Palaeogeography, Palaeoclimatology, Palaeoecology 460 (2016) 35–49

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

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

Biostratigraphy and palaeoecology of Lower Ordovician graptolites from the Fezouata Shale (Moroccan Anti-Atlas)

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ARTICLE INFO

Article history:
Received 30 October 2015
Received in revised form 4 July 2016
Accepted 20 July 2016
Available online 22 July 2016

Keywords:
Graptolites
Biostratigraphy
Chronostratigraphy
Palaeoecology
Lower Ordovician
Morocco
Gondwana platform

ABSTRACT

The Fezouata Shale (=Fezouata Formation) has produced the most complete Lower Ordovician graptolite succession known from the African continent, which was studied from 32 sections located along the western, central, and eastern Moroccan Anti-Atlas. A composite biostratigraphic and chronostratigraphic scheme is presented for the entire formation that, in ascending order, comprises the *Anisograptus matanensis–Rhabdinopora flabelliformis anglica* zones (uppermost lower Tremadocian), "*Adelograptus*" *tenellus* and *Aorograptus victoriae* zones (middle Tremadocian), *Araneograptus murrayi* and *Hunnegraptus copiosus* zones (upper Tremadocian), ?*Cymatograptus protobalticus* Zone (lower Floian), ?*Baltograptus jacksoni* Zone (middle Floian), and the *Baltograptus minutus* Zone plus an "*Azygograptus* interval" (upper Floian). Most of these zones or biozones are recorded for the first time in Africa, together with important graptolite species such as *Ancoragraptus bulmani* (Spjeldnaes), ?*Cym. protobalticus* (Monsen), ?*B. jacksoni* Rushton, *Clonograptus multiplex* (Nicholson), *B. minutus* (Törnquist) and *Azygograptus eivionicus* Elles. A correlation with the graptolite sucession from the Algerian Sahara is also suggested, reinforced by the common record of the minute anisograptid *Choristograptus louhai* Legrand, providing its second world occurrence in the Tremadocian of Morocco. The prior late Tremadocian dating of the Fezouata Lagerstätte is here extended to the middle Floian as revealed by the graptolite biochronology. The repeated record along the lower and middle parts of the Fezouata Formation of deep-water mesopelagic species of the genera *Araneograptus* — with mass occurrences of conical colonies, together with large horizontal rhabdosomes of *Paratemnograptus*, *Paradelograptus*, *Clonograptus*, "*Tetragraptus*" and *Hologratpus*/*Schizograptus* do not fit the sedimentological interpretation of deposition of these strata in much shallower inshore to mid-shelf environments. This inconsistency has implications when inferring the living conditions of the Fezouata soft-bodied assemblages.

1. Introduction

Ordovician graptolites are relatively rare fossils in the Anti-Atlas mountain range of southern Morocco, where identification of Tremadocian and Arenigian strata was mainly based on typical assemblages of trilobites and other shelly fossils (Choubert et al., 1955; Destombes, 1962a, 1967; Destombes in Destombes et al., 1985). Graptolites were first reported in this geological domain by Destombes and Willefert (1959) and Destombes (1960a, 1960b). They were discovered earlier in the Ordovician of the High Atlas (Roch, 1929; Termier and Termier, 1947; Du Dresnay and Willefert, 1960) and in the western Meseta (Yovanovitch, 1933; Gigout, 1946, 1948, 1951, 1956; Destombes and Jeannette, 1954; Delarue et al., 1956), with some specimens figured by Termier and Termier (1950) and Gigout (1951).

