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PALEOMAGNETISM OF THE HERVEY GROUP, CENTRAL NEW SOUTH WALES AND ITS TECTONIC IMPLICATIONS

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Abstract. Paleomagnetic work on the Hervey Group in southeast Australia reveals a predeformational magnetization as suggested by the retention of a predeformational compaction produced magnetic fabric and the effect of deformation on both the magnetic fabric and the direction of the magnetic remanence in cleaved rocks. The formation mean direction D=29.2°, I=-19.3° with $\alpha95$=15.5° gives a latest Devonian-Early Carboniferous palaeomagnetic pole at 54.4°S, 24.1°E with DP=8.4°, DM=16.2°. Comparing this pole with existing poles from Australia and North America, it is suggested that: (1) The Lachlan Fold Belt of southeast Australia has been part of cratonic Australia since at least the late Devonian, and consequently, the Late Palaeozoic palaeomagnetic data from the LFB may be applied to the whole of Gondwanaland. (2) Cratonic Australia and the New England Fold Belt were all in an equatorial position during the Early Carboniferous. (3) There was probably a rapid anticlockwise rotation of Gondwanaland during the Late Devonian around an axis close to Australia. (4) A "V"-shaped ocean existed between Laurussia and the northern margin of western Gondwanaland during the late Devonian-Early Carboniferous. The Appalachian-Hercynian Orogenic Belt is probably the result of the closure of this ocean.

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INTRODUCTION

The pre-Mesozoic apparent polar wander path (APWP) of Australia has long been considered as being representative for the whole of Gondwanaland, but some parts of the path, especially the middle-late Paleozoic section, are still poorly defined. Four different APWPs for Australia have been given [McElhinny and Embleton, 1974; Schmidt and Morris, 1977; Morel and Irving, 1978; Goleby, 1980]. The essential discrepancy between the four interpretations is whether the Lachlan Fold Belt (LFB) was a displaced terrane (the allochthonous model) or whether it was part of cratonic Australia (the in situ or autochthonous model) during the middle-late Paleozoic. To test these models, paleomagnetic data of the same age from both the LFB and cratonic Australia are needed. However, many of the existing data from the LFB show great discordancy between each other due to either misdating of the magnetizations, or misassignment of the paleohorizontal [Schmidt and Embleton, 1987]. The present work was thus designed to determine a well-dated paleomagnetic pole, with a field test, from the LFB, and by a comparison with good quality data from cratonic Australia and other continents, to assess the tectonic implications.

REGIONAL GEOLOGY AND SAMPLING

The Hervey Group is the local name of the Lambian Facies in the Parkes-Cowra region, New South Wales. It is a thick sequence of mainly terrestrial deposits with a maximum thickness of about 2700 m, estimated from the Parkes Syncline [Conolly, 1965]. Three subgroups are further divided according to their lithological characters: in stratigraphic order these are the Beargamil Subgroup, the Nangar Subgroup, and the Cookamidgera Subgroup. Both the basal and the top subgroups are continental facies, dominated by red measures. The middle subgroup has marine intercalations at the bottom [Williams, 1977; C. Powell and D. Crane, unpublished work, 1980], and is characterized by repetitious cycles of white quartzose sandstones, red and white sandstones with some red siltstones, and then red siltstones and shales. The Hervey Group unconformably overlies the mid-Devonian granite and other older Palaeozoic rocks in this region, while fish plates from the middle part of the sequence, e.g., the Nangar Subgroup, indicate a Late Devonian age [Conolly, 1965]. The marine unit at the bottom of the Nangar Subgroup is correlative with the Famennian marine unit of the Catombal Group at the Gap Creek region (Jones [1982] as shown in Figure 1). Thus the age of the Hervey Group could extend from the late Middle Devonian to Early Carboniferous.

The Hervey Group, together with the underlying rocks, was deformed during the mid-Carboniferous Kanimblan Orogeny (C. Powell and E. Scheibner, personal communication, 1987). The intensity of the deformation in this region is mild to locally strong (interlimb angles in folds are 30° - 70° according to Powell et al. [1980] and Powell [1984]). The folds generally trend north-south (Figure 1). High-angle reverse faults are found cutting through the formations. Cleavage is not visible in most of the area but is well developed in the pelitic units and some sandstones at the southern part of the Hervey Syncline and the Murga area southeast of Parkes. The strike of the cleavage is about 10°E, and the dip is usually greater than 60°.

Sampling was carried out mainly in the red units, although a few samples were taken from the white-brown sandstone members in the Murga area. As often as possible, both a sun compass and a magnetic compass were employed to orient the samples, while the sun compass measurements were preferred for data analysis wherever they were available. Sampling sites were located on different limbs of folds so that a fold test [Graham, 1949; McFadden and Jones, 1981] could be applied. Although most of the samples were from noncleaved rocks, some slightly to well-cleaved samples were specifically collected from the Murga area in order to further test the time relation between the remanent magnetization and the deformation.

A total of 104 samples, consisting both of short drill cores and block samples, were collected from 11 sites. Nine of the sites were either in, or just above the Famennian marine unit, and the other two just below it (Figure 1). Thus the studied rocks are believed to be latest Devonian (Famennian) in age.

MAGNETIC SUSCEPTIBILITY AND ITS ORIGIN

The bulk magnetic susceptibility and the anisotropy of susceptibility of 98 samples were measured before demagnetization, using the Commonwealth Scientific and Industrial Research Organizations (CSIRO) Balanced Transformer Susceptibility Bridge [Ridley and Brown, 1980] and an upgraded Digico Anisotropy Delineator. The bulk susceptibility of the samples varies with rock types, but most were less than 15 uG/Oe (~190×10-6 SI units) (Figure 2a). The magnetic susceptibility ellipsoids are represented by their three principal axes, the maximum axes (Kmax), the intermediate axes (Kint), and the minimum axes (Kmin). The anisotropies (Kmax/Kmin) of the samples are very low, generally ranging between 1.01 and 1.05, and only occasionally above 1.10 (Figure 2b). Nevertheless, the signal to noise ratio was well above the sensitivity limit of the upgraded anisotropy delineator.

