

MR F 573

Palaeomagnetic correlation of the Acraman impact structure and the Late Proterozoic Bunyeroo ejecta horizon, South Australia

P. W. SCHMIDT¹ AND G. E. WILLIAMS²

¹CSIRO Division of Exploration Geoscience, PO Box 136, North Ryde, NSW 2113, Australia.

²Department of Geology and Geophysics, University of Adelaide, GPO Box 498, Adelaide, SA 5001, Australia.

Palaeomagnetic data for meltrock from the Acraman impact structure, South Australia, indicate a stable magnetization and a virtual geomagnetic pole that is in close agreement with the palaeomagnetic pole for the Late Proterozoic (~600 Ma) Bunyeroo Formation in the Adelaide Geosyncline. The palaeomagnetic data are therefore consistent with the correlation of the Acraman impact event and deposition of the widespread impact ejecta horizon in the Bunyeroo Formation.

Key words: Acraman impact structure, Adelaide Geosyncline, Bunyeroo ejecta horizon, Bunyeroo Formation, Gawler Range Volcanics, Late Proterozoic palaeomagnetism, meteorite impact.

INTRODUCTION

The Acraman structure (Williams 1986, 1987, 1990) located in the Middle Proterozoic (~1590 Ma) Gawler Range Volcanics, South Australia (Fig. 1), is one of the largest known terrestrial impact structures. It is notable also as the likely source of a unique ejecta horizon of shock-deformed volcanic fragments within the Late Proterozoic (~600 Ma) Bunyeroo Formation of the Adelaide Geosyncline located 220–350 km east of the impact site (Gostin *et al.* 1986; Williams 1986) and within the correlative Lower Rodda Beds of the Officer Basin ~450 km northwest of the impact site (Wallace *et al.* 1989). The correlation of the Acraman structure with the Bunyeroo/Rodda ejecta horizon is based on the similarity of lithologies of the target and the ejecta material (both being dacitic), U–Pb zircon ages (Compston *et al.* 1987), and degree of shock metamorphism of ejecta clasts and rocks from the impact site, as well as the geographic distribution of the ejecta and lateral variation of clast size within the horizon (Gostin *et al.* 1986, 1990).

The structure comprises a central uplift area ~10–12 km across marked by sparse outcrops of intensely shattered and shock-deformed Yardea Dacite, within an inner topographic depression 30–35 km in diameter that contains the Lake Acraman salina. Rocks of the central uplift area exhibit shatter cones and multiple sets of shock lamellae in quartz grains that indicate shock pressures of ~15 GPa, strongly supporting an impact origin. The inner depression may mark the

site of the excavated area; a near circular 'ring' of structurally controlled valleys and low-lying country at 85–90 km diameter may indicate the limit of the final collapse crater (Williams 1987, 1990). The structure is now strongly degraded and

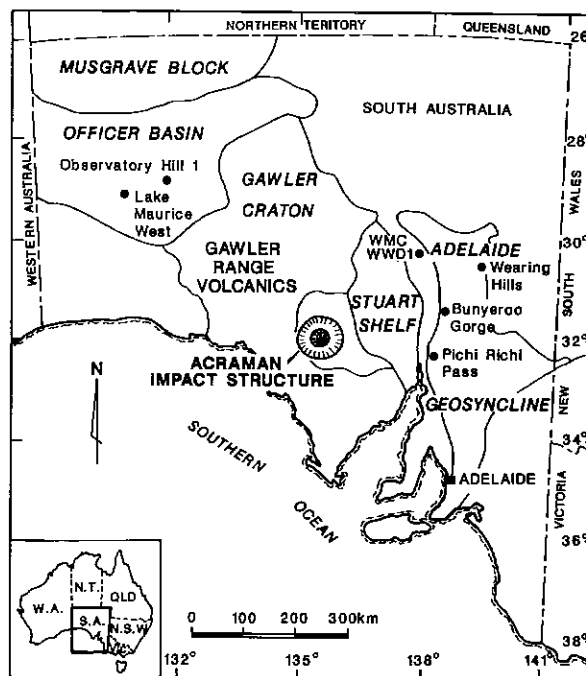


Fig. 1 Map of South Australia showing the Acraman impact structure in the Gawler Range Volcanics, and key ejecta localities (●) in the Adelaide Geosyncline and Officer Basin (after Wallace *et al.* 1989).

eroded to a level probably well below the former crater floor.

