Discovery of the *messaoudensis–trifidum* acritarch assemblage (upper Tremadocian–lower Floian, Lower Ordovician) in the subsurface of Morocco

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Abstract. The upper Tremadocian to lower Floian *messaoudensis–trifidum* acritarch assemblage was first described from the Skiddaw Group of England and subsequently from several localities on the Gondwanan margin that were positioned in high southern latitudes during the Early Ordovician. It is here reported for the first time from North Africa, from the Fezouata formations (Tremadocian to Floian) in the AZ-1 borehole, southeastern Morocco. The assemblage is comparable with that from the Skiddaw Group, with *Cymatiogalea deunffii*, *C. messaoudensis*, *C. velifera*, *Caldariola glabra glabra*, *Stelliferidium trifidum* and *Veryhachium lairdii* s.l. The Moroccan assemblage indicates a late Tremadocian age.

Key words: acritarchs, Lower Ordovician, Morocco, Anti-Atlas, biostratigraphy.

INTRODUCTION

The *messaoudensis–trifidum* acritarch assemblage is known from upper Tremadocian to lower Floian (Lower Ordovician) strata in many localities on the Gondwanan margin (Servais et al. 2003). It was first described as the 'Watch Hill assemblage' from the Watch Hill Formation of the Skiddaw Group in the English Lake District by Molyneux & Rushton (1988). Its seven most common species, considered to be the diagnostic taxa, are *Cymatiogalea messaoudensis* Jardiné et al., 1974, *Stelliferidium trifidum* (Rasul, 1974) Fensome et al., 1990, as well as *Acanthodiacrodium*? *dilatum* Molyneux in Molyneux & Rushton, 1988, *Caldariola glabra* (Martin, 1972) Molyneux in Molyneux & Rushton, 1988, *Cymatiogalea deunffii* Jardiné et al., 1974, *Stellechinatum sicaforme* Molyneux in Molyneux & Rushton, 1988 and *Vavrdovella areniga* s.l. (Vavrdová, 1973) Loeblich & Tappan, 1976 (cited in Molyneux & Rushton 1988 as '*Tetraniveum arenigum* (Vavrdová) Vavrdová 1976'). The assemblage was renamed the '*messaoudii–trifidum* assemblage' (and subsequently the '*messaoudensis–trifidum* assemblage' by Servais & Molyneux 1997) and divided into five sub-divisions by Cooper et al. (1995). The stratigraphical range of the assemblage has been correlated with the British and Baltic *Araneograptus murrayi* to *Tetragraptus phyllograptoides* graptolite zones (Molyneux et al. 2007). Reports have been published on its presence from other locations in England, Wales, Ireland, the Isle of Man, Argentina, Belgium, Germany, Spain and Turkey (Molyneux et al. 2007). Common palaeogeographical reconstructions place all these localities at high southern latitudes during the Early Ordovician (Servais et al. 2003; Molyneux et al. 2007). So far the assemblage has not been effectively reported from North Africa, although *Cymatiogalea messaoudensis* was originally described from the Algerian Sahara (Jardiné et al. 1974). Snape (1993), in an unpublished PhD thesis, recognized an association comparable to the one reported by Molyneux & Rushton (1988), marked by the co-occurrence of *Cymatiogalea deunffii*, *C. messaoudensis*, *Stelliferidium trifidum* and *Vogtlandia coalita* Martin in Dean & Martin, 1978, from surface samples of the Moroccan Lower Fezouata Formation.

The Lower and Upper Fezouata formations consist mainly of argillites and, together with the overlying Zini Sandstones and the Tachilla Formation, comprise the Outer Feijas Shale Group (Tremadocian to Darriwilian). The Fezouata formations range in age from the Tremadocian to the early Floian, with the lower formation disconformably overlying Cambrian sediments. Outcrops of the Fezouata formations are found in the Draa valley

near the city of Zagora, in the central Anti-Atlas region, and they are also known to extend further to the southwest in the subsurface (Destombes et al. 1985). Recently the formations gained attention after the discovery of fossils with exceptional preservation (Van Roy et al. 2010) and are currently being studied under the auspices of the French 'Agence Nationale de la Recherche' (ANR) RALI (Rise of Animal Life) project. Palynomorphs from the Fezouata formations have previously been studied by Deunff (1968a, 1968b, in Destombes et al. 1985), Elaouad-Debbaj (1984, 1988) and Snape (1993).

MATERIALS AND METHODS

The AZ-1 (or Adrar Zouggar-1) borehole was drilled for petroleum exploration by Petrofina in 1963 to 1964 on Adrar Zouggar Mountain, about 300 km southwest of Zagora. It had a total depth of 3398.13 m. The interval between 624 and 1134.8 m was assigned to the Fezouata formations without discrimination between the lower and upper parts. Sixteen well cutting samples from that interval (see Table 1) were each treated partly according to standard palynomorph extraction procedures and partly using a low manipulation technique similar to that described by Butterfield & Harvey (2012). The residue was filtered at 51 µm (for the standard technique) or 63 µm (for the low manipulation technique) and 15 µm mesh sizes. Slides were produced from the 15–51 µm or 15–63 µm fractions and examined under a light microscope.

All specimens figured herein are housed at the Evo-Eco-Paleo Department of University Lille 1 (France).

