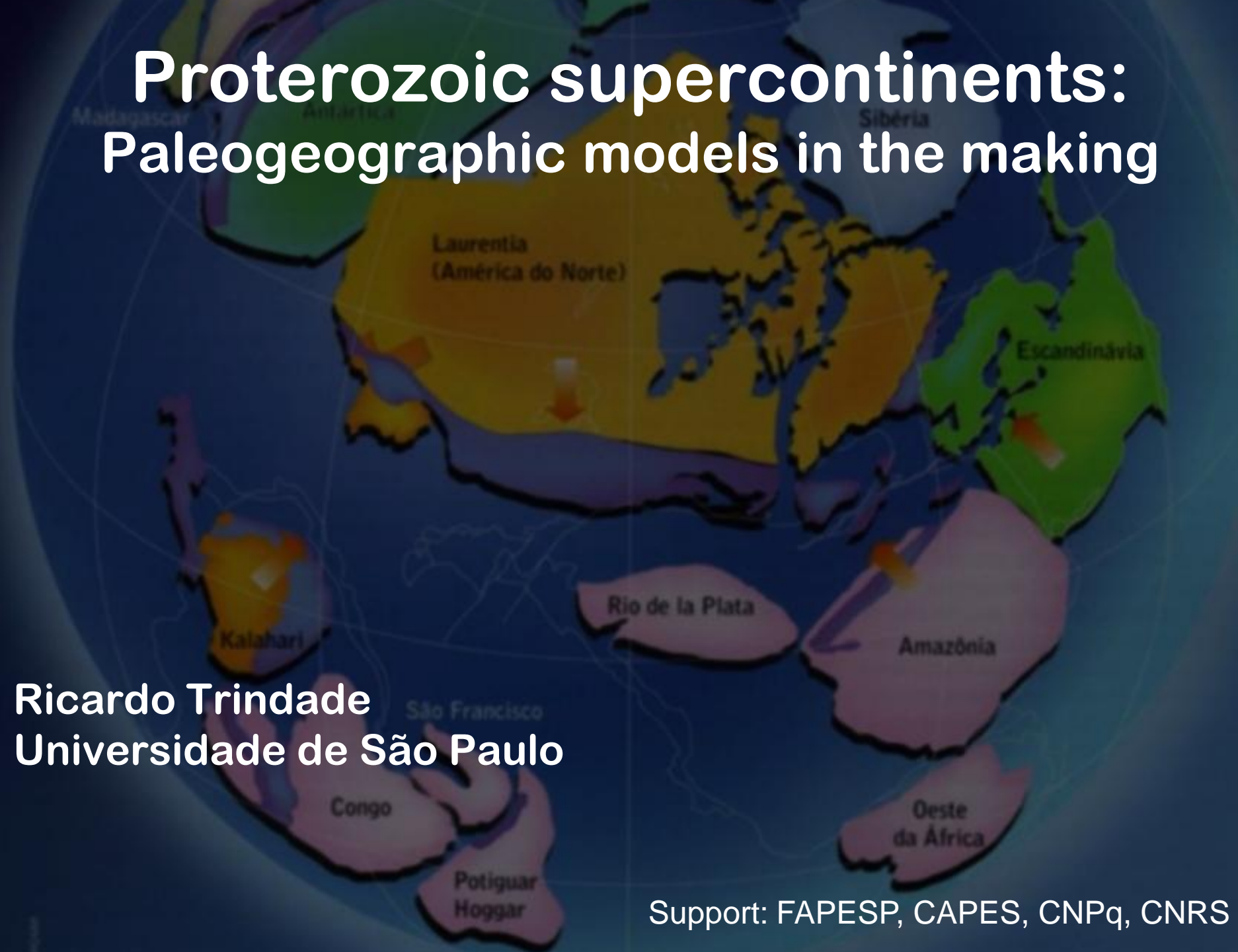


# Proterozoic supercontinents: Paleogeographic models in the making

Ricardo Trindade  
Universidade de São Paulo

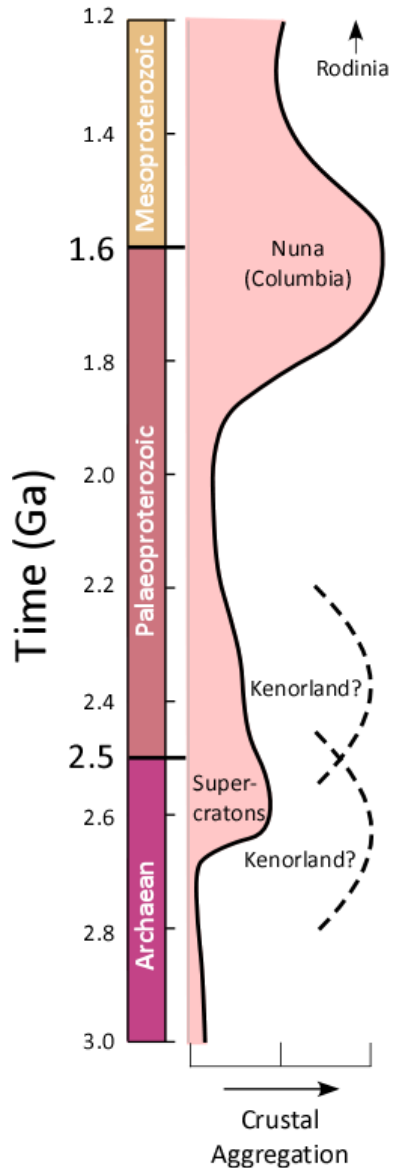
Support: FAPESP, CAPES, CNPq, CNRS



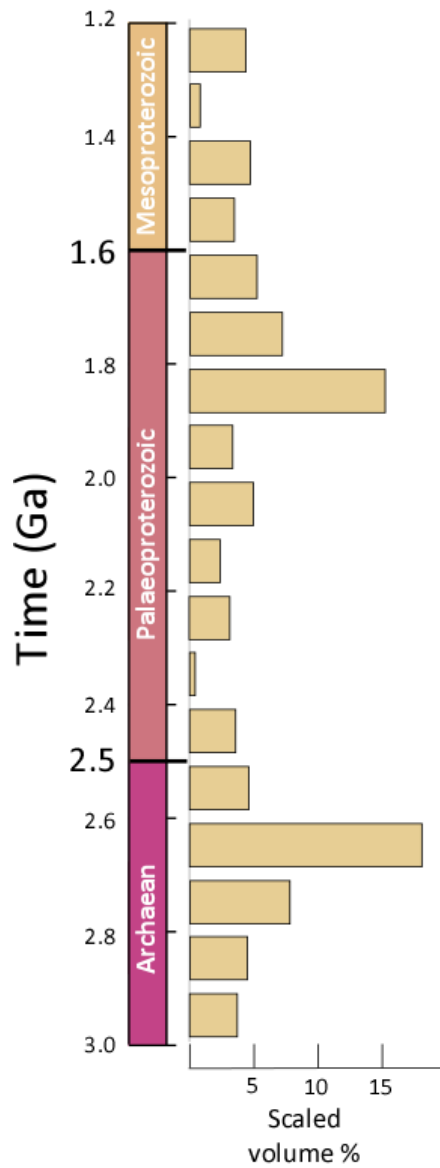
# Outline of the talk:

- 1) Supercontinents
- 2) How to build a Precambrian Supercontinent ?
- 3) Paleomagnetic poles: evaluating quality evaluation
- 4) Amazonia in Nuna/Columbia and Rodinia

# the Supercontinent cycle

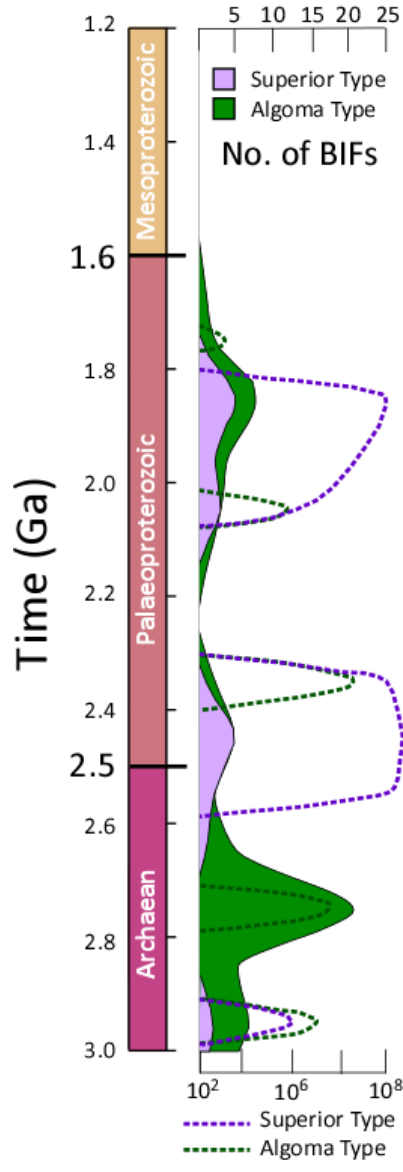


Williams et al (1991)  
Bleeker (2003)  
Barley et al (2005)

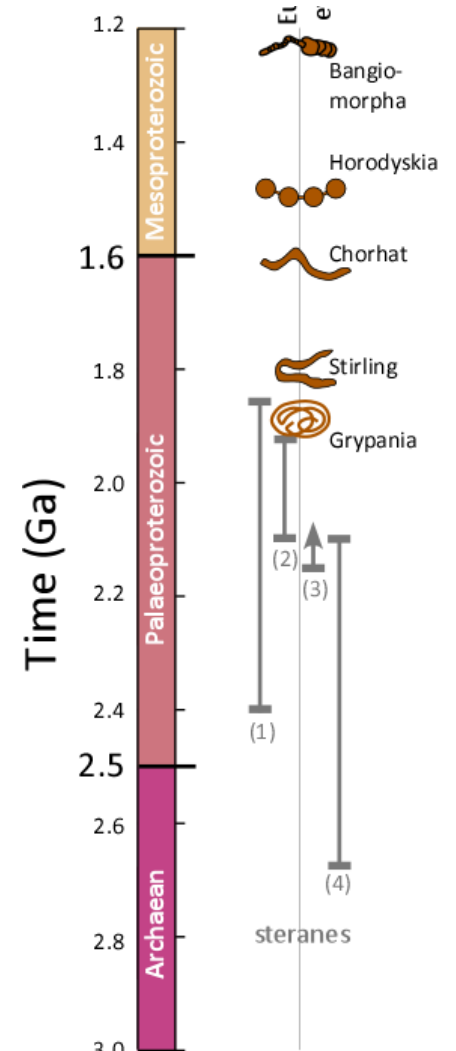


Condie (2000)

Reddy and Evans, 2009, *GSL* 323: 1-26.

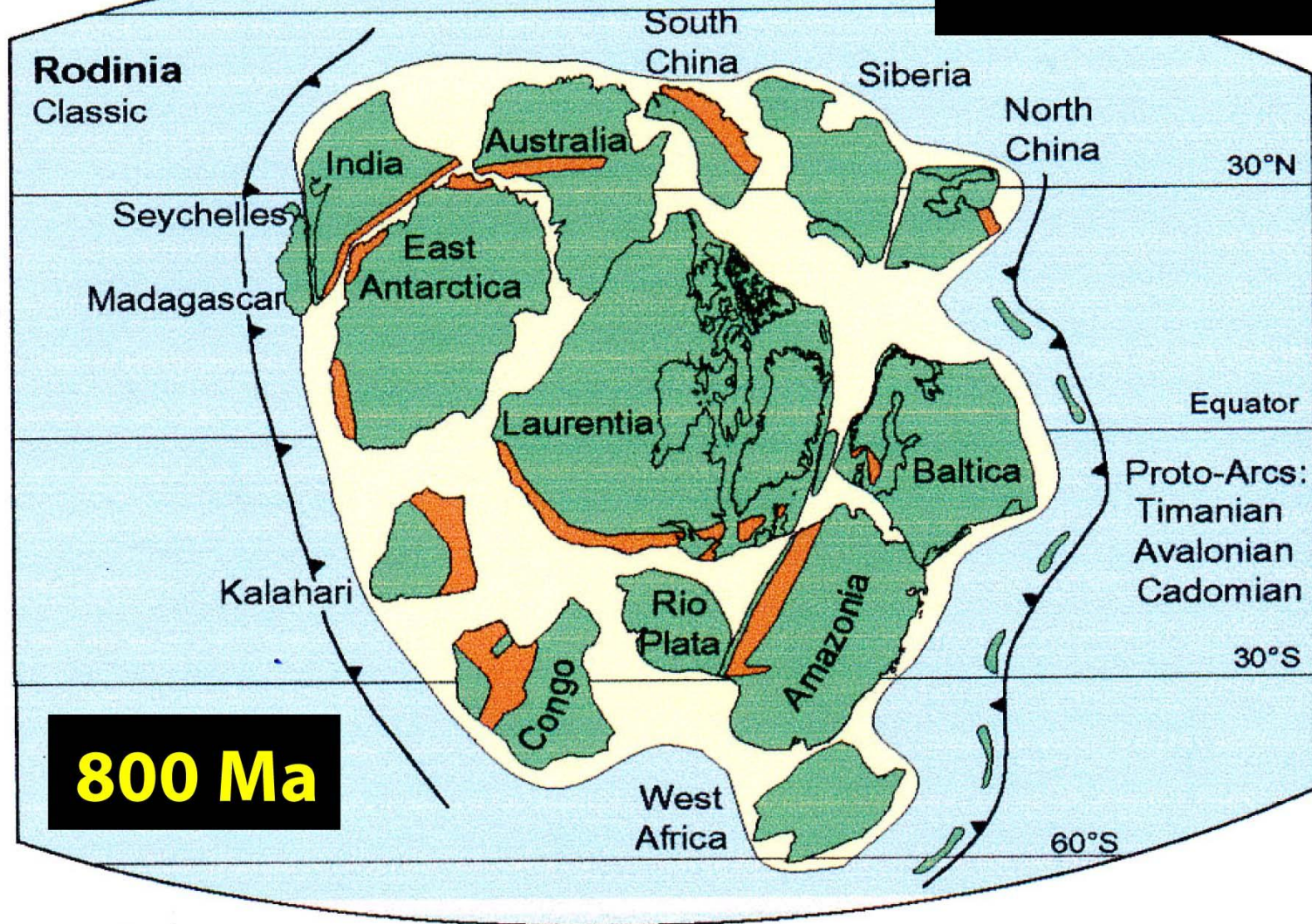


Huston & Logan (2004)



- 1) Dutkiewicz et al. (2006) & George et al. (2008)
- 2) Dutkiewicz et al. (2007)
- 3) Rasmussen et al. (2008)
- 4) Waldbauer et al. (2009)

