Online Supplementary Material for:

Rapid Early Cambrian rotation of Gondwana-Land

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This file contains:

Supplementary text

Supplementary figures (Fig. DR1, DR2, DR3, DR4)

Supplementary tables (Table DR1 and DR2)

Supplementary references

SUPPLEMENTARY TEXT

Discussion of Gondwana-Land paleomagnetic compilation. In their study of the Itabaiana mafic dikes, Trindade et al. (2006) provide a reasonably comprehensive review of the highest quality paleomagnetic poles from the Gondwana-Land constituents. Our pole list (Table DR2, Fig. 3) largely reflects theirs. We now discuss those poles included or excluded herein that are excluded or included, respectively, in their study.

A major difference between our pole list and that of Trindade et al. (2006) is their choice to include the numerous poles presented by Klootwijk (1980) from Australia (from oldest to youngest): Hawker Group, Pertaoorta Group, Kangroo Island, Billy Creek, Giles Creek, and Lower Lake Frome. We do not include the Klootwijk (1980) poles because they pre-date the application of principal-component analysis (Kirschvink, 1980), and rely on contour plots for distinguishing presumed primary versus secondary components. It is worth noting that Klootwijk's results do indicate a major declination shift, as we find.

The only result that Trindade et al. (2006) include from Antarctica is from the Sør Rondane intrusions. We exclude Sør Rondane pole because of the large uncertainty of its age, which is estimated from a compilation of U-Pb zircon, Rb-Sr biotite, Rb-Sr whole rock, and Ar/Ar biotite (Grunow, 1995). We tentatively include poles from the Zanuck granite, and from the Wyatt and Ackerman Formations and Mount Paine tonalite (Grunow and Encarnacion, 2000), although we recognize the possibility that they maybe allochthonous to Gondwana-Land at the time of emplacement (Grunow and Encarnacion, 2000; Paulsen et al., 2007). Zanuck granite is well-dated, with cooling estimates for the magnetite blocking temperature range between emplacement age of 521 ± 2 Ma (Encarnacion and Grunow, 1996) (which we use for pole age) and an argon closure age for biotite (i.e., cooling to 300˚C) by 496 ± 3 Ma (Grunow and Encarnacion, 2000). The Zanuck granite pole yields a Van der Voo (1990) reliability Q-value of 4. The combined pole from the Wyatt and Ackerman Formations and Mount Paine tonalite (Grunow and Encarnacion, 2000) yields a Q-value of 6. A Pb/Pb age of 526 ± 2 Ma on zircons from an ash bed within the Wyatt Formation provides a tight, concordant age constraint (Encarnacion and Grunow, 1996).

We follow Trindade et al.(2006) in the selection of the Ntyona ring structure, Sinyai metadolerite, Madagascar virgation zone, and Carion granite poles for Africa. Finally, for South America we include Itabaiana dikes pole and two from Sierra de las Animas Complex. Although Itabaiana dikes poles is highly reliable (Q=7), its baked contact test is inconclusive due to a lack of a stable host rock direction away from dike margins. We exclude poles from Equeefa dikes and Mzumbe gneiss because of large errors (524 ± 36 Ma; 2σ standard error from original data). Other Cambrian South American poles from Trindade et al. (2006) (C7, C8, C9, C11) are magmatic overprints with imprecise ages. Refer to Table DR2 for Q-values and references for all poles considered in Figure 3.