It was found that except for site 9, which is the most severely cleaved site, all of the sites have their minimum susceptibility axes close to their

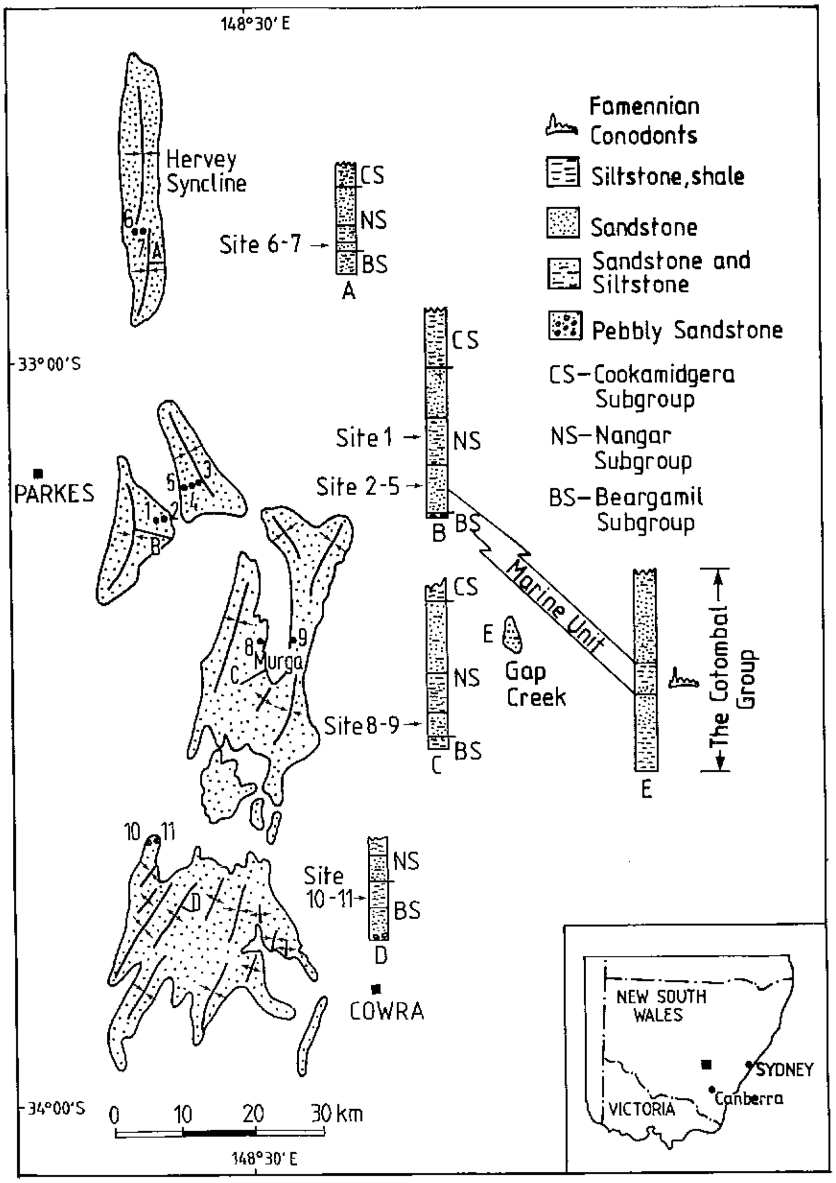

Fig. 1. Schematic diagram showing the localities and stratigraphic positions of sampling sites [after Conolly, 1965; Jones, 1982].

respective bedding poles. At sites where most of the samples retain a stable remanence, both the within-site dispersion of the Kmin axes and the angular distance between their mean direction and the pole to the bedding are very small (Figure 3a). However, at sites with low magnetic stability the dispersion of Kmin axes is large. This is probably the result of weathering evident at these sites, although the effect of any invisible cleavage could not be ruled out. A fold test [McFadden and Jones, 1981] was applied to the site mean directions of the Kmin axes, but it was inconclusive at the 95% level of confidence. However, it can still be seen from Figures 3c and 3d that apart from those with large $\alpha 95$ circles, all others group better around the common pole to the bedding after bedding correction. The normal to bedding directions of the Kmin axes indicate that the basal planes of the magnetic carriers in the red beds (mainly hematite) are aligned with the bedding. Graham [1967] and Van den Ende [1975] considered this phenomenon as evidence for the depositional origin of the magnetic

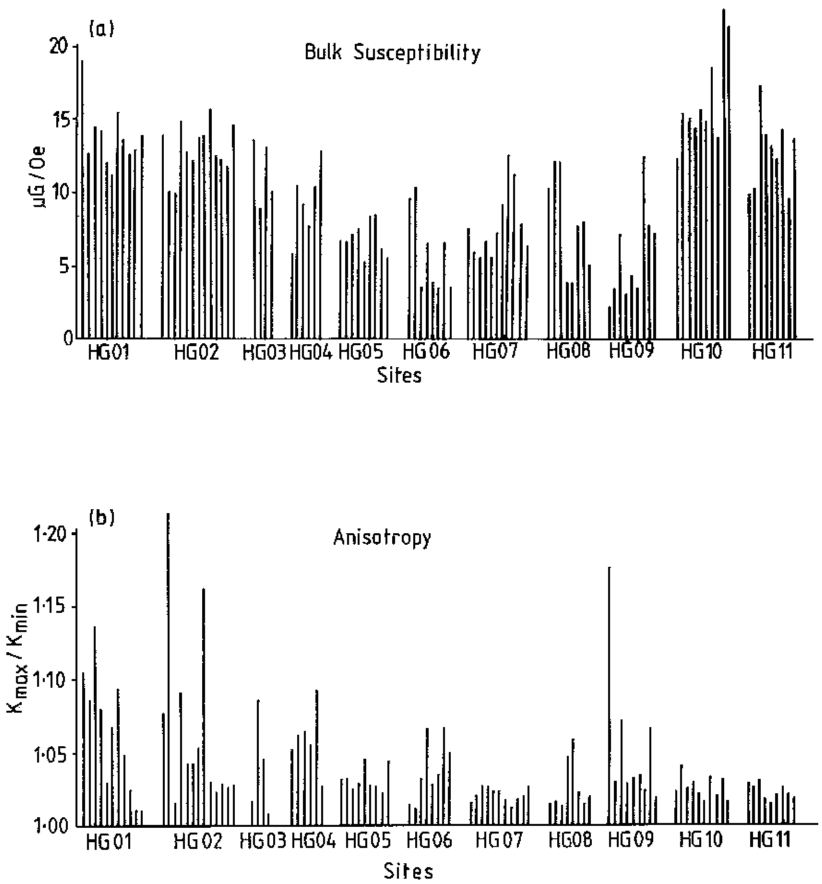

Fig. 2. (a) Bulk susceptibility and (b) ratio of anisotropy of the samples.

minerals in rocks. However, considering the probable secondary origin of hematite in red beds [Walker et al., 1981], the alternative explanation that this phenomenon may be the result of predeformational compaction [Kligfield et al., 1983] is preferred by the authors.