# Rodinia



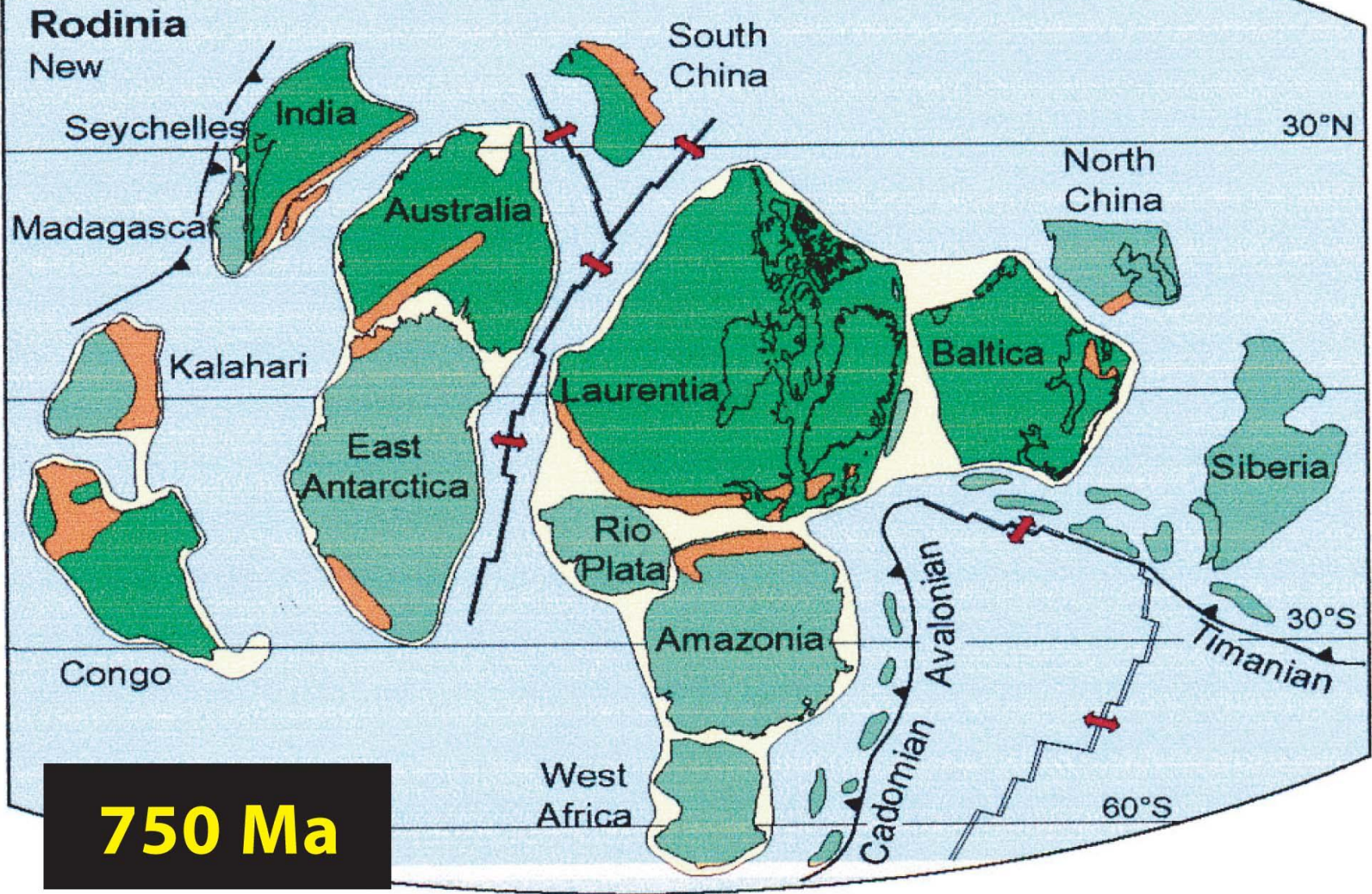
**Torsvik (2004)**



1300- to 1000-million-year-old mobile belts



# Rodinia breakup



**750 Ma**

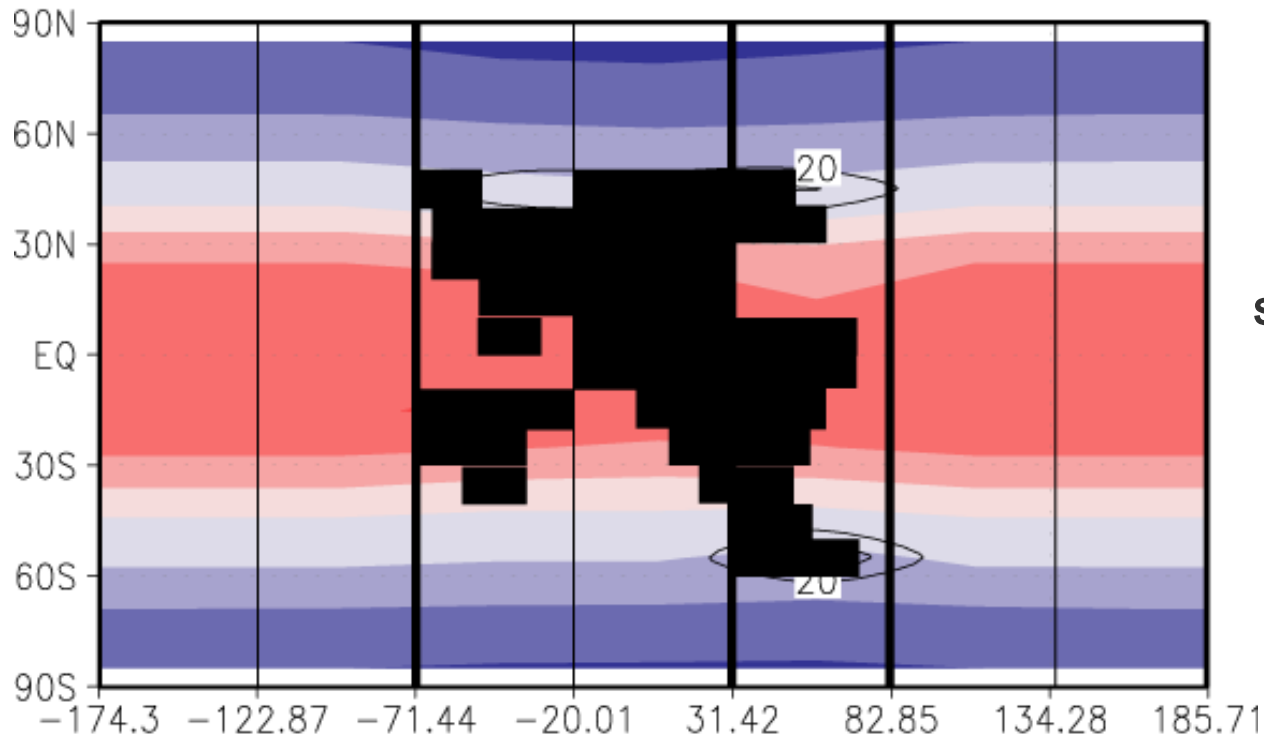
Continents with paleomagnetic data (~750 million years ago)

# Freezing the Earth: Climate and Geochemical model

Supercontinent configuration (800 Ma):

- pCO<sub>2</sub> equilibrates at 1800 ppm
- It corresponds to an average surface temperature of 10.2 °C

800 Ma reconstruction



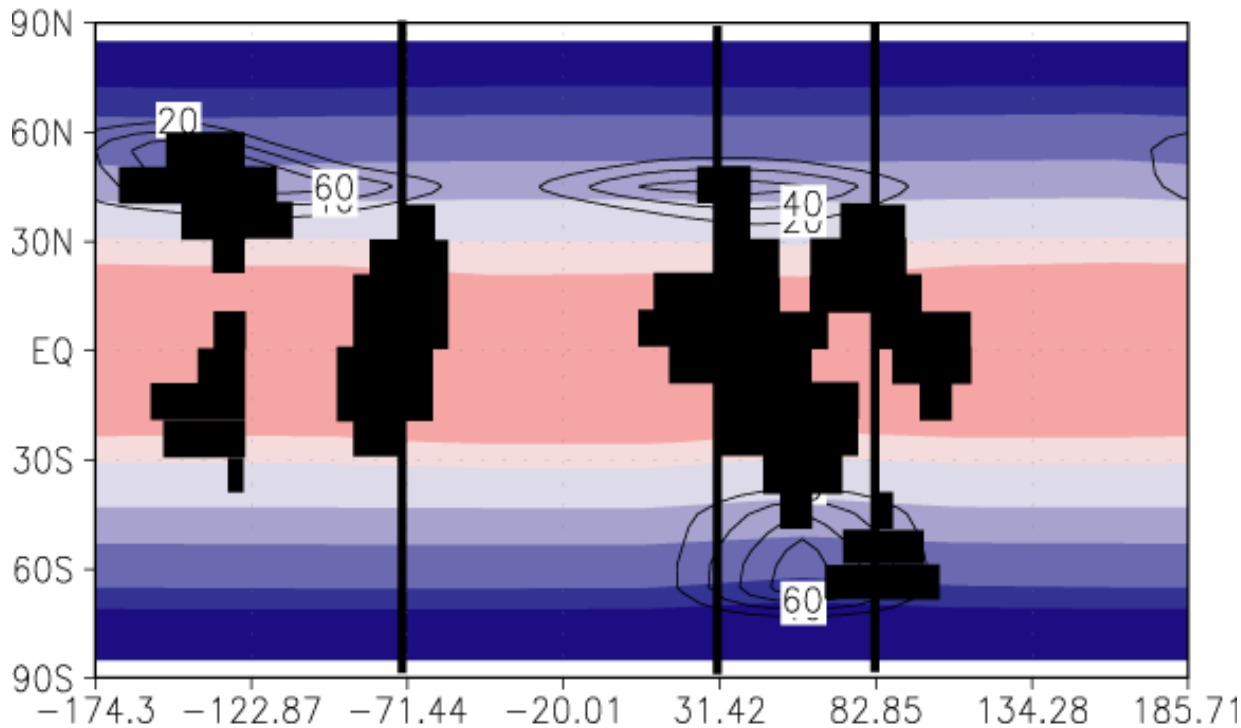
having continents in tropical latitudes is not sufficient to bring the Earth into total freeze: Snowball Earth

# Freezing the Earth: Climate and Geochemical model

Dispersed continents (Rodinia Break-Up at 750 Ma):

- pCO<sub>2</sub> equilibrates at 500 ppm
- It corresponds to an average surface temperature of 2 °C (-8.2°C than in Rodinia)

750 Ma reconstruction



A paleogeography with dispersed continents is more favorable to CO<sub>2</sub> drawdown (larger shelf surface).

Supercontinent break-up may have triggered the Neoproterozoic glaciations.

# How to bild a Precambrian Supercontinent ?

*“all earth sciences must contribute evidence toward unveiling the state of our planet in earlier times”*

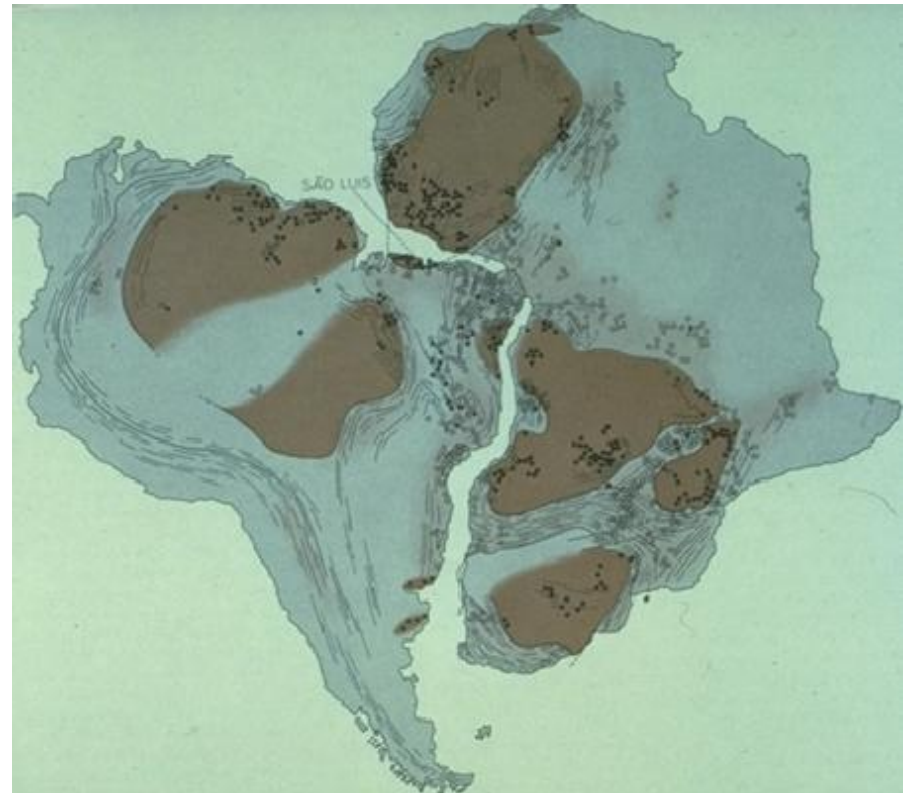
Alfred Wegener, The Origin of Continents and Oceans, 1915.



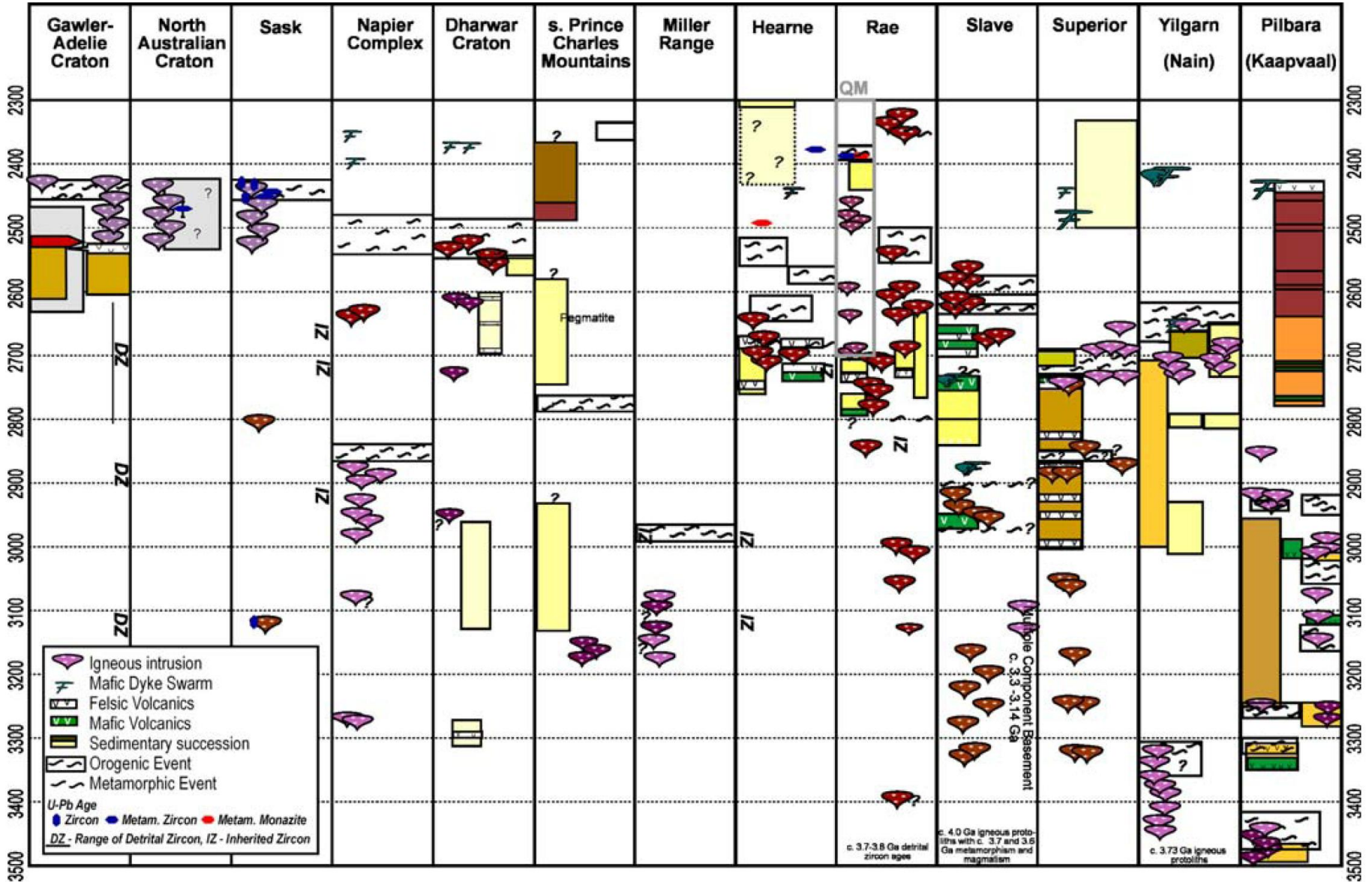
*Greenland stamp in honour of Alfred Wegener*

# Main criteria: Continuity of Geological Provinces

- 1) Isotopic Provinces
- 2) Provenance Studies
- 3) Large Igneous Provinces (LIPs) and Dyke Swarms
- 4) Paleomagnetism (the only quantitative way to test the models)



# Continuity of Geological Provinces: Geological Events Chart



## Taking the Pulse of Planet Earth / Completing the Plate Tectonic Revolution

### PROJECT:

**Reconstruction of Supercontinents Back To 2.7 Ga Using The Large Igneous Province (LIP) Record, With Implications For Mineral Deposit Targeting, Hydrocarbon Resource Exploration, and Earth System Evolution**

### Summary

Paleocontinental reconstructions are critical to providing a tectonic context for major ore deposits, the tracing of metallogenic belts between blocks, and identifying new prospective regions for mineral deposits of a wide variety of types. They are equally important to understanding the full context of sedimentary basins, their evolution, and their hydrocarbon reserves and potential.

