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Additional tables and appendices for:

Sohl, L.E., Christie-Blick, N., and Kent, D.V., 1999, Paleomagnetic polarity reversals in Marinoan (~600 Ma) glacial deposits of Australia: Implications for the duration of low-latitude glaciation in the Neoproterozoic: Geological Society of America Bulletin, v. ***, p. ****-****.

The following table is a summary of Australian paleopoles compared to the results of this study (as seen in Fig. 12).

TABLE DR1. NEOPROTEROZOIC-CAMBRIAN PALEOPOLES FOR AUSTRALIA

Lithologic unit	Unit location	Pole ID	λ* (°N)	ϕ (°E)	α_{95} (°)	Reference
Neoproterozoic						
Yaltipena Fm - total	C. Flinders Ranges	YA	-44.2	352.7	11.0	this study
Elatina Fm - total	C. Flinders Ranges	EA	-38.9	5.6	12.7	this study
Elatina Fm	C. Flinders Ranges	E1	-50.9	337.1	2.2	Embleton and Williams, 1986
Elatina Fm	C. Flinders Ranges	E2	-52.4	347.1	7.4	Schmidt and Williams, 1995
Brachina Fm	Mt. Lofty Ranges	BR1	-45.7	355.6	11.3	Karner, 1974
Brachina Fm	C. Flinders Ranges	BR2	-33.0	328.0	2.0	McWilliams and McElhinny, 1980
Bunyeroo Fm	C. Flinders Ranges	BY1	-7.0	17.0	14.0	McWilliams and McElhinny, 1980
Bunyeroo Fm	C. Flinders Ranges	BY2	-18.1	16.3	11.8	Schmidt and Williams, 1996
Bunyeroo Fm (meteorite impact meltrock)	C. Flinders Ranges	BA	-8.6	353.4	6.0	Schmidt and Williams, 1991
Lower Arumbera Sandstone	NE Amadeus Basin	LA	-44.3	341.9	12.0	Kirschvink, 1978a
Cambrian						
Hawker Group - base (avg)	C. Flinders Ranges	HG1	-26.7	2.3	12.5	Klootwijk, 1980
Upper Arumbera Sandstone	NE Amadeus Basin	UA	-46.6	337.3	4.1	Kirschvink, 1978a
Todd River Dolomite	NE Amadeus Basin	TRD	-43.2	339.9	6.7	Kirschvink, 1978a
Hawker Group - top (avg)	C. Flinders Ranges	HG2	-12.6	30.7	15.9	Klootwijk, 1980
Lake Frome Group - base (avg)	C. Flinders Ranges	LFG	-29.3	26.1	13.1	Klootwijk, 1980
Tempe Fm	NE Amadeus Basin	T	-35.9	13.0	14.1	Klootwijk, 1980
Illara Sandstone	NE Amadeus Basin	IS	-29.5	11.1	10.8	Klootwijk, 1980
Pantapinna Sandstone (upper Lake Frome Grp)	C. Flinders Ranges	PS	-36.4	29.2	16.6	Klootwijk, 1980
Deception Fm	NE Amadeus Basin	D	-32.2	10.6	6.5	Klootwijk, 1980

Note: Pole ID is the mnemonic used in Fig. 11; λ, ϕ are the latitude, longitude of the paleopole; α_{95} is the radius of 95% circle of confidence for the paleopole.

* All poles are listed here as south poles for comparison purposes.

The following table gives the breakdown of NNE vs. SW directions in this study as compared to previously published results. See text in the section "Comparison with Other Neoproterozoic Paleomagnetic Results" for a further discussion of this data.

TABLE DR2. COMPARISON OF ELATINA FORMATION SAMPLE AND SITE DATA

	N	Dm (°E)	Im (°N)	α_{95} (°)	Number of NNE directions	Number of SW directions
Schmidt and Williams (1995)						
Elatina Fm sample data	79	197.3	-5.3	7.4	52	27
Elatina Fm site mean data	10	197.4	-7.1	15.2	7	3
This study						
Elatina Fm sample data	126	215.1	-17.2	4.5	45	81
Elatina Fm site mean data	58	212.1	-16.9	6.2	25	33

Note: N is the number of sites or samples; Dm, Im are the mean declination, inclination; α_{95} is the radius of 95% circle of confidence for the mean direction.

PART A
SAMPLING AND ANALYTICAL PROCEDURES FOR SAMPLES FROM THE CENTRAL FLINDERS RANGES

Stratigraphic sections for sampling were chosen on the basis of completeness of outcrop exposure and the possibility of performing a fold test to constrain the age of magnetization. Sample sites were spaced an average of 1.5 meters apart for the glacial deposits, and at varying intervals for non-glacial deposits depending upon the thickness of the section and the quality of outcrop. Most samples were collected with a portable rock drill directly from outcrop as 2.5-cm-diameter cores and were oriented with a Brunton compass. A few of the sites, including all of the Trezona carbonate sites, were sampled as oriented blocks and later cored in the lab. One to four cores were collected from each outcrop site or oriented block. Sample cores were trimmed to 2.2 cm in length; cores that were more than 5 cm in length were divided into subsamples.

