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Remagnetisation of Strata during the Hunter-Bowen Orogeny

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Abstract

Palaeomagnetic studies of strata within the southern New England Fold Belt show evidence of a northward migration of remagnetisation of the Belt during the Permian. In some rock units, such as the Kiah Limestone a syn-deformational remagnetisation is observed, while in others a pre-folding magnetisation is observed.

Key words: New England Fold Belt, Hunter-Bowen Orogeny, remagnetisation, Permian, Kiah Limestone, Werrie Basalt.

Introduction

The southern New England Fold Belt underwent a "single but complex compressive tectonic event, the Hunter-Bowen Orogeny" in the Late Permian (Collins, 1991). This event caused remagnetisation which is ubiquitous in sediments and very common in igneous rocks of all preceding ages (Klootwijk and Giddings, 1988). In light of the widespread magnetic overprinting, other aspects of the palaeomagnetic data from the New England Fold Belt require re-evaluation. The apparent polar wander path (APWP) for Australia (Fig. 1) indicates rapid movement of Australia from low to high palaeolatitudes between the Late Devonian/Early Carboniferous and the Late Carboniferous (Irving, 1966; Schmidt, 1988). Recent SHRIMP ion microprobe dating of zircons from Carboniferous volcanics of the southern New England Fold Belt (Roberts *et al.*, 1991) show that the age of the Paterson Volcanics, and consequently the age of the base of the Seaham Formation, are about 330 Ma. Overlying the Seaham Formation is the Early Permian Dalwood Group (Roberts *et al.*, 1991). This implies that the Seaham Formation may have been deposited over a period of 55 Ma. As rapid as the Carboniferous polar shift was previously thought to be (Schmidt, 1988; Li *et al.*, 1989), this revised older date for the high latitude Paterson Volcanics implies plate velocities of ~6.0°/Myr, or >60cm/yr. This is an order of magnitude larger than average plate motions over the last 200 Ma, and given that the Gondwana continents were contiguous at this time, it is unacceptably large. It is noteworthy that although the Seaham Formation may represent 55 Ma, it apparently records no polar wandering during this period. In addition, the older date for the Seaham Formation pole requires backtracking of the pole path to the younger Late Carboniferous Alice Springs Orogeny pole. We propose that widespread magnetic updating of Devonian and Carboniferous strata in the New England Fold Belt during the Permian accounts for this enigma.

Results

Sixty oriented samples were collected from ten sites within the Kiah Limestone over a strike length of 100km (Fig. 2). The Kiah Limestone is thought to be Late Devonian or Early Carboniferous in age (Voisey and Packham, 1969). Thermal demagnetisation of the samples reveals two components, a soft remanence directed in the present geomagnetic field direction which is usually demagnetised by 300°C and a second component which is usually demagnetised between 500°C and 550°C. The in-situ directions of the harder component of samples from the different sites are scattered (Fig. 3). On progressive correction for bedding tilt the site directions firstly converge and then diverge (Fig. 4). This phenomenon is common in folded strata that have been remagnetised and is attributed to syn-deformational remagnetisation (SDR, Schmidt and Embleton, 1987). If we apply a fold test that assumes a uniform rate of tilting (McFadden, 1990), then 62 percent of tilting yields the best

