Precambrian Research 236 (2013) 16–30

Contents lists available at ScienceDirect

Precambrian Research

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

Paleogeography of Baltica in the Ediacaran: Paleomagnetic and geochronological data from the clastic Zigan Formation, South Urals

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ARTICLE INFO

Article history:
Received 8 December 2012
Received in revised form 12 June 2013
Accepted 24 June 2013
Available online 4 July 2013

Keywords:
Ediacaran
Paleogeography
Paleomagnetism
Geochronology
Baltica
South Urals

ABSTRACT

The paleoposition of Baltica at the end of Neoproterozoic is of utmost importance for global paleogeography, but paleomagnetic data of Ediacaran age are very controversial. Neoproterozoic and Ediacaran clastic rocks are wide spread along the deformed eastern margin of Baltica. Paleomagnetic and geochronological studies were carried out at the several sections of the uppermost Zigan Formation of the Ediacaran Asha Series along with Paleozoic rocks from the same region. An ash bed interlayered in the upper part of the Asha series yields a zircon deposition age of 547.6 ± 3.8 Ma. With the aid of stepwise thermal demagnetization, a dual polarity high-temperature remanence was successfully isolated from red beds of the Zigan Fm, and its primary origin is indicated by the positive reversal test and regional consistency test. The overall mean direction of this remanence (declination $D^{\circ} = 107.7$ (287.7), inclination $I^{\circ} = -15.4$ (15.4), radius of confidence circle $\alpha_{95}{}^{\circ} = 4.8$, $N = 36$ sites) corresponds to a paleolatitude of $7.8^{\circ} \pm 2.5^{\circ}$, N or S. Geological data indicate that the study area was a part of the Baltic craton at least since the early Neoproterozoic, while paleomagnetic results on Paleozoic rocks from the westernmost zones of the Ural fold belt reveal not local and regional rotation with respect to Baltica. Also, several lines of evidence imply that the inclination shallowing in these rocks either absent altogether, or at worst less than 10°; hence the position of Baltica can be reliably reconstructed for time about 550 Ma. The analysis of the existing paleomagnetic and geological data place Baltica to the east of Laurentia in tropical southern latitudes with the Uralian margin facing north in Late Ediacaran time.

1. Introduction

A 300 Ma span of time from the middle Neoproterozoic through the Middle Cambrian (~800–500 Ma) heralded major developments such as the evolution of complex bauplans and bioturbation (Crimes, 1992; Signor and Lipps, 1992; Bowring and Erwin, 1998; Knoll, 2001; Babcock et al., 2001; McCall, 2006). This same time interval was also punctuated by severe glacial epochs (Roberts, 1976; Kirschvink, 1992; Meert and Van der Voo, 1994a,b; Hoffman et al., 1998; Evans, 2000); saw increased oxygen levels in the atmosphere and in the shallow and deep oceans (Canfield and Teske, 1996; Berner et al., 2003; Holland, 2006; Canfield et al., 2007); included many (and sometimes rapid) changes in continental configurations (Meert et al., 1993; Kirschvink et al., 1997; Evans, 1998; Meert, 1999; Meert and Tamrat, 2004; Maloof et al., 2006; Li et al., 2008) along with other enigmatic geological, biological, astronomical and geophysical events (Williams, 1975, 1986; Walter et al., 2000; Puffer, 2002; Kirschvink and Raub, 2003).

Many of these changes may be interrelated and connected (at least in part) to the distribution of continents across the globe. There have been numerous attempts to provide a robust Neoproterozoic paleogeography using paleomagnetic data, however; both data and reconstructions are controversial. The Ediacaran time period (~635–542 Ma) is a prime example of such a situation (McCausland et al., 2007; Meert et al., 2007; Meert, 1999, 2013; Kirschvink et al., 1997; Pisarevsky et al., 2008; Abrajevitch and Van der Voo, 2010; Schmidt and Williams, 2010). The problems are particularly acute for Laurentia and Baltica, where available paleomagnetic data lead to contrasting interpretations. These include high or low latitude positions of Laurentia and Baltica, rapid continental drift, rapid true polar wander, inertial interchange true polar wander and non-dipole fields depending on the perspective of the author (for examples see Meert et al., 2007; Pisarevsky et al., 2008; Abrajevitch and Van der Voo, 2010; Meert, 2013). The following is a brief review the Ediacaran paleomagnetic database of Baltica.

