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Cryptospore and trilete spore assemblages from the Late Ordovician (Katian–Hirnantian) Ghelli Formation, Alborz Mountain Range, Northeastern Iran: Palaeophytogeographic and palaeoclimatic implications

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ABSTRACT

Well-preserved miospore assemblages are recorded from the Late Ordovician (Katian–Hirnantian) Ghelli Formation in the Pelmis Gorge, located in the Alborz Mountain Range, Northeastern Iran. The palynomorphs were extracted from siliciclastic deposits that are accurately dated using marine palynomorphs (acritarchs and chitinozoans). The spore assemblages consist of 14 genera and 28 species (26 cryptospores and 2 trilete spore species). Six new cryptospore species are described: *Rimosotetras punctata* n.sp., *Rimosotetras granulata* n.sp., *Dyadospora asymmetrica* n.sp., *Dyadospora verrucata* n.sp., *Segestrespora iranense* n.sp., and *Imperfectotriletes persianense* n.sp. The study furthers knowledge of the development of the vegetative cover during the Late Ordovician. Various and abundant cryptospores in the Late Ordovician (Katian–Hirnantian) Ghelli Formation are probably related to the augmentation of land-derived sediments either during the global sea-level fall linked to the Late Ordovician glaciation or adaptation of the primitive land plants in a wide range of climatic conditions. These miospore taxa were produced by the earliest primitive land plants, which probably grew close to the shoreline and were washed in from adjacent areas, producing a high volume of miospores. The associated marine palynomorphs consist of acritarchs (13 genera and 18 species), chitinozoans (9 genera and 10 species), prasinophycean algae, scolecodonts, and graptolite remains, which are not discussed in detail herein. The established chitinozoan biozones of this part of the Palaeozoic sequence are the *Armoricochitina nigerica* Biozone, the *Ancyrochitina merga* Biozone, the *Tanuchitina elongata* Biozone, and the *Spinachitina oulebsiri* Biozone, suggesting a Late Ordovician age (Katian–Hirnantian). These chitinozoan biozones are widely evidenced only in the peri-Gondwanan Domain, indicating that the study area was part of this palaeo-continent in the Late Ordovician.

1. Introduction

The investigation of terrestrial spores of Early Palaeozoic strata (cryptospores and trilete spores) has a long history beginning several decades ago. In fact, our current knowledge stems from research in this field of geology, ranging from Precambrian to Early Devonian strata (Combaz, 1967; Volkova, 1962, 1976, 1997, 1990; Taylor, 1995; Taylor and Strother, 2008; Taylor and Strother, 2009; Richardson, 1996b; Steemans et al., 1996; Steemans, 2000; Wellman and Gray, 2000; Strother et al., 1996, 2004, 2015; Le Hérissé et al., 2007; Rubinstein and Vaccari, 2004; Rubinstein et al., 2010, 2011; Wellman and Gray, 2000; Wellman et al., 2015; Vecoli et al., 2011; Thusu et al., 2013). The study of cryptospores is important because land plant macrofossils have not been found in sediments older than the Silurian, so cryptospores are the oldest witnesses of the earliest continental vegetation. It is now accepted that cryptospores were produced by early primitive land plants, which probably grew close to the shoreline and were washed in from adjacent areas. In the Middle East, cryptospores and trilete spores have been recorded from the Middle–Upper Ordovician Qasim Formation of the Arabian Peninsula (Strother et al., 1996, 2015; Steemans et al., 2009), from the Caradoc Series of the Hasirah Member Safiq Formation of Oman (Wellman et al., 2003), and from the Upper Ordovician–Silurian of Southeastern Turkey (Steemans et al., 1996). To date, however, only one published paper is available that discusses the record of cryptospore assemblages below the Devonian strata and is devoted to the well-dated Ghelli Formation of Iran (Mahmoudi et al., 2014). Therefore, the present paper is a complementary contribution to the knowledge of the taxonomy and palaeophytogeography of cryptospores and trilete spores from the Iranian Platform located at high palaeolatitudes (peri-Gondwanan Domain) in the Upper Ordovician (Katian–Hirnantian).