All sample treatments and measurements were made within a shielded room with an ambient magnetic field of <300 nT. AF demagnetization in fields up to 100 mT performed on a subset of twelve samples of red sandstones and siltstones from the Flinders Ranges was ineffective in decomposing the NRM, suggesting that very high coercivity hematite was likely the principal remanence carrier. Subsequent samples were therefore thermally demagnetized, in 15 to 20 steps, to a maximum of 695°C in a custom-built, shielded thermal demagnetizer where the ambient magnetic field was checked and reduced to less than 5 nT at each heating step. Each sample's magnetic remanence remaining after each heating step was measured in a 2G three-axis superconducting rock magnetometer, and its low-field magnetic susceptibility was measured with a Bartington instrument to monitor any alteration in magnetic mineralogy after heating. A group of 31 samples, representing different lithologies and grain sizes from each stratigraphic section, was subjected to thermal demagnetization of isothermal remanent magnetization (IRM) after the method of Lowrie (1990) to help identify the magnetic mineralogy present in the samples.

The thermal demagnetization trajectories of NRM for samples from the central Flinders Ranges (e.g., Fig. 4) revealed the presence of up to three components of magnetization, designated as A = low-temperature stable component, B = possible intermediate stable component, and C = high temperature stable component. Initial principal component analysis (pca) of the thermal demagnetization data (method of Kirschvink, 1980) on a sample-by-sample basis revealed some variation in the temperature ranges of the same components between sites, and in some cases even between different samples from the same site, even though the remanence directions are similar and susceptibility χ remained relatively constant at values less than 15-20. The A components, with overall moderately steep inclinations and northerly declination in geographic coordinates, persisted from NRM (i.e., no treatment) to 200°-400°C; the C component, with its shallow inclinations and SSW and NNE declinations, ranged from 575-620°C to 650-690°C; and the B component, with a range of shallow to moderately steep inclinations and largely NW declinations, appeared to extend from 200-400°C up to 575-650°C.

Such variability was also encountered in previous paleomagnetic studies, particularly from the Flinders Ranges (e.g., Embleton and Giddings, 1974; Klootwijk, 1980; Schmidt et al., 1991). Klootwijk (1980) attributed the variability to the presence of a mixture of authigenic materials at the outset (Larson and Walker, 1975), possibly enhanced by variability of thermomagnetic properties of these minerals upon oxidation (Ryabushkin, 1976). In these studies, the researchers addressed the analytical problem by using individual sample directions, rather than site means, to calculate average directions and paleopole positions, which has the additional result of yielding a statistically more precise result. While such an approach is generally considered valid in paleomagnetism, it is worth questioning whether we can actually "know" mean directions with such great precision when the thermal demagnetization data clearly show that the rocks' magnetization histories are not simple.

We have taken several steps to address the problem of intra- and inter-site variability in calculating the mean directions and paleopoles. First, the principal component analysis (pca) for each formation was redone, using temperature endpoints that represented the most common result for that formation in that section. (These generally corresponded to components defined as A = NRM to 300°C, B = 300°-575°C, and C = 575°-680°C.) Any component vector defined by the blanket pca whose maximum angular deviation (MAD) was greater than 15° was considered ill defined, and was not included in subsequent analyses (Butler, 1992). The remaining data were plotted on equal-area stereoplots to identify spatial clusters or trends. Since the A component was typically well defined, any sample with an A component direction that deviated widely from the general group cluster was considered to be possibly mis-oriented, and all data pertaining to that sample were discarded as potentially unreliable. For all components, scattered data points that did not cluster with the bulk of the data were also discarded in order to improve the statistics, as long as the overall mean was not significantly affected. Discard of sample data from each of the Flinders Ranges sections owing to excessive MAD was an average 34.4%; scattered data points totaled an average of 28.8%. The data for a total of 358 out of 567 samples from the Yaltipena and Elatina formations were therefore not used for subsequent analyses or interpretations. Site mean directions were calculated, where possible, from the remaining data. For some sites, the mean direction is represented by the sole remaining sample for that site, and has been included because the sample direction resembles site means calculated from multiple samples elsewhere in the section.