Unfortunately, the state of understanding of pre-Pangea reconstructions and their specific paleogeography is tentative at best. There is good evidence, based for instance on the episodic nature of orogenic belts, that there have been several Precambrian supercontinents, specifically, in the late Archean (e.g. Kenorland, or perhaps three supercratons, Superia, Slavia, Vaalbara), the late Paleoproterozoic (supercontinent Nuna; also referred to as Columbia), and the Neoproterozoic (Rodinia). Beyond these general concepts, the exact reconstructions are poorly constrained. The high-quality information content of the LIP record (precise ages,

# Taking the Pulse of Planet Earth / Completing the Plate Tectonic Revolution

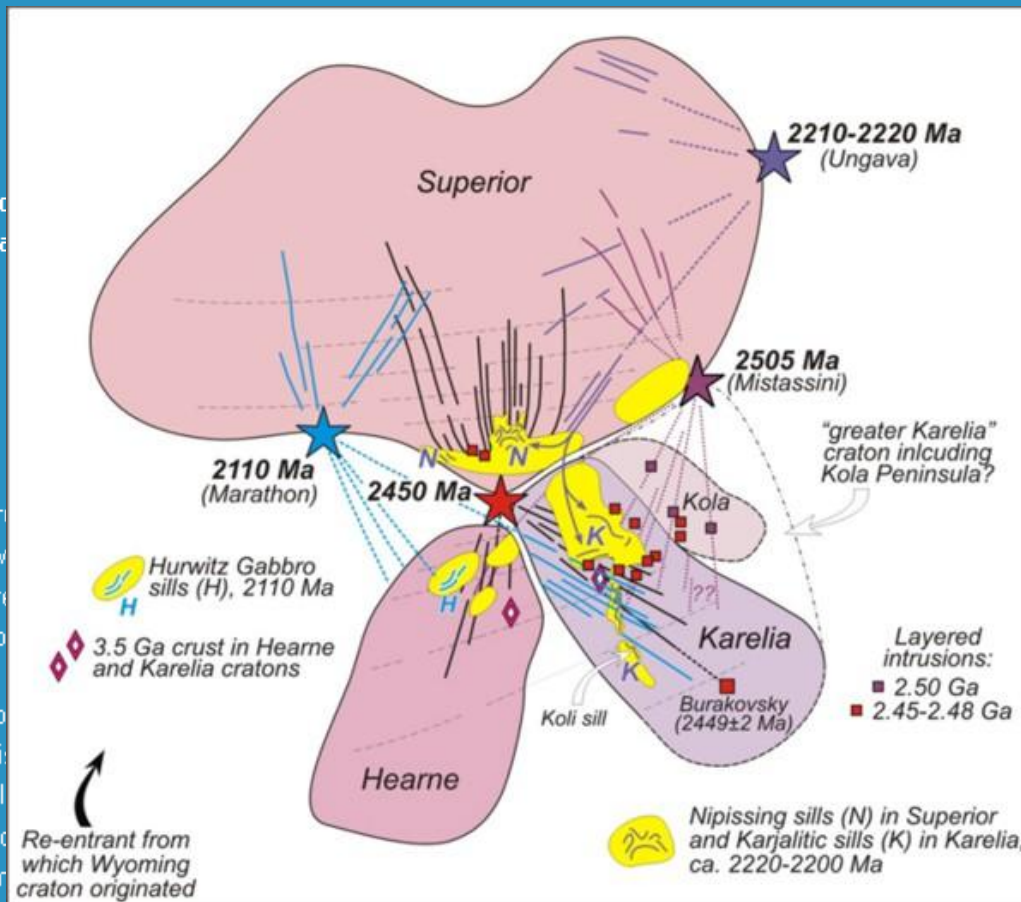
## PROJECT:

Reconstruction of Supercontinent Evolution  
Implications For Mineral  
Evolution

## Summary

Paleocontinental reconstruction of metallogenic belts between a variety of types. They are related to the evolution, and their hydrothermal systems.

Unfortunately, the state of knowledge is tentative at best. There is evidence that there have been several supercontinents, perhaps three supercontinents, also referred to as Columbia. These reconstructions are poorly constrained. The high-quality information content of the LIP record (precise ages,

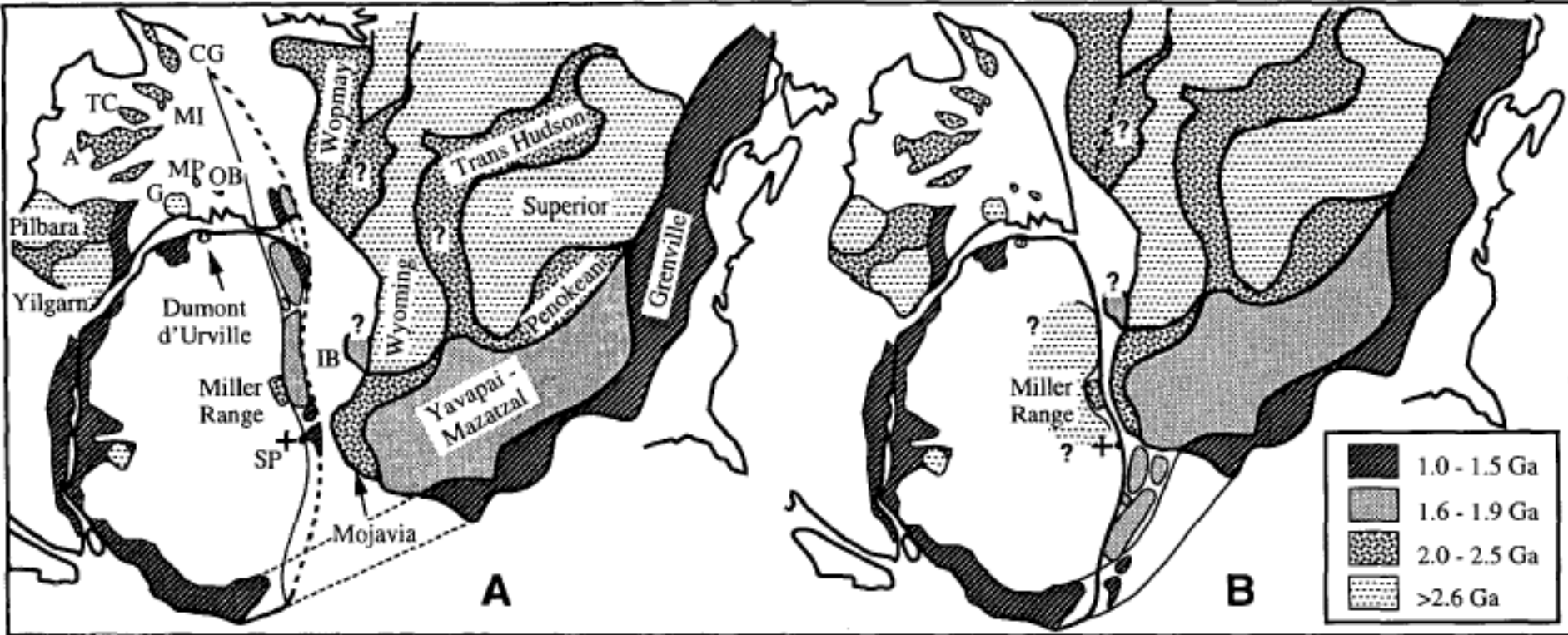


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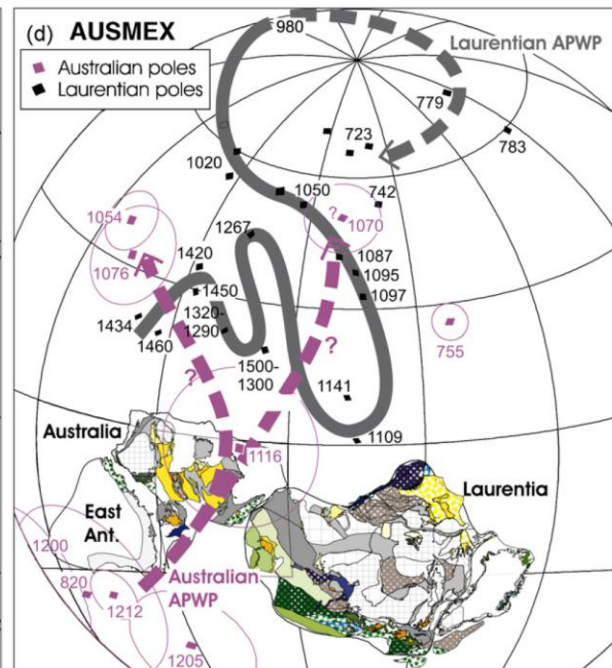
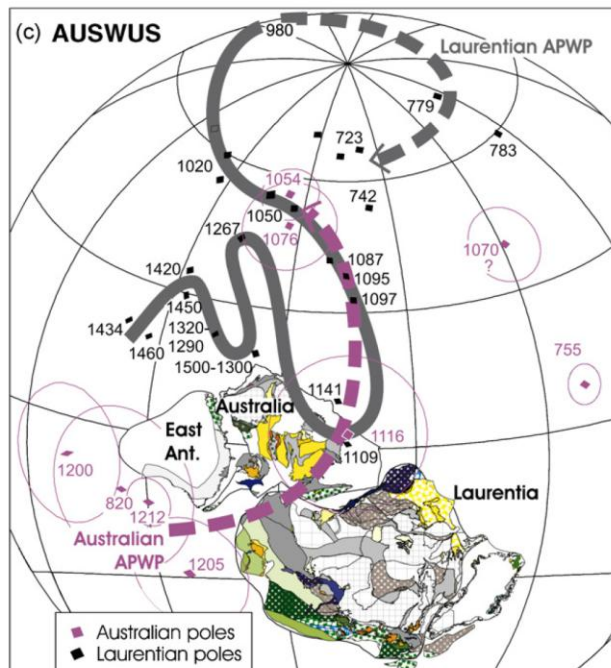
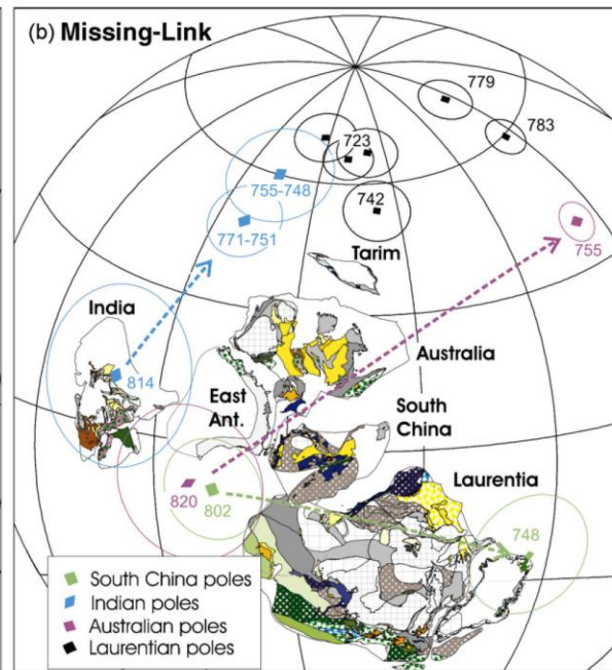
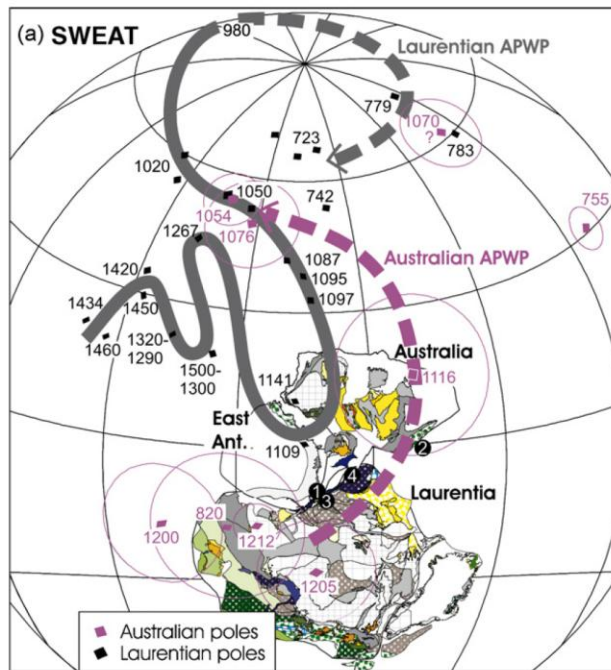
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# Isotopic Provinces: western Laurentia by 1.0 Ga



Borg and DePaolo, 1994, *Geology* 22: 307-310.

Improving the SWEAT fit



# Paleomagnetism:

## Precambrian database and data quality

### Reliability criteria

---

No.	Brief description
1	Well-determined rock age and a presumption that magnetization is the same age
2	Sufficient number of samples ( $N > 24$ ), $k$ (or $K$ ) $\geq 10$ and $\alpha_{95}$ ( $A_{95}$ ) $\leq 16.0$
3	Adequate demagnetization that demonstrably includes vector subtraction
4	Field tests that constrain the age of magnetization
5	Structural control and tectonic coherence with craton or block involved
6	The presence of reversals
7	No resemblance to paleopoles of younger age (by more than a period)

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# Paleomagnetism: Precambrian database and data quality

