>SV05</td>
<td>6</td>
<td>5.822</td>
<td>001.8</td>
<td>-78.8</td>
<td>12.9</td>
</tr>
<tr>
<td>SV06</td>
<td>6</td>
<td>5.956</td>
<td>340.9</td>
<td>-72.9</td>
<td>6.3</td>
</tr>
<tr>
<td>SV07</td>
<td>6</td>
<td>5.927</td>
<td>007.1</td>
<td>-68.8</td>
<td>8.2</td>
</tr>
<tr>
<td>SV08</td>
<td>5</td>
<td>4.980</td>
<td>012.8</td>
<td>-64.8</td>
<td>5.4</td>
</tr>
<tr>
<td>SV09</td>
<td>3</td>
<td>2.816</td>
<td>033.8</td>
<td>-62.4</td>
<td>39.4</td>
</tr>
<tr>
<td>SV10</td>
<td>5</td>
<td>4.799</td>
<td>065.8</td>
<td>-65.8</td>
<td>17.6</td>
</tr>
<tr>
<td>SV12</td>
<td>4</td>
<td>3.805</td>
<td>066.1</td>
<td>-76.5</td>
<td>24.2</td>
</tr>
<tr>
<td>SV13</td>
<td>4</td>
<td>3.965</td>
<td>005.4</td>
<td>-66.4</td>
<td>10.1</td>
</tr>
<tr>
<td>SV14</td>
<td>4</td>
<td>3.905</td>
<td>029.2</td>
<td>-58.8</td>
<td>16.6</td>
</tr>
<tr>
<td>SV15</td>
<td>4</td>
<td>3.975</td>
<td>005.0</td>
<td>-78.1</td>
<td>8.4</td>
</tr>
<tr>
<td>SV16</td>
<td>6</td>
<td>5.895</td>
<td>018.5</td>
<td>-67.1</td>
<td>9.8</td>
</tr>
<tr>
<td>SV17</td>
<td>8</td>
<td>7.604</td>
<td>004.3</td>
<td>-75.3</td>
<td>13.5</td>
</tr>
<tr>
<td>SV21</td>
<td>4</td>
<td>3.987</td>
<td>351.3</td>
<td>-67.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Mean</td>
<td>77</td>
<td>74.132</td>
<td>010.5</td>
<td>-72.3</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Pole*  
lat. = 68.7° S, long. = 132.5° E (dp = 5.0°, dm = 5.7°)

* Based on the mean site direction before tilt correction.

Abbreviations: N = number of unit direction, R = resultant of N unit directions, D = declination, I = inclination (H = horizontal), $\alpha_{ss}$ = radius of confidence cone (Fisher 1953).
magnetizations appear to be more scattered than the normal directions (not withstanding site SV01). Again this may reflect uncertainties in the palaeohorizontal or bias due to small overprint magnetizations. The latter will affect reversed directions to a greater extent than normal directions because all the overprints are of normal polarity (Fig. 5b). We stress, though, that the procedure of LSA (Schmidt 1983) suppresses bias by combining the results from many samples simultaneously and extracting only that information which is common. Pseudolinear segments composed of two components crop up occasionally, but are not expected to occur as a general feature unless the unblocking temperature spectra are heavily overlapped. The fact that the overprint magnetizations and the pre-folding magnetizations of the Snowy River Volcanics are well resolved (Fig. 2) is good evidence for distinct unblocking spectra, so biased segments should be minimal. This is also evidence for a thermal, rather than thermochemical, origin of the overprinting (McClelland Brown 1982). The palaeomagnetic pole positions have been calculated from the mean of the site mean high-temperature directions after simple tilt correction. The average pole lies at 74.3°S, 222.7° (dp = 10.9°, dm = 14.5°).

The sample directions derived from LSA for low temperature components are plotted with respect to present horizontal and bedding planes in Fig. 5(b), and site means are

![Figure 6. Orthogonal projections of in situ magnetization vectors during demagnetization of samples of Buchan Caves Limestone. The steps following initial measurement of NRM were 5 mT (50 Oe), 200, 300, 350 and 400°C. Open (closed) symbols refer to the vertical (horizontal) (close to origin) plane.](https://academic.oup.com/gji/article-abstract/91/1/155/594739/15554769)
tabulated in Table 2. The scattering of the directions after unfolding indicates that these low-temperature components are post-folding and the pole position (Table 2) has been calculated accordingly. The pole lies at 68.7°S, 132.5°E (dp = 5.0°, dm = 5.7°). Unit weight is given to samples for this calculation since the relevance of the site unit to overprint magnetizations is unclear.

