Earth and Planetary Science Letters 293 (2010) 164–170

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Incompatible Ediacaran paleomagnetic directions suggest an equatorial geomagnetic dipole hypothesis

Alexandra Abrajevitch [a,*], Rob Van der Voo [b]

[a] Center for Advanced Marine Core Research, Kochi University, Kochi, 783-8502, Japan
[b] University of Michigan, Ann Arbor, 48109, USA

ARTICLE INFO

Article history:
Received 7 October 2009
Received in revised form 15 February 2010
Accepted 20 February 2010

Editor: L. Stixrude

Keywords:
paleomagnetism
Ediacaran
Laurentia
Baltica
paleogeography
equatorial dipole

ABSTRACT

Paleomagnetic results obtained from rocks of Ediacaran age in several localities in Laurentia and Baltica persistently display co-existence of two magnetization components, one shallowly and the other steeply inclined. Both components pass criteria for a primary magnetization while geological considerations and radiometric age dating indicate that these magnetizations are surprisingly close in age. The conventional interpretation of these results, translating the inclination into paleolatitudes using the geocentric axial dipole hypothesis, would imply that rocks acquired magnetizations in positions switching back and forth between equatorial and near-polar latitudes. In a geographic reference frame, such large-scale and fast (>45 cm/yr) migrations of a continent have been rejected as dynamically implausible; neither plate tectonics nor True Polar Wander are thought to be able to attain the required velocities. A highly irregular behavior of the geomagnetic field during the Ediacaran, possibly an alternation of the geomagnetic dipole axis between a co-axial and an equatorial alignment, remains the only viable explanation for the paleomagnetic data. Such a behavior entails specific outer core conditions, which in turn impose strong constraints on the possible models for the thermal evolution of the Earth's interior.

1. Introduction

The Neoproterozoic is an anomalous period in Earth's history. Postulated extreme climatic fluctuations from snowball to greenhouse conditions (Hoffman and Schrag, 2002) and the diversification of early life that culminated in the Cambrian Explosion (Briggs et al., 1992; Wills et al., 1998) are unparalleled in the Phanerozoic geological record. These climatic and biological transformations occurred against a backdrop of a disintegrating Rodinia supercontinent. Reconstructing the paleogeography, one of the most important factors in climate control, is essential for understanding these unusual conditions. The Late Neoproterozoic, or Ediacaran (542–635 Ma; Knoll et al., 2004), paleogeography, however, is a matter of considerable debate that is fuelled by discordant paleomagnetic data. These results have been derived primarily from the Neoproterozoic stable nucleii of North America ("Laurentia") and Europe ("Baltica") and will be discussed next.

2. The Ediacaran paleopoles from Laurentia

Laurentia, rimmed by Neoproterozoic rifted margins, is thought to have formed the core of the supercontinent Rodinia (Hoffman, 1991). Paleomagnetic data unambiguously indicate that Laurentia was situated at equatorial latitudes at ~615 Ma and from ~555 Ma onward (McCausland et al., 2007). Representative of the 615–555 Ma time interval, some seven results are available (Table 1, Figs. 1 and 2). Three of them have a characteristic feature, namely that they revealed two magnetization components, one shallow and the other steep. Neither component can be shown to be secondary; usually, the shallow as well as the steep components are of dual polarity, passing fold- or baked-contact tests, or both. The studied rock units have an adequate structural control and a demonstrated relationship to Laurentia at the time of their remanence acquisition; most of the studied units are reasonably well dated. Thus, both paleomagnetic components satisfy major reliability criteria and yielded paleopoles which generally have quality value (*Q*, Van der Voo, 1990) of four or greater of maximally seven (Table 1).

Conventionally, interpretations of the Ediacaran paleomagnetic data have been based on the axiomatic assumption that only one of the two components can be primary. The preference of which one is regarded as primary, has divided paleomagnetists into two broad camps. Proponents of the first camp argue that the shallow directions are primary, so that Laurentia is inferred to have stayed in equatorial latitudes throughout the Ediacaran; steep directions are explained as an overprint (Pisarevsky et al., 2001; Hodych et al., 2004). The steep direction, however, is unique in the sense that it does not resemble any of the younger directions expected from the Phanerozoic Apparent Polar Wander Path (APWP) for Laurentia; thus, this direction cannot

* Corresponding author. Tel.: +81 88 864 6724; fax +81 88 864 6713.
E-mail addresses: alexandra.abrajevitch@gmail.com (A. Abrajevitch), voo@umich.edu (R. Van der Voo).

0012-821X/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsl.2010.02.038

Table 1
Selected Ediacaran paleomagnetic results for Laurentia, Baltica and Gondwana.