Destombes and Willefert (1959) reported the occurrence of early Tremadocian rhabdinoporinids at the base of the Fezouata Shale (=Fezouata Formation) in the central Anti-Atlas, followed by the record of late Tremadocian adelograptids and *Bryograptus* at a few localities of the same formation from the central and eastern Anti-Atlas (Destombes, 1960a, 1963) and also by some Arenig isograptids, tetragraptids and didymograptids, in the western Anti-Atlas (Destombes, 1960b). From these early records, the production of the Geological Map of Morocco at 1:200,000 scale, covering all the Palaeozoic rocks of the Anti-Atlas in ten sheets, led the French geologist Jacques Destombes to discover during the following twenty-four years about one hundred localities or horizons with Tremadocian and Arenigian graptolites in the Fezouata Formation (Destombes, 2000, 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i, 2006j). These records demonstrate the existence of a regional

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http://dx.doi.org/10.1016/j.palaeo.2016.07.026
0031-0182/

diachronous and transgressive contact between the base of the Fezouata Formation and the different sandstone and shale units that comprise the middle–upper Cambrian Tabanite Group (Destombes, 1962b and Destombes in Destombes et al., 1985). Also, the southwestern equivalent of the Fezouata Formation unconformably overlies Archean rocks of the West African Craton, for example, the graptolite-bearing shales in the Zemmour region of northern Mauritania (Destombes et al., 1969).

However, none of the Lower Ordovician graptolite records reported in these seminal papers and in the map field-notes from the Anti-Atlas were ever described, although some graptolites from fifteen localities around Zagora were illustrated by Aceñolaza et al. (1996) and Destombes (2006a). In contrast to this, Tremadocian graptolites and trilobites from the southwestern extension of the Anti-Atlas in Mauritania were described and illustrated by Sougy (1961 — with *Araneograptus* identified as a bryozoan) and Destombes et al. (1969).

The recent discovery of the Fezouata Lagerstätte in the Zagora region renewed the interest in graptolites as the best means of accurate correlation of the soft-bodied metazoan-bearing beds. For this purpose, Lefebvre and Botting (2007) cited "dendroid" graptolites (=*Araneograptus*) and the late Tremadocian form *Paradelograptus norvegicus* from a locality approximately 20 km north of Zagora. From these and nearby outcrops, Van Roy et al. (2010, Figs. S2h–i), figured specimens of ?*Clonograptus* (=*P. norvegicus*) and putative tuboids, ranging from Tremadocian to early Floian in age. A detailed stratigraphic and palaeonvironmental study of the same strata (Martin et al., 2016) was accompanied by the identification of ten graptolite species within the range of the Fezouata Lagerstätte, and these species supported a correlation with the upper Tremadocian biozones of *Araneograptus murrayi* and *Hunnegraptus copiosus*. Nine planktonic species plus two benthic dendroids were figured in the same paper (Martin et al., 2016, Fig. 4A–P), and a comprehensive taxonomic list of the most recent finds was provided by Van Roy et al. (2015, Table 1).

In the present paper, a general overview of the graptolite data from the Fezouata Formation is presented, focusing on the review of some important localities of Destombes and presenting new data that allow for a better reappraisal on the Lower Ordovician from a regional and international perspective. The precise position of most of the graptolite localities was indicated in the papers by Destombes and Willefert (1959) and Destombes (1960a, 1960b, 1963, 2000, 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i, 2006j). Figured specimens belonging to Jacques Destombes' collection (prefixed JD) are housed in the Ministry of Energy, Mines, Water and Environment (Rabat). Additional material collected by the authors was deposited in the Faculty of Sciences and Technics of the Cadi-Ayyad University of Marrakesh (prefixed AA, material from Martin et al., 2016), and in the Department of Palaeontology of the Complutense University of Madrid (temporary deposit, prefixed DPM).

2. Geological setting

Lower Ordovician rocks of the Moroccan Anti-Atlas are included in the Fezouata and Zini formations. They are overlain by the lower to middle Darriwilian Tachilla Formation in the External (or Outer) Feijas Group (Choubert, 1952; Destombes, 1962a, 1971; Destombes et al., 1985). The Fezouata Formation (=the lower half of the Outer Feijas Shales of Choubert and Termier, 1947) consists of blue-green to yellow-green sandy mudstones and siltstones that coarsen upwards, and they are up to 900 m thick. Due to the regionally transgressive character of the Ordovician sedimentation over Cambrian strata, some thin microconglomeratic and glauconitic horizons are frequently intercalated at or near the base of the unit, and are rare in the middle part of the formation, where a single glauconitic and ferruginous horizon was used traditionally as a boundary-marker to separate the "Lower" and "Upper" Fezouata "formations" on geological maps (Destombes, 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i, 2006j), and later treated as a single formation named Fezouata Shale (Martin et al., 2016).