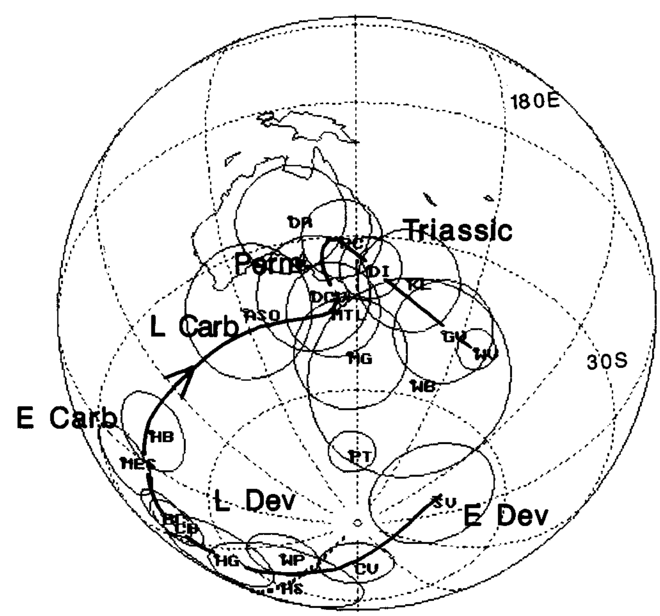

FIGURE 1
Apparent polar wander path (APWP) for Australia from the Devonian to Jurassic. SV, Snowy River Volcanics, Schmidt *et al.* (1987). CV, Comerong Volcanics, Schmidt *et al.* (1986). HS, Hermannsburg Sandstone, Li (1988). WP, Worange Point Formation, Thrupp *et al.* (1991). HG, Hervey Group, Li *et al.* (1988). CB, Canning Basin, Hurley and Van der Voo (1987). BC, MES, Brewer Conglomerate, Mount Eclipse Sandstone, Chen *et al.* (1993). HB, Hartley area/Bathurst Batholith, Wahyono (1992). ASO, mean Alice Springs Orogeny pole, this study, see note in Table 2. MG, PT Main Glacial Stage (Seaham Formation), Paterson Volcanics, Irving (1966). MTL, Mount Leyshon diatreme, Lackie *et al.* (1991). DCV, Conway-Bimurra volcanics, Lackie *et al.* (1992). DR, DI, Dundee Rhyodacite, Dundee Ignimbrite, Lackie (1989). PC, Patonga Claystone, Embleton and McDonnell (1980). WB, KL, Werrie Basalt, Kiah Limestone, this study. WV, Western Victorian Basalt, Schmidt (1976a). GV, Garrawilla Volcanics, Schmidt (1976b). All palaeomagnetic poles are listed in Table 2. Plot type: orthographic. Centre of plot 45°S, 150°E.

correlation between the site mean directions. However, if we allow for non-uniform tilting, then a much better correlation between site mean directions is possible. That is, if we make the reasonable assumptions that the geomagnetic field axis did not change grossly while these rocks were being remagnetised, and that they acquired remanences parallel to the field at that time, then to satisfactorily explain these data we are led to the conclusion that the beds were remagnetised during different stages of deformation. In detail, there is a trend along strike suggesting that subsequent to remagnetisation more tilting has occurred in the south than in the north. Directions from sites in the north (KL02-KL06) require a small amount of untilting to bring them into agreement, while southerly sites (KL01,KL10) require almost complete untilting. Fifty percent untilting has been applied to sites KL07-KL09 (i.e. those between the most northerly and southerly sites) which produces a tight group of directions as displayed in figure 3. Thus, with respect to the time of folding, the time of remagnetisation appears to have migrated from the southeast to the northwest.

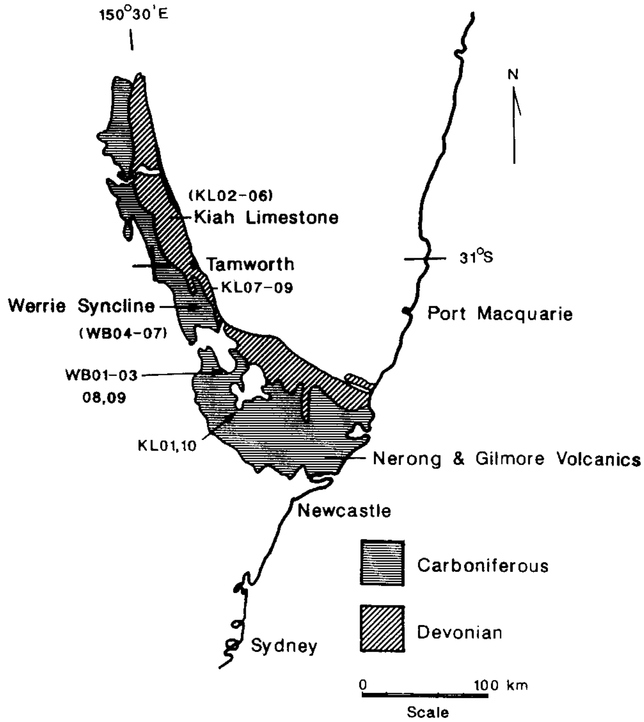

FIGURE 2
Geological sketchmap of the Tamworth Belt and sample areas for the Kiah Limestone (KL) and Werrie Basalt (WB).