At site 9 the Kmin directions of the cleaved samples are obviously different from the pole to the bedding but not far from the pole to the cleavage plane (Figure 3b). Such a phenomenon was also reported from strongly cleaved or metamorphased rocks elsewhere [e.g., Hrouda and Jana'k, 1976; Hrouda, 1978; Kligfield et al., 1977; Hirt et al., 1986], and it is widely accepted as the result of deformation. The demonstration of such a relationship between deformation and magnetic fabric at this site further supports the interpreted predeformational origin of the magnetic fabrics, and hence magnetic minerals, at the uncleaved sites. At another site (site 8) from the deformed region the rocks are probably not cleaved enough to have their magnetic fabrics reset. This synthesis is further supported by magnetic remanence study discussed below.

DEMAGNETIZATION AND REMANENCE INTERPRETATION

A total of 286 specimens was demagnetized. Most of them were subjected to 8-12 steps of thermal demagnetization, using a nonmagnetic automated furnace within a magnetic field free space (~±5nT) [Coward et al., 1985]. It is shown that this demagnetization technique is usually effective for resolving the different magnetic components carried in the samples. Alternating magnetic field demagnetization was applied to a small number of specimens before further thermal demagnetization, using a Schonstedt GSD-1 alternating magnetic field demagnetizer. Chemical demagnetization [Collinson, 1965; Roy and Park, 1974] was also carried out for 27 samples from sites 1-4. Both

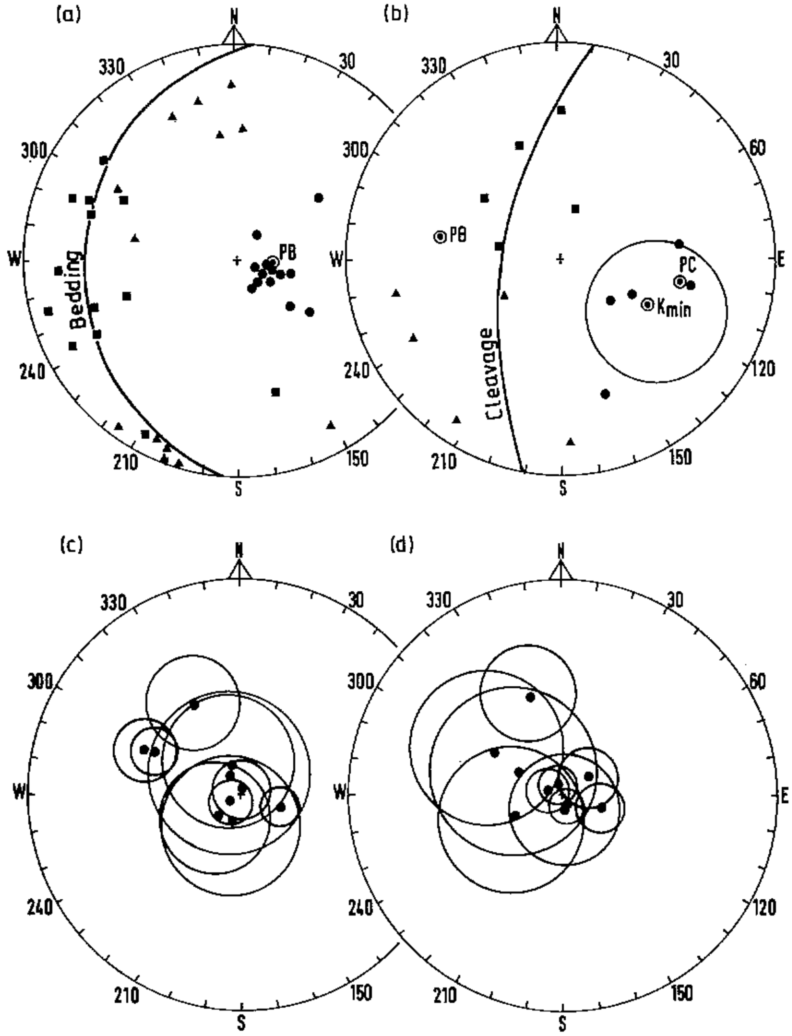

Fig. 3. Equal angle projection of magnetic fabric data in relation with bedding and cleavage. Figures 3a and 3b show the in situ directions of principal susceptibility axes from site 2 (no cleavage in site) and site 9 (cleaved samples), respectively. Solid squares, triangles, and circles are the directions of Kmax, Kint, and Kmin axes, respectively, plotted on the lower hemisphere. PB is pole to bedding. PC is pole to the cleavage. Kmin is mean direction of the Kmin axis. Figures 3c and 3d are site mean directions of the Kmin axis from the noncleaved or less cleaved sites before (Figure 3c) and after (Figure 3d) bedding correction. Also plotted are α95 circles for each site mean.

concentrated (32%) and dilute (8%) hydrochloric acid were used. In order to dissolve the hematite pigment evenly throughout the specimens, three or four cuts were made in each specimen. A crock-pot cooker with controlled temperature of 60°-70°C was also employed to accelerate the dissolution rate. However, the final results show that this technique is not more effective than the thermal method for these specimens.

All the measurements were made using a shielded three-axis CTF cryogenic magnetometer, with a computerized data handling system. Orthogonal plots [Zijderveld, 1967] and principal component analysis [Kirschvink, 1980] were used for each demagnetized specimen. Linear