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http://dx.doi.org/10.1016/j.precamres.2013.06.006

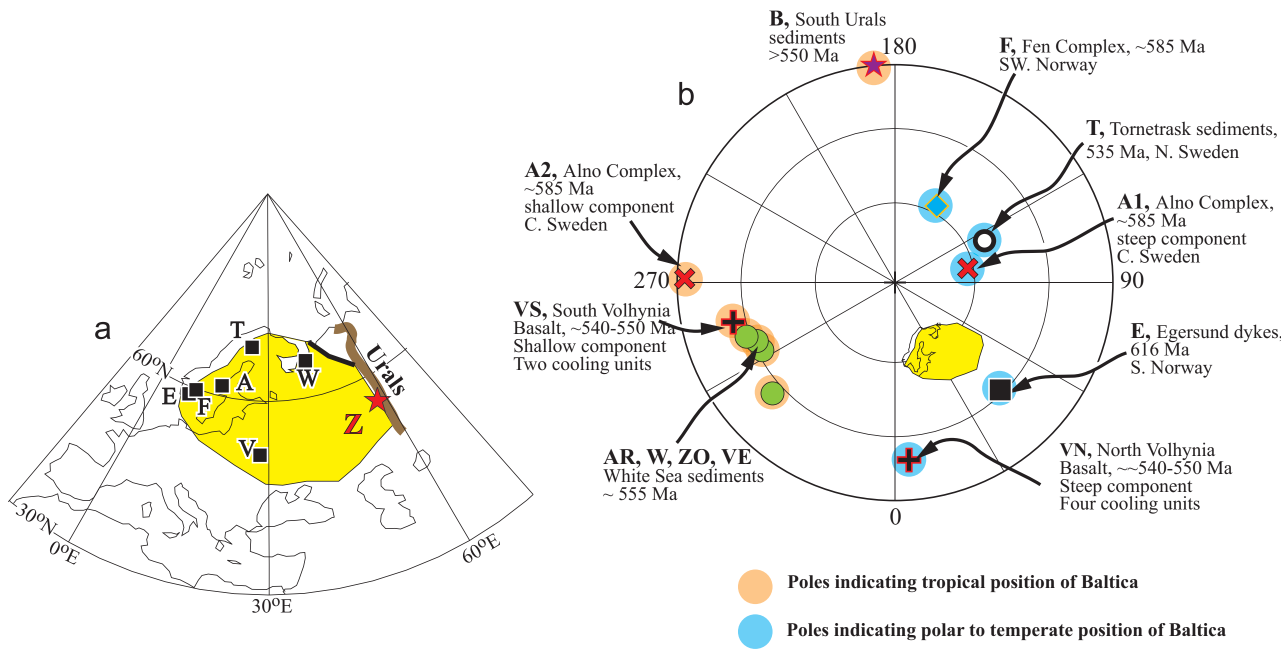

Fig. 1. (a) Location of the Baltica block with Precambrian basement (shaded), the Urals (brown band), the Timan Range (thick black line), previously sampled <650 Ma units (full squares) and the study area in the South Urals (Zigan formation, Z, red star), where Ediacaran sediments have been studied by Golovanova et al. (2011). (b) Stereoplot of Ediacaran and Early Cambrian paleomagnetic poles from Baltica projected onto the northern hemisphere. (A) A = Alnö Complex (Piper, 1981; Meert et al., 2007); E = Egersund dykes (Walderhaug et al., 2007); F = Fen Complex (Piper, 1988; Meert et al., 1998); V = Volhynia, Ukraine (Elming et al., 2007); W (poles A, W, VE, ZO) = White Sea region, Russia (Popov et al., 2002, 2005; Iglesia Llanos et al., 2005); T = Tornetrask Formation (Torsvik and Rehnström, 2001) and (B) Ediacaran Basu Formation (Golovanova et al., 2011). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

The sole Early Ediacaran pole comes from the Egersund dykes in SW Norway (E in Fig. 1a; Table 1; Walderhaug et al., 2007). This pole is reliably dated at 616 ± 3 Ma (zircon U-Pb age; Bingen et al., 1998), and its paleomagnetic quality is seemingly confirmed by a positive baked contact test. The pole places Baltica at intermediate to high paleolatitudes.