## Reliability criteria

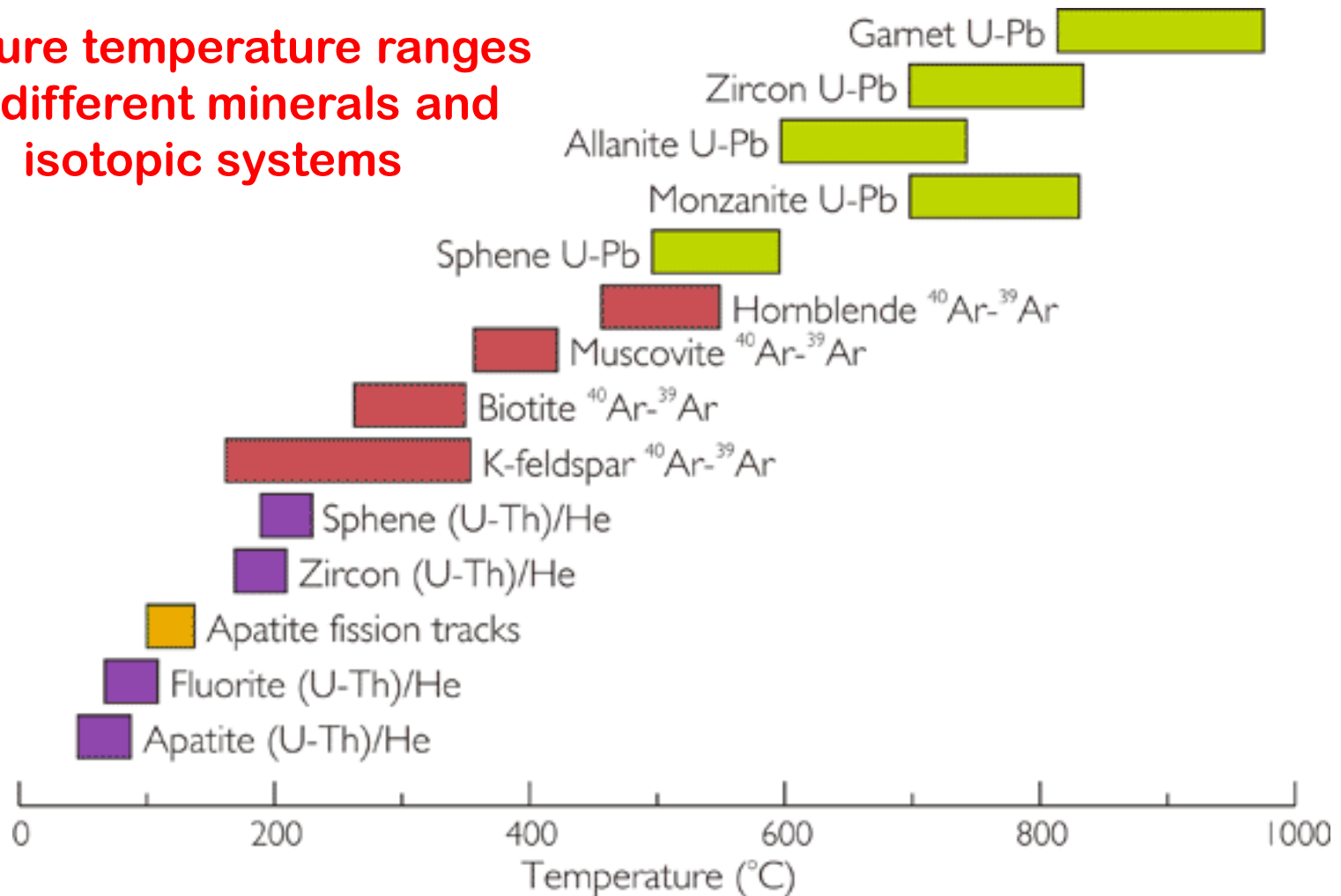
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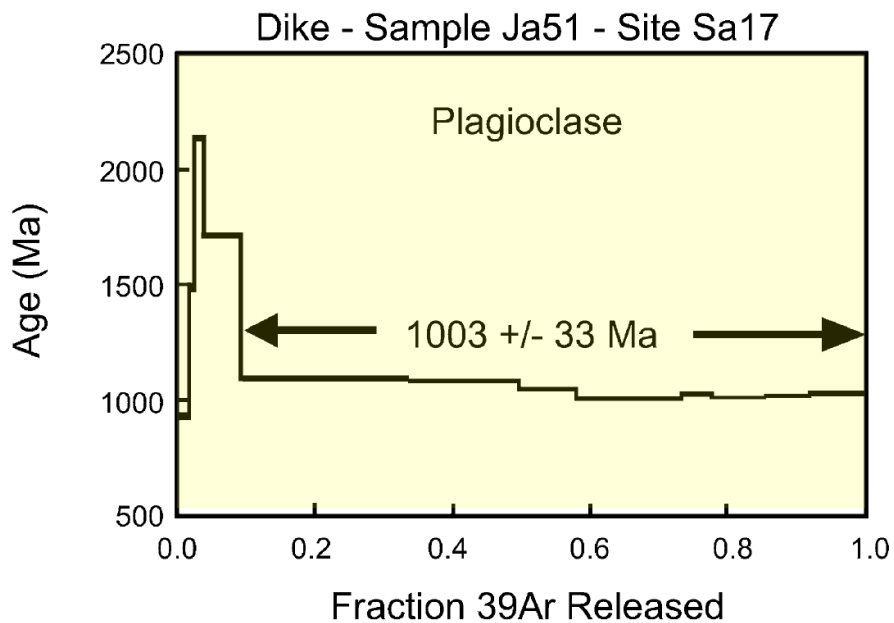
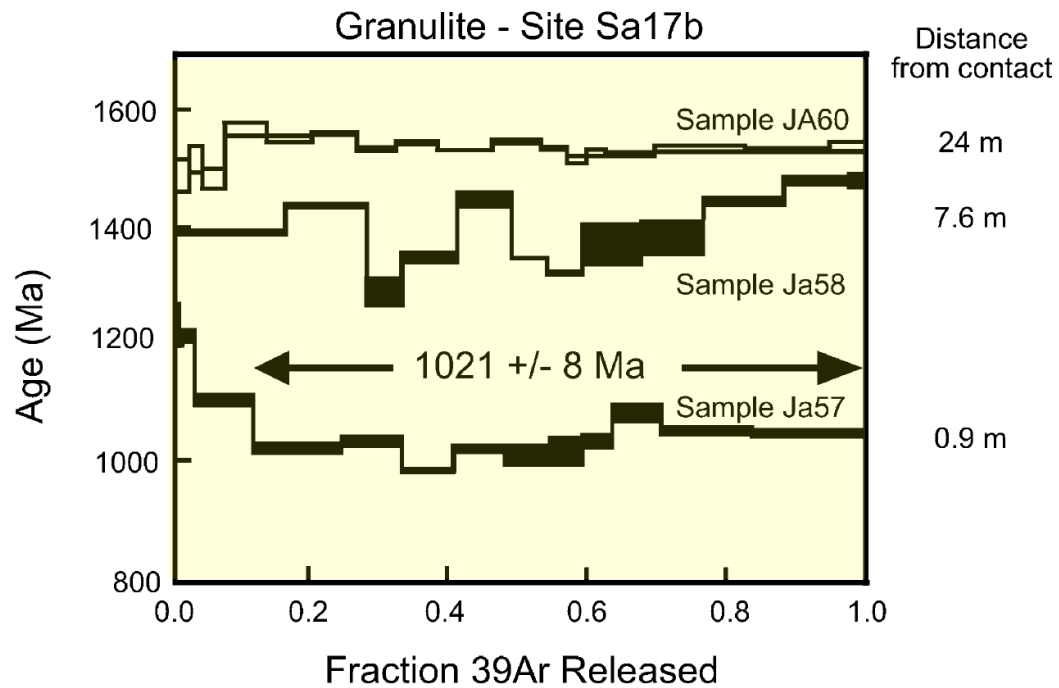
No.	Brief description
1	Well-determined rock age and a presumption that magnetization is the same age
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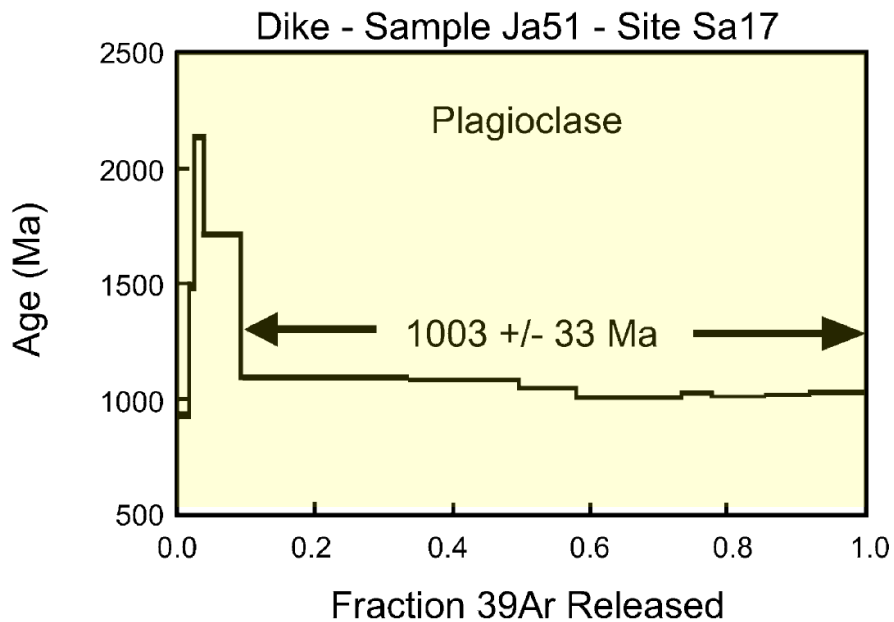
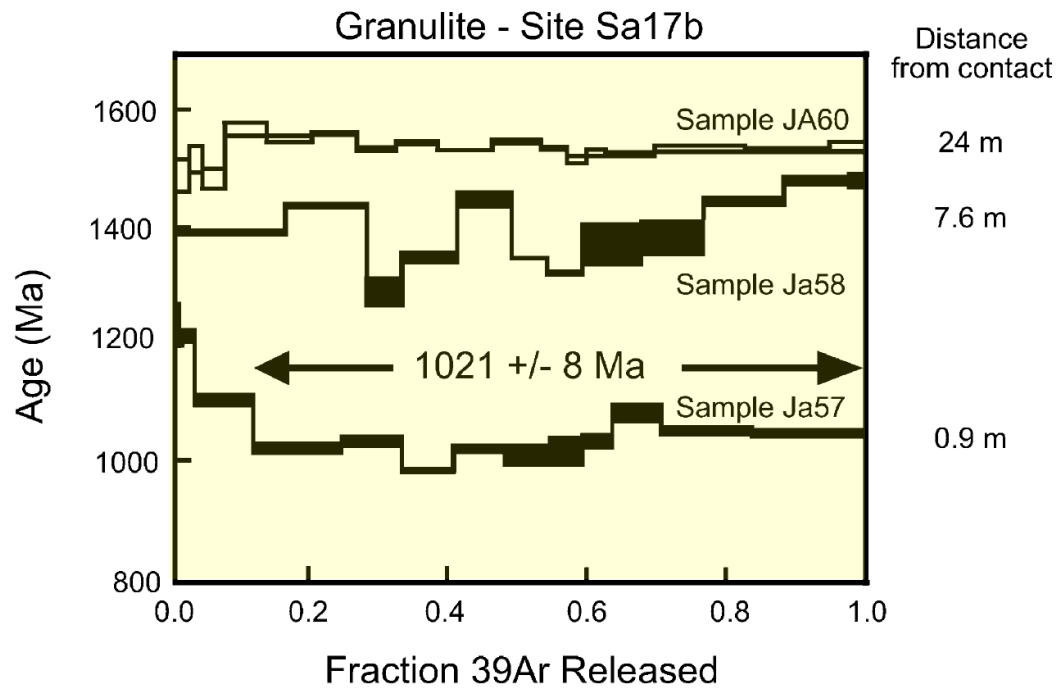
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# Age of the rock vs. Age of magnetization acquisition

Closure temperature ranges  
for different minerals and  
isotopic systems







**Geochronological  
'baked contact test'**

**three new U-Pb  
baddeleyite ages  
at 923 +/- 2 Ma !**

# Paleomagnetism:

## Precambrian database and data quality

### Reliability criteria

---

No.	Brief description
1	Well-determined rock age and a presumption that magnetization is the same age
2	Sufficient number of samples ( $N > 24$ ), $k$ (or $K$ ) $\geq 10$ and $\alpha_{95}$ ( $A_{95}$ ) $\leq 16.0$
3	Adequate demagnetization that demonstrably includes vector subtraction
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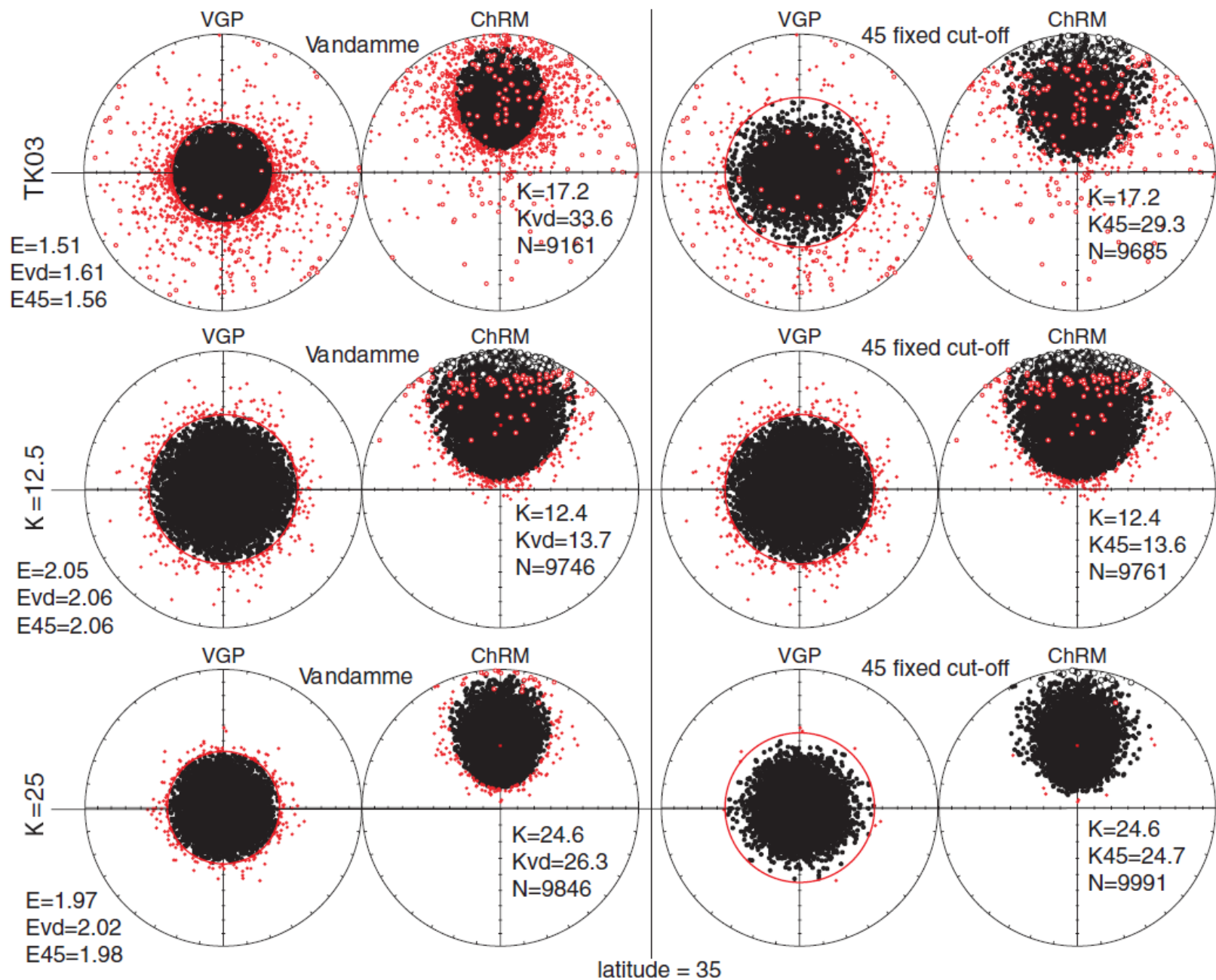
# Geomagnetic secular variation and the statistics of palaeomagnetic directions

Martijn H. L. Deenen,<sup>1</sup> Cor G. Langereis,<sup>1</sup> Douwe J. J. van Hinsbergen<sup>1,2</sup>  
and Andrew J. Biggin<sup>1,3</sup>