After partial untilting (Table 1) nine sites in the Kiah Limestone yield a mean direction of Dec= 125.3°, Inc= 83.7° (α_{95} = 5.5°), and a pole position at Lat= 38.0°S, Long= 162.3°E (A_{95} = 10.0°).

The Permian Werrie Basalt was sampled near Murrurundi, in the upper Hunter Valley (sites WB01-03, WB08-09, Fig. 2) and from the Warrigundi Complex (sites WB04-07, Fig. 2), which was recently shown to be of similar chemistry and age to the Werrie Complex (Flood *et al.*, 1988). Fourty-five oriented samples were collected from 9 sites within the Werrie Basalts and the Warragundi Complex. Samples from sites WB04 and WB07, within the topographically prominent Warrigundi Complex have been affected by lightning and did not yield useful information. Another site, WB09 from within the Werrie Basalt proper, also failed to yield a useful result for an unknown reason. The other 6 sites provided internally consistent results that are discussed below.

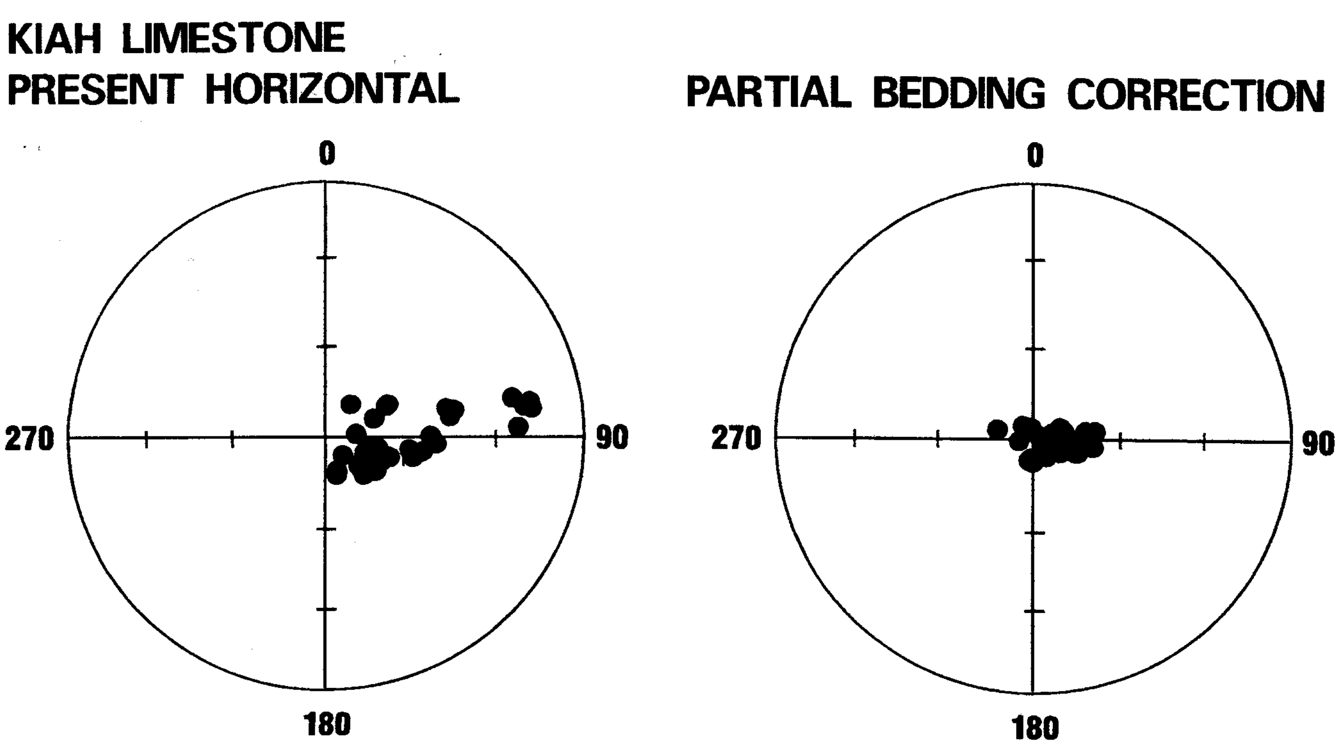

FIGURE 3
Equal area stereographic plots of sample directions from the Kiah Limestone. Closed (open) symbols represent lower (upper) hemisphere projections. Plots are of sample directions with respect to the present horizontal and after partial bedding correction has been applied. Partial bedding correction as per Table 1.

