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Ediacaran glaciations of the west African Craton – Evidence from Morocco

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ABSTRACT

The northern margin of the West African Craton preserved in the Anti-Atlas area of southern Morocco, represents an outstanding geological archive covering parts of the Neoproterozoic and the Paleozoic. Despite isolated mentions in the literature, relics of Neoproterozoic glaciations have hitherto not received much attention in this area and tight geochronological constraints had been lacking. This paper documents the sedimentology and stratigraphic context of several occurrences from the eastern and central Anti-Atlas. Based on outcrop-scale sedimentological and microsedimentological investigations, different types of diamictites are distinguished and their origin with reference to modern glacial systems is discussed. The sedimentary record is explained by one single glacial period (albeit interrupted by interglacial phases) affecting both mountainous terrestrial and marine realms. Sedimentary facies and preserved paleotopographies are best accounted for by invoking a fjord-like depositional system with steep-sided valleys being repeatedly drowned by marine water or occupied by valley glaciers. High-precision geochronological constraints suggest that this glacial period must have taken place sometimes between 592 Ma and 579 Ma. Hence it is suggested that this is the first temporally constrained report of the Ediacaran Gaskiers glaciation on the West African Craton (WAC). Existing Ediacaran paleomagnetic data from the WAC are sparse and allow different interpretations regarding paleolatitude of this glaciation. The latter is finally discussed vis-à-vis potential rapid true polar wander events and the possibility that the Gaskiers glaciation was more global in extent than hitherto assumed and might even have brought Earth close to a true panglacial state.

1. Introduction

It has long been suspected that the late Neoproterozoic had been an era of repeated glaciations of considerable spatial extent (e.g. Harland, 1964). However, the lack of reliable dating tools had remained a serious obstacle for intercontinental correlations. Furthermore, concomitant with an increasing interest in turbidity currents and mass flow processes during the 1950s and 1960s, sedimentologists started questioning the glacigenic nature of many supposed and real tillites (with the term tillite being used throughout this paper in a broad sense as describing a sedimentary rock whose clasts have predominantly been transported by ice i.e. glaciers, icebergs, or icefloes, Harland et al., 1966). This eventually resulted in a kind of hyper-skepticism culminating with Schermerhorn's (1974) almost idiosyncratic review which explained many diamictites (previously interpreted as tillites, including many African examples) simply as the product of debris flow phenomena and sedimentary mixing in active tectonic settings ("mixtites"). Interest in Precambrian glaciations was renewed in the 1990s by the proposal of the "Snowball Earth" theory (Kirschvink, 1992, Hoffman et al., 1998) which, combining new evidence from different fields of Earth Sciences, proposed repeated glaciations of all the continents and oceans. Critical tests of the idea of widespread (possibly global) glaciations require robust, very precise, and accurate time constraints on the deposition of diamictites in different paleogeographical and environmental settings on different paleocontinents. Improved dating techniques have allowed to group Neoproterozoic diamictites and related phenomena into three distinct time spans which have been linked to three glacial periods, generally referred to as Sturtian, Marinoan, and Gaskiers (Hoffman and Li, 2009). Except for the well-studied terrestrial tillites in Mauretania and Mali (Deynoux, 1985, Deynoux et al., 2006, Fig. 1), Northwest Africa, being otherwise a classic ground for Precambrian geology (Letsch, 2017), remains a white spot on recent compilations of Neoproterozoic glacigenic formations (e.g. Allen and Etienne, 2008; Hoffman and Li, 2009, Spence et al., 2016). However, Precambrian diamictites resembling glacigenic deposits have been mentioned repeatedly from the Anti-Atlas Belt (Fig. 2) in Southern

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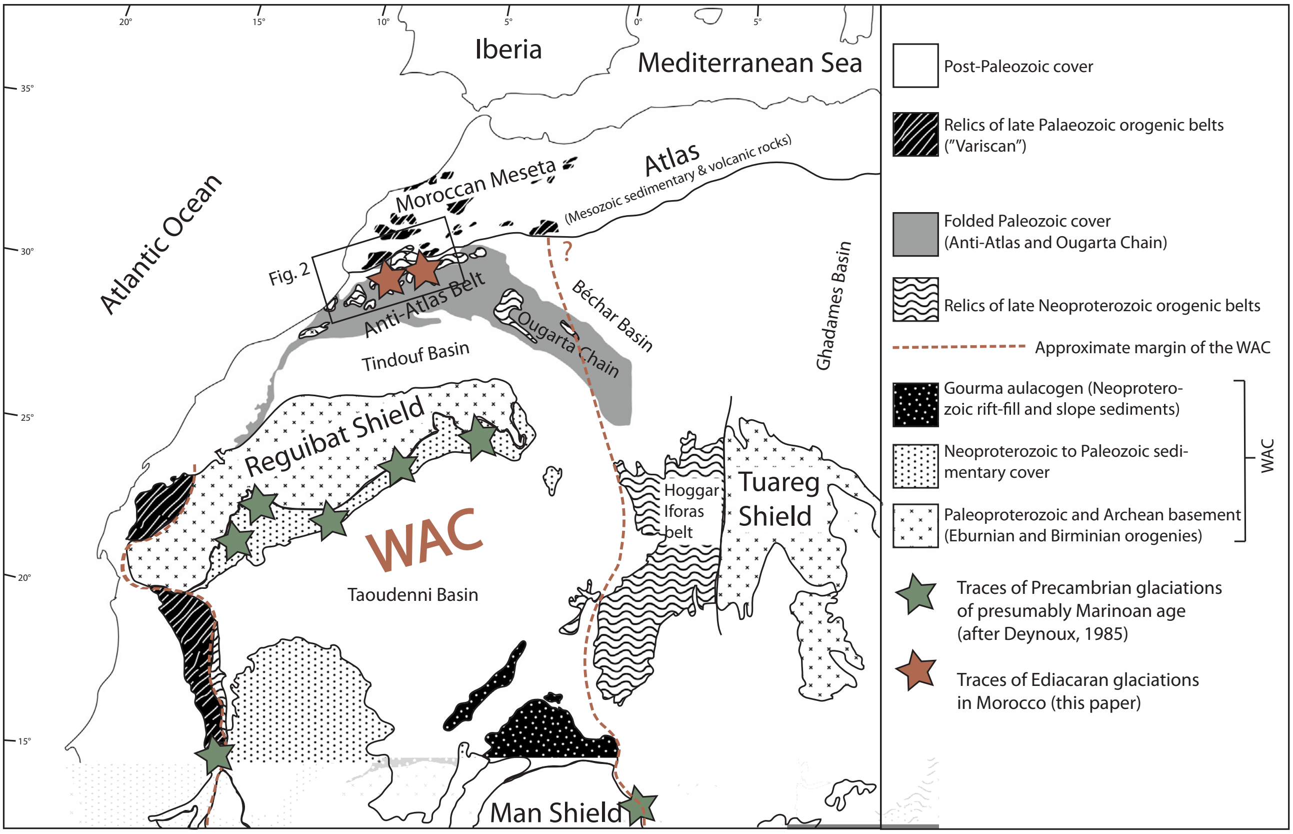

