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The Great Atlasian Reef Complex: An early Cambrian subtropical fringing belt that bordered West Gondwana

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ABSTRACT

The so-called Great Atlasian Reef Complex developed during early Cambrian time throughout the Moroccan margin (Souss Basin) of West Gondwana. According to the syndepositional tectonic activity associated with its intracratonic Ediacaran–Cambrian rift, the great reef complex can be subdivided into four major archaeocyathan-microbial reef episodes:

(i) The Atdabanian episode is recorded by a SW–NE-trending, 400 km long barrier reef that extended across the western Anti-Atlas. It was controlled by large-scale reactivation of an inherited rifting branch, which resulted in the nucleation and growth of linear reef complexes located along its margin. The interplay of block tilting, sharp modifications in accommodation space, and relative sea-level rise led to a composite retrogradational–aggradational reef systems tract, characterized by archaeocyathan-microbial kalyptrate complexes (Tiout Member and Amouslek Formation) that protected stromatolite-dominated, back-barrier environments (lower member of the Igoudine Formation).

(ii) The western Anti-Atlas recorded an early Botoman reactivation of the same rifting branch that triggered a lateral migration of frame-building centres of carbonate productivity. As a result, the involved grabens and half-grabens recorded the development of fringing mound complexes (lower Issafen Formation). These occupied some linear intra-platform, deeper depressions capped by marls and shales, whereas laterally equivalent shallower environments recorded the development of patch-reefs and bioherms.

(iii) The western Anti-Atlas subsequently recorded a late Botoman interval of tectonic quiescence superimposed to a local interval of progradational pulses. This favoured the nucleation of dispersed archaeocyathan-microbial patch-reefs and bioherms.

(iv) A distinct palaeogeographic area is recognized in the southern High Atlas, where the entire Atdabanian–Botoman interval recorded small-scale, synsedimentary block tilting and high rates of volcaniclastic input. As a result, this sector was characterized by the record of microbial and archaeocyathan-microbial patch-reefs and bioherms, preferentially developed on the uplifted parts of tilted blocks.

The end of reef development and carbonate productivity in the Souss Basin is related to the progradation of siliciclastic depositional systems (Toyonian regression), considered to have caused the collapse of reef communities throughout West Gondwana.

1. Introduction

Carbonate sedimentation across the Neoproterozoic–Cambrian transition was constrained in West Gondwana by the diachronic character of the Pan-African and Cadomian orogenies. The end of the Pan-African orogeny (ca. 690–605 Ma; Gasquet et al., 2005) was rapidly succeeded by the development of a carbonate belt that is exposed in the upper Ediacaran–lower Cambrian strata of the Atlas Mountains, Morocco. By contrast, carbonate productivity only spread throughout southwestern Europe after the end of the Cadomian orogeny (ca. 645–540 Ma; Miller et al., 1999; Samson and D'Lemos, 1999). The Botoman interval (Spizharski et al., 1986) marks the peak for early Cambrian archaeocyathan-microbial reef development in this Gondwanan margin (Debrenne, 1964; Debrenne and Debrenne, 1995). However, the dimensions achieved by these reefs and reef complexes in the Armorican Massif and Montagne Noire, France (Saint-Jean de la Rivière, Pardailhan and Lastours formations), Ossa-Morena, southern Iberian Peninsula (Sierra Gorda, La Hoya and Pedroche formations), central Iberian Peninsula (Navalucillos Formation), Sardinia (Matoppa and Punta Manna formations), and Germany (Zwethau Formation) were largely exceeded by the Great Atlasian Reef Complex (GARC; Álvaro et al., 2000, 2003; Álvaro and Clausen, 2007). The GARC spread over more than 400 km along NW Africa, with a thickness peak in the Anti-Atlas.