Alternating field (AF) and thermal demagnetisation of thirty-two samples from the remaining sites, WB01-03, 05-06 and 08, define single remanent components with high unblocking temperatures and high coercivities of remanence, consistent with magnetite. The remanence directions display good within-site agreement but poor between-site agreement with respect to present horizontal (Fig. 5). Applying a fold test (McFadden, 1990) the magnetisation appears to have been acquired prior to significant tilting of the various flow units. In their present attitudes the directions yield a fold test statistic of 5.4, while after tilt correction the test statistic drops to 1.6, compared to 95% and 99% confidence values for the test that are 2.9 and 3.9 respectively. This shows that the magnetisation predates folding. After correction for simple bedding tilt the site-mean direction (Table 1) for the Werrie Basalt is Dec= 158.8°, Inc= 74.4°, k= 34.9, α_{95}= 11.5°, yielding a pole position at Lat= 57.2°, Long= 170.3° and an A_{95}= 20.2°. We have no reason to doubt that the magnetisation of the Werrie basalt is not original, since it was magnetised before folding and therefore before the syndeformational remagnetisation in the northwest.

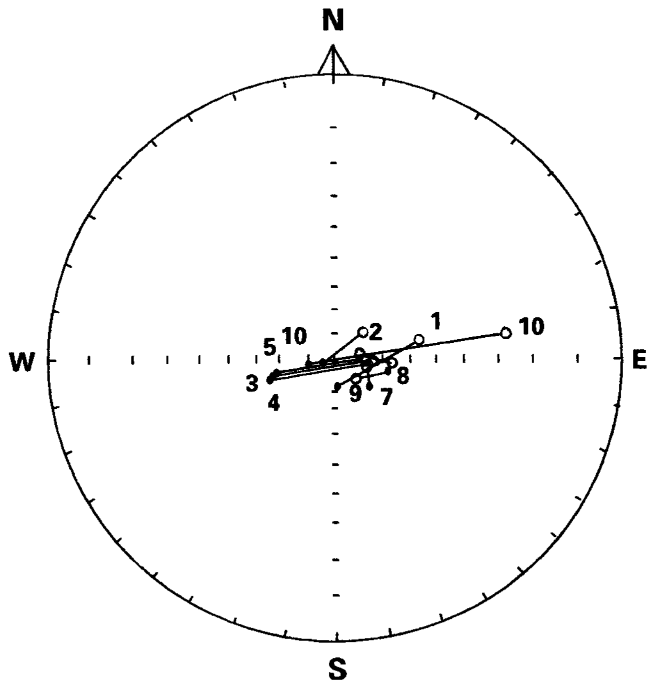

FIGURE 4
Equal area stereographic plot of site directions from the Kiah Limestone. Open (closed) symbols are directions before (after) full bedding correction. Note the scatter of site directions before and after a full bedding correction, compared to the partial bedding correction results observed in figure 3.

Discussion

The current APWP for Australia (Fig. 1) indicates large latitudinal movement of Australia from low palaeolatitudes in the Late Devonian/Early Carboniferous, as shown by the Worange Point (WP), Hervey Group (HG) and Mount Eclipse Sandstone (MES) poles, to high palaeolatitudes in the Late Carboniferous/Early Permian, as shown by the mean Alice Spring Orogeny pole (ASO comprises overprint poles referenced by Camacho *et al.* 1991) and the Early Permian Mount Leyshon pole (MTL). The Seaham Formation pole (MG), referred to previously as the Main Glacial Stage pole (Irving, 1966) falls quite close to the Early Permian MTL pole, suggesting an Early Permian age of magnetisation for the Seaham Formation rather than a Visean/Namurian age for the magnetisation.

