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The Tindouf Basin, a marine refuge during the Serpukhovian (Carboniferous) mass extinction in the northwestern Gondwana platform

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ABSTRACT

Several macrofaunas and microfossils of the Carboniferous Saharan basins have longer stratigraphic ranges than those of other basins in the western Palaeotethys realm, particularly in the Tindouf Basin (Morocco–Algeria). Foraminifers are particularly abundant and diverse in the Serpukhovian and basal Bashkirian compared to coeval basins, and some taxa have longer ranges than in the neighbouring Reggan and Béchar basins, although this effect is more marked compared to the western Palaeotethyan assemblages in Europe. Several rugose coral species are recorded from the early Bashkirian that previously were considered to have disappeared in the Serpukhovian. The Tindouf Basin, as one of the most western Saharan basins in North Africa, shows the greatest stratigraphic ranges of taxa which diminish eastwards. Evidence for a mass extinction event during the Serpukhovian in the Tindouf Basin has not been clearly recognized, although a possible influence of glaciation is observed in the faunal diversity. Eustatic sea-level changes were experienced in Tindouf with the cyclic pattern of sedimentation, but warm water ocean currents from the palaeoequator were able to maintain tropical conditions on the platform. Tectonics in the area, led to emerging land masses and barriers, and created a partly isolated basin in this sector of the western part of the Sahara Platform in northern Gondwana. The combination of those factors controlled the environmental conditions in the area, allowing the persistence of the fauna for longer stratigraphic ranges than its equivalent counterparts in the western Palaeotethys.

1. Introduction

The Serpukhovian Stage in the Carboniferous is widely acknowledged as recording a severe mass extinction event in its upper part. Stanley (2007) regarded it as the eighth most important mass extinction, with a biodiversity loss in marine invertebrates of 26.5%. Sepkoski (1996) recorded a similar biodiversity loss (24%), in positioning the Serpukhovian as the seventh most important mass extinction event of the Phanerozoic. Most recently, McGhee et al. (2012) considered the Serpukhovian mass extinction as the fifth largest in ecosystem changes, lower than that of the Late Devonian, but greater than the End-Ordovician mass extinction. Independent of the criteria used for categorizing mass extinctions, and their exact position, it is clear that the Serpukhovian was one of the biggest crisis events in the loss of biodiversity and ecosystem changes in the geological record, with a significant turnover in marine fauna and continental flora (McGhee et al., 2012).

The causes for this Serpukhovian mass extinction event are generally associated with a glaciation, and establishment of continental ice caps. The maximum development of the ice cap was situated in the southern hemisphere, where ice covered the Gondwanan continent northward up to latitude 35°S from the south pole (Frakes et al., 1992). The development of glaciers in the northern hemisphere was not so extensive, and in some cases may have been reduced to isolated patches (e.g., Stephenson et al., 2010). This Gondwanan glaciation is considered as the onset of the longest icehouse period, the Late Palaeozoic ice age (LPIA), which extended from the late Viséan up to the Sakmarian in the Early Permian (Stanley and Powell, 2003), c. 45 Myr (335 to 290 Ma). The exact onset of the LPIA is still in a flux of controversy (Fig. 1). According to Wright and Vanstone (2001) the commencement of glacioeustatic cyclic sedimentation in Britain, and hence the onset of the LPIA is considered to be located at the base of the Asbian (base of the late Viséan; Fig. 1). Smith and Read (2000) and Bonelli and Patzkowsky (2008, 2011), studying similar glacioeustatic cycles (cyclothems) in the Midcontinent (USA), located this onset of glaciation in rocks of slightly younger age (middle part of the Chesterian; Fig. 1, latest late Viséan age). The main criterion used by the former authors for the recognition