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This paper describes the early Cambrian microbial and archaeocyathan-microbial reefs and reef complexes of the Atlas Mountains, and outlines their development in relation to the palaeoclimate and the tectonostratigraphic evolution of the Moroccan margin in West Gondwana. The close association of these reef complexes with subtropical conditions and the southward migration of West Gondwana was also primarily controlled by relative sea-level changes, in part a product of the tectonic disturbances recorded in the Moroccan rift.

2. Palaeogeographic and stratigraphic background

The subdivision of the Moroccan margin of West Gondwana into Ediacaran–early Palaeozoic basins and platforms has suffered from a multiplication of nomenclatures due to the approaches of the various researches of numerous research workers. In their synthesis, Destombes et al. (1985) distinguished two lower Palaeozoic palaeogeographic domains in Morocco and neighbouring areas: the southern 'Anti-Atlas domain' (or Anti-Atlas Basin *sensu* Helg et al., 2004), limited by the Tindouf Basin to the South, and the northern 'Atlas domain', where subsequent palaeogeographic subdivisions are controlled by the ranges of the High and Middle Atlas, and the Jebilet, Rehamna, and Coastal Meseta (Fig. 1A). Another current terminology used for palaeogeographic descriptions of the Anti-Atlas has employed geographical terms, such as eastern (Jbel Ougnate), central (Jbel Saghro and El Graara massif), and western Anti-Atlas (Fig. 1A). Although the Cenozoic–Quaternary Souss depression separates the Anti-Atlas and High Atlas, Geyer and Landing (1995) introduced the term 'Souss Basin' to document an Ediacaran–Carboniferous sedimentary trough that included the aforementioned Anti-Atlas domain and the southern rim of the High Atlas. Taking into account the lithological and facies similarities of the Ediacaran–lower Cambrian strata exposed on both domains, the northern boundary of the Souss Basin can be located at the South Atlas Fault (SAF in Fig. 1A). This also marks the edge of the deepening of the West African Craton under Neoproterozoic basement series (Ennih and Liégeois, 2008), whereas the northern limit of the craton is situated along the Anti-Atlas Major Fault (AAMF in Fig. 1A), where two Pan-African ophiolitic complexes are preserved (Saquaque et al., 1989; El Boukhari et al., 1992).

After the Pan-African orogeny, a broad shallow epeiric sea occupied extensive areas of the Souss Basin. There, a phase of intracontinental extension took place, ranging from Ediacaran to middle Cambrian in time. This led to development of a multi-stage rifting, which reflects the diachronous opening of a finally aborted rift (Piqué et al., 1995; Soulaimani et al., 2003; Fig. 1B). The magmatism associated with this intra-plate extension shows tholeiitic and alkaline affinities, and a distinct diachroneity: it started earlier (Ediacaran) in the Anti-Atlas, reached the western High Atlas after the earliest Cambrian, and propagated even later (middle Cambrian) in the Meseta domain (Ouali et al., 2000, 2003; Gasquet et al., 2005; Álvaro et al., 2006a, 2008a; Ezzouhairi et al., 2008).

During the Ediacaran and early Cambrian, the Souss Basin recorded evidence for several main up-building phases dominated by microbial and archaeocyathan-microbial consortia. These can be lithostratigraphically grouped in: (i) the Adoudou, Lie-de-vin, and lower member of the Igoudine formations across the entire basin; (ii) the Tiout Member (Igoudine Formation) and the Amouslek Formation in the