PART B
ADDITIONAL DATA ON SAMPLING SITES OUTSIDE THE CENTRAL FLINDERS RANGES

Stratigraphic Context

Stuart Shelf. The Marinoan glacial unit in this region is the Whyalla Sandstone, a buff-colored, tectonically undeformed, poorly cemented unit containing coarse, very well-rounded and frosted quartz grains in a bimodal distribution with fine-grained angular quartz, feldspar and lithic fragments (Preiss, 1987). At its type location, the Cattlegrid Copper Mine at Mt. Gunson (Fig. 1A), the Whyalla Sandstone includes at least four generations of sand wedges, periglacial features associated with the cracking and subsequent in-filling by sand of frozen ground (i.e., permafrost; Williams and Tonkin, 1985). The most spectacular of these wedges (up to 1.5 m in diameter at their widest points) lie at the contact between the Whyalla Sandstone and the underlying Mesoproterozoic Pandurra Formation (Busbridge, 1981; Fanning et al., 1983; Drexel et al., 1993), a reddish-purple quartzite that is brecciated at the contact. The upper 10 m within the mine pit contains four or five major surfaces bounding cross-beds up to 5 m thick that are considered to be hallmarks of eolian deposition (Gersteling and Heape, 1975; Williams and Tonkin, 1985). A cap carbonate equivalent to the Nuccaleena Formation of the central Flinders Ranges can be observed in some drill cores, such as SLT 106, near the edge of the Stuart shelf (Preiss, 1986). The presence of extremely well-rounded, frosted quartz grains within granule layers within the Elatina Formation, as well as the local presence of the Nuccaleena Formation above it, provide the bases for correlating the Whyalla Sandstone with the Elatina (Fig. 2; Preiss, 1987).

Amadeus Basin. In the northeastern Amadeus basin (the Ooraminna sub-basin) the Marinoan glacial unit is the Olympic Formation, which consists predominantly of red siltstone with minor boulder diamictite and gritty and pebbly dolomite (see Fig. 1B; Preiss et al., 1978; Preiss, 1987; Field, 1991; Kennedy, 1994). Another stratigraphic unit partly time-equivalent to the Olympic is the Gaylad Sandstone, a relatively coarse feldspathic sandstone that represents the shallow marine equivalent of the cap carbonates (Fig. 2). Beneath the Olympic Formation, the thick mixed carbonate-siliciclastic Aralka Formation represents pre-glacial conditions similar to those inferred for the entire Sturtian-Marinoan interglacial interval in the central Flinders Ranges

(Fig. 2; Preiss, 1987; Shergold et al., 1991; Kennedy, 1994). Its uppermost member, the Limbla Member, lies disconformably to unconformably below the Olympic Formation.

Analytical Results

Stuart Shelf. Paleomagnetic samples were taken from eight sites within the Whyalla Sandstone, distributed throughout the ~20-meter section exposed in the walls of the Cattlegrid Copper Mine at Mt. Gunson (31°45'S lat., 137°15'E long.). The sampled sites included were taken both within and alongside the sand wedges in the Whyalla Sandstone, as well as from two sites in the Pandurra Formation where the uppermost breccia had been folded by cryoturbation processes. Sample collection and thermal demagnetization proceeded as described above for the central Flinders Ranges samples.

The Stuart shelf samples typically display two poorly defined components, designated as A = lower temperature component and B = higher temperature component. Although these A and B components have fairly consistent temperature ranges from sample to sample (i.e., A = 0°-200°C, B = 300°-450°C), the remanence directions as defined by pca is widely scattered. Thermal demagnetization of IRM applied to the Whyalla Sandstone and Pandurra Formation samples show that the principal magnetic mineral present is goethite. The wide scattering of remanence directions and the presence of goethite suggests that the Stuart shelf samples carry unstable magnetizations that cannot be compared to the central Flinders Ranges paleomagnetic data; no further analysis has been attempted.

Amadeus Basin. The Limbla Member of the Aralka Formation was sampled at a total of 25 sites in four stratigraphic sections on Ringwood Station, a ranch ~125 km east of Alice Springs (Fig. 1B). Two of these sections are located at the Olympic Structure, approximately 12 km WNW of the Ringwood Homestead (23°46'S lat., 135°47'E long.); these sections have average bedding attitudes of strike 149°, dip 11°SW, and strike 044°, dip 82°NW. The remaining two sections are located at Olympic Bore, approximately 16 km SE of the Ringwood Homestead (23°50'S lat., 134°50'E long.); these sections have average bedding attitudes of strike 085°, dip 25°SE, and strike 027°, dip 35°SE. In both areas, the sections sampled are on opposing limbs of Devonian-Carboniferous synclines with an eye toward performing a fold test.

Samples from all sites in the Amadeus Basin yield an extremely weak, single-component magnetic remanence, designated as the A component, that persisted from 0°-575°C. Although the A component is typically well defined within a given sample, the overall remanence directions are widely scattered. Thermal demagnetization of IRM applied to test samples from the Amadeus basin suggests that the dominant magnetic mineral present is magnetite, which has the potential to yielded stable remanence directions; however, there may simply be too little magnetic material present within the sandstone sampled to yield a coherent magnetization. As with the data from the Stuart shelf, the wide scatter of the magnetization in these samples does not permit comparison with the central Flinders paleomagnetic data; no further analysis has been attempted.

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