WERRIE BASALT
PRESENT HORIZONTAL

BEDDING

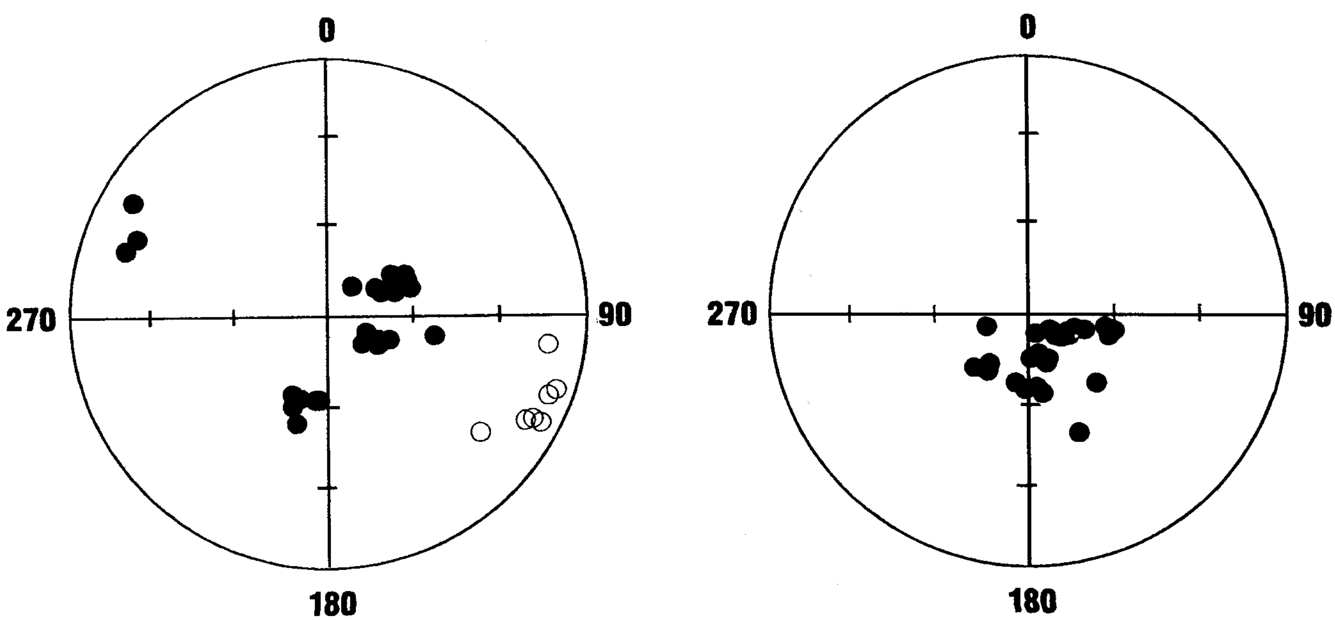

FIGURE 5
Equal area stereographic plots of sample directions from the Werrie Basalt. Closed (open) symbols represent lower (upper) hemisphere projections. Plots are of sample directions with respect to the present horizontal and after bedding correction.

The pole for the Paterson Volcanics (Irving, 1966), which are now considered to be 330 Ma old (Roberts *et al*, 1991), falls approximately 60° away from the mid-Carboniferous Hartley area/Bathurst Batholith pole (HB). As is discussed above for the Seaham Formation, such an early date for the Paterson Volcanics requires backtracking of the pole path from PT to the younger HB pole (Fig. 1). Thus, it is possible that the Paterson Volcanics have been remagnetised after Australia had moved to higher palaeolatitudes, although it is of normal polarity and would have had to be remagnetised some time after the Seaham Formation (i.e. post-Kiaman). It should be noted that the Paterson Volcanics is a D-class pole (using the palaeomagnetic data quality filter of Li, 1993) and is therefore of questionable quality.

The results from the Seaham Formation show a positive fold test (Irving, 1966) indicating that magnetisation occurred pre-folding. The pole position of the Seaham Formation suggests an Early Permian age of magnetisation. Data from the Werrie Basalt also shows that magnetisation has occurred prior to

TABLE 1
Summary of Palaeomagnetic Results

A. Kiah Limestone

Site	N	D_h(°)	I_h(°)	%b	D_b(°)	I_b(°)	k	α_{95}(°)	lat(°S)	long(°E)	A_{95}(°)	DDA(°)	Dip(°)
01	14	77.7	55.7	100	170.4	78.8	1662	1.0	52.9	156.9	1.8	238	37
02	4	50.6	74.5	30	274.9	86.7	239	6.0	30.0	143.3	11.7	237	18
03	4	96.0	76.0	30	132.1	85.9	293	5.4	36.0	158.1	10.6	262	38
04	5	102.3	77.3	30	159.1	85.7	409	3.8	38.6	154.5	7.5	"	"
05	5	99.3	77.9	30	162.1	86.5	589	3.2	37.2	153.2	6.3	"	"
07	6	91.4	77.1	50	115.1	75.4	1048	2.1	39.0	183.5	3.6	177	13
08	6	92.3	68.4	50	89.3	73.2	148	5.5	26.3	185.5	9.3	282	10
09	5	129.4	78.0	50	112.7	75.0	178	5.8	38.0	184.1	9.9	067	10
10	5	82.7	27.8	90	270.9	88.2	557	3.2	31.6	146.9	6.5	262	71
Mean	9	—	—		125.3	83.7	95.6	5.5	38.0	162.3	10.0		