4.2 Buchan Caves Limestones

Intensities of NRM were very weak in these samples, being 1–2 mAm⁻¹ (x 10⁻⁶ emu cm⁻³). NRM directions are generally scattered and after experimenting with different demagnetization strategies, partial AF demagnetization of 5 mT (50 Oe) was found to be a very effective pre-treatment in eliminating spurious magnetizations. The precision parameter for N = 64 increased from \( k = 6 \) to \( k = 19 \) after this treatment, suggesting that isothermal remanent magnetizations (IRMs), possibly due to the effects of lightning, dominate the lower coercivity components. The efficacy of 5 mT AF treatment can be seen in the orthogonal projections displayed in Fig. 6 (see also Schmidt & Embleton 1985). Further thermal demagnetization resulted in magnetization decay directly to the origin and by 400°C no sensible magnetizations were present. The magnetic carriers in these limestones are apparently characterized by low coercivities and low unblocking temperatures. Magnetization directions derived from LSA are plotted in Fig. 5(c) where it is apparent that these directions are very similar to the post-folding magnetizations found in the Snowy River Volcanics. The directions scatter when corrected for tilting. It is reasonable to consider the limestones as being remagnetized after deformation at a similar time as the Snowy River Volcanics appear to have been (partially) overprinted. The limestone samples yield a mean direction of dec. = 017.4°, inc. = 74.0° (\( \alpha_{95} = 2.5° \)) and a pole position of lat. = 64.7°S, long. = 127.9°E (dp = 4.0°, dm = 4.5°).

5 Discussion

The results from the Snowy River Volcanics provide a pre-folding pole position (SR – Fig. 7a) while post-folding directions from both the Snowy River Volcanics and the Buchan Caves Limestone provide a post-folding pole position (SB – Fig. 7a). These pole positions are compared with other Palaeozoic pole positions from Australian rock formations in Fig. 7(a). Since the age of their last deformation is mid-Devonian (Tabberabberan), the pre-folding pole from the volcanics is most likely to be related to their initial cooling following extrusion in the early Devonian. On the other hand, the age of the remagnetizing event,
while clearly post-dating the Tabberabberan deformation can only be adjudged by comparison with pole positions from younger Australian rock formations. The proximity of the overprint pole (SB) to that from the Paterson Toscanite (PT) suggests that the age of remagnetization is approximately late Carboniferous [304 Ma, from Evernden & Richards (1962) using time constants recommended by Steiger & Jäger (1977)].

However, it should also be pointed out that the pole is similar to the Cretaceous overprint poles reported from seaboard rock formations (Schmidt & Embleton 1981), but since this study area is well inland it is unlikely that the Cretaceous event which heralded rifting in the Tasman Sea is responsible for the overprints encountered here, although it is noted that evidence from fission tracks (Moore, Gleadow & Lovering 1986) suggests that the effects of this Cretaceous event may have been felt further inland in Victoria than in New South Wales. However, the SB pole position is about 10° south of the Cretaceous overprint poles and is therefore most likely to be of late Carboniferous age, perhaps associated with the cooling phase following the Tabberabberan Orogeny.

Our interpretation of the Devonian and Carboniferous segments of the pole path follows that of Schmidt et al. (1985), where it was suggested that many pole positions previously argued as relating to original magnetizations are, in fact, related to secondary magnetizations or magnetizations acquired late, during diagenesis. The pole from the Mereenie Sandstone (MS – Embleton 1972) exemplifies this re-evaluation. This pole, being from a central Australian rock unit, has formed the basis for interpreting south-eastern Australia as allochthonous (Embleton et al. 1974; McElhinny & Embleton 1974) although no field test is available to establish its timing. Quite distinct from the Mereenie Sandstone pole position is the latest Early or early Late Devonian Comerong Volcanics pole position [CV – Fig. 7(a), Schmidt et al. 1985]) with an associated positive fold test. Clearly further evidence on the age of the Mereenie Sandstone magnetization is required before an unequivocal interpretation can be made, but it appears that the most conservative interpretation at present is that the Mereenie Sandstone has either been remagnetized or acquired its magnetization some.
time after deposition, in the Carboniferous. That red beds undergo protracted magnetization periods, or are magnetized rapidly following deposition, is still disputed in the literature, but the general consensus appears to favour the former (e.g. Roy & Park 1974; Larson et al. 1982). Sedimentary sequences nearby the Mereenie Sandstone, at Ross River (Northern Territory) have been strongly affected by the Alice Springs Orogeny in the Carboniferous yielding the overprint pole RRO (Kirschvink 1978 – Fig. 7a), which is fairly close to the MS pole. This suggests that the Mereenie Sandstone, which has also been strongly affected by the Alice Springs Orogeny, may have been largely remagnetized in the Carboniferous. There are therefore at least two reasonable mechanisms to explain the difference between the CV pole and the MS pole. It is emphasized that the CV pole is interpreted to be representative of cratonic Australia during the Late Devonian, as evidenced by the palaeocurrent and provenance correlations across the entire Lachlan Fold Belt of the paraconformably overlying quartzose clastic Lambie facies.