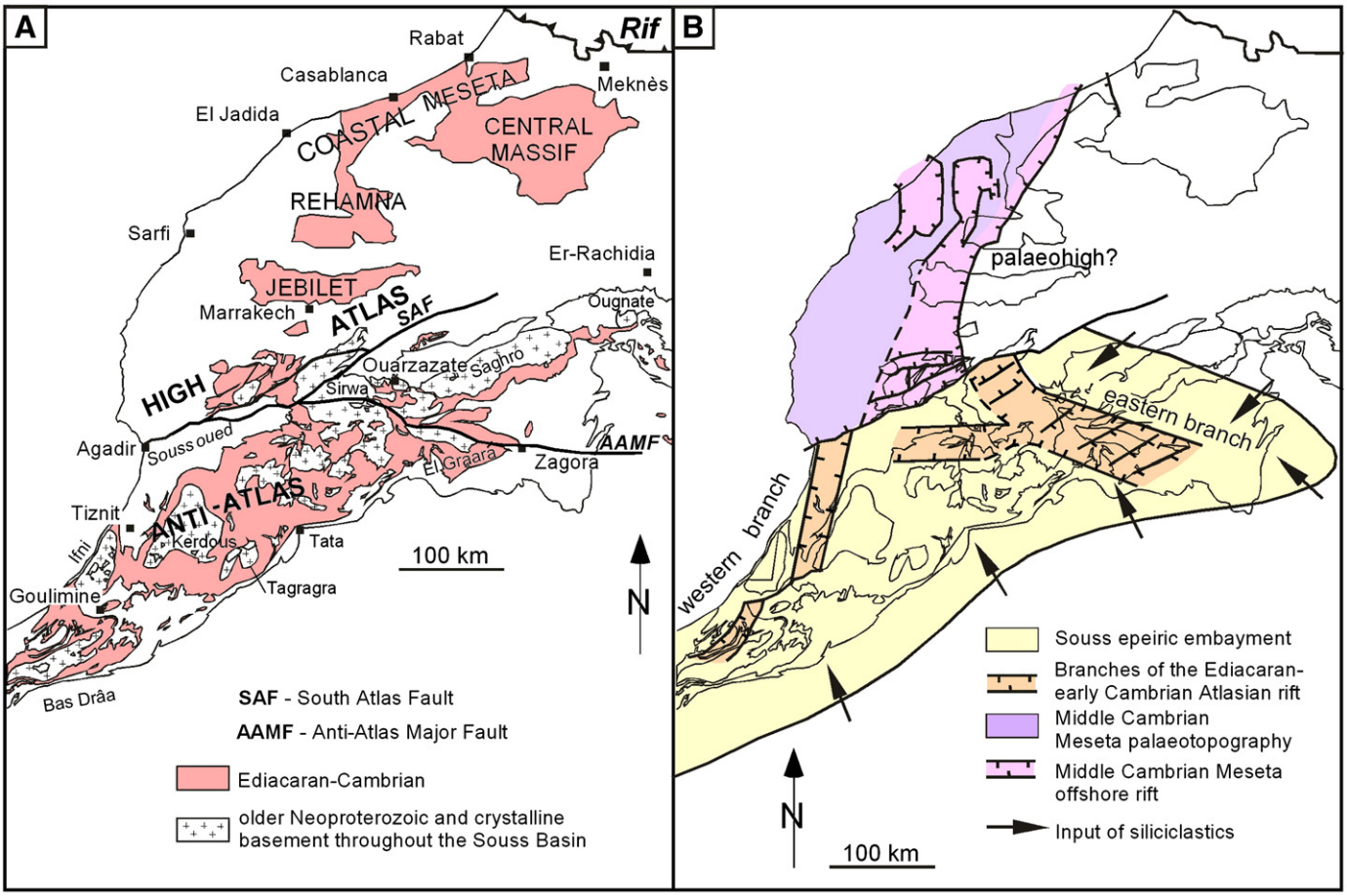

Fig. 1. A. Geological sketch showing the main pre-Variscan geological units of Morocco and neighbouring areas. B. Tentative reconstruction of the late Ediacaran–Cambrian branches of the Moroccan rift, based on isopachs and centres of volcanic activity published by Choubert and Faure-Muret (1970), Boudda et al. (1975, 1979), Benziane et al. (1983), Bernardin et al. (1988), Azizi Samir et al. (1990), Piqué et al. (1995), and Álvaro et al. (2008a).