B. Werrie Basalt

Site	N	D_h(°)	I_h(°)	D_b(°)	I_b(°)	k	α_{95}(°)	lat(°S)	long(°E)	A_{95}(°)	DDA(°)	Dip(°)
01	7	57.6	63.1	180.1	69.7	146	5.0	67.9	151.3	8.0	213	42
02	7	185.5	51.5	133.5	77.9	226	4.0	45.3	174.8	7.1	024	33
03	4	122.3	66.8	99.1	66.2	532	4.0	29.0	199.0	5.8	024	10
05	4	88.0	64.2	152.1	71.9	26.9	18.0	56.5	177.1	29.0	225	25
06	3	301.9	17.5	221.9	70.6	63.1	15.7	51.7	112.3	26.0	142	75
08	7	119.4	-9.7	163.0	66.6	42.3	9.4	67.3	180.8	13.9	278	90
Mean	6	—	—	158.0	74.4	34.9	11.5	57.2	170.3	20.2		

N, number of samples. D_h, I_h, Declination, Inclination with respect to present horizontal. %b, percentage of unfolding, Werrie Basalt sites are all 100%. D_b, I_b, Declination, Inclination with respect to bedding after %b of unfolding. k, α_{95}, precision parameter of the Fisher Distribution, radius of confidence cone (Fisher 1953). lat, long, A_{95}, latitude, longitude and radius of the confidence cone of the palaeomagnetic pole. DDA, Dip, down dip azimuth and dip of bedding.

TABLE 2
Palaeomagnetic poles for APWP.

Mnemonic	Age(Ma)	Lat(°S)	Long(°E)	A_{95}/dp,dm(°)	Ref
WV	E Jur	47	186	4	1
GV	E Jur	46.1	175.2	10	2
DI	E Tr	36.2	153.5	6,6	3
DR	L Perm	25.1	135.9	11,11	3
PC	E Tr	30.4	146.9	7.8	4
WB	L Perm	57.2	170.3	20.2	TS
KL	L Perm	38.0	163.2	10	TS
MTL	E Perm	44.3	143.8	8.8,9.4	5
DCV	E Perm	40.6	139.0	10.9,11.4	6
MG	E Perm	53	148	11	7
PT	?	73	147	4,5	7
ASO	L Carb	40.8	120.8	13.2	TS#
HB	E Carb	45.3	71.9	6.8,10.2	8
MES	E Carb	38.2	54.4	8.1	9
BC	L Dev	47.1	41.0	6.4	9
CB	L Dev	49.1	38.0	4.7,8.6	10
HG	L Dev	54.4	24.1	8.4,16.2	11
WP	L Dev	70.8	19.7	7.1	12
HS	L Dev	61.0	0.9	15.6	13
CV	L Dev	76.9	330.7	7.2	14
SV	E Dev	74.3	222.7	10.9,14.5	15

Note, age refers to the age of magnetisation. The age is quoted to the Epoch, although authors may be more specific. A_{95}, radius of the confidence cone of the palaeomagnetic pole. dp, dm, the semiaxes of the elliptical error around the pole at a probability of 95%, dp in the colatitude direction and dm perpendicular to it.

#, the mean Alice Springs Orogeny pole is calculated from the poles discussed by *Li et al.* (1989) and Camacho et al. (1991). The final episode of thrusting during the Alice Springs Orogeny was 300-320 Ma (Shaw et al., 1992). This is considered to be the age of magnetisation.