Extending the above interpretation to pole positions derived from other Devonian rock units implies that (re)magnetization during the Carboniferous is widespread, not only in central Australia but also in other areas. Thus the Bowning Group (BG) pole (Luck 1973), the Mulga Downs Group (MD) pole (Embleton 1977) and the Canning Limestone (CL) pole (Hurley & Van der Voo 1986) are interpreted here as being possibly of Carboniferous age. We note that Hurley & Van der Voo (1986) infer a primary magnetization for the limestone on the basis of magnetic polarity reversal patterns, although Hurley (1986) documents extensive evidence for a series of diagenetic events, including fluctuating reducing and oxidizing conditions. While this evidence does not disprove the primary nature of the magnetization, we would suggest that, given the above conditions, magnetic polarity reversal patterns may arise from mechanisms other than initial sedimentation. Also, as discussed below it is no longer valid to use the rotated pole position of the African Msissi Norite (Hailwood 1974) in support of a Devonian magnetization age of either the Mereenie Sandstone or the Canning Limestone.

Even though there are reversals of magnetizations present in the Mulga Downs Group, this is not necessarily a valid reason for rejecting remagnetization, although remagnetization is often manifest in single polarity. We note that prior to correction for bedding tilt the direction of magnetization from the Mulga Downs Group sediments are reminiscent of dual polarity directions found in many sedimentary sequences throughout Australia that have been interpreted as reflecting Tertiary remagnetization during deep weathering (Schmidt & Embleton 1976; Schmidt et al. 1976). The early-middle Devonian pole position of Goleby (1980) plotted as G4 in Fig. 7(a) has a large associated error which intersects the error circle of the Snowy River Volcanics reported here. However, the directions reported by Goleby (1980) scatter upon correction for tilting raising uncertainties regarding the age of magnetization of those rocks. The APWP for Australia therefore moves from the pole of the Comerong Volcanics at 370 Ma (CV, Fig. 7a) to that from the Mereenie Sandstone (MS), thence to the late Carboniferous poles at about 300 Ma of the Curraubulla Formation (CF), the Rocky Creek Conglomerate (RC) and the Main Glacial Stage (MG) of Irving (1966).

The dashed APWPs shown in Fig. 7(a) for times earlier than that represented by the Comerong Volcanics pole, summarize the various interpretations that have been made depending upon the data available at the time. The path joining at CV, trending southerly along the 210°E meridian, is supported by the pre-folding pole from the Snowy River Volcanics (SR) and thus favours the option proposed by Schmidt & Morris (1977) who reversed the conventional polarity of lower Palaeozoic pole positions, thus obviating the collision (allochthonous) model proposed by Embleton et al. (1974) and McElhinny & Embleton (1974). However, this does not altogether solve the question of possible Silurian
allochthonous terranes in the Lachlan Fold Belt since there appears to be a diversity of Silurian pole positions from several studies. Perhaps the greatest divergence of poles are those reported by Goleby (1980) for the early-middle Silurian and the middle-late Silurian, represented by the dashed track from poles G2 to G3 in Fig. 7(a). It is noteworthy that although a positive fold test is associated with these poles, the fold test is unconventional, in that the directions compared are from a number of rock formations of a range of ages, rather than sites or samples from within a particular formation. To us this compromises the validity of the test. Other Silurian poles from Australia are the poles from the Mugga Mugga Porphyry (MP*), the Ainslie Volcanics (AV*) and the Silurian Volcanics (SV). The asterisks refer to relocated poles as reported by Goleby (1980) on the basis of new structural information. How to relate these poles to the pole from the Snowy River Volcanics remains ambiguous at present. They may be interpreted in terms of displaced terranes, or given that no field tests are available for any of the poles MP*, AV* or SV, their magnetizations may not be original. Clearly, further work is required on Australian Silurian rock formations before a pole path can be defined joining the Early Palaeozoic poles for Australia to the Late Palaeozoic poles.