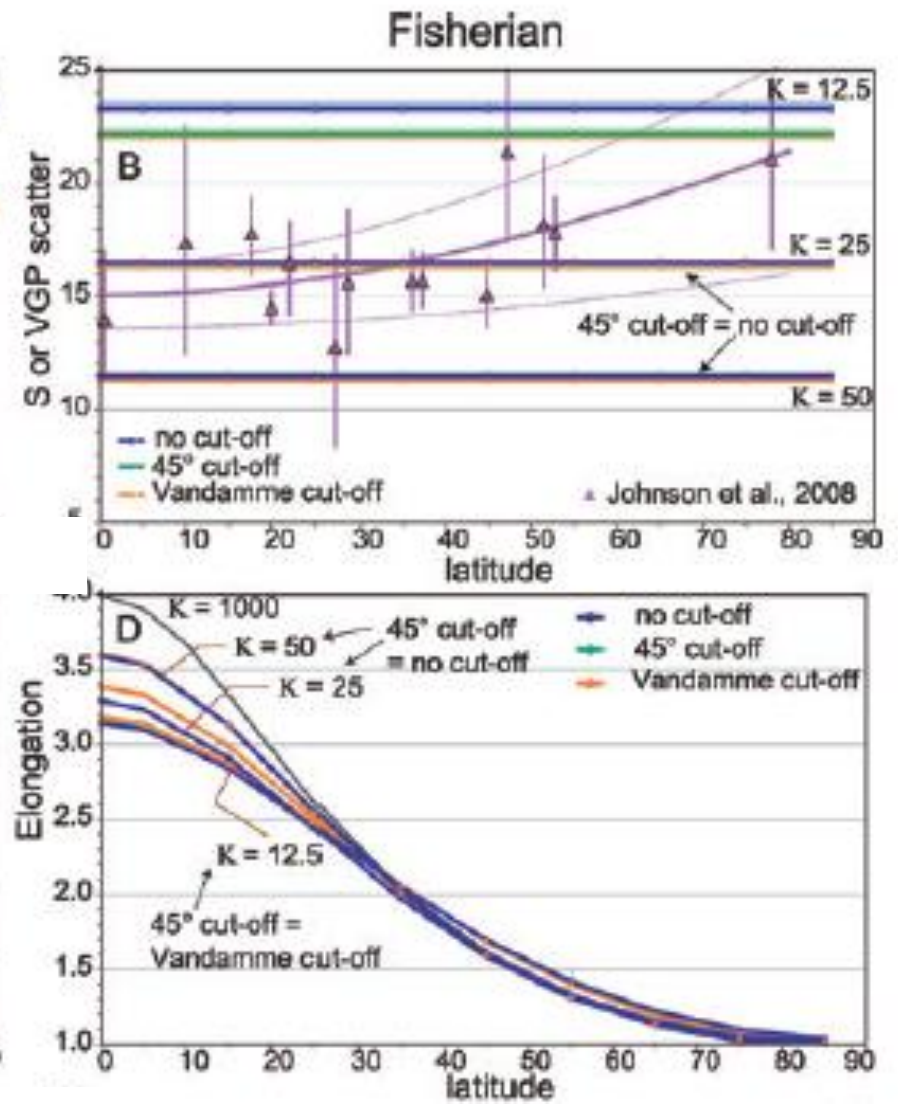
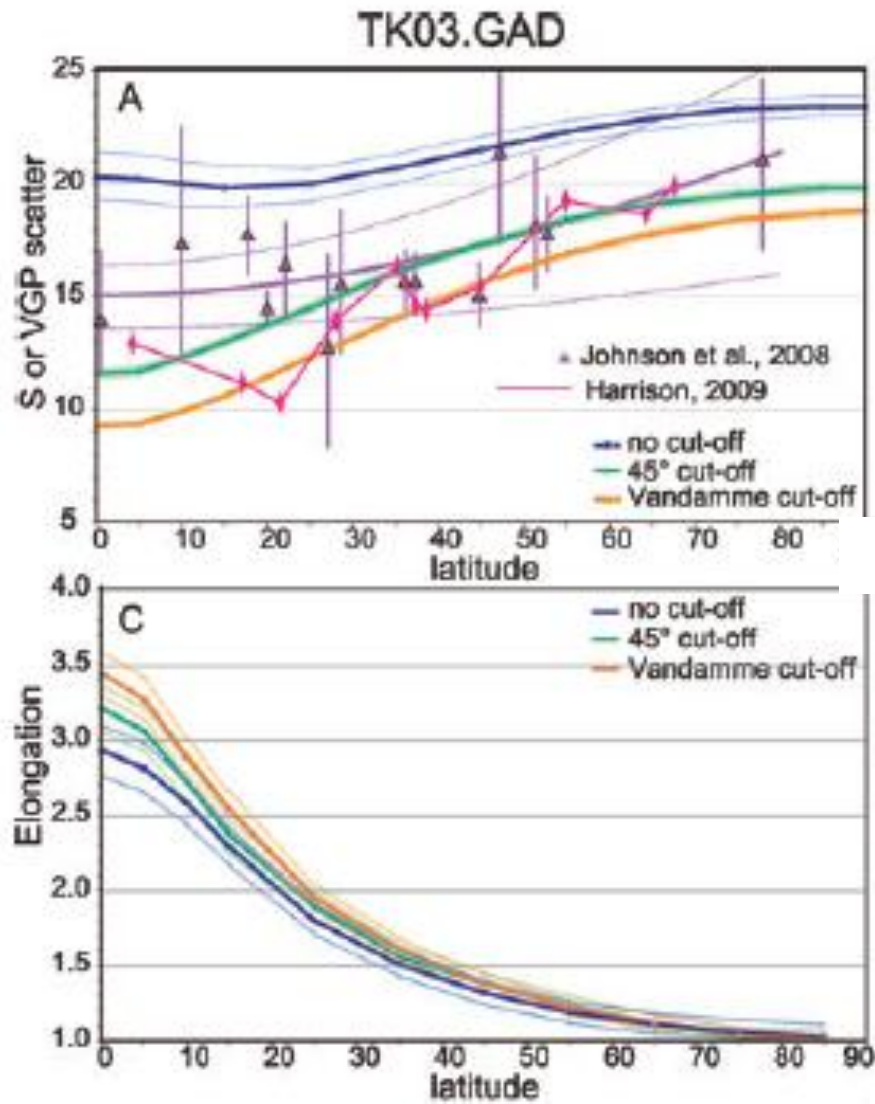
<sup>1</sup>*Palaeomagnetic Laboratory 'Fort Hoofddijk', Utrecht University, Budapestlaan 17, 3584 CD Utrecht, The Netherlands. E-mail: deenen@geo.uu.nl*

<sup>2</sup>*Physics of Geological Processes, University of Oslo, Sem Sælands vei 24, 0316 Oslo, Norway*

<sup>3</sup>*Geomagnetism Lab, University of Liverpool, Oliver Lodge Laboratories, Oxford Road, Liverpool L69 7ZE, UK*



# Comparing models with 0-5 Ma data: K25 Fisher distribution matches TK03.GAD



# Reliability envelope: higher N implies higher A95 and lower K

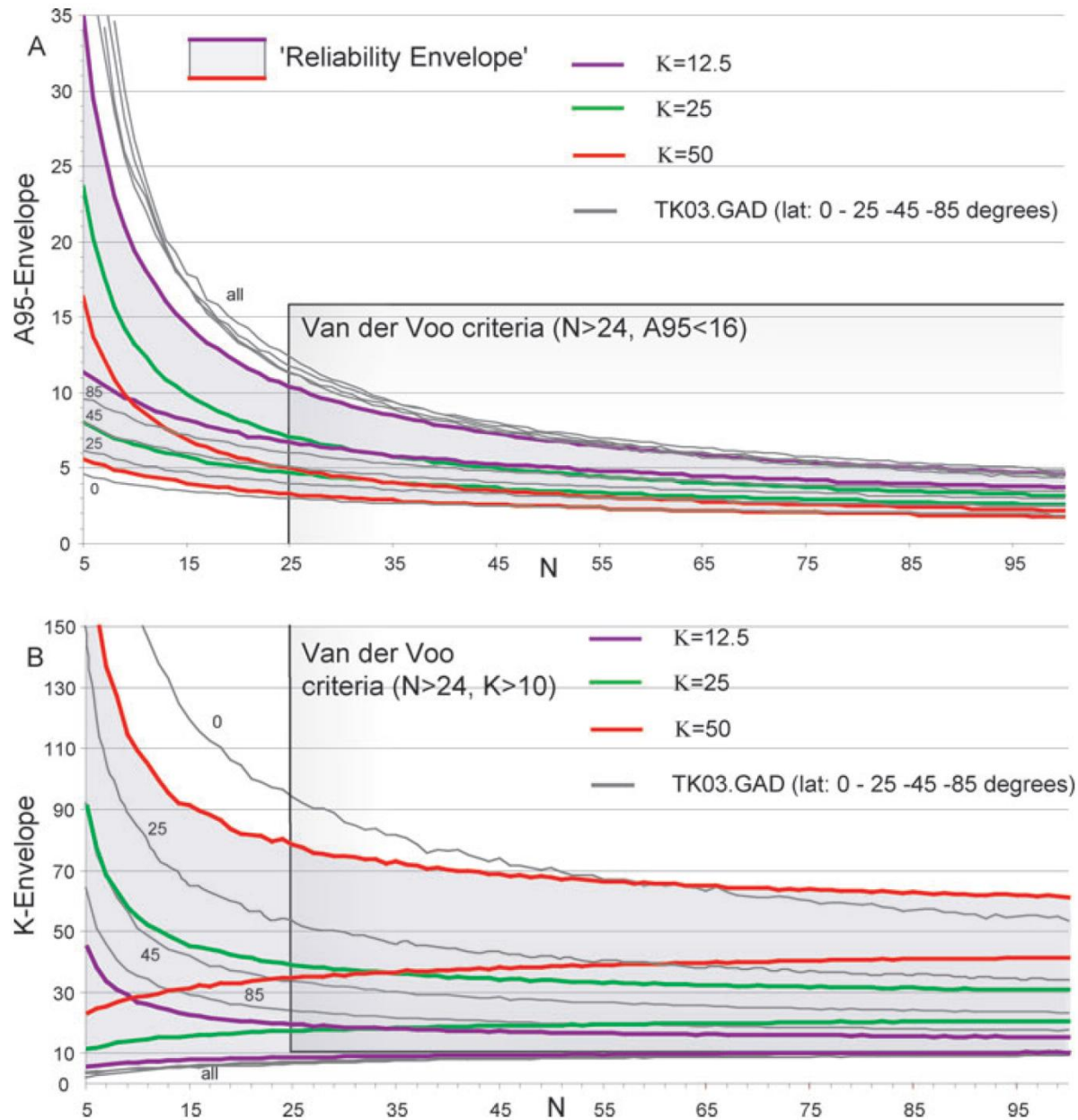


TABLE 1. PRECISELY DATED PRE-800 Ma PALEOMAGNETIC POLES FROM STRATIFIED ROCKS OR UNDEFORMED DIKE SWARMS IN STABLE CRATONIC BLOCKS

Rock unit (craton)	Age (Ma)	Test*	Pole (°N,°E)	A <sub>95</sub> °	Pole or age reference
Kandyk suite (Siberia)	1005 ± 4	f	-03, 177	4	Pavlov et al. (2002)
Poronomezh intr. (Siberia)	1070 ± 6	C	34, 165	9	Pavlov et al. (2002)
Lake Shore traps (Laurentia)	1087 ± 2	f, C	22, 181	7	Dien and Haig (1994)
Portage Lake volc. (Laurentia)	ca. 1095	f, G	27, 178	5	Hnat et al. (2006)
Logan sills mean (Laurentia)	1109 ± 4/-2	C	49, 220	4	Buchan et al. (2000)
Umkondo mean (Kalahari)	ca. 1110	C	64, 039	4	Gose et al. (2006)
Abitibi dikes (Laurentia)	1141 ± 2	C	43, 209	14	Elst and Buchan (1993)
Madbury dikes (Laurentia)	1235 ± 13	C	-6, 152	3	Halls et al. (1993); Torsvik and Symons (1982)
Post-Jotnian intr. (Baltica)	ca. 1265	C	04, 158	4	Buchan et al. (2000)
McKenzie mean (Laurentia)	1267 ± 2	C	04, 190	5	Buchan and Halls (1990)
McNamara Fm (Laurentia)	1401 ± 6	f	-14, 208	7	Elston et al. (2002)
Purocell lava (Laurentia)	ca. 1440	f	24, 216	5	Elston et al. (2002)
Leysville intr. (Laurentia)	1452 ± 1	C	-25, 219	1	Elston et al. (2002)
St. Francois Mtns (Laurentia)	ca. 1476	g, c, F	-13, 219	6	Meert and Stuckey (2002)
Wangshu char. (N. China)	ca. 1500	f	09, 245	7	Irving et al. (1972, 2004); Hamilton and Buchan (2007)
Emmeruga Dol. (N. Australia)	ca. 1645	f	-79, 203	6	Idnurm et al. (1995)
Tatoula Sandstone (N. Australia)	1650 ± 3	f	-61, 187	6	Idnurm et al. (1995)
North Star intr. (N. Australia)	1651 ± 1	G	15, 211	1	Hnat et al. (2006)
Peters Creek volc. (N. Australia)	ca. 1725	g	-26, 221	5	Idnurm (2000)
Cleaver dikes (Laurentia)	1740 ± 5/-4	c, C	19, 277	6	Irving et al. (2004)
Taihang dikes (N. China)	1769 ± 3	f, C	36, 247	3	Halls et al. (2000)
Post-Waterberg (Kalahari)	ca. 1875	C	09, 055	17	Hanson et al. (2004); de Kock (2007) <sup>†</sup>
Minton dikes (E. Superior)	ca. 1911	C	17, 111	9	Halls and Heaman (2000)
Minto dikes (E. Superior)	1998 ± 2	C	38, 174	10	Buchan et al. (1998)
Bushveld mean (Kaarvaal)	ca. 2050	f	12, 077	4	Evans et al. (2002)
Waterberg sequence (Kalahari)	ca. 2050	f, C	37, 051	11	de Kock et al. (2007)
Kuetsyarvi lavas (Karelia)	2058 ± 6	G	23, 298	7	Torsvik and Meert (1995); Melezhik et al. (2007)
Cachon dikes (W. Superior)	2091 ± 2	C	59, 08	9	Halls and Heaman (2000)
Matachewan R. pol. (W. Superior)	ca. 2100	f	52, 187	9	Buchan et al. (1996); Halls and Heaman (2000); Halls et al. (2005)
Marathon N pol. (W. Superior)	2126 ± 1	C	45, 199	7	Buchan et al. (1996); Halls et al. (2005)
Biscotasing dikes (E. Superior)	2167 ± 2	C	28, 223	11	Buchan et al. (1993)
Nipissing sills N1 (E. Superior)	2217 ± 4	C	-17, 272	10	Buchan et al. (2000)
Orinjeluk lav. (Kaarvaal)	2222 ± 13	G	-01, 10	5	Evans et al. (1997)
Dhany dikes (Kalahari)	2396 ± 1	C	13, 15	6	Halls et al. (2007)
Widgiemooltha (Yilgarn)	ca. 2415	c	68, 387	8	Evans (1968); Smirnov and Evans (2006)
Karelian comp (Karelia)	ca. 2445	C	-12, 244	15	Mertanen et al. (2006)
Mitchellian Cr. (Kalahari)	ca. 2470	C	55, 244	9	Halls and Davis (2004)
Matachewan R. pol. (W. Superior)	2459 ± 5	C	-1, 257	9	Halls and Davis (2004); Halls et al. (2005)
Great Dike mean (Zimbabwe)	2575 ± 1	c	21, 058	6	Jones et al. (1976); Wilson et al. (1987); Mushayandebwu et al. (1994); Oberthür et al. (2002)
Nyanziani lava (Tanzania)	ca. 2600	g, f	-14, 330	6	Meert et al. (1994)
Otto Stock (E. Superior, Abitibi)	2680 ± 1	c	-69, 047	5	Pullaiah and Irving (1975); Buchan et al. (1990)
Stillwater complex (Wyoming)	2705 ± 4	c	-67, 292	17	Xu et al. (1997)
Fortescue Package 1 (Pilbara)	2772 ± 2	f, g	-41, 160	4	Schmidt and Embleton (1985); Strik et al. (2003)
Derdepoort lavas (Kaarvaal)	ca. 2782	G	-40, 005	18	Wingate (1998)
Duffer M component (Pilbara)	3467 ± 5	f	44, 086	7	McElhinny and Senanayake (1980); Van Kranendonk et al. (2002)

\*Field stability test abbreviations: f—fold test, F—folding penecontemporaneous with rock formation, c—inverse contact test, C—baked-contact test, g—conglomerate test, G—intraformational conglomerate test. Note: capitalized symbols indicate primary magnetization, whereas lowercase symbols indicate merely ancient remanence relative to the geological feature of the test.

<sup>†</sup>de Kock (2007) has shown that the ca. 1875 Ma post-Waterberg sills are distinctly older than the Sibasa lavas, so only the mean from the sills, rather than the combined pole (Hanson et al., 2004), is listed here.