Paleomagnetic data are available on the Fen Complex in southern Norway (Poorter, 1972; Piper, 1988; Meert et al., 1998) and Alnö Complex in central Sweden (Piper, 1981; Meert et al., 2007; F and A, respectively, in Fig. 1a; Table 1). These carbonatite complexes are nearly coeval (~585 Ma), and their corresponding paleomagnetic data (Fig. 1b) can place the study locations in Baltica at intermediate latitudes (Fen pole, F), close to the geographic pole (Alnö steep component, A1) or in the tropics (Alnö shallow component, A2). Meert et al. (2007) rightly concluded that these data should be regarded with extreme care when attempting continental reconstructions (see also Meert, 2013).

In Volhynia (southwestern Baltica; V in Fig. 1a; Table 1), the Ediacaran section is comprised of a several hundred meters thick succession of lava flows and tuffs (known mostly from boreholes) that is overlain by a 200 m thick sedimentary cover. Relatively few U-Pb ages on zircons from the volcanic rocks yield a late Ediacaran-Fortunian age of ca. 550–540 Ma (Compston et al., 1995; Nosova et al., 2010), although older ages of ~580 Ma were inferred from $^{40}Ar/^{39}Ar$ data (Elming et al., 2007) that may suffer from an inherited Ar-component. Three teams independently studied paleomagnetism of these volcanics (Iosifidi et al., 2001; Nawrocki et al., 2004; Elming et al., 2007). The sampling was limited to two small

Table 1
Paleomagnetic North Poles from Baltica (Ediacaran–Early Cambrian).

Key	Location	Slat	Slong	Plat	Plong	Age	Δ	IA	Reference
T	Tornetrask Fm/N Sweden	68.2	19.5	55.9	115.5	535	<5	Tr-J (210)	Torsvik and Rehnström (2001)
Z	Zigan Fm/S. Urals	53.7	56.7	−16.2	138.4	~550[a]	~20		This paper
W	Winter Coast/N. Russia	65.5	39.8	−25.2	132.1	555	≫20		Popov et al. (2002)
AR	Arkhangelsk/N. Russia	65.6	40.5	−28.3	110.0	555	≫20		Iglesia Llanos et al. (2005)
ZO	Zolotitsa/N. Russia	65.5	40.0	−31.7	112.9	555	≫20		Popov et al. (2005)
VH	Verkhotina/N. Russia	64.8	40.5	−32.2	117.0	555	≫20		Popov et al. (2005)
VS	Volhynia South/W. Ukraine	50.9	26.4	−24.1	103.1	540–550	≫20		Elming et al. (2007)
	Mean 2–7/ZWV pole	–	–	−26.9	115.0				This paper
VN	Volhynia North/W. Ukraine	51.2	26.1	19.8	4.4	540–550	≫20		Elming et al. (2007)
B	Basu Fm/S. Urals	54	57	1.1	187.3	≥550[b]	<5	O-S (440)	Golovanova et al. (2011)
F	Fen Complex/S. Norway	59.3	9.3	56.7	151.2	583	<3	P (240)	Meert et al. (1998)
A1	Alnø steep/C. Sweden	62.5	17.5	62.7	101	584	~1	Tr-J (190)	Meert et al. (2007)
A2	Alnø shallow/C. Sweden	62.5	17.5	3.5	269	584	≫20		Meert et al. (2007)
E	Egersund Dikes/S. Norway	58.4	6.2	31.4	44.1	616	~11	Oe (480)	Walderhaug et al. (2007)

Notes: Slat, Site latitude (°N). Slong, Site longitude (°E). Plat, Paleomagnetic pole latitude (°N if positive). Plong, Paleomagnetic pole longitude (°E). Age, rock age: Age determination by pole (1) fossil correlation; (2) inferred; (3–7 and 9) U–Pb zircon; (11–13) $^{40}Ar/^{39}Ar$ biotite; (14) U–Pb zircon and $^{40}Ar/^{39}Ar$ biotite. Δ (°), Angular distance from the nearest point on the Phanerozoic APWP for Baltica (Torsvik and Cocks, 2005). IA, Age of the remanence inferred from this APWP, with the numerical age of the nearest referent pole: Tr-J, Late Triassic-Early Jurassic; P, Permian; O-S, Late Ordovician-Early Silurian; and Oe, Early Ordovician.

[a] See text for discussion of the age of the Zigan Fm in the South Urals.

[b] Indicated by our results from the Ust-Katav locality (see text for more details).