SUPPLEMENTARY FIGURES

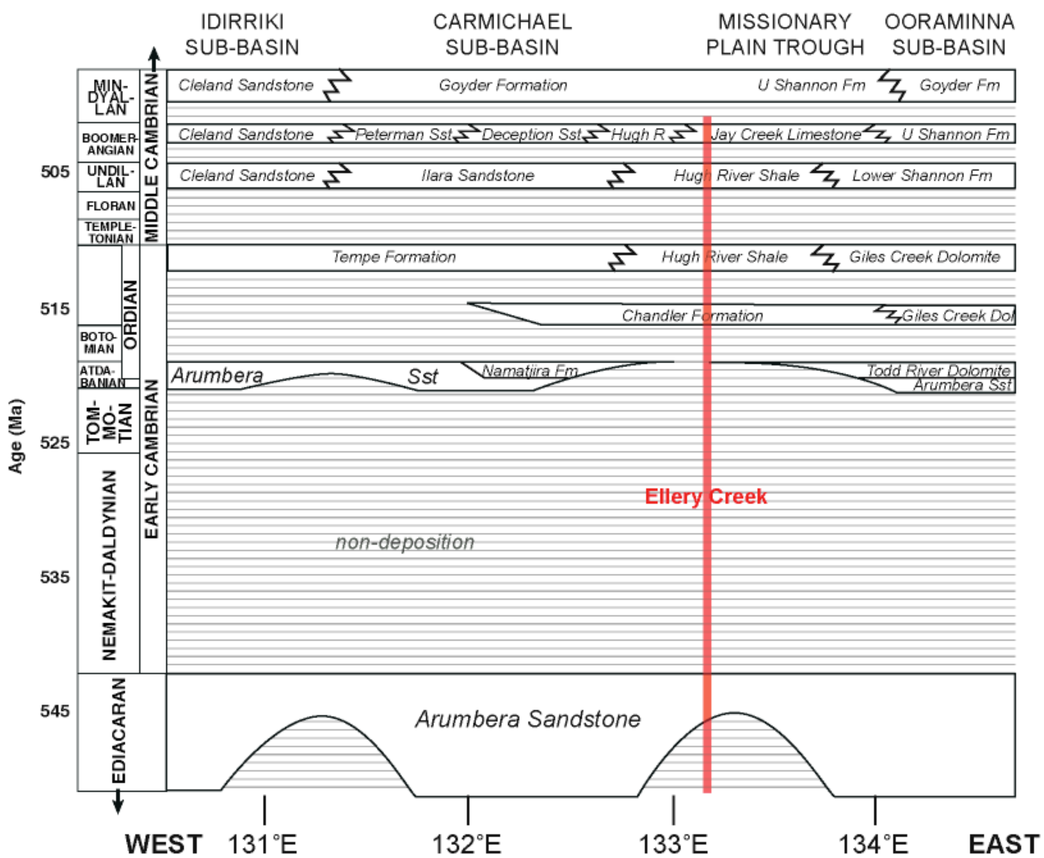

Fig. DR1 Cambrian sequence stratigraphy of the Amadeus Basin showing age ranges of units sampled: upper Arumbera sandstone, Hugh River Shale, and Jay Creek Limestone. Modified after Kennard and Lindsay (1991) and Gravestock and Shergold(2001) according to revised time scale (Maloof et al., 2005). The evaporitic Chandler Formation, although present at 133˚-133.5˚E elsewhere in the Amadeus Basin, is not exposed at Ellery Creek.