Fig. 1. Regional tectonic overview map of the West African Craton (WAC) and the bordering Anti-Atlas Belt. Redrawn and modified after Choubert and Faure-Muret (1969). Location of Fig. 2 is indicated by a rectangle.

Morocco (Cahen et al., 1953, 1963; Choubert, 1972, Vernhet et al., 2012). They have also been used as a correlation tool under the assumption that they are real tillites (which has been contested in the aftermath of the Schermerhorn 1974 paper, e.g. Leblanc, 1981) and must correspond to one of the globally known glaciation periods, specifically to the Sturtian (Thomas et al., 2002), the Marinoan (Abati et al., 2010), the Gaskiers or a new, hitherto unknown, late Ediacaran glaciation (Vernhet et al., 2012). These diamictites have so far not been described in any great detail and tight age constraints were lacking. The purpose of the present paper is to provide further critical data both in terms of sedimentology (evidence for glaciation) and geochronology from a hitherto neglected part of Gondwana. In doing this, emphasis will be placed on demonstrating a clear glacial influence on sedimentary rocks from different sedimentary environments (terrestrial and marine), and providing robust age constraints to test correlation with the Ediacaran Gaskiers glaciation of North America.

2. Geologic setting

The Anti-Atlas Belt of southern Morocco (Fig. 2) exhibits excellent outcrops of crystalline and sedimentary rocks of Paleo- and Neoproterozoic age (e.g. Choubert, 1963, Leblanc and Lancelot, 1980, Thomas et al., 2002, 2004, Walsh et al., 2012, Hefferan et al. 2014). They are unconformably covered by a thick pile of latest Precambrian to Paleozoic sedimentary rocks with generally only modest tectonic deformation and no metamorphic overprint (Burkhard et al., 2006). Proterozoic rocks crop out in several erosional inliers. Some of them expose crystalline basement composed of a metamorphic framework, intruded by felsic magmatic rocks (Choubert, 1963). The latter are of Paleoproterozoic age (around 2 Ga, e.g. Thomas et al., 2002) and suggest a close spatial and genetic relation to the northern margin of the WAC (Reguibat Shield, see Fig. 1), where intrusions of the same age are common (Schofield et al., 2006). The whole basement is traditionally referred to as PI in the literature (Fig. 2).

Neoproterozoic sedimentary successions covering the former basement in the eastern Anti-Atlas record the development of a passive-margin during the late Tonian to early Cryogenian (Bouougri et al., 1994). Relics of a coeval oceanic basin are preserved in the Bou Azzer ophiolite body (Leblanc, 1975) and at least one oceanic arc remnant has so far been identified (Triantafyllou et al., 2016). Ophiolite obduction, arc-continent, and finally continent-continent collision with an originally WAC-derived continental block, the Moroccan Meseta (Letsch et al., 2018), accompanied by intense tectonic deformation is documented by Cryogenian to early Ediacaran sedimentary and volcanic/magmatic rocks in the eastern and central Anti-Atlas (e.g. Leblanc and Lancelot, 1980, Thomas et al., 2002, 2004, El Hadi et al., 2010, Walsh et al., 2012, Triantafyllou et al., 2016). Collectively, the heterogeneous assemblage of all these sedimentary, metamorphic, magmatic, and volcanic rocks are traditionally subsumed under the designation PII (e.g. Choubert, 1963). They are younger than the PI basement but overlain by the next younger major group PIII. Albeit with some deviations from the original scheme proposed by Choubert (1963), the rocks designated as PII on Fig. 2, following the excellent map compilation of Saadi et al. (1985), correspond exactly with the Anti-Atlas Supergroup (defined by Thomas et al., 2004) and we hence retain the convenient term PII.

Both PI and PII are unconformably covered by generally flat-lying, undeformed or only mildly deformed and non-metamorphic terrestrial sedimentary and volcanic rocks (referred to as PIII, Chouber, 1963, or Ouarzazate Supergroup, Thomas et al., 2004). PIII rocks are in turn covered by a thick pile of non-metamorphic Paleozoic successions. The Ouarzazate Supergroup displays substantial and abrupt lateral thickness and facies changes pointing towards deposition in a tectonically active intra-continental setting with abundant syn-sedimentary