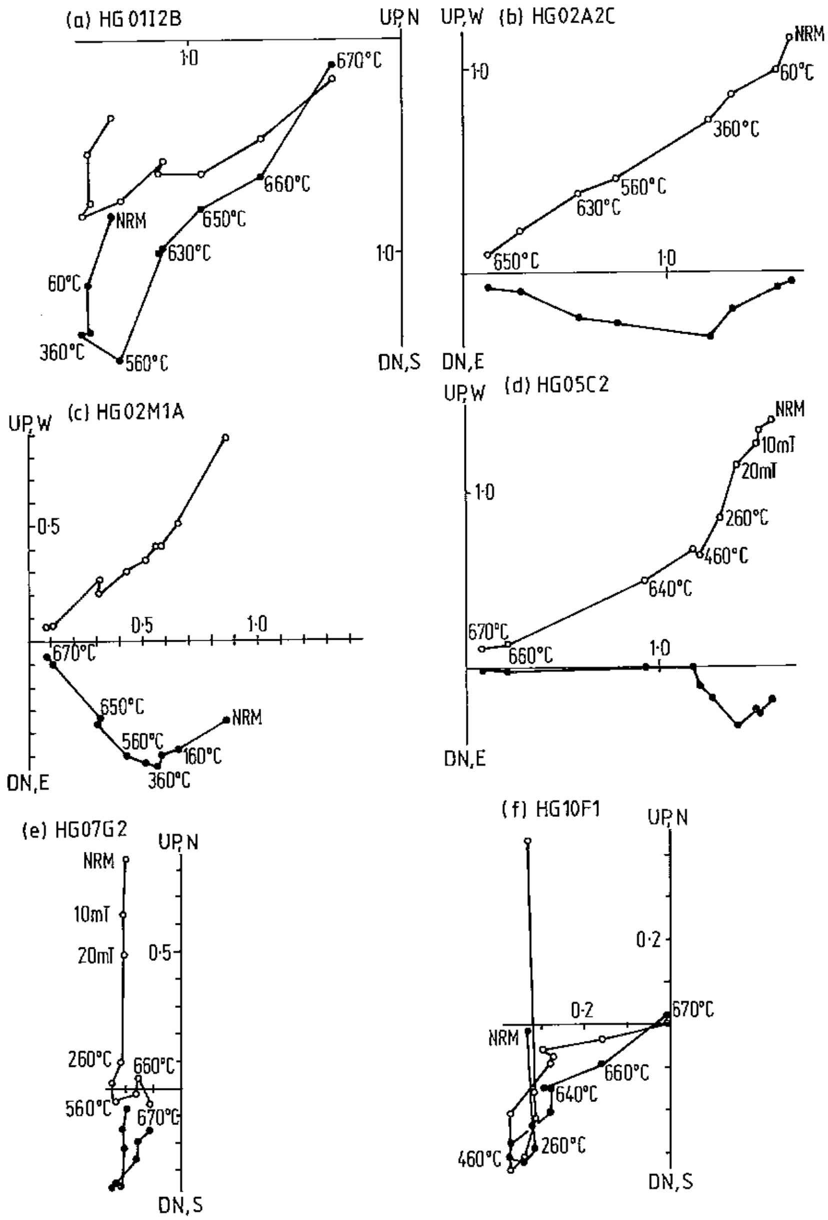

Fig. 4. Representative orthogonal projection of magnetization vectors from the uncleaved sites. Solid (open) circles are projections on horizontal (vertical) planes while all units are in mAm^{-1} ($\times10^{-6}$ emu cm^{-3}). All data are pre-bedding-correction.

demagnetization trends were selected by comparing these two sets of information.

The intensities of natural remanent magnetization before demagnetization were very weak, normally ranging from less than 1.0×10^{-6} emu cm-3 (1.0 mAm^{-1}) to 2.0-3.0×10^{-6} emu cm^{-3}. Eleven of the 104 samples either failed to reveal any stable remanent magnetization, or the remanent magnetizations do not have any within-sample consistency. These samples were discarded from further data analysis.

Representative orthogonal plots of the remaining samples are given in Figures 4, 5, and 6. About 90% of them contain a soft component with unblocking temperatures usually less than 600°C. Except for a few outliers [Fisher et al.,

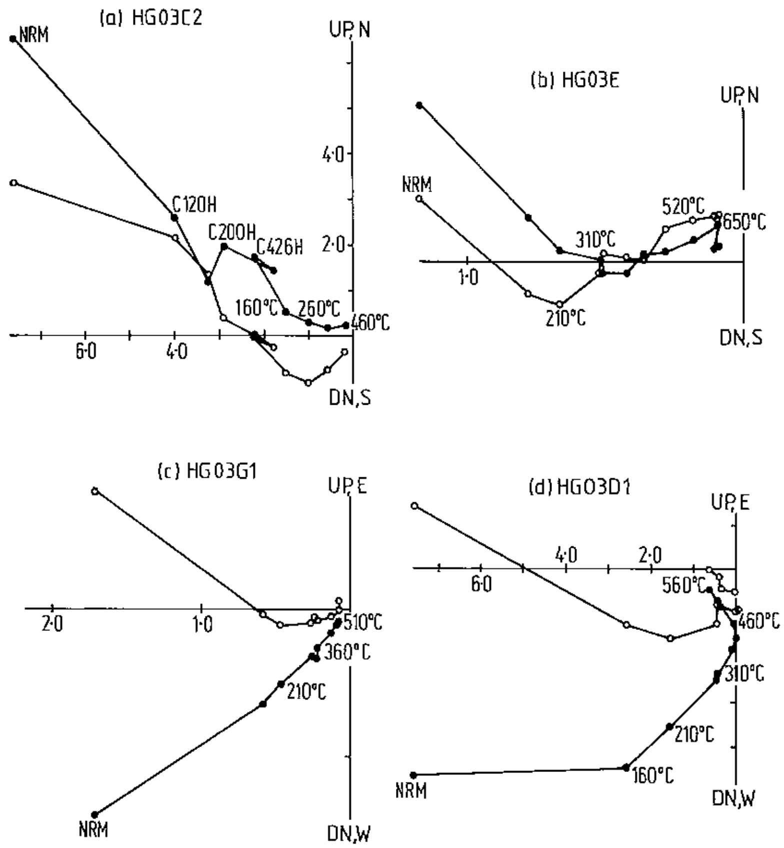

Fig. 5. Representative orthogonal projections of samples from site 3. C120H represents 120 hours' chemical leaching in condensed hydrochloric acid. Other symbols are the same as in Figure 4. All data are pre-bedding-correction.

1981], these components are all directed northerly and moderate-steep upward, and are close to the present geomagnetic field direction and the present dipole field direction (Figure 7a). Bedding correction scatters the directions indicating that the magnetizations are postfolding (Figure 7b). Thus this component is interpreted as a Recent overprint.

The harder components have different behaviors between the cleaved and noncleaved samples. They are discussed separately below.

The Noncleaved Sites

Figure 4 shows the orthogonal plots of the typical samples from the noncleaved sites. The demagnetization spectra of the soft and the hard components are well separated in these samples, with the unblocking temperature of the hard component ranging from 400°C up to about 680°C. The hard components decay to the origin and are directed either toward the north-northeast, shallow upward, or approximately the reverse of this. This component is later determined to be the characteristic magnetization of the Hervey Group. Different from the above direction, six samples from one site (site 3) yielded a hard component directed northwest downward (Figure 5). The demagnetization trends are often offset from the origin, or are curved (Figures 5b and 5d), and are considered to be either the result of unsuccessful cleaning of the magnetization, or possibly the indication that the magnetization was affected by the deformation and cleavage (see next section). Of the visibly uncleaved sites, only this site showed this peculiarity.