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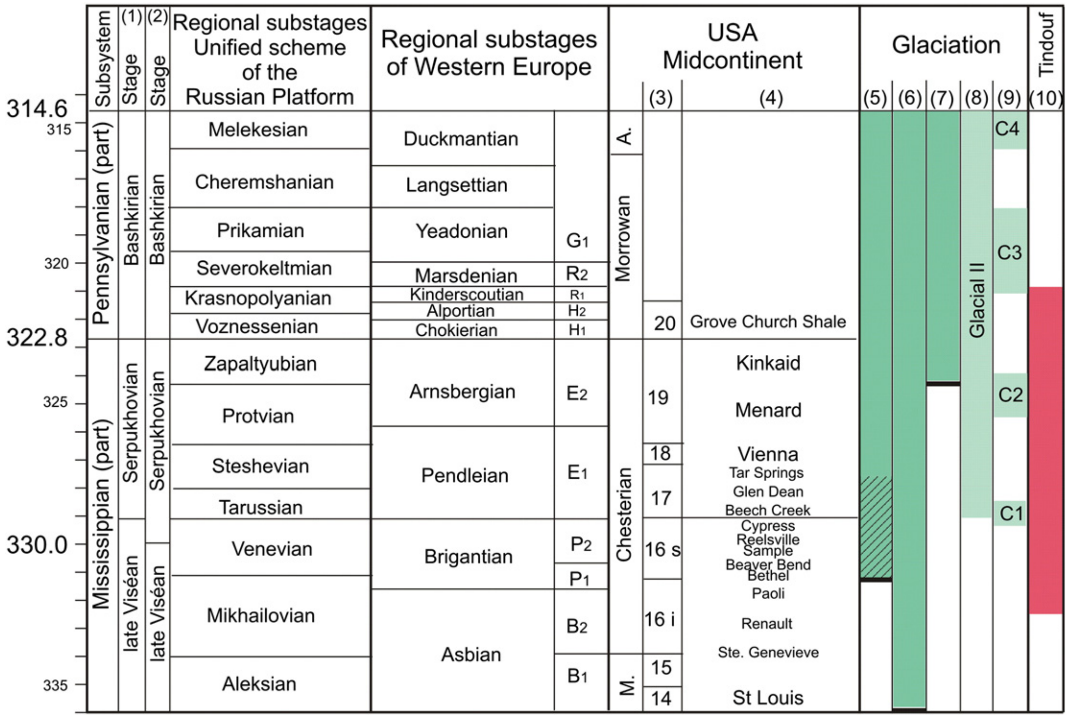

Fig. 1. Chronostratigraphic scale for the middle part of the Carboniferous in Western and Eastern Europe, and North America. Absolute ages are those of Davydov et al. (2010), and correlations are modified from the former authors, as well as from Cózar et al. (2011, in press), and references therein. Abbreviations, M. Meramecian, A. Atokan. Column numbers: (1) Current valid stages, with the formal Viséan/Serpukhovian boundary. (2) Stages including the potential future position of Viséan/Serpukhovian boundary based on the First Occurrence of the conodont *Lochriea ziegleri* Nemyrovskaya et al. (1994). (3) Foraminiferal zones of Mamet (1974). (4) Some of the main limestones in the Midcontinent in Illinois sensu Smith and Read (2000) and Kulagina et al. (2008). (5) Lower part of the Late Palaeozoic ice age (LPIA) according to Smith and Read (2000), the thick solid line is the onset of the LPIA, the oblique lines are the studied interval by Bonelli and Patzkowsky (2008, 2011). (6) Lower part of the LPIA in Wright and Vanstone (2001); the onset is located at the base of the column, thick solid line. (7) Lower part of the LPIA by means of isotopic characterization of brachiopod shells (e.g., in Mii et al., 1999, 2001; Grossman et al., 2002, 2008; and also for Stanley and Powell, 2003). (8) Extent of the Glacial II event of Isbell et al. (2003). (9) Glaciation events of Fielding et al. (2008); the correlation follows absolute ages given by the authors. (10) Stratigraphic interval studied in the Tindouf Basin.