Unshattered meltrock with textures typical of quenched glassy material envelops fragments of shattered dacite at one locality in the central uplift area. The meltrock is an apparent dyke that is gently dipping, ~1 m thick, and crops out over a few square metres at the margin of an island in Lake Acraman (32°3'4"S, 135°26'8"E — AMG 543453 Yardea 1:250 000 Sheet SI 53-3). It consists mainly of small laths of albite and numerous scattered grains of variably oxidized titaniferous magnetite up to ~30 μm diameter, some showing exsolution intergrowths of ilmenite, set in a devitrified matrix of cloudy potassium feldspar and finely intergrown quartz (Williams 1990). The inner depression has an aeromagnetic signature that is generally subdued compared with that over the surrounding Gawler Range Volcanics. The aeromagnetic signature of the Gawler Range Volcanics and that attributable to meltrock reflect different sources. The smooth magnetic field over the meltrock indicates homogeneous magnetic properties as opposed to the pronounced anomalies typical of volcanic areas. In addition, a distinctive dipolar aeromagnetic anomaly occurs in the centre of the structure, apparently related to the central uplift area (BMR Aeromagnetic Map Sheet, Yardea SI 53-3).

This paper reports the palaeomagnetic pole position for the Acraman meltrock and compares it with that from the Bunyeroo Formation. The value of aeromagnetic and palaeomagnetic investigations in determining the age of impact events has been demonstrated previously for a number of impact structures, including Gosses Bluff in the Northern Territory (Milton *et al.* 1972; H. C. Halls in Schmidt & Embleton 1981), Manicouagan in Quebec (Laroche & Currie 1967; Robertson 1967), Rochechouart in France (Pohl & Soffel 1971), Lonar Lake in India (Poornachandra Rao & Bhalla 1984) and the Kentland structure, Indiana (Jackson & Van der Voo 1986). The palaeomagnetic data presented here are indeed consistent with the correlation of the Acraman impact and the Bunyeroo ejecta blanket.

PALAEOMAGNETIC DATA FOR THE ACRAMAN MELTROCK

Sampling

Four to six oriented drill core and hand samples were collected from each of eight sites within the Acraman impact structure using a suncompass/

clinometer. Two sites comprise intensely shattered dacite, one site is the meltrock, and the remainder are normal, unshattered dacite at distances up to 20 km from the inner depression. The shattered dacite could not be drilled in the field because of intense fracturing.

Methods

Routine palaeomagnetic methods (McElhinny 1973; Collinson 1983) were applied to all samples. A CTF cryogenic magnetometer and DIGICO fluxgate magnetometer were used for measuring magnetic remanence. Magnetic remanence was cleaned by both thermal and alternating field (AF) methods. The furnace used was the CSIRO carousel furnace housed in a 10-coil Helmholtz set with feedback to maintain quasi-field free space in the coil centre. A Schonstedt GD1 AF demagnetizer was used for AF demagnetization. Magnetic components were identified and determined by a method modified from that described by Kent *et al.* (1983). Susceptibilities and the temperature dependence of susceptibility ($k-T$) were measured on the transformer bridge described by Ridley and Brown (1980).

The electron microprobes used were those at the University of Adelaide (JEOL 733 Microprobe facility, Electron Optical Centre) and at CSIRO North Ryde (Camebax scanning microprobe fitted with four wavelength dispersive X-ray spectrometers and a Kevex 7000 energy dispersive X-ray system). The CSIRO XRD equipment is a Philips PW1700 unit incorporating APD software for rapid interactive investigation of powder diffraction data.

Results

Natural remanent magnetization (NRM) directions were scattered at all sites. In some sites the cause of this was evidently lightning since some samples displayed very intense remanences (>100 A/m or 0.1 emu/cm³). The only samples that responded to cleaning were those of the meltrock, which exhibits a very stable remanent magnetization. The magnetic phase present in the meltrock has a coercivity of remanence of 32 kA/m (400 Oe), which is sufficient to withstand all but a direct lightning strike. The coarser grained dacite has a coercivity of remanence of 20 kA/m (250 Oe).