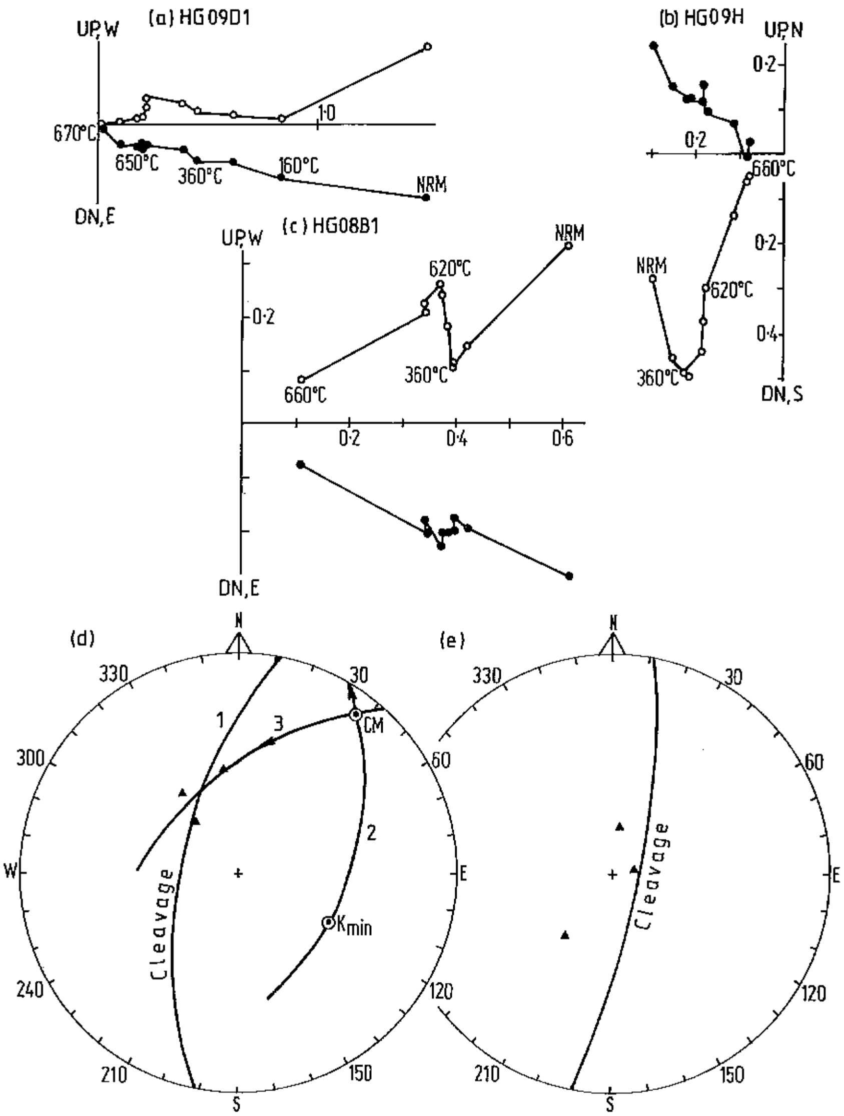

Fig. 6. (a)-(c) Representative orthogonal plots of samples from the cleaved sites. Symbols are the same as Figure 4. (d) - (e) Lower hemisphere equal angle projection of the deformation-related component in relation with cleavage, Kmin axis, and characteristic magnetization. Solid triangles are the directions of the deformation-related component. CM is the in situ direction of the characteristic magnetization transferred from the bedding-corrected mean direction of the other sites. All the directions are pre-bedding-correction.

The Cleaved Sites

In the cleaved sites the effect of the deformation is clearly shown by their remanent magnetizations. At site 9, whereas one sample from the slightly cleaved quartzites shows a similar hard component to the noncleaved samples (except for a small kink in the demagnetization othogonal plot, Figure 6a), three samples from the strongly cleaved fine-grained units revealed a hard component directed northwest, steep down (Figure 6b). This suggests that the northwest, steep downward component is related to the deformation and that the hard components present in the noncleaved samples are earlier than that. The

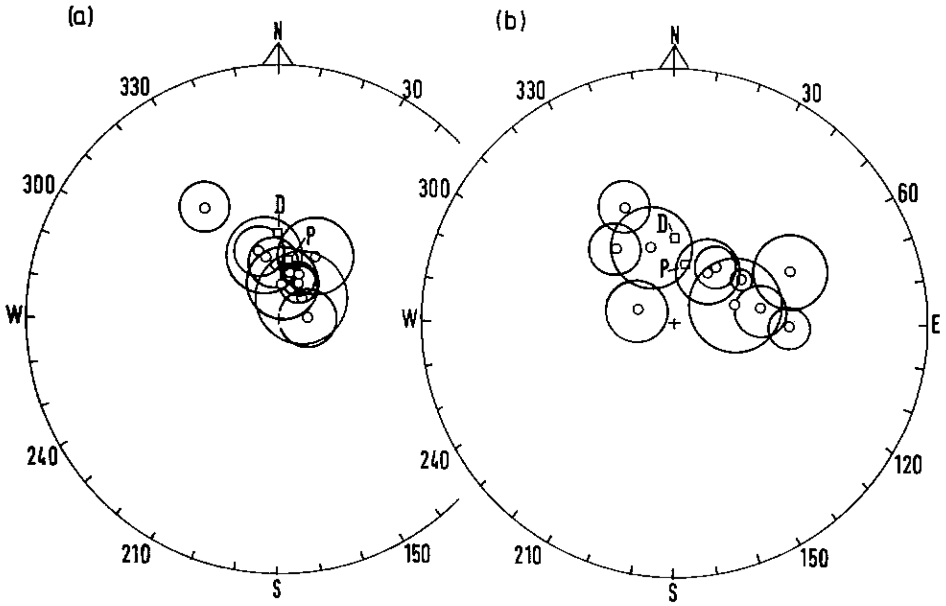

Fig. 7. Upper hemisphere equal angle projection of the site mean directions of the soft component (a) before and (b) after bedding correction. P, direction of the present geomagnetic field, D, direction of the present dipole field.

direction of the deformation-related component is obviously distinct from that of the characteristic magnetization. However, they do not fall on the great circle joining the Kmin direction and the characteristic magnetization direction (great circle 2 in Figure 6d), as suggested of deformation-related components by Hargraves [1959]. This is probably because the rocks here are strongly sheared rather than simply compressed. However, according to the "simple shear" model suggested by Hirt et al. [1986], the directions of the rotated remanence should be on a great circle joining the direction of the characteristic magnetization and the direction of shearing. In our case, the limited number of directions are all concentrated close to the cleavage plane (Figure 6d), which could be the extreme case of the simple shear model since the cleavage plane is the ultimate position for any passive line marker during simple shear movement. Another noteworthy phenomenon is that the deformation-related hard components have similar directions as the Kmax axes of the magnetic susceptibility ellipsoids. This may be just a coincidence, but it may also suggest that the hematite grains were aligned, or even recrystallized, along this direction. The actual process of the deformational remagnetization might be much more complex than the above models. More detailed rock magnetism and paleomagnetism study is needed to fully reveal the remagnetization mechanism.