of the onset of glaciation is the change from small eustatic cycles (with 20 to 30 m sea-level fall) to cycles with larger falls (up to 100 m). This late Viséan age assignment contrasts significantly with ages obtained from isotopic records (e.g., Mii et al., 1999, 2001; Grossman et al., 2002, 2008; Buggisch et al., 2008). These studies repositioned the onset of the LPIA in the late Serpukhovian (c. 324 Ma), although accompanied by severe extinctions of marine fauna in the early Serpukhovian (Stanley and Powell, 2003; Powell, 2008). This is a simplistic model and, as is currently known, several glacial and non-glacial episodes occurred during the LPIA, of which the Glacial II event of Isbell et al. (2003) coincides with the entire Serpukhovian–Bashkirian interval (328.8 to 314.6 Ma; Fig. 1) and the glaciation event C2 of Fielding et al. (2008), within the late Serpukhovian (326.5 to 324 Ma; Fig. 1).

Despite the significance of the Serpukhovian mass extinction, studies on the ecological patterns through this event are scarce. Nevertheless, there are many published records listing families and genera of marine fauna which did not survive the crisis (Higgins, 1975; Fedorowski, 1981; Aldridge, 1988; Sweet, 1988; Sando, 1991; Wang et al., 2006; Somerville, 2008). More recently, Bonelli and Patzkowsky (2008, 2011) have drawn attention to the persistence of brachiopod species of the Midcontinent during the onset of the LPIA. These studies were focused on mostly pre-LPIA glacioeustatically-driven sedimentation (uppermost late Viséan–earliest Serpukhovian), in which the regional distribution due to glacioeustacy allowed basinal migrations and thus, taxonomic persistence in different areas. Similar local refuges have been also described for terrestrial plants during the Serpukhovian (e.g., Gastaldo et al., 2009), in which some families of plants migrated along the coast seeking similar environmental conditions.

Within this analysis, most of the database was extracted from the Tindouf Basin, in the western extreme of the Sahara Platform. In the Saharan Tindouf Basin, some genera and species of marine invertebrates (rugose corals, brachiopods), foraminifers, calcareous algae and problematica survived longer than in neighbouring European basins, up to the middle part of the Early Bashkirian (Fig. 1).

The marine succession in Tindouf contains much of the Glacial II interval (Fig. 1), and is considered an excellent stratigraphic succession to evaluate the potential influence of this icehouse event on the marine fauna and flora. The aims of this study are to: (i) demonstrate the development of the Sahara Platform (particularly in the Tindouf Basin) as a refuge basin for several marine faunal and microfloral groups during the Serpukhovian and the lower Bashkirian, (ii) evaluate the possible biological, ecological, palaeogeographic, tectonic and climatic factors, which influenced those 'anomalous' distributions, and (iii) distinguish any faunal peculiarities of this northwestern platform of Gondwana.

2. Geological and stratigraphical setting

The main structural feature in the Tindouf Basin is a major W–E trending syncline, approximately 600 km long and 200 to 300 km wide, extending from southern Morocco into western Algeria (Fig. 2). The Tindouf Syncline is composed of mainly Late Devonian–Carboniferous rocks folded in the Variscan Orogeny. The region is part of a vast epicontinental platform in the northern margin of Gondwana which had evolved from Cambrian times (e.g., Guiraud et al., 2005).

In the western sector of the northern flank of the Tindouf Syncline (Fig. 2), the intersected succession examined in this study comprises the Djebel Tazout Sandstones (Late Devonian to early Tournaisian), Betaina Formation (late Tournaisian to late Viséan), Djebel Ouarkziz Formation (late Viséan to early Bashkirian), Djebel Reouina Formation (Namurian) and the Merkala Formation (Westphalian to Stephanian). Marine carbonate beds are mostly concentrated in the Djebel Ouarkziz Formation, where the Viséan/Serpukhovian and Serpukhovian/