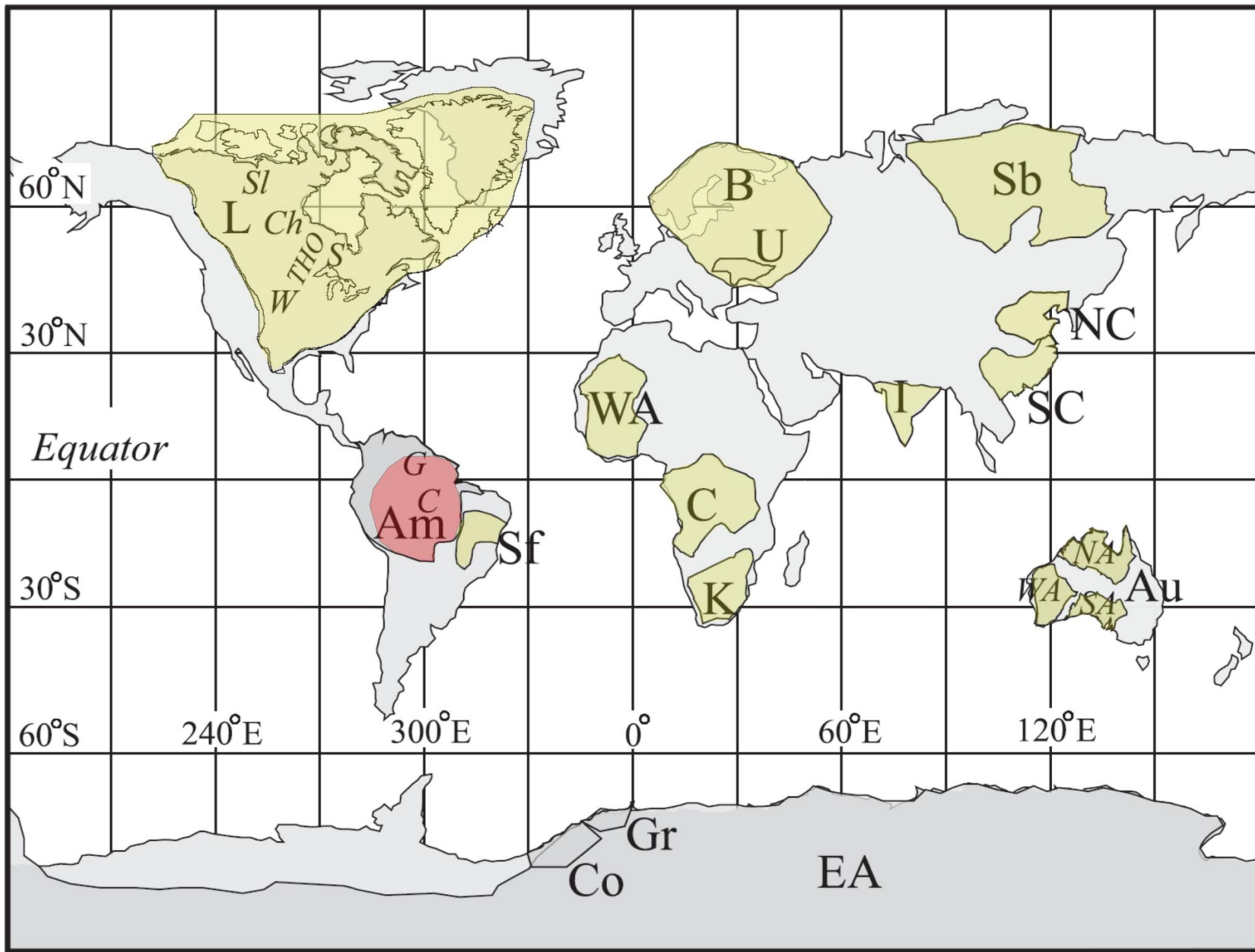
## Evans and Pisarevsky (2008) criteria:

- ✓ Age error < 15 Ma (~1500 km for ~5 cm/yr plate speed)
- ✓ A<sub>95</sub> < 20°
- ✓ Complete demagnetization and PCA analysis
- ✓ At least one positive stability test
- ✓ Structural continuity with the craton (check for tilting in plutonic rocks)

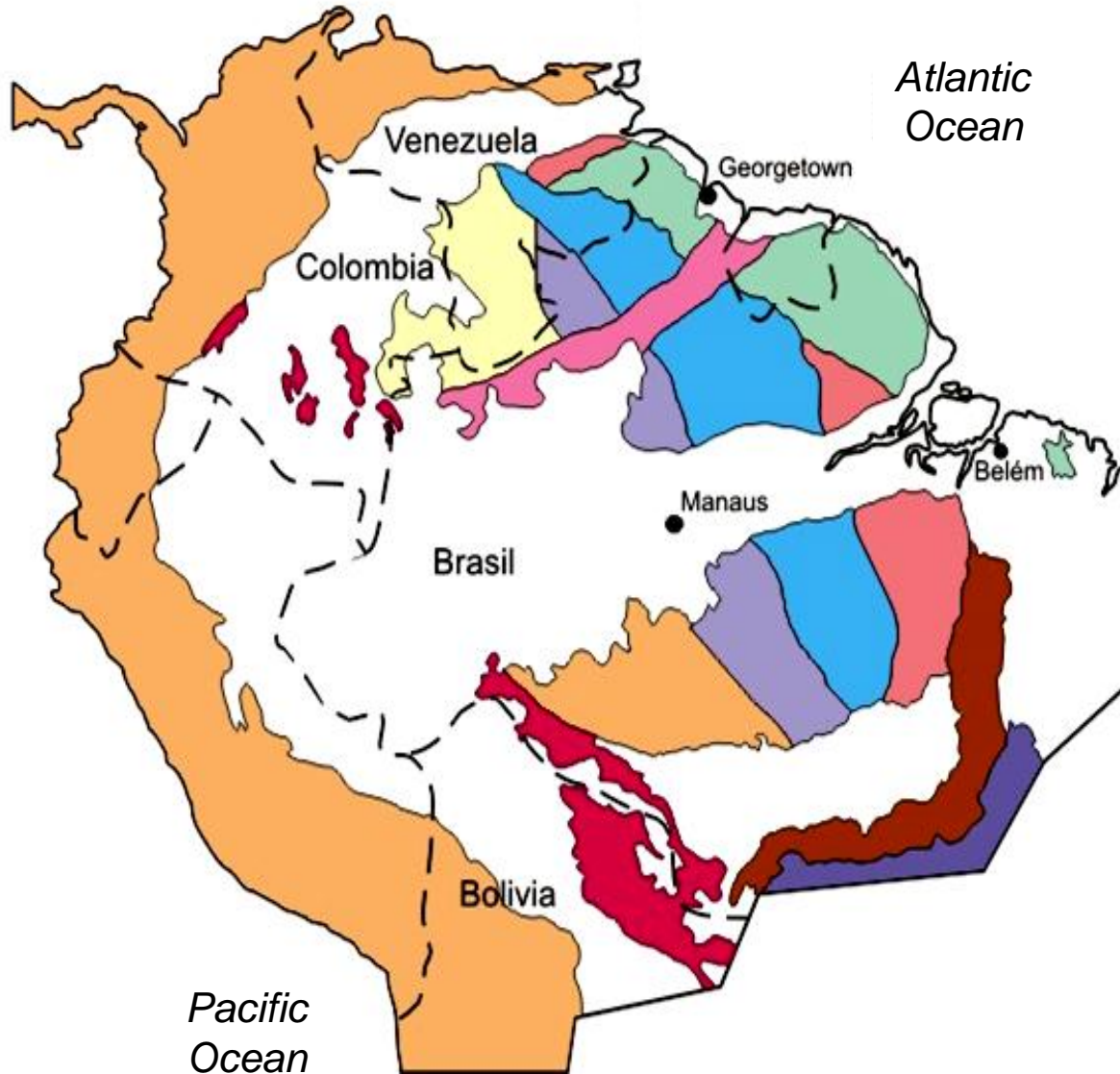
According to these criteria they identified ...

50 results for the whole period before 800 Ma.  
It corresponds to only 3% of the Precambrian database.

It would be helpful to know where and at which ages we could improve old results, where we need new targets and which targets we should avoid.

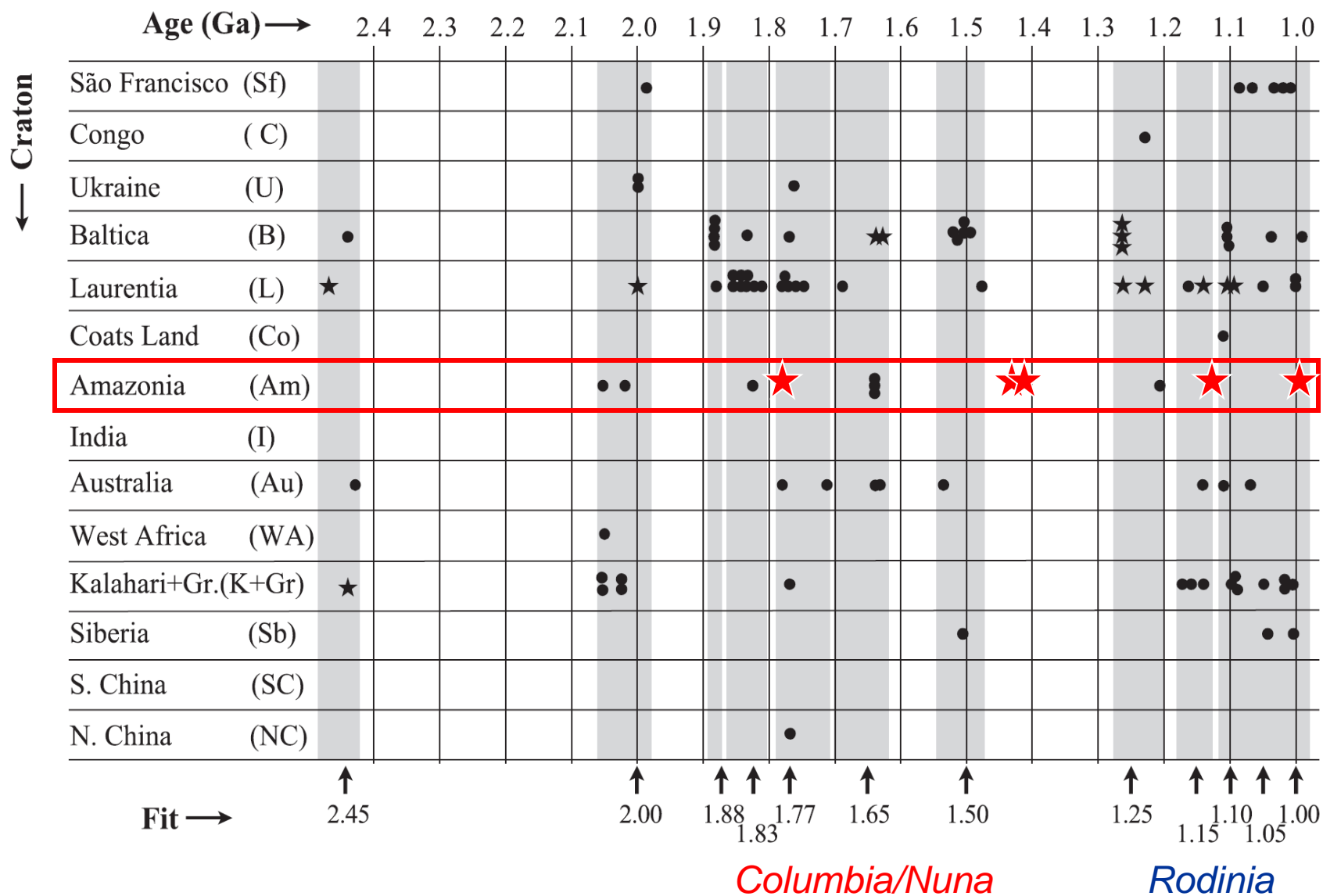


# Amazonian Craton



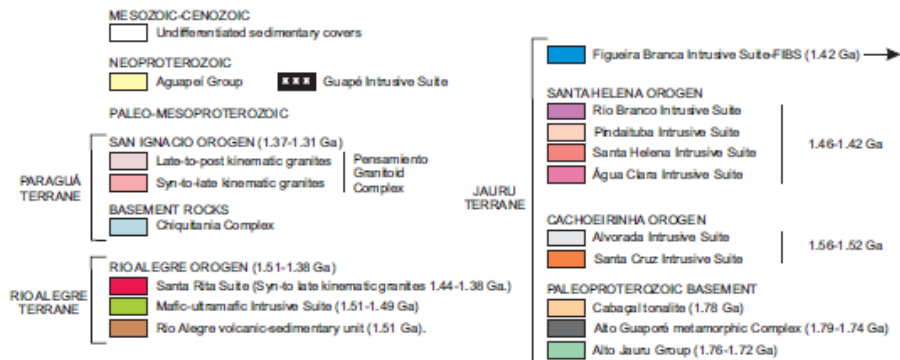
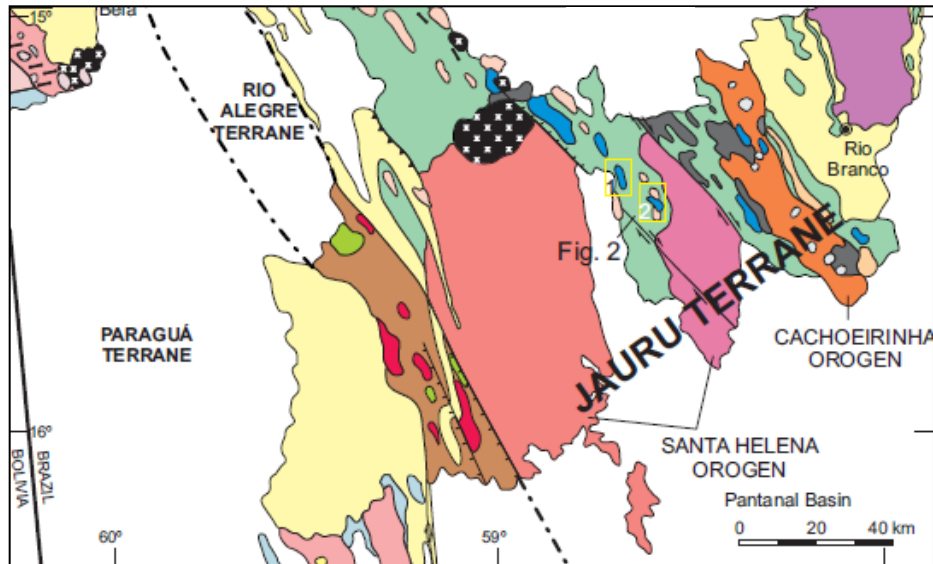
## Provinces