At the lesser of the cleaved sites, site 8, an intermediate magnetization component is revealed between the Recent overprint and the characteristic magnetization (Figure 6c). The direction of this component is close to the great circle of the cleavage plane (Figure 6e); thus it is also considered as being deformation related. The intensity of this component is no more than a quarter of the total intensity, which may explain why these samples display their predepositional magnetic fabric.

Site mean directions of both the Recent overprint and the characteristic magnetization are listed in Table 1. Sites with less than three acceptable samples are rejected. Although compaction-produced magnetic fabric exists in all the sites which retain the characteristic magnetization, a strain removal technique [Kligfield et al., 1981; Cogne and Perroud, 1985] has not been applied because the effect of the

TABLE 1. List of the Paleomagnetic Results

Site	n'	D(°)	I(°)	n	k	α95(°)
			Recent Overprint*			
01	14	47.0	-76.2	5	15.3	20.2
02	13	346.2	-59.4	10	22.6	10.4
03	7	326.1	-35.4	5	65.7	9.5
04	6	22.9	-69.5	4	97.1	9.4
05	9	4.0	-73.5	6	20.5	15.2
06	8	85.7	-77.2	7	22.0	13.2
07	11	13.0	-68.7	9	142.5	4.3
08	8	30.9	-57.5	7	15.7	15.7
09	9	348.4	-61.1	5	28.7	14.5
10	10	31.2	-71.6	10	35.2	8.3
11	10	356.4	-66.4	8	25.9	11.1

	Pre-Bedding-Correction		Post-Bedding-Correction				
Site	D(°)	I(°)	D(°)	I(°)	n	K	α95(°)
			Characteristic Magnetization†				
01	225.8	23.2	229.5	12.2	5	155.2	6.2
02	31.8	-29.6	39.2	-20.0	13	133.0	3.6
04	43.8	-29.1	40.8	-39.8	3	159.9	9.8
05	2.1	-27.0	354.2	-33.9	9	11.3	16.0
07	19.6	-6.7	15.4	-11.7	7	9.0	21.3
08	17.4	-20.8	27.0	-14.6	4	23.0	19.6
10	216.1	19.1	198.6	21.1	10	4.9	24.3
11	215.2	-17.3	224.3	-5.1	5	6.9	31.4

*Mean: D=5.5°, I=-68.1° N=11, K=22.6, α95=9.8°, R=10.56. South Pole: (71.6°S, 137.5°E) DP=13.8°, DM=16.5°

†Mean before bedding correction: D=29.0°, I=-18.0°, N=8, K=15.2, α95=14.7°, R=7.54. Calculated south pole: (54.0°S, 22.9°E) DP=7.9°, DM=15.3°. Mean after bedding correction: D=29.2°, I=-19.3°, N=8, K=13.8, α95=15.5°, R=7.49. Calculated south pole: (54.4°S, 24.1°E) DP=8.4°, DM=16.2°.

D, declination, I, inclination. n', number of samples collected, n, number of samples accepted. N, number of sites accepted. k (K), Fisher [1953] precision parameter, α95, half angle of the 95% confidence corn; R, length of the resultent vector, DP,DM, = the semiaxes of the elliptical error around the pole at a probablity of 95%, DP in the colatitude direction and DM perpendicular to it.

compaction on the remanent magnetization is not significant [Kligfield et al., 1983].

A fold test is applied to the characteristic magnetization. Although Figure 8 shows that the population of the site mean directions becomes slightly more dispersed after bedding correction, a statistical test [McFadden and Jones, 1981] shows that the hypothesis of the directions sharing a common mean direction could not be rejected at 95% level of confidence both before and after bedding correction. This is because the directions of the magnetization are too close to the directions of the fold axes. However, the existence of predeformational magnetic fabric in the less or uncleaved samples suggests that unless all the rocks have been heated up to more than 650°C, for which no evidence exists, they should retain their predeformational magnetization. The coexistence of the deformation-related

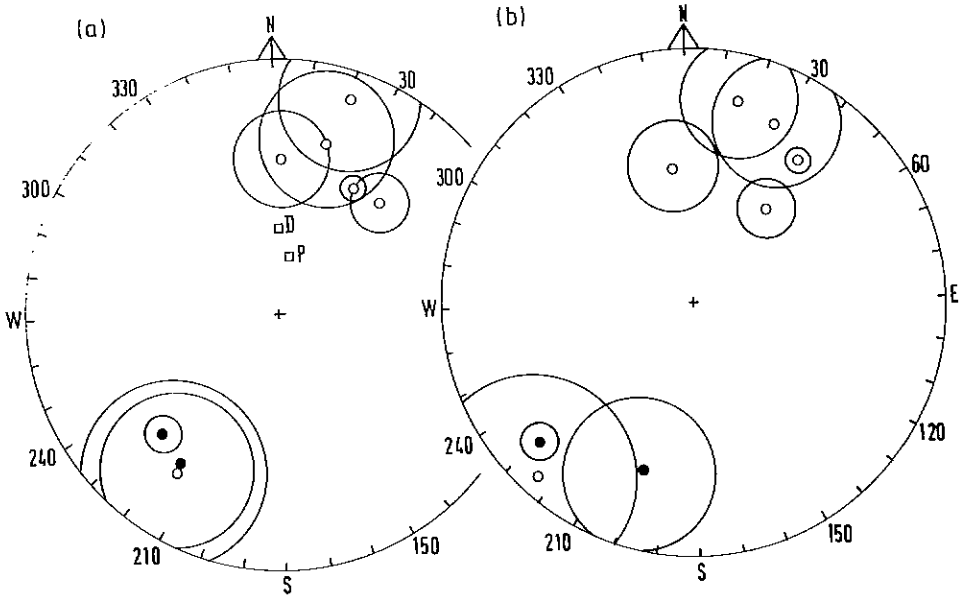

Fig. 8. Equal angle projections of site mean directions of the characteristic magnetization (a) before bedding correction and (b) after bedding correction. Solid (open) small circles are projections on the lower (upper) hemisphere. The associated larger circles are the α95 circles.

magnetization with the characteristic magnetization, and the mixed polarities, further supports this conclusion. Thus a predeformational origin, e.g., latest Devonian-Early Carboniferous, is assigned for the characteristic magnetization. The total site mean corresponding palaeopole is at 54.4°S, 24.1°E with dp=8.4°, dm=16.2°. This gives a palaeolatitude of 9.9±8.4°S for the Parkes region. One point that should be emphasized is that because the bedding correction does not make a significant difference to the total mean direction and the corresponding pole (Table 1), this pole is considered to be a true paleomagnetic pole although the assignment of its exact age may be uncertain.