Rock unit	Unit age (Ma)	Nature of the component	Pole °N	Pole °E	A95° or dp°/dm	Q	REFNO
Laurentia (from McCausland et al., 2007)							
LR: Long Range dikes	615 ± 2	Shallow	19	355	18/25	5	2657[a]
GD: Grenville Dikes	590 ± 2	Steep	60	240	14/14	3	682
		Shallow	3	331	10/15	2	682
CC: Callander Alkaline Complex	577 ± 1	Steep	46	301	6/6	6	2508
CT: Catoctin Basalts	572 ± 5	Steep	42	297	17/17	6	2868
		Shallow	4	3	7/13	5	2868
SI: Sept-Iles intrusion	564 ± 4	Shallow (older)	−20	321	5/9	4	1925
		Steep (younger)	61	295	10/10	5	1925
BF: Buckingham flows (*in situ*)	573 ± 32	Shallow	0	351	5/9	4	1870
JF: Johnnie Fm. (unrotated)	ca. 555	Shallow	10	342	5/10	4	1216
SC: Skinner Cove Fm	550 ± 3	Shallow	−16	338	9/9	4	3214
Baltica (from Meert et al., 2007; Elming et al., 2007)							
ED: Egersund Dikes	616 ± 3	Intermediate	31	44	14/17	6	447, 689
A: Alno carbonatite complex	584 ± 7	Steep	63	101	12/14	4	b
		Shallow	−8	92	5/9	3	1739
		Shallow	−4	89	16/33	3	b
F: Fen carbonatite complex	583 ± 15	Steep	57	151	7/11	4	3447
UA: Ukranian traps, A-pole	c. 580	Shallow	−20	184	26/31	6	c
UC: Ukranian traps, C-pole	c.580	Shallow	−24	104	4/12	3	c
BM: Mean for Baltica	c.a. 555	Shallow	−30	118	7/12	6	b
TR: Tornetrask/Dividal	543–520	Steep	56	116	12/15	4	3425
AN: Andrarum Limestone	500	Steep	52	110	7/10	3	3425
West Gondwana (reported in African coordinates, from Tohver et al., 2006)							
AD: Adma diorite	613 ± 3		34	344	17	3	1170
CA: Campo Allegre rhyolites	595 ± 5		82	234	12	6	1369
IB: Itabana dikes	525 ± 5		31	331	10	6	d
Sobral Dikes	543–581	Comp 1-shallow	76	294	9	2	e
		Comp 3-steep	0	279	9	0	e
Taua Dikes	442–615	Comp 2-shallow	80	61	14	2	f
		Comp 3-steep	−10	53	19	1	f

Q — quality value (maximum of 7; Van der Voo, 1990); unit age is as listed in the source publications; REFNO is the paleomagnetic result reference in the Global Paleomagnetic Database (version 4.6; Pisarevsky, 2005). Single letters in the REFNO column mark results which are not included in the Paleomagnetic Database, and are referenced as follows:

a recalculated for five dikes by Hodych et al. (2004).
b Meert et al. (2007).
c Elming et al. (2007).
d Trindade et al. (2006).
e Guerreiro and Sial (1982) as reported in Tohver et al. (2006).
f Ponte-Neto (2001) as reported in Tohver et al. (2006).

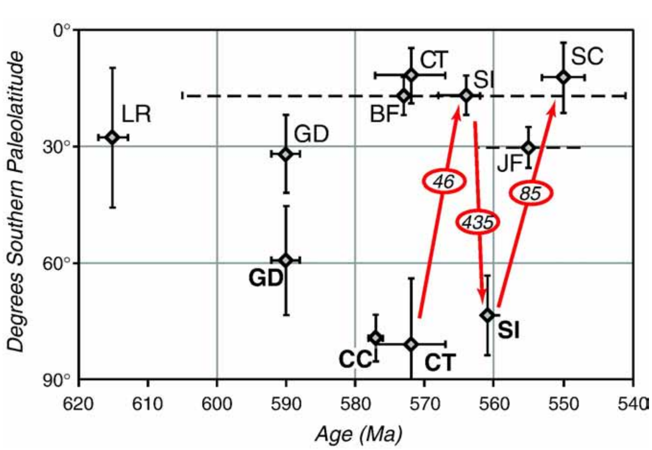

Fig. 1. Assuming that all plotted points (with abbreviations as in Table 1) have validity in terms of their representing the geomagnetic field at the time span indicated by the horizontal error bars, then the nearly coeval lower and higher paleolatitudes inferred from these data for Laurentia would indicate extremely high velocities of the continent (numbers within the ovals) during the Late Ediacaran. Conversely, if one or other of the points is eliminated as unreliable, these velocities are much lower although in general still higher than the plate tectonic or true polar wander speed limits of about 30 cm/yr.

be a "simple" overprint. The idea that the steep magnetization is an unresolved combination of two or more components (Pisarevsky et al., 2001; Hodych et al., 2004) is also very unlikely. To produce a composite magnetization that would mimic behavior of a single component, so that it would decay linearly during demagnetization, the coercivity or blocking temperature spectra of the constituent components must be finely tuned. This would imply, in turn, that the components are defined by remanence-carrying grains with very narrow variations in size and composition. The steep components that revealed a well-defined direction have been isolated by different demagnetization techniques (alternating field and thermal), in rocks of different lithologies (intrusive, metamorphic and sedimentary) and at several localities. Directional consistency of a composite magnetization in all these cases would be a highly improbable situation. More likely, the steep direction is a true magnetization component that has to be explained.

Supporters of the second camp advocate a primary origin for the unique steep magnetization, whereas the shallow one is considered as an overprint of Cambrian age. The primary nature of the steep magnetization would imply that Laurentia drifted from equatorial latitudes at ~615 Ma to high southern latitudes by 580 to 590 Ma, and then back to the equatorial area by 555 to 548 Ma (McCausland et al., 2007) (Fig. 1). This model, however, is not without problems either.