References: 1, Schmidt (1976a). 2, Schmidt (1976b). 3, Lackie (1989). 4, Embleton and McDonnell (1980). 5, Lackie *et al.* (1991). 6, Lackie *et al.* (1992). 7, Irving (1966). 8, Wahyono (1992). 9, Chen *et al.* (1993). 10, Hurley and Van der Voo (1987). 11, Li *et al.* (1988). 12, Thrupp *et al.* (1991). 13, Li (1988). 14, Schmidt *et al.* (1986). 15, Schmidt *et al.* (1987). TS, this study.

significant tilting of the flow units. Data from the Kiah Limestone in the south of the Tamworth Belt are interpreted to indicate that magnetisation occurred just before, or at the beginning of folding. This is similar to the Werrie Basalt result. However, in the central part of the Tamworth Belt the Kiah Limestone results indicate that magnetisation was acquired at various stages of folding.

In the mid to Late Permian, meridional folds developed throughout the Tamworth Belt producing the Werrie and Gloucester Synclines and the Timor Anticline (Collins, 1991). If folding was synchronous within the Tamworth Belt then the Permian remagnetisation event progressively moves from the southeast in the Early Permian to the northwest in the mid to Late Permian. It can also be argued that if the remagnetisation was synchronous, then folding of the belt has progressed from the northwest to the southeast although this is not favoured on geological grounds. For instance, Collins (1991) notes that deformation normally migrates towards the foreland, or east to west for the southern New England Fold Belt.

We hypothesise, therefore, that remagnetisation and deformation both began in the southeast, but that the remagnetisation predated the deformation. Both remagnetisation and deformation progressed northwest but at different rates with the latter catching up to the former, so that strata in the northwest were deformed at about the same time as they were remagnetized. The mechanism for remagnetisation in fold belts may be due to fluid movements as originally suggested by Oliver (1986) or if these fluids are related to granite intrusion, the ages of granites might also be expected to reflect the remagnetisation trends. We therefore speculate whether the age trend from the Barrington Tops Granodiorite in the southeast (265-270 Ma, Roberts and Engel, 1987) to the Moombi Suite granites (247-249 Ma, S.E.Shaw unpubl. data) in the northwest, is germane to remagnetisation.

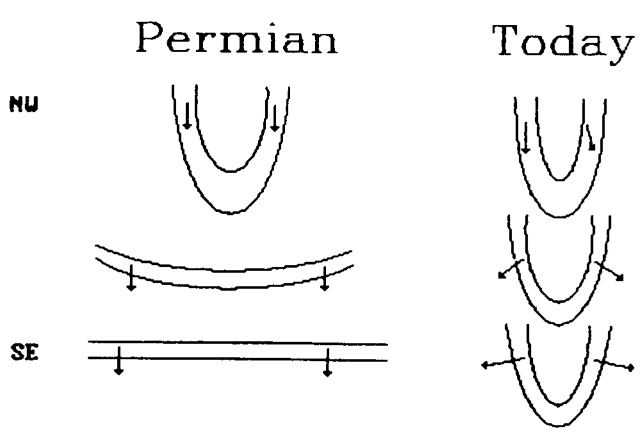

FIGURE 6
The left diagram depicts the relationship between the degree of folding and remagnetisation within the Tamworth Belt during the Permian. In the southeast, remagnetisation occurs pre-folding, while progressively further to the northwest remagnetisation occurs during greater degrees of folding. The right side, shows the relationship of the remanence to the units with respect to the structure of those units. Note, that in the south (Seaham Formation) the remanence of the sediments is dissimilar between limbs (because it is a pre-folding remanence) while in the north (northern Kiah Limestone samples) the remanence is close to parallel between limbs (reflecting the syn-folding remanence).

Diachronous remagnetisation along a fold belt is not unique to the New England Fold Belt. Remagnetisation data from the Appalachian Fold Belt in North America also indicate that remagnetisations were diachronous over the length of the belt (Miller and Kent, 1988). These workers observed prefolding remagnetisations in the southern Appalachians, synfolding magnetisations in the central region and postfolding remagnetisations in the north-central Appalachians.

The relationship between the sequence of folding and remagnetisation within the Tamworth Belt during the Permian is shown in figure 6. In the southeast remagnetisation occurred in the flat lying units, while further to the northwest, the remagnetisation occurred at the initiation of folding and still further northwest, remagnetisation was synfolding. As a consequence of the time of remagnetisation of the units and the corresponding attitude of the strata, the present *in-situ* remanence is steeply inclined in the northwest but only moderately inclined in the southeast.

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