DISCUSSION

The paleomagnetic pole obtained from the Hervey Group (HG) is plotted in Figure 9, together with some existing mid-Paleozoic data from Australia [Schmidt et al., 1986, 1987; Hurley and Van der Voo, 1987] and Africa [McElhinny and Opdyke, 1968; Kent et al., 1984; Hargraves et al., 1987], which are classified as class A or B poles according to the criteria set by Briden and Duff [1981]. Tectonic implications that can be drawn from these data include:

The Tectonic Development of the Lachlan Fold Belt

As we discussed before, there are two models for the LFB based on interpretations of the early paleomagnetic data: one is the allochthonous model; the other one is the in situ model. Although from a geological point of view, there is no sign of any large-scale movement either within the LFB or between the LFB and cratonic Australia since the mid-Devonian [Schmidt et al., 1986; Leitch and Scheibner, 1987], there is still room for doubt on paleomagnetic grounds [McElhinny and Embleton, 1974; Hurley and Van der Voo, 1987]. Figure 9 shows that the HG pole largely overlaps with the Canning Basin (CB) pole, which was obtained from the Late Devonian Canning Basin reefal limestones of Western Australia and was argued to be acquired very early on the basis of magnetostratigraphy [Hurley and Van der Voo, 1987]. Considering the existence of multistage diagenesis in the limestone [Hurley and Lohmann, 1986] and the lack of a fold test, it is feasible to extend the possible age of the

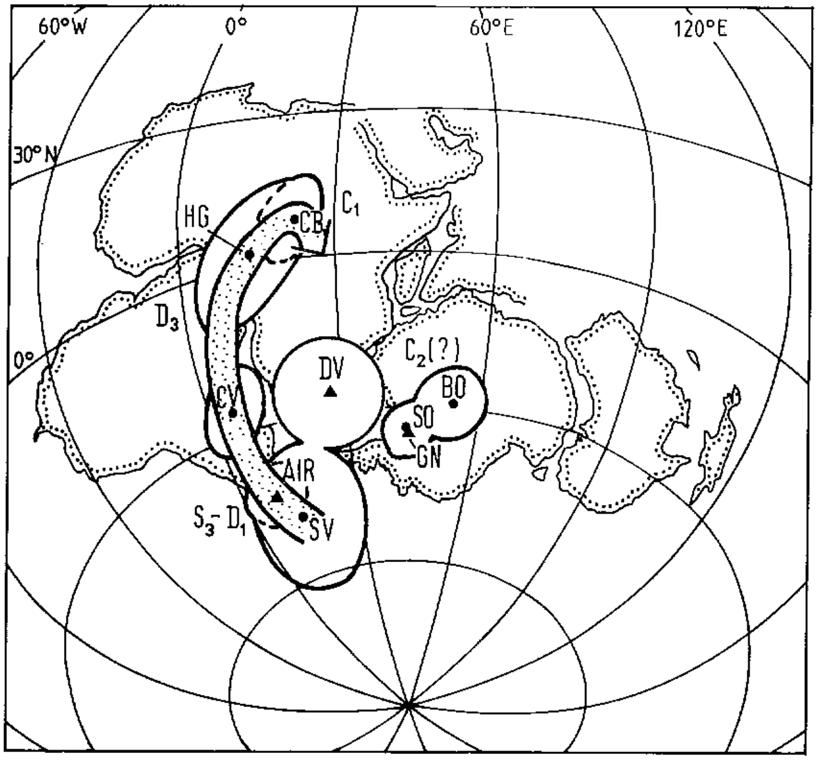

Fig. 9. Mid-Palaeozoic palaeomagnetic poles from Gondwanaland and the proposed apparent polar wander path. The model given by Smith and Hallam [1970] is used for continental reconstruction. The poles are SV, Snowy River Volcanics; LFB [Schmidt et al., 1987]; CV, Comerong Volcanics, LFB [Schmidt et al., 1986]; HG, Hervey Group sandstone, LFB (this study); CB, Canning Basin Limestone, Western Australia [Hurley and Van der Voo, 1987]; SO, postfolding overprint from the Snowy River volcanics [Schmidt et al., 1987]; BO, postfolding overprint from the Buchan Caves Limestone, LFB [Schmidt et al., 1987]; AIR Silurian ring complex, Western Africa [Hargraves et al., 1987]; DV, Dwyka glacial varves, Central Africa [McElhinny and Opdyke, 1968]; GN, Gneiguira Supergroup, Western Africa [Kent et al., 1984]. The 95% confidence ovals of the poles are shown.

magnetization up to latest Devonian or Early Carboniferous. Thus the age of the HG pole and the CB pole could be identical. The close relation between these two poles implies that the LFB has been part of cratonic Australia since at least the late Devonian. This conclusion is further supported by the new paleomagnetic pole from Silurian ring complexes in western Africa (pole AIR; Hargraves et al., [1987]), which falls close to the pole obtained from the Late Silurian to Early Devonian Snowy River Volcanics in southeast Australia (pole SV; Schmidt et al., [1987]). Therefore the Late Palaeozoic paleomagnetic poles obtained from the LFB could be applied to the whole Gondwanaland. In Figure 9 the GN pole from the Geniguira Supergroup of Western Africa is off the proposed apparent polar wander parth (APWP) and is therefore treated as a Carboniferous overprint as suggested by Schmidt et al. [1986] and Hurley and Van der Voo [1987].

The Tectonic History of the New England Region

Klootwijk [1985] reported an Early Carboniferous magnetization from the Isismurra Formation ignimbrites which gave the New England region an equatorial palaeolatitude. By comparing this data with the existing data from cratonic

Australia, he tentatively concluded that the New England region was about 30° north of cratonic Australia in Early Carboniferous and that a large-scale southward movement of this region relative to the craton occurred during the mid-Carboniferous. The new data from the Hervey Group indicating attachment to the craton also give a semiequatorial palaeolatitude for the New England region, which makes the relative latitudinal motion of the scale suggested by Klootwijk [1985] unnecessary. However, since the north-northwest declination of the Isismurra Formation ignimbrites is quite different from that of the Hervey Group, the question of whether the New England region was since joined to the craton remains open.