The maximum Curie temperature (T_C) of the magnetic carriers in the meltrock was found to be 630°C from low-field thermomagnetic ($k-T$)

analysis. There were a number of distinct titanomagnetite phases present with variable TiO_2 contents reflected by lower T_C in the k - T analysis. The 630°C is higher than the Curie temperatures for either pure end-member magnetite (575°C) or pyrrhotite (360°C). Although titaniferous hematite may have a Curie temperature of 630°C , the coercivity of remanence is consistent with the magnetic phase having a spinel structure, rather than a magnetically hard rhombohedral phase such as that of hematite. These observations are very similar to those of Pohl (1971) who found that the main remanence carrier in impactites is commonly magnetite, or somewhat titaniferous magnetite, largely of single-domain grain size. Hematite, which is not stable with respect to magnetite $>1400^\circ\text{C}$, is usually absent. Microprobe and XRD analyses show that the magnetic carriers are variably altered and oxidized, cation-deficient titanomagnetite. Extreme cation deficiency yields maghemite, which inverts to hematite on heating to $\sim 350^\circ\text{C}$ but is estimated to have a Curie temperature of $\sim 750^\circ\text{C}$ (Stacey & Banerjee 1974, p. 31). No such inversion was observed here, suggesting that the oxidation of the Acraman meltrock titanomagnetite has been partial.

The cause of the oxidation/cation-loss is unknown but may be an original feature of the meltrock. Although titanomagnetite may oxidize to produce cation-deficient phases, the direction of their remanent magnetization is not affected (Readman & O'Reilly 1971). For example, sea-floor basalts are known to oxidize producing cation-deficient titanomagnetite (Bleil & Petersen 1983), but the direction of their remanence is retained, being the cause of marine magnetic anomalies. Thus even if the slight oxidation of the magnetite in the meltrock has occurred subsequent to its formation, it is likely to have retained an original magnetic direction from the time of the impact.

Figure 2 shows the behaviour of a sample of meltrock on demagnetization. AF (partial) demagnetization was applied initially, since this is more effective in eliminating lightning-induced isothermal remanent magnetization (IRM). The soft IRM component is removed up to 20 mT (200 Oe), leaving a hard component that, on thermal demagnetization, only decays appreciably $>580^\circ\text{C}$. Some remanence persists to 630°C which substantiates the Curie temperature determined from k - T analysis. This magnetic material is of optimum single domain/pseudo-single domain grain size, capable of retaining an original magnetic remanence for a very long time unless chemical alteration completely changes the mineralogical structure, or it is heated for a long geological time at

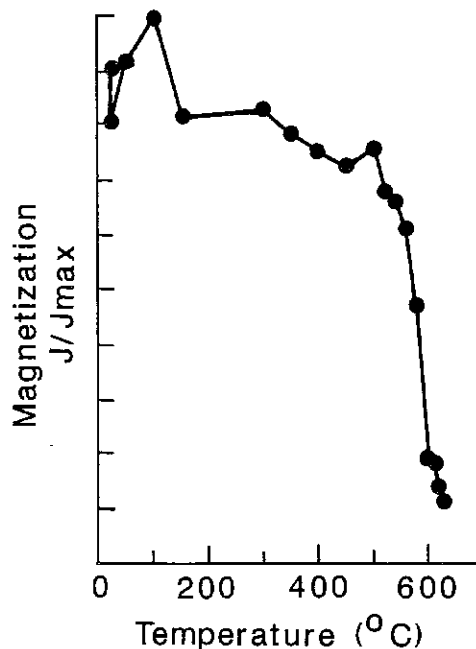
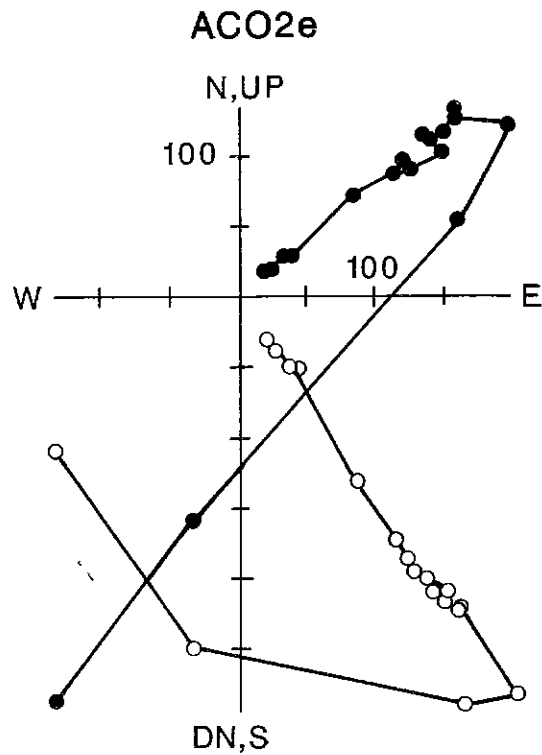