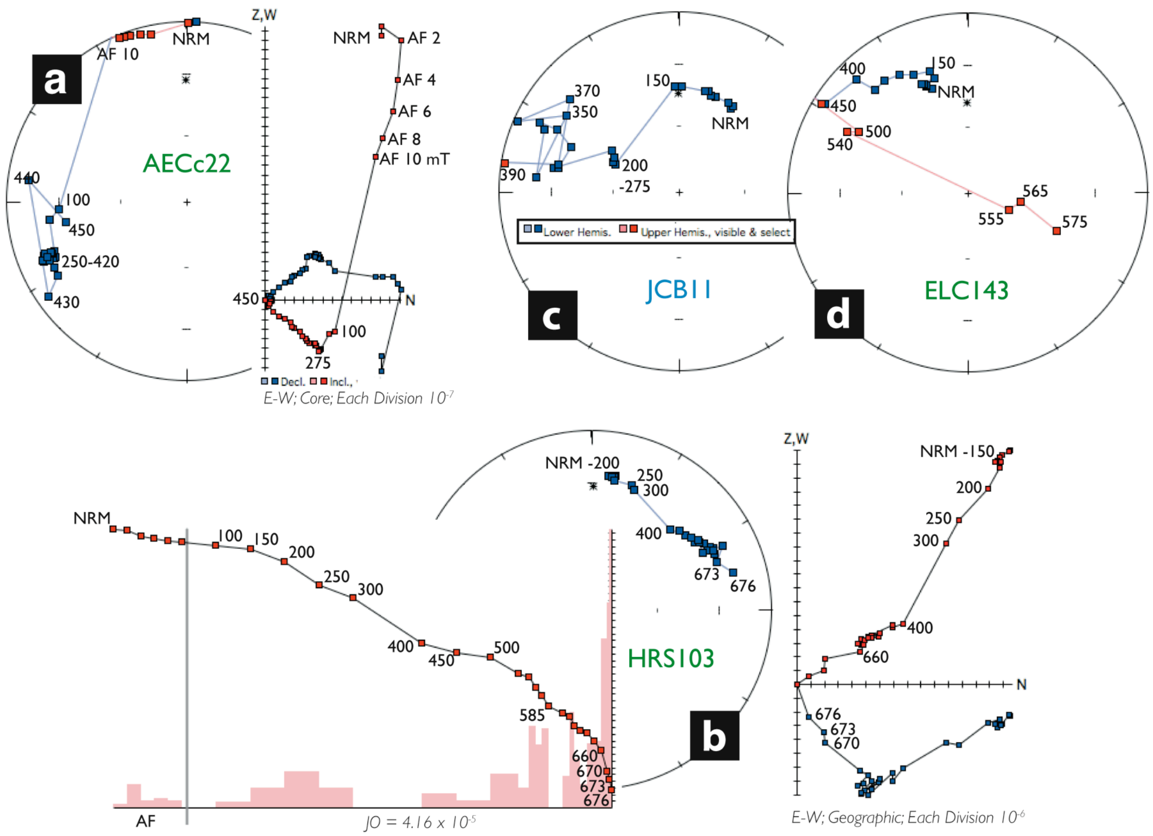

Figure DR2. Example equal area, orthogonal, and normalized intensity (J/J_o) demagnetization projections for (A, B, and D) the Hugh River Shale and (C) the Jay Creek Limestone. See text for a description of the various levels of data quality represented above and employed in the study.