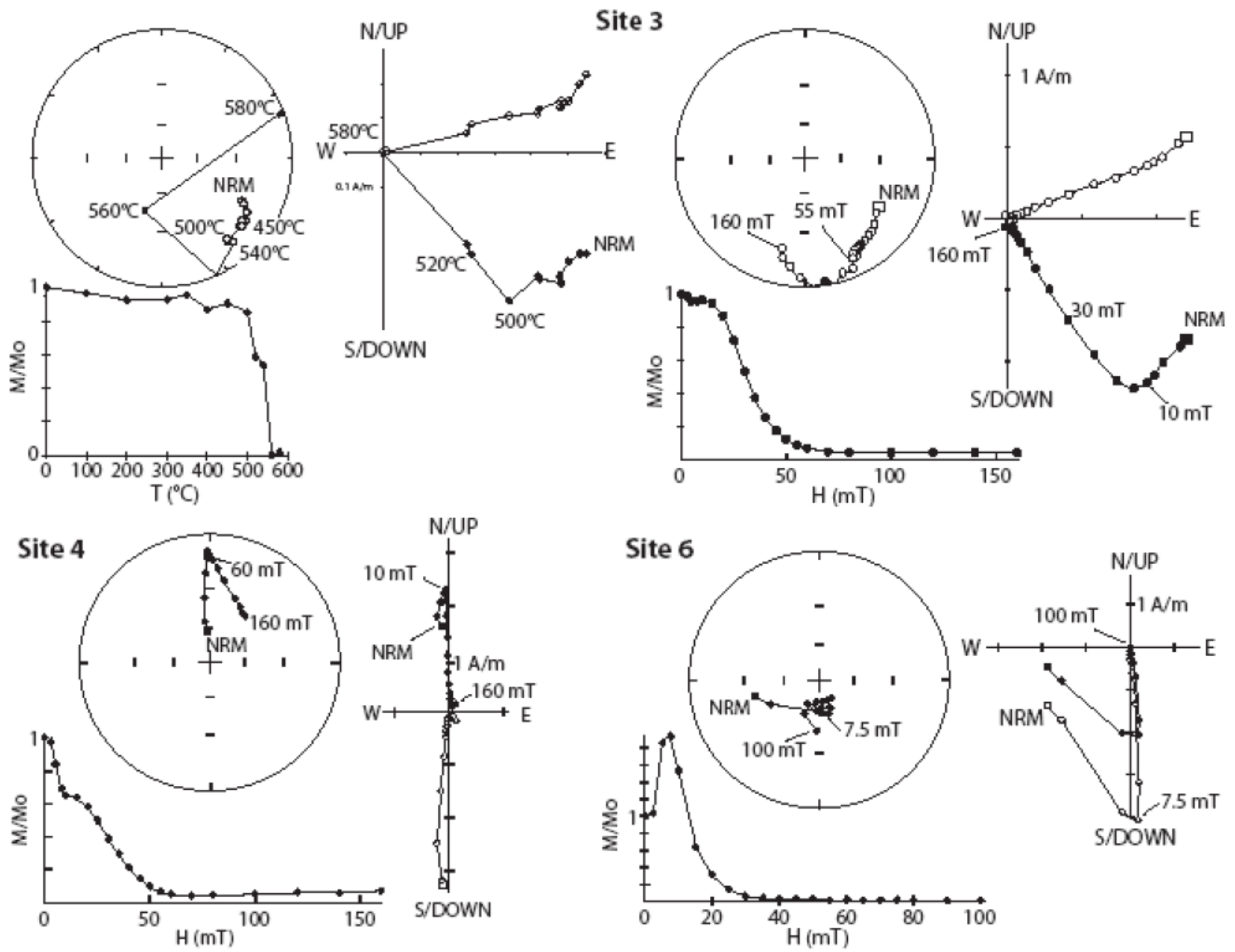
- 1.2 – 1.0 Ga Sunsás
- 1.5 – 1.3 Ga Rondonian
- 1.8 – 1.5 Ga Rio Negro - Juruena
- 2.0 – 1.8 Ga Ventuari - Tapajós
- 2.2 – 2.0 Ga Maroni - Itacaiunas
- > 2.3 Ga Central Amazonia



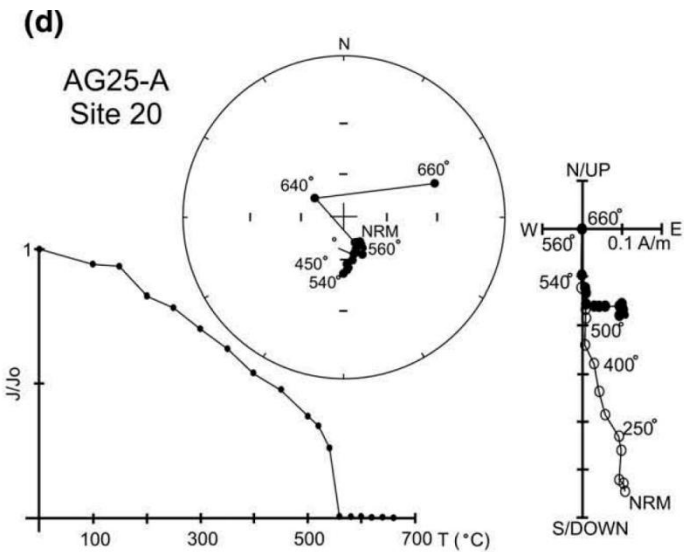
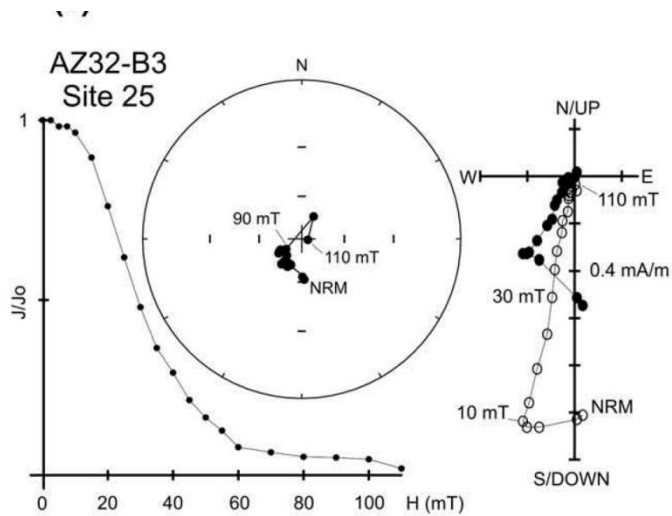
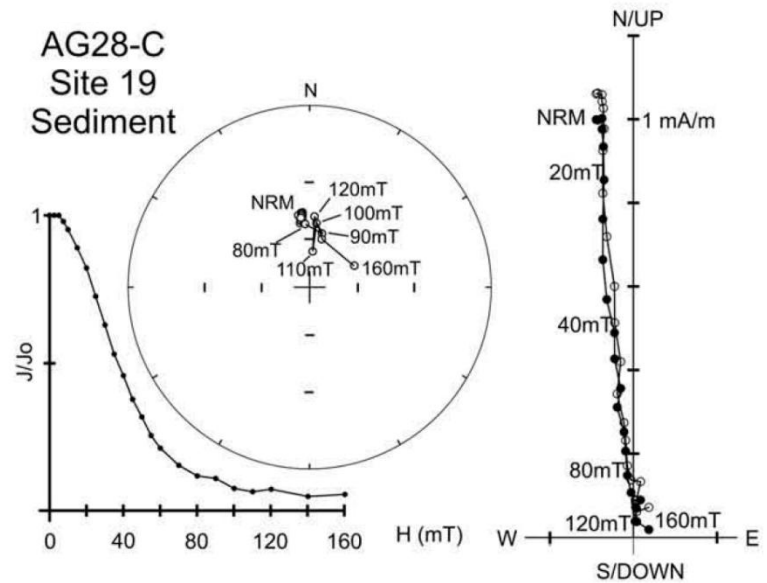
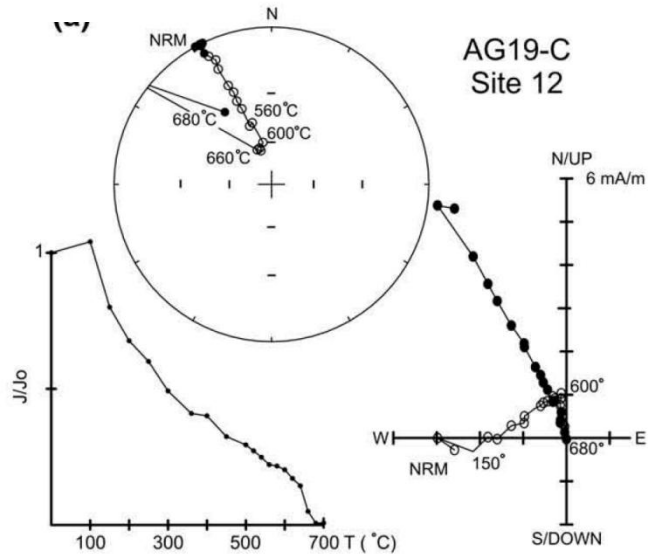
*Stars = key poles*

# Sandstones and sills from Aguapeí region



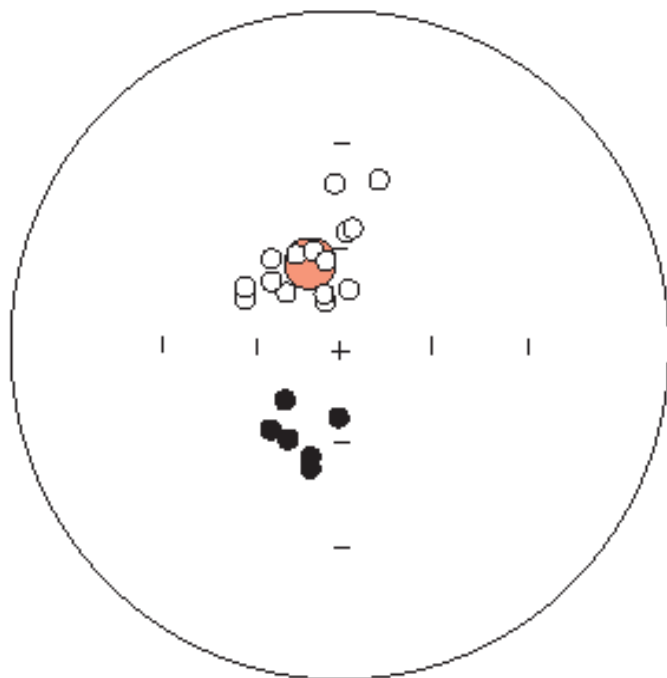


# *Aguapeí sills*

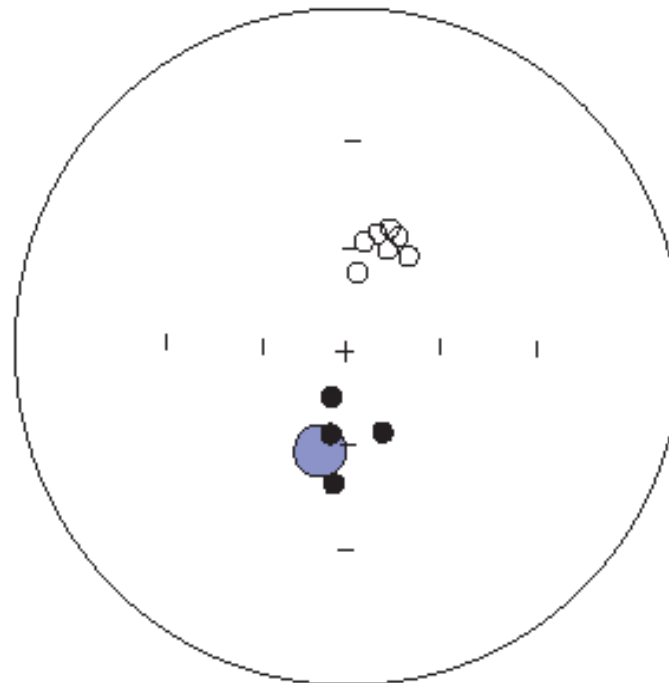


# *Aguapeí sediments: Fortuna Formation*

**Aguapei metasediments**  
**Site Means\*\* (N=21)**



**Aguapei sills**  
**Site Means\*\* (N=11)**

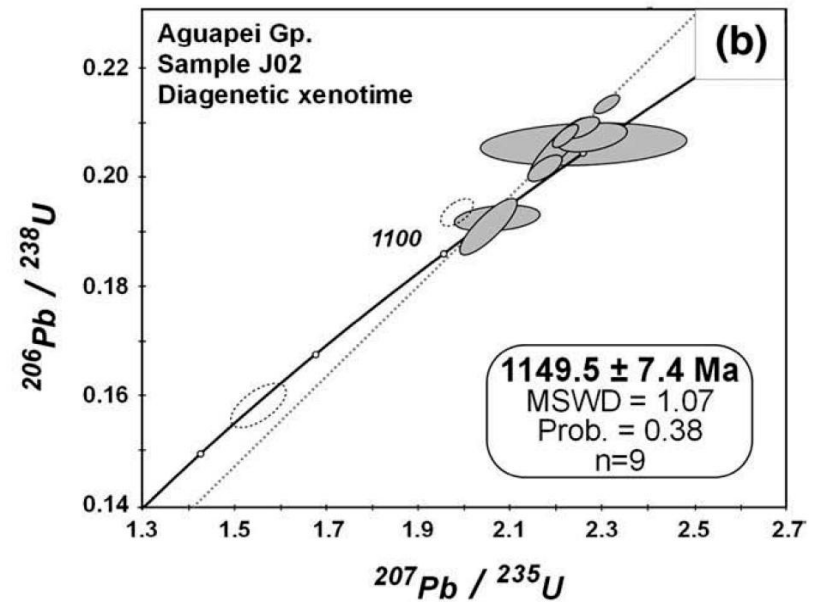
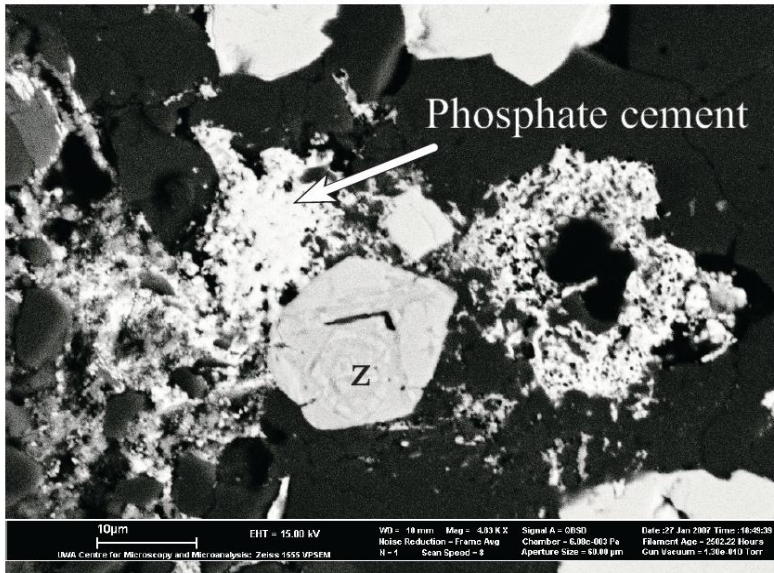
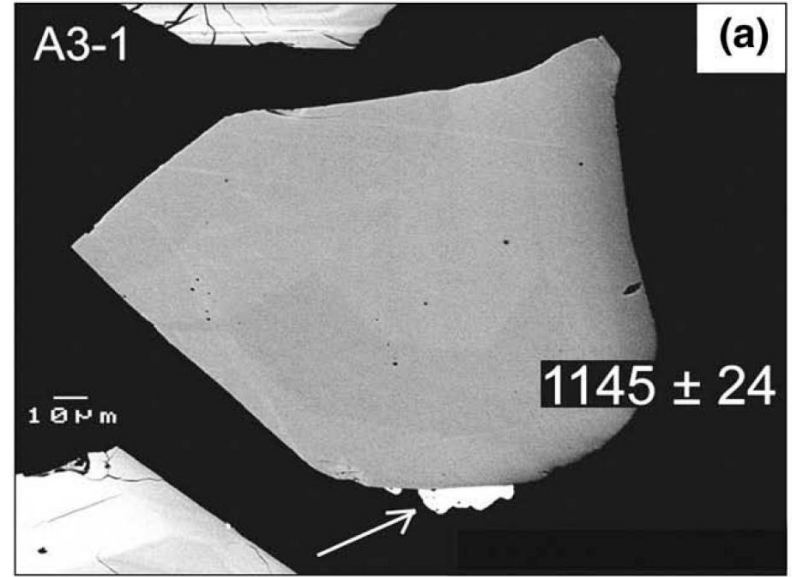
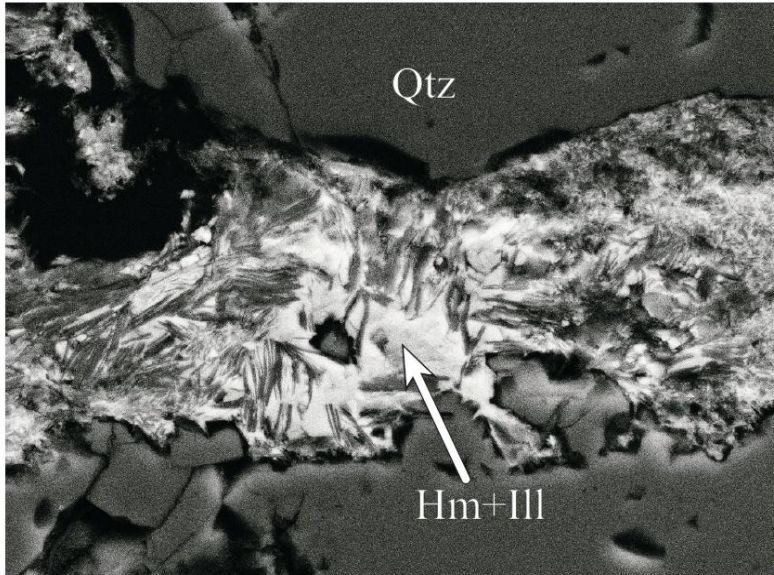