Fig. 2 Palaeomagnetic results: (a) orthogonal projection of magnetization vector on demagnetization (\bullet : the horizontal plane; \circ : vertical plane); and (b) intensity decay curve, the first three treatment steps being 5 mT (50 Oe), 10 mT (100 Oe) and 20 mT (200 Oe) alternating field demagnetization, and the remainder being thermal demagnetization at the temperatures shown.

high temperatures ($> 500^{\circ}\text{C}$). Neither the meltrock nor the parent volcanics shows evidence of any such heating event. There is no sign of Delamerian (Ordovician) overprinting of the Gawler Range Volcanics from the palaeomagnetic study by Chamalaun and Dempsey (1978). It should also be emphasized that the direction of the meltrock magnetization is unlike the palaeomagnetic direction found in the Gawler Range Volcanics. There is no sign of a present field direction that may arise from weathering, or viscous remanent magnetization (although the lightning-induced component may have obliterated the latter). We therefore conclude that the high-temperature component of the magnetization dates from the time of the impact.

The directions of the high-temperature components from eight specimens, and their mean direction and error circle (declination = 48.3° , inclination = 54.7° , $\alpha_{95} = 5.2^{\circ}$), are plotted in Fig. 3. The directions yield a mean pole position at latitude = 8.6°S and longitude = 353.4°E ($A_{95} = 6.3^{\circ}$). The character of the meltrock remanence (e.g. low directional dispersion and high stability) is similar to that displayed by impactites containing melt material from other impact structures (Laroche & Currie 1967; Pohl 1971; Pohl & Soffel 1971).

An estimate of the NRM of the Acraman meltrock, when combined with an induced magnetization proportional to the susceptibility of the meltrock, may be used to accurately model the dipolar aeromagnetic anomaly in the central uplift area.

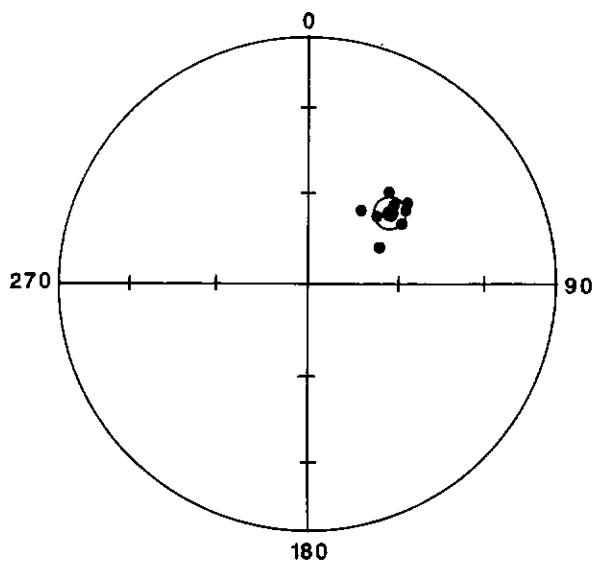


Fig. 3 Equal area projection of cleaned remanence directions (small solid dots) and mean direction (large solid dot) with cone of 95% confidence (all directions plot on the lower hemisphere).

The axis of this anomaly is deflected to the north-east by the remanence. The magnetization direction of the subsurface central uplift is apparently similar to that observed in the meltrock. We note that because of the lightning-induced IRM the actual NRM intensity of the meltrock had to be estimated.

PALAEOMAGNETIC DATA FOR THE ADELAIDE GEOSYNCLINE

The palaeomagnetism of the Adelaide Geosyncline, including the Bunyeroo Formation containing the ejecta horizon, has been reported by McWilliams and McElhinny (1980). The Proterozoic and Early Palaeozoic rocks of the geosyncline were folded during the Late Cambrian–Ordovician Delamerian Orogeny. The Late Proterozoic (~ 600 Ma) Bunyeroo Formation is a fine-grained redbed horizon of marine-shelf origin. Such rocks are ideal for palaeomagnetic investigations. The direction of the cleaned magnetization component of the Bunyeroo Formation is of pre-folding origin, which is evidence that its remanence may be original and dates from the time the strata were deposited. McWilliams and McElhinny (1980, table 2) listed possible primary poles from the Adelaide Geosyncline. Table 1 gives an update of this list of primary poles. The pole for the Bunyeroo Formation is at latitude = 7°S and longitude = 17°E ($dp = 9^{\circ}$, $dm = 14^{\circ}$). As shown in Fig. 4, this is very close to the pole for the Acraman meltrock.