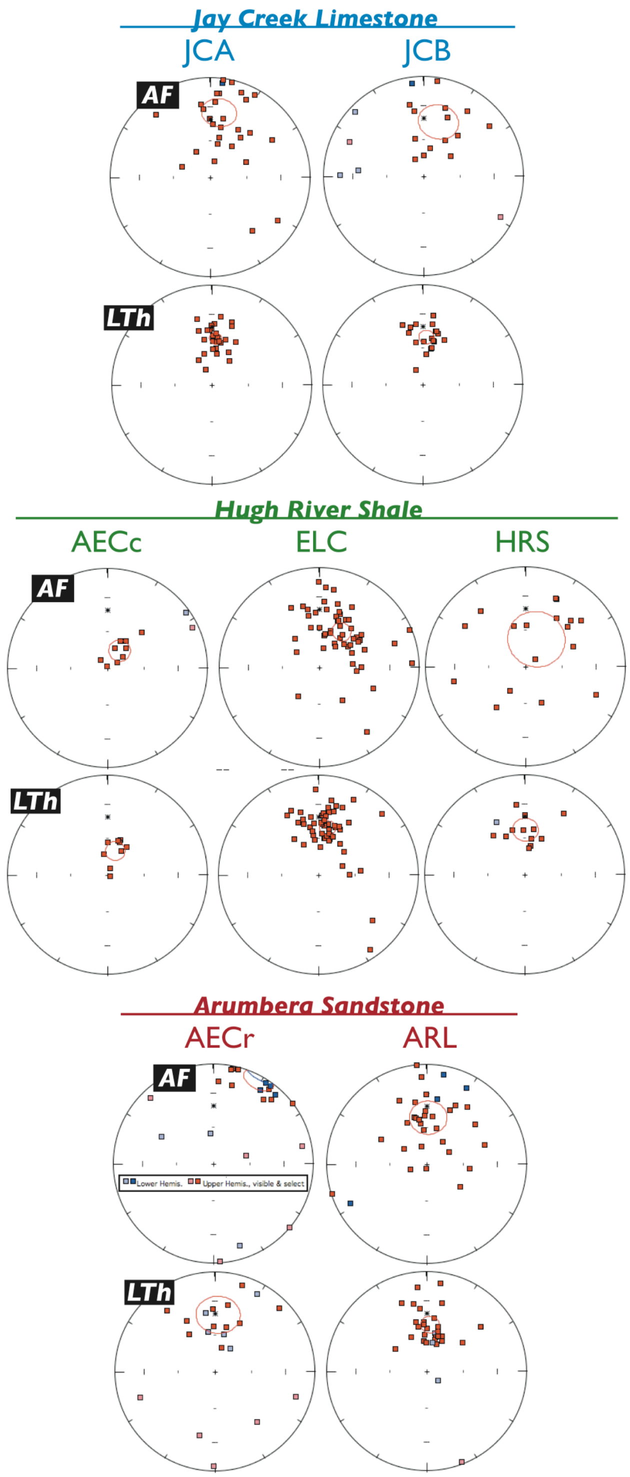

Figure DR3. Equal area projections of low-stability components determined for each site and formation. Components are determined by both demagnetization techniques (used in tandem on all samples) alternating-field (AF) and low thermal demagnetization (LTh).