The new pole positions from the Snowy River Volcanics (SR) and from the Comerong Volcanics (CV, Schmidt et al. 1985) are both reliable, from their fold tests, and well constrained age-wise. We interpret the pole path for these times, through to the late Carboniferous, to be representative for Australia, and (by implication) Gondwanaland. It remains to compare this pole path with that for Africa, the only other Gondwanaland fragment for which there are a number of Mid-Late Palaeozoic pole positions. The position of the Msissi Norite (MN, Hailwood 1974) is usually accepted as representing the late Devonian, although there is no fold, conglomerate or contact tests available. Hailwood (1974) uses the flat-lying adjacent and immediately overlying Devonian deposits as evidence that the norite is in its original attitude. This implies that the sediments are older and the Devonian appears therefore to only indicate a lower age limit. Indeed, in a recent study by Salmon et al. (1986) K–Ar analyses on biotites and a new palaeomagnetic investigation suggest that the magnetization determined by Hailwood is not older than 140 Myr, and the Msissi Norite (or teschenite as Salmon et al. prefer) may be this age. Salmon et al. (1986) conclude that the Msissi pole 'can no more be used as a stable African Devonian paleopole'.

Other poles shown are that of the Dwyka Varves (DV) and K-3 red beds (KK and KG – McElhinny & Opdyke 1968), each reasonably placed according to their original interpretation, and that of the middle Devonian Gneiguira Supergroup (GS, Kent, Dia & Sougy 1984). This last pole is distinctly misplaced from the position expected for a mid-Devonian pole (which should be between CV and SR) but as suggested by Kent et al. (1984) in the absence of a fold-test, and bearing in mind the similar magnetic directions determined from nearby rock units of upper Proterozoic–Cambrian (?) age by themselves and Morris & Carmichael (1978), it seems likely that these red beds have been remagnetized during the Carboniferous. As pointed out by Schmidt et al. (1985) the persistent reversed magnetizations of these formations supports a Kiaman age, or late Carboniferous age for the time of their magnetization.

6 Conclusions

The pole positions determined from the early Devonian Snowy River Volcanics presented here, and that of the late Early to early Late Devonian Comerong Volcanics (Schmidt et al. 1985) enable the Devonian pole path for Australia to be defined for the first time from magnetization directions which satisfy fold tests. It is argued that these poles are not only...
representative for Australia but also for Gondwanaland, leading us to reassess the magnetization ages of many other Devonian rock units. In particular, the central Australian Mereenie Sandstone pole position (Embleton 1972) and the African Msissi Norite pole position (Hailwood 1974), in the past used as cornerstones for Devonian palaeo-reconstructions of Pangaea, both appear to relate to younger times. This reassessment is consistent with the geological and palaeomagnetic information available for these rock units.

With the present state of knowledge we are in a position to compare the previously proposed pole paths for Gondwanaland. The two-path model advocated by Embleton et al. (1974) and McElhinny & Embleton (1974) relies heavily upon a Siluro-Devonian age for the magnetization of the Mereenie Sandstone. It is feasible that this unit has been magnetized in post-Devonian times, since there is no positive field test, especially in light of the positive fold test for the late Devonian Comerong Volcanics pole reported by Schmidt et al. (1985). With the denunciation of the Msissi pole (Salmon et al. 1986) and uncertainties associated with the age of magnetization of other crucial rock units, the two-path model as originally formulated can not be sustained.

It remains to compare the one-path models which have been proposed. The first of these was that of Schmidt & Morris (1977) who argued that the Mereenie Sandstone was not magnetized during the Siluro-Devonian but sometime later and favoured the Silurian poles from south-eastern Australia as representing the pole position for Australia for these times. The early Devonian Snowy River Volcanics pole falls between the late Devonian Comerong Volcanics (CV) pole and the Silurian Ainslie Volcanics (AV) and other Silurian Volcanics (SV) pole, suggesting a temporal sequence without large gaps. The Silurian poles proposed by Goleby (1980) have been questioned on the basis of their internal consistency but cannot be unequivocally dismissed. These poles and the pole path proposed by Morel & Irving (1978), suggest over 60° of polar wandering between the early Silurian and the Devonian. It remains speculative whether such motion is reasonable and we must await the determination of Silurian pole positions accompanied with field tests.

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References


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