Rapid Rotation of Gondwanaland During the Late Devonian

Figure 9 also shows that the HG pole and the CB pole are significantly away from the Comerong Volcanics (CV) pole, which is from the Middle-Late Devonian (~370 Ma) Comerong Volcanics and has passed a positive fold test [Schmidt et al., 1986]. Hurley and Van der Voo [1987] invoked local structural rotations in the LFB to reduce the discrepancy between the CV pole and the CB pole, based on the argument that the CB pole is of the same age as the CV pole. But if the possible latest Devonian-Early Carboniferous age is used for the CB and HG pole as discussed before, this ~40° declination discrepancy could be considered to be the result of a rapid rotation of the whole of Gondwanaland during the Late Devonian. Because Australia remained at a very low palaeolatitude during this rotation, the rotation axis was probably not far from Australia. This seems to be the only model that explains all the observations without invoking large displacements which in turn demand fortuitous coincidences, vis-a-vis the agreement between the Siluro-Devonian Australian SV pole and African AIR pole. A rapid polar shift for Gondwanaland is implied in the APWP of Morel and Irving [1978], although this was largely based on low-grade poles without fold tests, i.e., the Mereenie Sandstone pole [pole MS; Embleton, 1972] or poles that have been discredited, i.e., the Msissi Norite pole [pole MN; Hailwood, 1974; Salmon et al., 1986]. However, the rapid shift proposed here is based largely on reliable data.

The Reconstructions of the Atlantic-Bordering Continents During Late Paleozoic

There are two different hypotheses for the reconstruction of the Atlantic-bordering continents. One suggests that there was an ocean of about 3000±700 km wide between the facing margins of Laurussia and Gondwanaland during Middle-Late Devonian. This ocean was not closed until Middle-Late Carboniferous when Gondwanaland collided with Laurussia, which produced the Appalachian-Hercynian Orogenic Belt [Irving, 1977; Lefort and Van der Voo, 1981; Van der Voo, 1982]. The other hypothesis suggests that the width of any ocean between Laurussia and the facing margin of Gondwanaland was likely to be very small during the Late Devonian and the Early Carboniferous, and thus the Appalachian-Hercynian Orogenic Belt is probably not related to the closure of a large ocean [Kent et al., 1984; Kent and Opdyke, 1985]. The differences between the two hypotheses are all caused by the controversy of the Middle-Late Devonian to Early Carboniferous paleomagnetic data from Gondwanaland [Kent and Opdyke, 1985]. Recent work shows that the age of the Msissi Norite is probably Jurassic [Salmon et al., 1986], and the Mereenie Sandstone pole is probably affected by Tertiary overprinting [Schmidt and Embleton, 1987; Z.X. Li et al., unpublished manuscript, 1988]. Therefore purely on the basis of the old data, the first hypothesis can be disqualified. However, the new Late Devonian-Early Carboniferous data from the Canning Basin reefal limestone and the Hervey Group all indicate a similar paleolatitude for Gondwanaland as the MN and MS poles do (Figure 10). Thus the first hypothesis can still be sustained. One thing that should be noted is the shape of the paleocean between these two supercontinents. As first suggested by Hurley and Van der Voo [1987], although a wide ocean could exist between Africa and Europe during the Late Devonian to Early Carboniferous, North and South America could be already in, or close to, contact (Figure 10). This is consistent with the model given by Copper [1986], which suggests that it was the elimination of the easterly tropical currents between

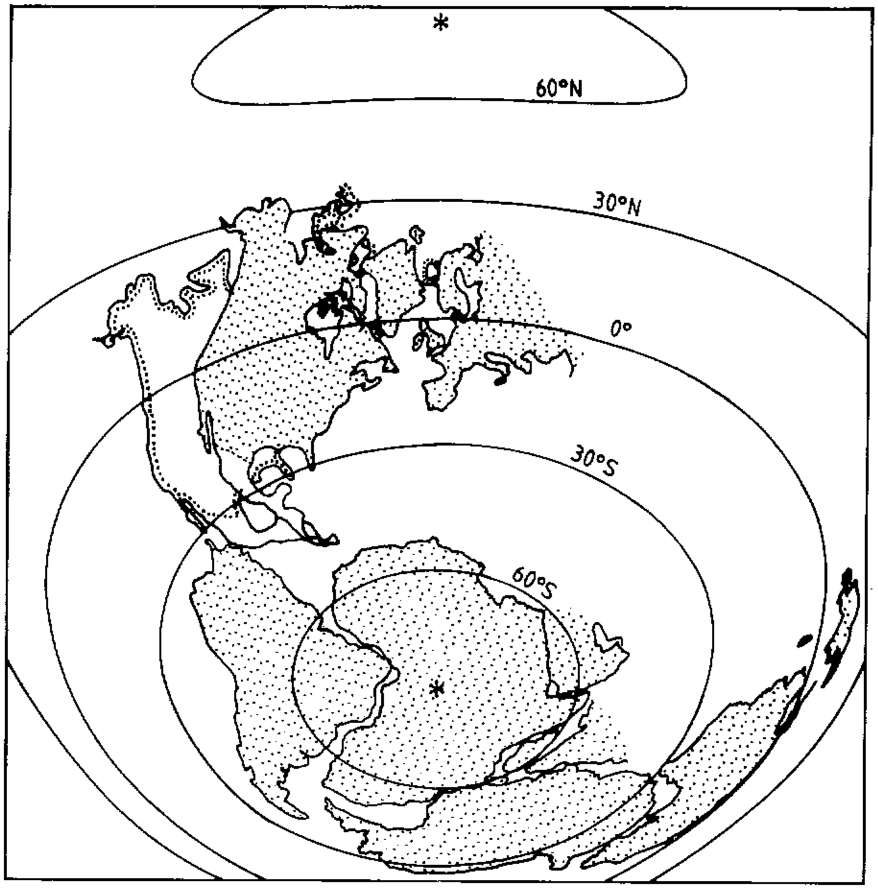

Fig. 10. Late Devonian-Early Carboniferous paleoreconstruction of Gondwanaland and Laurussia. The position of Gondwanaland (model of Smith and Hallam [1970] is determined using the mean of poles HG and CB. The Early Carboniferous reconstruction of the Laurussia (shaded) is adopted from Kent and Opdyke [1985]. The Late Devonian reconstruction of the Laurassia (unshaded) is obtained using the southwest pole from the Catskill Formation of Eastern Pennsylvania [Miller and Kent, 1986]. Lambert equal area projection is used. The palaeolongitudes are arbitrary.

these two supercontinents that led to the mass extinction in the latest Devonian.

This work also shows that in addition to field tests such as the fold test, conglomerate test, and unconformity test, the effect of deformation on the magnetic fabric and the remanence of rocks can also be used to test the age of the remanent magnetization in sedimentary rocks. This may be called a fabric test. It is particularly useful when the "conventional" tests are unavailable or insensitive.

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