McWilliams and McElhinny (1980) discussed the implications of the 50° difference in the pole positions between the Bunyeroo Formation and the underlying Brachina Formation. Their favoured interpretation was that the Bunyeroo Formation was remagnetized during the Middle to Late Cambrian, albeit before Delamerian folding; the Bunyeroo pole is quite distinct from Delamerian poles for ~ 450 Ma (inset, Fig. 4). However, the presence of both normal and reverse magnetizations within the Bunyeroo Formation equally suggests that the magnetizations may be primary (M. O. McWilliams, pers. comm. 1990). Most overprints are of a single polarity. Indeed, the presence of reversals is one of Van der Voo's (1990) 'reliability criteria' for palaeomagnetic data; of the other six reliability criteria listed by Van der Voo a well-determined rock age, sufficient samples and statistical precision, adequate laboratory treatment, a field test and good structural control are all satisfied by the Bunyeroo data, yielding a score of 6 out of 7. Although the importance of both normal and reversed magnetizations was not noted by McWilliams and McElhinny (1980), their inclusion

Table 1 Palaeomagnetic data.

Pole	Rock unit	Age (Ma)	Latitude (°S)	Longitude (°E)	K	A ₉₅ (°) dp, dm (°)	Reference
AC	Acraman meltrock	~600	8.6	353.4	78.3	6.3	Herein
PF	Pantapinna Fm	ϵ_m	36	29	—	8,17	A
BC	Billy Creek Fm	ϵ_m	37	20	—	7,14	A
LFL	Lake Frome (lower)	ϵ_m	40	25	—	9,19	B
LFB	Basal Lake Frome	ϵ_m	29	26	—	7,13	A
AD	Aroona Dam	$\epsilon_e?$	36	33	—	10,19	B
KG	Kangaroo Is. Sediments	ϵ_e	34	16	—	6,12	A
HG	Hawker Group	ϵ_e	27	2	—	8,13	A
BU	Bunyeroo Fm	~600	7.0	17.0	19.8	9,14	C
BRM	Brachina Fm	P ₁	33	328	—	12,20	C
BRK	Brachina Fm	P ₁	45	334	—	4,7	C
EF	Elatina Fm	~650	50.9	337.1	—	2.2	D
AF	Angepena Fm	P ₁	33	344	—	9,16	C
TH	Tapley Hill Fm	750 ± 53	39	28	—	8,15	C
MT	Merinjina Tillite	~750–800	45	346	—	6,11	C
CQ	Copley Quartzite	~800–850	36	10	—	7,15	C
ND	Northampton Dykes	> 550	47	317	8	—	E
GR	Gawler Range Volcanics	1590	60.4	50.0	—	6.2	F

K: precision parameter. A₉₅: half-angle of cone of 95% confidence for poles (Fisher 1953). dp, dm: semi-minor, semi-major axes polar error ellipse. ϵ = Cambrian; P = Proterozoic; e = early; m = middle; l = late.

^AKlootwijk (1980)

^BEmbleton and Giddings (1974)

^CMcWilliams and McElhinny (1980)

^DEmbleton and Williams (1986)

^EEmbleton and Schmidt (1985)

^FChamalaun and Dempsey (1978)

of the Bunyeroo Formation pole in their table of possible primary pole positions (McWilliams & McElhinny 1980, table 2) serves to illustrate their ambivalence. While outside the scope of the present study, a detailed magnetostratigraphic study of both the Brachina Formation and the Bunyeroo Formation would distinguish between these two possible interpretations.