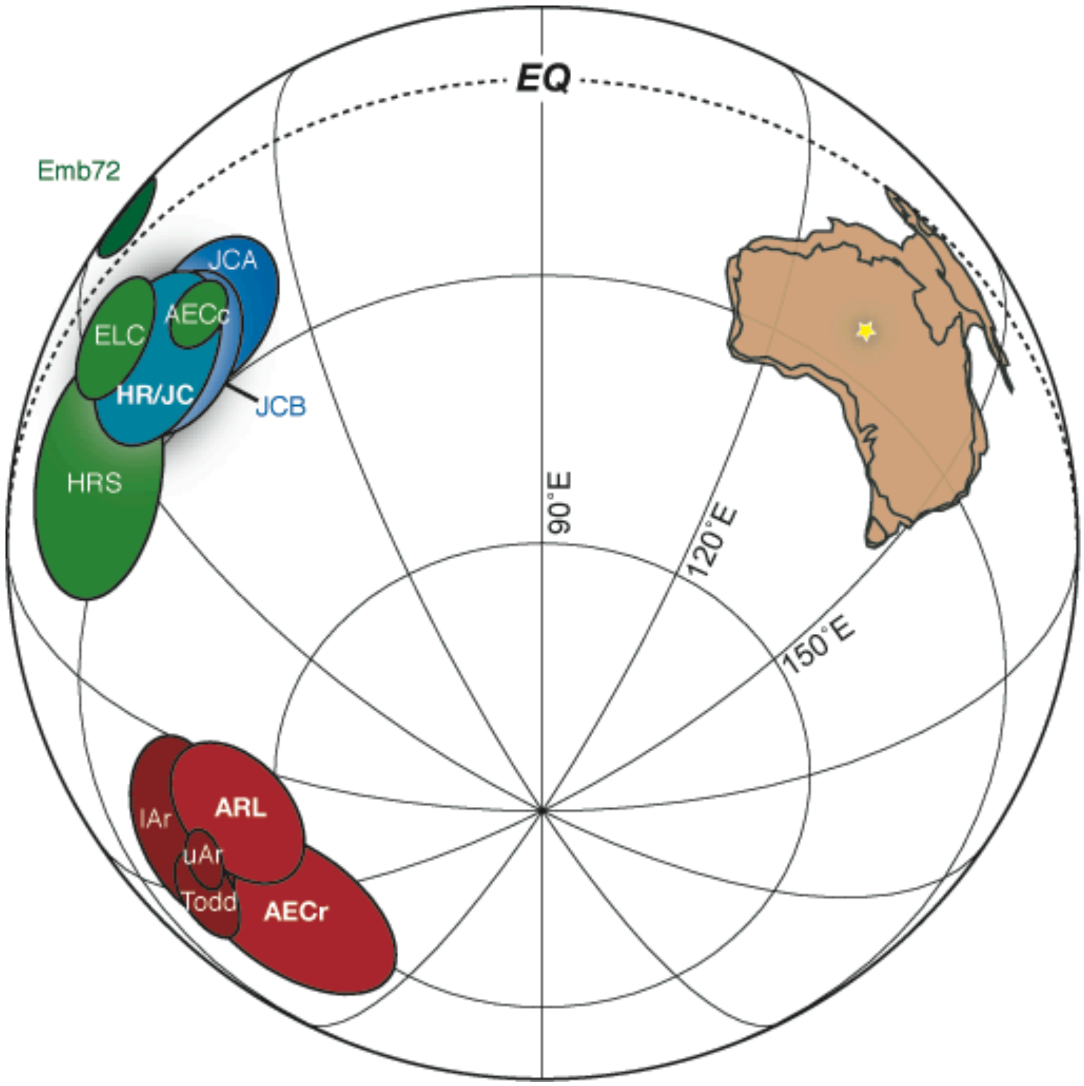

Figure DR4 Paleomagnetic poles from Ellery Creek section. HR/JC is mean paleomagnetic pole from HRS, ELC, JCB, JCA, and AECc from Hugh River Shale and Jay Creek Limestone of this study. 'Emb72' (dark green) is preliminary pole from Hugh River Shale (Embleton, 1972). lAr, uAr, and Todd are poles from lower and upper Arumbera Sandstone and Todd River Dolomite as exposed at Ross River (Kirschvink, 1978). Plot in present-day Australia coordinates. Star indicates sampling locality.

SUPPLEMENTARY TABLES

Table DR1. Calculated mean palaeomagnetic directions in this study and plotted in Fig. 3. ID = identification refers to text, Dec = declination, Inc = inclintion, a95 = radius of circle of 95% confidence, n = samples, Site = latitude and longitude of sampling site, Pole = latitude and longitude of palaeomagnetic pole, A95 = radious of circle of 95% confidence of palaeomagnetic pole, λ = palaeolatitude, ± = uncertainty of palaeolatitude.

ID	Dec (°)	Inc (°)	a95 (°)	n	Site (°N)	Site (°E)	Pole (°N)	Pole (°E)	A95 (°)	λ (°)	±
ARL	199.9	-13.1	12.1	23.0	-23.8	133.1	-53.9	348.1	8.8	-6.6	6.4
AECr	185.6	-11.4	17.6	12.0	-23.8	133.1	-59.9	324.3	12.7	-5.8	9.3
AECc*	253.3	21.5	5.2	7.0	-23.8	133.1	-19.6	46.9	4.0	11.1	2.9
ELC*	256.1	-5.3	10.0	50.5	-23.8	133.1	-11.6	34.9	7.1	-2.7	5.1
HRS*	241.3	-15.4	17.9	17.0	-23.8	133.1	-22.3	23.1	13.2	-7.8	9.7
JCA*	253.1	23.6	12.1	21.0	-23.8	133.0	-20.2	47.9	9.4	12.3	7.0
JCB*	249.8	14.5	13.0	15.0	-23.8	133.5	-21.4	42.2	9.5	7.4	6.9
HR/JC				110.5			-19.3	39.1	10		

*Averaged for HR/JC mean pole.