According to Destombes et al. (1985) and Michard et al. (2008), Ordovician sedimentation began during the Tremadocian in an east-west trending sag-basin south of the Saghro-Ougnate high. Afterwards, a gently subsiding shallow-water shelf extended progressively over the entire area, gently deepening northwards and with a shoreline located some distance from the northern rim of the Reguibat Shield (West African Craton). In the absence of significant synsedimentary tectonics, the Tremadocian to lower Floian marine clays and silts unconformably overlie middle to upper Cambrian strata.

The passive margin sedimentation of the Fezouata and Zini formations occurred in a wave-dominated and tide-modulated shallow-marine shelf within a general transgressive-regressive trend (Martin et al., 2016). The interpreted palaeoenvironments range from proximal offshore to foreshore (Vaucher and Pittet, 2014; Vaucher et al., 2015a, 2015b; Martin et al., 2016). Additional data derived from trilobite biofacies indicate a deepening trend reaching its climax in the middle part of the Fezouata Formation succeeded by a progressive shallowing (from upper offshore to shoreface environments) in its upper third (Martin et al., 2016–in this volume).

The record of identifiable early Ordovician graptolites is so far limited to the Fezouata Formation, where a few graptolite horizons have been recognized in 32 sections along the western, central and eastern Anti-Atlas. Identifiable graptolites have not yet been recorded from the overlying Zini sandstone. Fig. 1 shows the examined localities in the Fezouata Formation, mainly discovered by Destombes (2000, 2006a, 2006b, 2006c, 2006d, 2006e, 2006f, 2006g, 2006h, 2006i, 2006j) and Martin et al. (2016).

Graptolites occur generally in fine argillites and siltstones as flattened imprints preserving some organic material, often coated by iron oxides and, in some instances, by pressure-shadow minerals. In the limited interval with soft-bodied and slightly-sclerotised organisms, associated graptolites are usually preserved in partial to full relief, involving an early diagenetic pyritisation and subsequent weathering to reddish iron oxides. These are responsible for the strong contrast shown by many graptolites compared to the surrounding green, blue-grey, or yellow matrix. Some internal graptolite casts preserve delicate details such as thecal budding and fusellar rings. None of the specimens examined have traces of stolons or zooidal bodies within the thecae, although an exceptional case of preserved zooids has been claimed to occur in a benthic tuboid colony (Van Roy et al., 2010, Fig. S2i). Besides their common preservation in argillites, some graptolites are found in medium-grained sandstones, micaceous siltstones and slightly carbonaceous lenses, where their preservation with some of their original relief may indicate an early diagenetic pyritisation, as well.

3. Graptolite biochronology

Most of the graptolite localities occurring in the Fezouata Shale are isolated exposures, or occur in partial stratigraphic sections with one or a few graptolite horizons, but commonly within a single graptolite biozone. However, some sections include two to five graptolite zones. These sections are in a large region around the city of Zagora, west of Foum Zguid and east of N'kob (central Anti-Atlas) as in the Jbel Tazoult n'Ouzina (eastern Anti-Atlas). The sections near Zagora are located on the flanks of the Bou-Dehir anticline and in the graben of Zagora (sections 14 to 16, Fig. 1).

A composite biostratigraphic scheme based on these sections and from single outcrops is presented for the entire formation (Fig. 2). The graptolite zones recognized are as follow.

3.1. *Anisograptus matanensis and Rhabdinopora flabelliformis anglica zones*

This interval corresponds to the lowermost 6–70 m of the Fezouata Formation in the localities of Adrar n'Tassefat, Sidi Blal, N Zagora, Jbel Amergou, E Jbel Bou Dehir, E N'kob and Bou Ljir (numbers 9, 12, 14, 15, 16, 20 and 21 in Fig. 1, respectively). The assemblage is numerically