The Acraman meltrock pole must be considered a virtual geomagnetic pole because the geomagnetic field direction recorded at the time of cooling immediately after the impact is an instantaneous sample of a geomagnetic field direction subject to secular variation. The Bunyeroo Formation pole probably represents an average virtual geomagnetic pole at about the time of deposition, and is therefore considered to be a palaeomagnetic pole (*sensu stricto*). A test that detects an outlier can determine whether the Acraman virtual geomagnetic pole may or may not be a subset of the Bunyeroo Formation pole position. Several such tests in the literature are discussed by Fisher *et al.* (1981) and a more recent test is given by McFadden (1982). The test favoured

by Fisher *et al.* (1981) for distributions with precision parameters >10 is denoted E_n. This yields a value of 1.148 which is much less than the 0.05 cut-off for F_{2,16} equal to 3.63. Similarly, the 0.05 outlier angle, γ_m , of McFadden (1982) for the Bunyeroo Formation data is 33°. The Acraman virtual geomagnetic pole is 23° from the Bunyeroo mean pole position that is well inside γ_m . These tests show that the Acraman virtual geomagnetic pole is statistically indistinguishable from the Bunyeroo Formation pole.

The Acraman virtual geomagnetic pole is also similar to some other Adelaidean and Early to Middle Cambrian poles (e.g. the Hawker Group pole) because the Late Proterozoic/Cambrian represents a quasi-static interval during which little apparent polar wander occurred. Thus it is not possible to precisely date rocks using palaeomagnetism for this time period. The mean pole for this quasi-static interval and poles for the Acraman meltrock and the Bunyeroo Formation are, however, quite distinct from poles for ~450 Ma resulting from magnetic overprinting during the