RESULTS

The lowermost sample (1129.5 m) and the samples from 905 m upwards yielded no or very few, poorly preserved acritarchs (see Table 1). The seven remaining samples from 1100.65 to 930.0 m provided comparatively rich and diverse acritarch assemblages. Chitinozoans are also abundant in all levels except for the lowermost sample. Graptolite prosiculae and nema fragments occur sporadically. Scolecodonts are very rare. The residues produced by both techniques are comparable in terms of palynomorph richness.

Several, but not all species typical of the *messaoudensis–trifidum* assemblage of the Skiddaw Group are present, including four out of the seven diagnostic taxa: *Cymatiogalea deunffii* Jardiné et al., 1974 (Fig. 1B), *C. messaoudensis* Jardiné et al., 1974 (Fig. 1C), *Caldariola glabra glabra* (Martin, 1972) Molyneux in Molyneux & Rushton, 1988 (Fig. 1A) and *Stelliferidium trifidum* (Rasul, 1974) Fensome et al., 1990 (Fig. 1F). The other taxa recorded are *Cymatiogalea velifera* (Downie, 1958) Martin, 1969 (Fig. 1D), *Veryhachium lairdii* s.l. Deflandre, 1946 ex Loeblich, 1970 (Fig. 1G), *Impluviculus milonii* (Deunff, 1968b) Loeblich & Tappan, 1969 (Fig. 1E), *Vulcanisphaera frequens* Górka, 1967 (Fig. 1H) and various species of *Acanthodiacrodium*, *Actinotodissus*, *Baltisphaeridium*, *Cymatiogalea*, *Leiofusa*, *Goniosphaeridium*, *Impluviculus*?, *Leiosphaeridia*, *Micrhystridium*, *Multiplicisphaeridium*, *Polygonium*, *Priscogalea*, *Solisphaeridium*, *Stellechinatum*? and *Stelliferidium*.

The occurrence of *Cymatiogalea velifera* and the absence of *Coryphidium* and *Veryhachium trispinosum* (Eisenack, 1938) Stockmans & Willière, 1962 would be

Table 1. Occurrences of palynomorph groups and selected acritarch species in the Fezouata formations of borehole AZ-1

	Depth (m)															
	1129.5	1100.65	1077	1038	1014	999	965	930	905	874	749	734	699	669	653	634
Acritarchs	+	+	+	+	+	+	+	+	+	+				+	+	+
Chitinozoans		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Graptolites		+			+		+				+			+	+	
Scolecodonts						+					+					
Caldariola glabra glabra		+					+									
Cymatiogalea deunffii			+													
Cymatiogalea messaoudensis							+									
Cymatiogalea velifera			+	cf.			+									
Impluviculus milonii			+													
Stelliferidium trifidum		+	+	+	+	+	+	cf.								
Veryhachium lairdii s.l.			+	cf.			+									
Vulcanisphaera frequens		+	+	cf.												

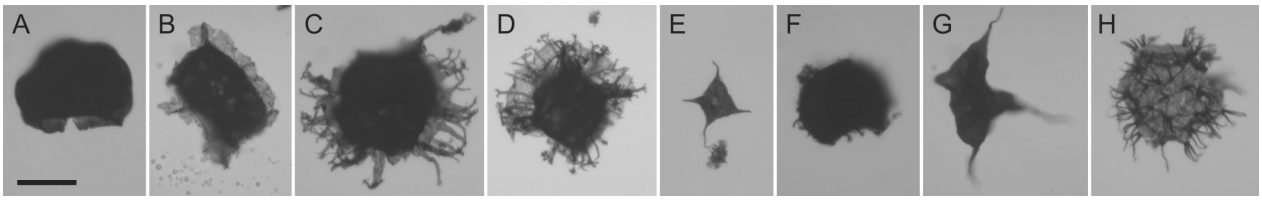

Fig. 1. Selected acritarchs from borehole AZ-1. **A**, *Caldariola glabra glabra* (Martin, 1972) Molyneux in Molyneux & Rushton, 1988, 965 m. **B**, *Cymatiogalea deunffii* Jardiné et al., 1974, 1077 m. **C**, *Cymatiogalea messaoudensis inconnexa* Servais & Molyneux, 1997, 965 m. **D**, *Cymatiogalea velifera* (Downie, 1958) Martin, 1969, 965 m. **E**, *Impluviculus milonii* (Deunff, 1968b) Loeblich & Tappan, 1969, 1077 m. **F**, *Stelliferidium trifidum* (Rasul, 1974) Fensome et al., 1990, 999 m. **G**, *Veryhachium lairdii* s.l. Deflandre, 1946 ex Loeblich, 1970, 1077 m. **H**, *Vulcanisphaera frequens* Górka, 1967, 1077 m. Scale bar = 20 μm.

consistent with an attribution to the *messaoudensis–trifidum* subassemblages 1 and 2 and thus indicate a late Tremadocian age, corresponding to the *Araneograptus murrayi* or *Hunnegraptus copiosus* graptolite zones (Molyneux et al. 2007).

DISCUSSION

The presence of the *messaoudensis–trifidum* assemblage in Morocco adds further evidence to the importance and wide distribution of this assemblage in high southern latitudes during the Early Ordovician. It allows for correlation of the studied part of the AZ-1 borehole with surface samples from the Zagora area and with other regions. The late Tremadocian age in the borehole fits well with the established age of the Lower Fezouata Formation from the outcrop areas (Destombes et al. 1985). Similarities between surface and borehole samples (Snape 1993) also support the assumption that the respective sediments are contemporaneous and palaeoecologically comparable. The full range of diversity of acritarchs and other palynomorph groups present as well as their potential for high-resolution biostratigraphy are planned to be reported in a future publication.

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