**\*\*Site means inverted to calculated mean**

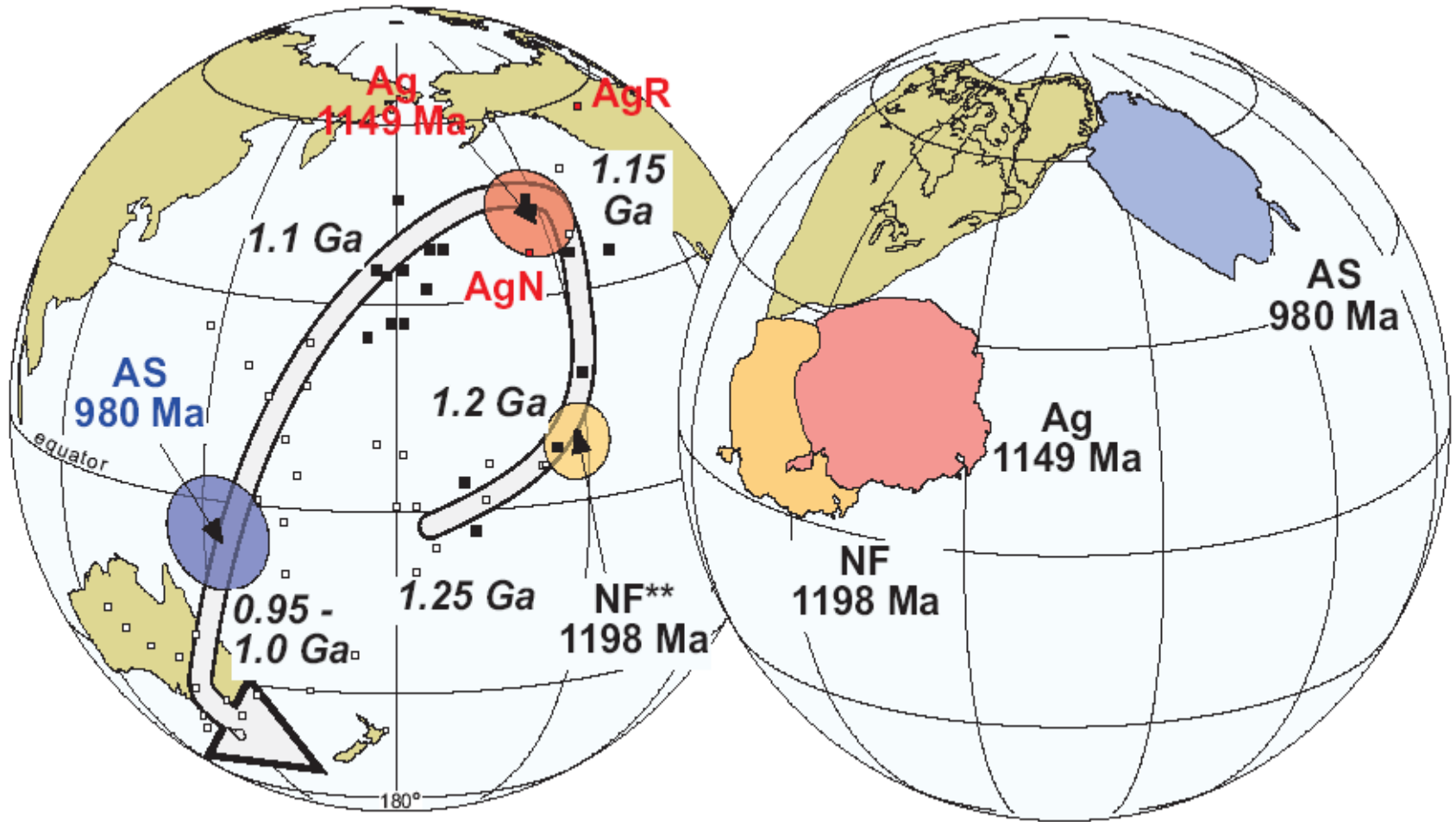
**1149.6 +/- 7.4 Ma**  
**SHRIMP U-Pb xenotime**  
**dating**

**981 +/- 2 Ma**  
**Ar-Ar in biotite**

# SHRIMP dating of diagenetic xenotime



# Laurentia and Amazonia APWPs



\*\*NF pole reported in Tohver et al. EPSL (2002)

# Synthesis/Implications for MagIC:

## 1) Quality of the Precambrian database.

Which are the age gaps in each craton? What is lacking in the available data : Dating? Field test? Statistics? Where not to go.

## 2) Age reliability.

Dating and paleomag should be performed in the same site, if possible by multiple dating methods, so that the age can be linked to the remanence acquisition process.

Link to other global initiatives, like the [supercontinent.org](http://supercontinent.org)?

## 3) Statistical quality of results using SV-based assumptions.

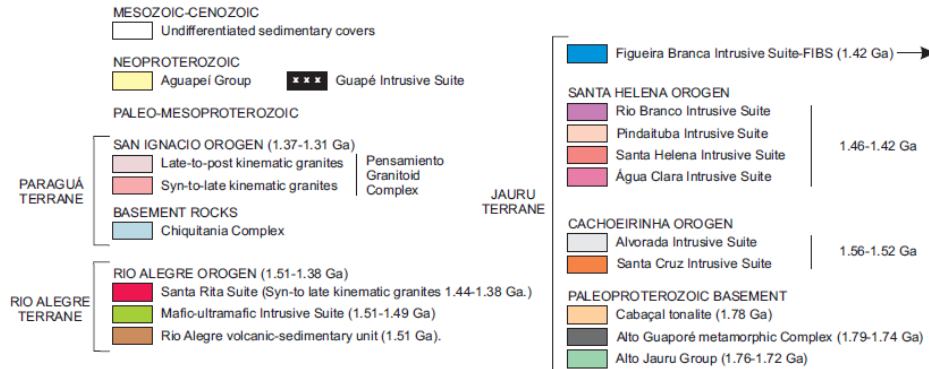
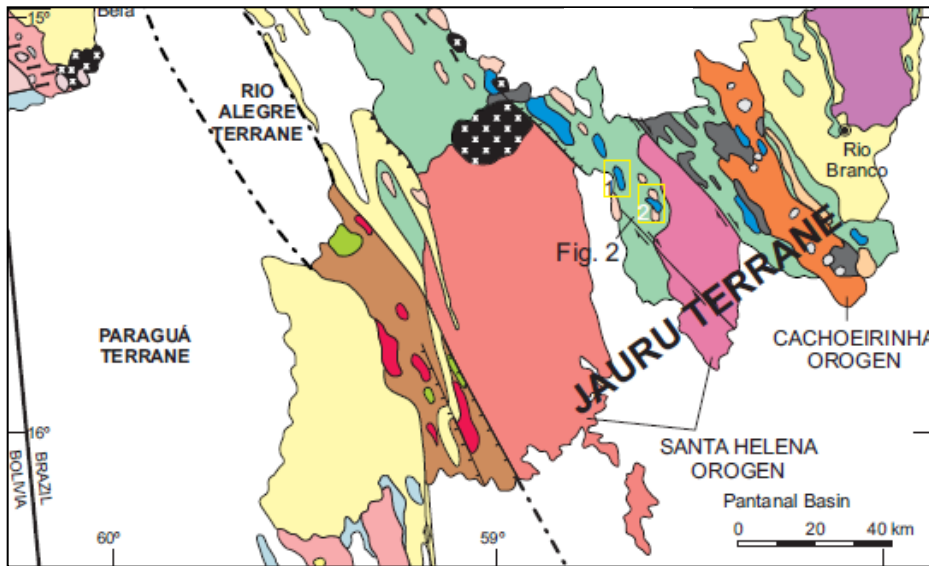
Allows one to infer better whether the pole has averaged out  
But requires at least the site-based means to be in the database.

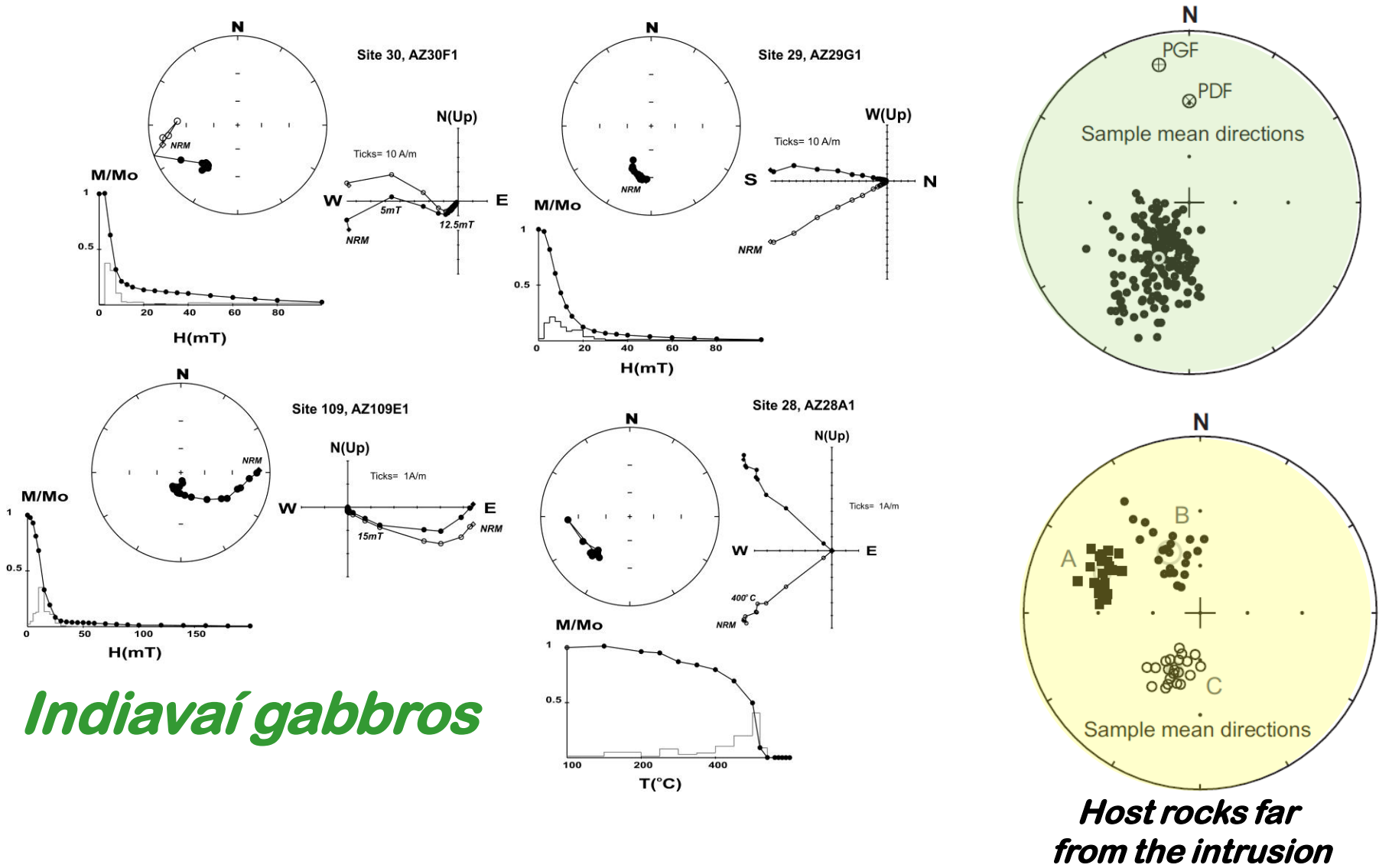
*Thanks !*





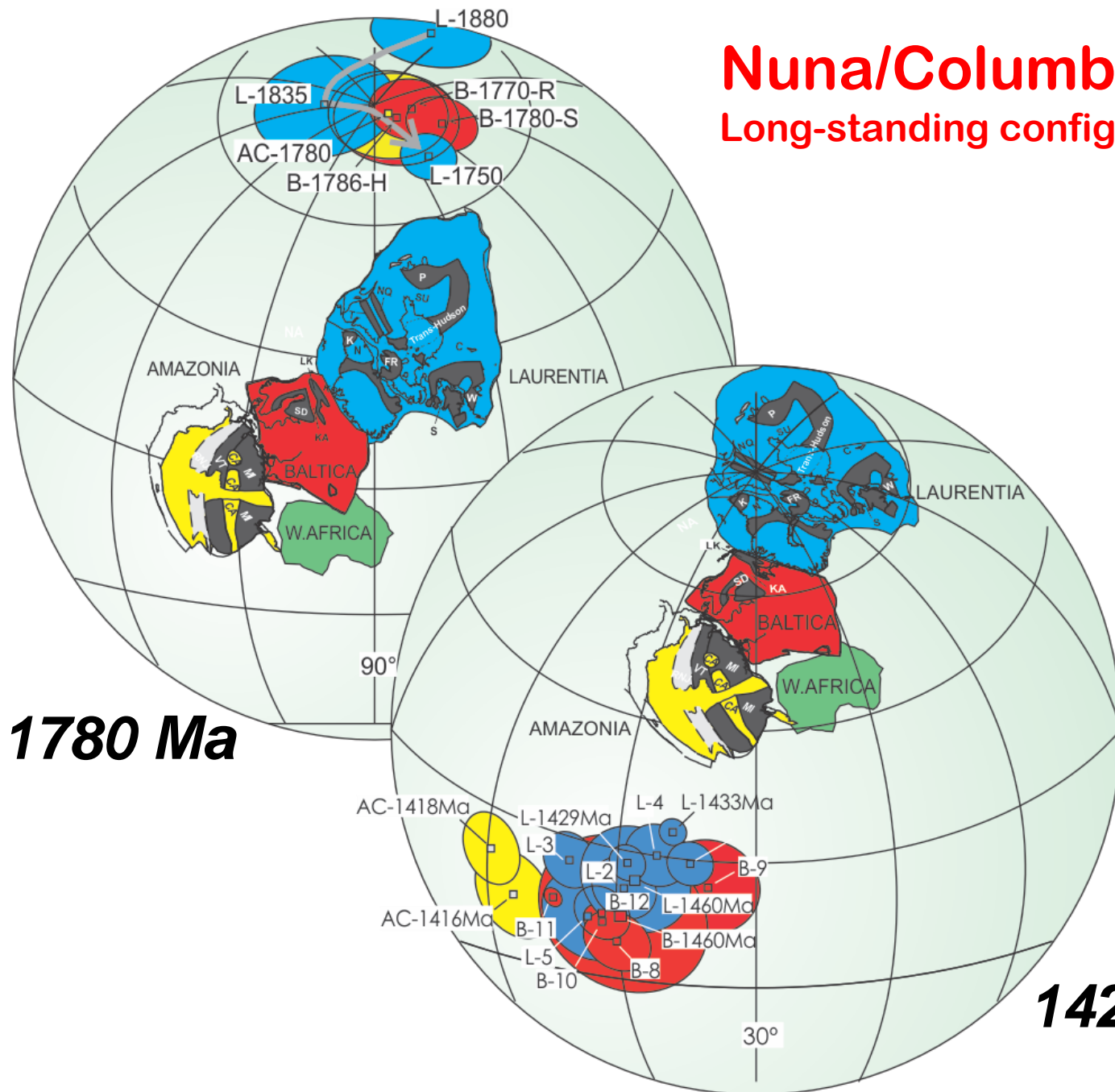
# Gabbros from Indiavaí





# Nuna/Columbia:

Long-standing configuration (>350 Ma)



**1780 Ma**

**1420 Ma**