Table DR2. List of paleomagnetic poles according to craton and position in Gondwana-Land. ID = identification refers to text, Plat and paleomagnetic pole latitude and longitude, respectively, PlatR and Plong = rotated paleomagnetic pole latitude and longitude, respectively, into Northwest Africa Gondwana-Land reference frame according to McElhinny et al. (2003), A95 = radius of circle of 95% confidence, Distance = calculated great circle distance from Wyatt paleomagnetic pole. Ages for biostratigraphically-dated units employ time scale of Maloof et al. (2005). Q-value is paleomagnetic reliability value (Van der Voo, 1990).Explanation of paleomagnetic pole choices are explained in the supplementary text.

Rock Unit by Continent and Sector	ID	Plat (˚N)	Plong (˚E)	PlatR (˚N)	PlongR (˚E)	A95 (˚)	Distance (˚)	Subsystem (Stage)	Age (Ma)	± (Myr)	Age Range Max	Min	1234567	Q	Reference(s)
East Gondwana-Land															
Australia															
Hugh River Shale (previous)*	Emb72	11.2	37.2	56.8	12.1	6.8		Ordian-Boomerangian			520	501	1000111	4	Embleton (1972)
Hugh River shale, Jay Creek limestone	HR/JC	-19.3	39.1	26.2	13.3	10.0	21.2	Ordian-Boomerangian			520	501	1110111	6	This study
Todd River dolomite, Allua Fm., Eninta Fm.	Todd	-43.2	339.9	-10.9	332.1	5.9	69.6	Tommotian-Atdabanian			526	519	1111111	7	(Kirschvink, 1978)
Aroona Dam sediments	Aroo	-26.0	33.0	19.5	7.2	16.5	28.6	late Botomian-Toyonian			517	513	1000011	3	(Embleton and Giddings, 1974)
Arumbera sandstone (Upper)	uAr	-46.6	337.4	-14.7	332.8	3.5	72.5	early Early Cambrian			542	526	1111111	7	(Kirschvink, 1978)
Arumbera (Lower), Pertatataka Fm. (Upper)	lAr	-44.3	341.9	-11.0	334.0	10.2	68.7	upper Ediacaran			580	542	1111111	7	(Grey and Corkeron, 1998; Kirschvink, 1978)
Antarctica (Mawsonland)															
Zanuck granite	Zanu	-7.1	38.8	39.8	19.0	7.7	8.2				516	513	1110001	4	(Grunow and Encarnacion, 2000)
Wyatt Ackerman Mt. Paine tonalite	Wyatt	1.1	39.3	47.4	14.7	4.0	0.0		526, 524	2,2	528	522	1111011	6	(Encarnacion and Grunow, 1996; Grunow and Encarnacion, 2000)
West Gondwana-Land															
Africa' (Congo and Kalahari)															
Sinyai metadolerite	Sin	-29.0	319.0	-23.2	315.2	3.9	88.5		547	4	551	543	1110101	5	(Meert and Van der Voo, 1996)
Ntonya ring structure	Nton	27.8	344.9	30.4	347.7	1.8	26.8		522	13	535	509	1110111	6	(Briden et al, 1993)
Madagascar															
Carion granite	Carion	-7.0	1.0	8.2	356.9	11.0	42.0		508.5	11.5	520	497	1110011	5	(Meert et al., 2003)
Madagascar virgation zone	MadV	-7.0	353.0	7.8	348.5	14.0	45.5		521.4	11.9	533.3	509.5	1110011	5	(Meert et al., 2001)
South America															
Itabaiana Dikes	Itabai	34.9	314.6	34.7	334.8	7.3	32.2		525	5	530	520	1111111	7	(Trindade et al., 2006)
Sierra de las Animas 1	SA1	6	338	24.1	12.1	22.9	23.4		510	10	520	500	1110111	6	(Sanchez-Bettucci and Rapalini, 2002)
Sierra de las Animas 2	SA2	-17	251	-41.9	307.3	18.5	107.4		551	10	561	541	1010101	4	(Sanchez-Bettucci and Rapalini, 2002)

*Not plotted in Figure 3.

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