LATE PROTEROZOIC - CAMBRIAN

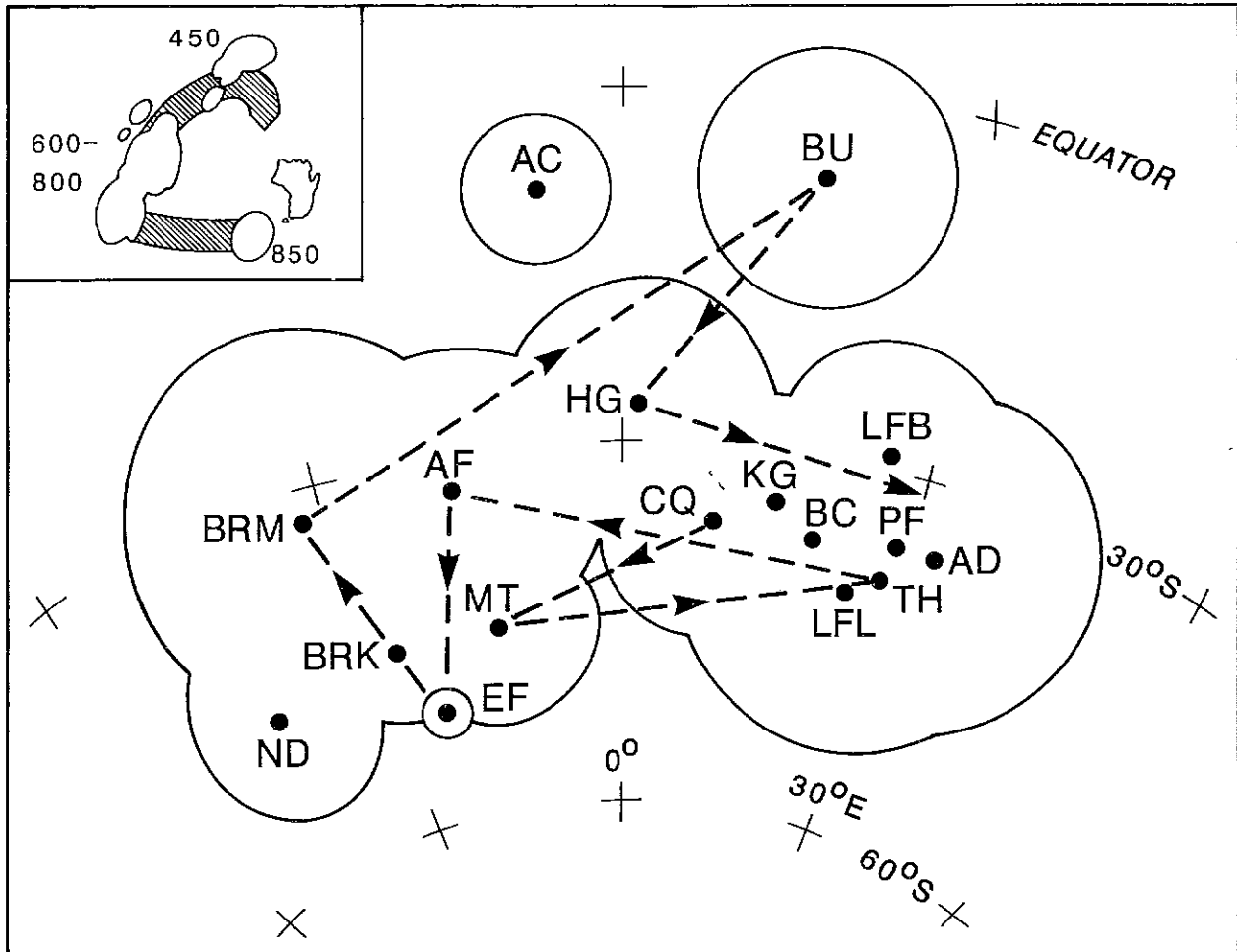


Fig. 4 Pole path for the Late Proterozoic to the Early Palaeozoic updated from McWilliams and McElhinny (1980). The proximity of the Bunyerroo Formation and the Acraman meltrock pole positions indicates their contemporaneity. Inset shows the Australian apparent polar wander path for ~850–450 Ma. Abbreviations as for Table 1.

Delamerian Orogeny. The simplest explanation of the palaeomagnetic data is that the Acraman impact structure and the Bunyerroo ejecta horizon formed at the same time and the remanent magnetization of the Acraman meltrock and the Bunyerroo Formation date from ~600 Ma ago.

CONCLUSIONS

The palaeomagnetic pole position for the Acraman meltrock differs greatly from the pole position for the Gawler Range Volcanics (Chamalaun & Dempsey 1978). Clearly the meltrock has recorded a magnetization direction very different from that of its parent rock (Table 1) and also from Ordo-

vician overprint directions in South Australia (inset, Fig. 4).

The pole position for the Acraman meltrock is, however, statistically indistinguishable from the palaeomagnetic pole for the Bunyerroo Formation, which crops out up to 350 km to the east. This agreement strongly supports the postulate that the ejecta blanket contained within the Bunyerroo Formation has been derived from the Acraman impact structure.

ACKNOWLEDGEMENTS

We thank David French of CSIRO, North Ryde, for identification of the opaque phases using the electron microprobe and XRD, and Hugh Rosser

for assistance with electron microprobe analyses at the University of Adelaide.

REFERENCES

- BLEIL U. & PETERSEN N. 1983. Variations in magnetization intensity and low-temperature titanomagnetite oxidation of ocean floor basalts. *Nature* **301**, 384–388.
- CHAMALAUN F. H. & DEMPSEY C. E. 1978. Palaeomagnetism of the Gawler Range Volcanics and implications for the genesis of the Middleback hematite orebodies. *Journal of the Geological Society of Australia* **25**, 255–265.
- COLLISON D. W. 1983. *Methods in Rock Magnetism and Palaeomagnetism: Techniques and Instrumentation*. Chapman & Hall, London.
- COMPSTON W., WILLIAMS I. S., JENKINS R. J. F., GOSTIN V. A. & HAINES P. W. 1987. Zircon age evidence for the Late Precambrian Acraman ejecta blanket. *Australian Journal of Earth Sciences* **34**, 435–445.
- EMBLETON B. J. J. & GIDDINGS J. W. G. 1974. Late Precambrian and Lower Palaeozoic palaeomagnetic results from South Australia and Western Australia. *Earth and Planetary Science Letters* **22**, 355–365.
- EMBLETON B. J. J. & SCHMIDT P. W. 1985. Age and significance of magnetizations in dolerite dykes from the Northampton Block, Western Australia. *Australian Journal of Earth Sciences* **32**, 279–286.
- EMBLETON B. J. J. & WILLIAMS G. E. 1986. Low palaeolatitude of deposition for Late Precambrian periglacial varvites in South Australia: implications for palaeoclimatology. *Earth and Planetary Science Letters* **79**, 419–430.
- FISHER R. A. 1953. Dispersion on a sphere. *Proceedings of the Royal Society of London A* **217**, 295–305.
- FISHER N. I., LEWIS T. & WILLCOX M. E. 1981. Tests of discordancy for samples from Fisher's distribution on the sphere. *Journal of the Royal Statistical Society (Series C)* **30**, 230–237.
- GOSTIN V. A., HAINES P. W., JENKINS R. J. F., COMPSTON W. & WILLIAMS I. S. 1986. Impact ejecta horizon within Late Precambrian shales, Adelaide Geosyncline, South Australia. *Science* **223**, 189–200.
- GOSTIN V. A., WALLACE M. W. & KEAYS R. R. 1990. Sedimentology and geochemistry of the Bunyeroo impact ejecta horizon, South Australia. *International Workshop 'Meteorite Impact on the Early Earth'*, Perth, Western Australia, 21–22 September 1990, Abstracts, pp. 16–17.
- JACKSON M. & VAN DER VOO R. 1986. A paleomagnetic estimate of the age and thermal history of the Kentland, Indiana cryptoexplosion structure. *Journal of Geology* **94**, 713–723.
- KENT J. T., BRIDEN J. C. & MARDIA K. V. 1983. Linear and planar structure in ordered multivariate data as applied to progressive demagnetization of palaeomagnetic remanence. *Geophysical Journal of the Royal Astronomical Society* **62**, 699–718.
- KLOOTWIJK C. T. 1980. Early Palaeozoic palaeomagnetism in Australia. *Tectonophysics* **64**, 249–332.
- LAROCHELLE A. & CURRIE K. L. 1967. Paleomagnetic study from the Manicouagan structure, Quebec. *Journal of Geophysical Research* **72**, 4163–4169.
- MC ELHINNY M. W. 1973. *Palaeomagnetism and Plate Tectonics*, p. 358. Cambridge University Press, Cambridge.
- MC FADDEN P. L. 1982. Rejection of palaeomagnetic observations. *Earth and Planetary Science Letters* **61**, 392–395.
- MC WILLIAMS M. O. & MC ELHINNY M. W. 1980. Late Precambrian paleomagnetism of Australia: the Adelaide Geosyncline. *Journal of Geology* **88**, 1–26.
- MILTON D. J., BARLOW B. C., BRETT R., BROWN A. R., GLIKSON A. Y., MANWARING E. A., MOSS F. J., SEDMIK E. C. E., VAN SON J. & YOUNG G. A. 1972. Gosses Bluff impact structure, Australia. *Science* **175**, 1199–1207.
- POHL J. 1971. On the origin of the magnetization of impact breccias on Earth. *Zeitschrift für Geophysik* **37**, 549–555.
- POHL J. & SOFFEL H. 1971. Paleomagnetic age determination of the Rochechouart impact structure. *Zeitschrift für Geophysik* **37**, 857–866.
- POORNACHANDRA RAO G. V. S. & BHALLA M. S. 1984. Lonar Lake: palaeomagnetic evidence of shock origin. *Geophysical Journal of the Royal Astronomical Society* **77**, 847–862.
- READMAN P. W. & O'REILLY W. 1971. Oxidation processes in titanomagnetites. *Zeitschrift für Geophysik* **37**, 329–338.
- RIDLEY B. H. & BROWN H. E. 1980. The transformer bridge and magnetic susceptibility measurement. *Bulletin of the Australian Society of Exploration Geophysicists* **11**, 110–114.
- ROBERTSON W. A. 1967. Manicouagan, Quebec, palaeomagnetic results. *Canadian Journal of Earth Sciences* **4**, 641–649.
- 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.
- STACEY F. D. & BANERJEE S. K. 1974. *The Physical Principles of Rock Magnetism*, p. 195. Elsevier, Amsterdam.
- VAN DER VOO R. 1990. The reliability of paleomagnetic data. *Tectonophysics* **184**, 1–9.
- WALLACE M. W., GOSTIN V. A. & KEAYS R. R. 1989. Discovery of the Acraman impact ejecta blanket in the Officer Basin and its stratigraphic significance. *Australian Journal of Earth Sciences* **36**, 585–587.
- WILLIAMS G. E. 1986. The Acraman impact structure: source of ejecta in Late Precambrian shales, South Australia. *Science* **233**, 200–203.
- WILLIAMS G. E. 1987. The Acraman structure — Australia's largest impact scar. *Search* **18**, 143–145.
- WILLIAMS G. E. 1990. The Acraman impact structure, South Australia. *International Workshop 'Meteorite Impact on the Early Earth'*, Perth, Western Australia, 21–22 September 1990, Abstracts, pp. 60–61.

(Received 30 July 1990; accepted 14 January 1991)