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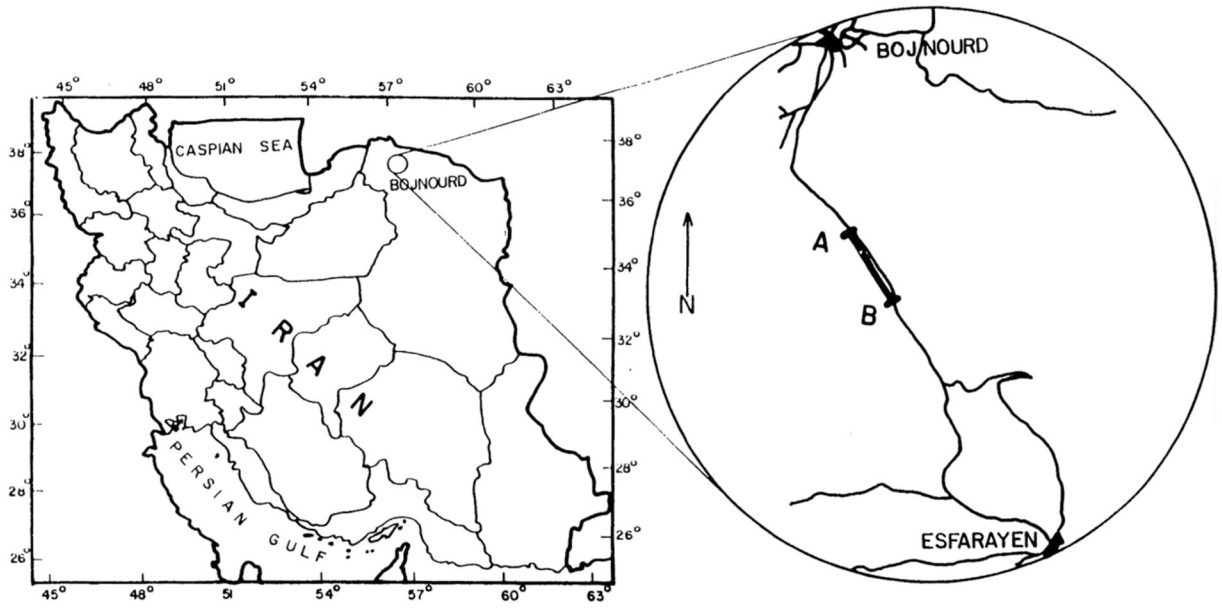

Fig. 1. Location map of the studied area (Ghavidel-Syooki, 2001).

The cryptospore and spore assemblages sampled herein were recorded from the well-dated Ghelli Formation using independent fossil evidence, such as acritarchs, chitinozoans, prasinophycean algae, conodonts, and brachiopods.

2. Geological setting and previous studies

The study area is located approximately 32 km south of Bojnourd. The road from Bojnourd to Esfarayen is the main link to the region (Fig. 1). The measured and sampled stratigraphic section was chosen along this road (Fig. 2) because it cuts across the entire Palaeozoic strata and is easily accessible. In this area, the Lower Palaeozoic strata are 1200 m thick. They are divided in ascending stratigraphical order into the Mila (Cambrian), Lashkarak (Early–Middle Ordovician), Ghelli (Middle–Late Ordovician), and Niur (Early Silurian) formations (Afshar-Harb, 1979). The study area falls within the Kopeh–Dagh region (Northeastern Alborz Mountain Range), where the Lower Palaeozoic rock units extend toward the southern and eastern Caspian Sea. The Mila Formation consists mainly of medium to thick-bedded, cream reddish-brown limestones with poorly preserved megafossils (e.g., brachiopod and trilobites) that have not been identified at the level of genera and species. Therefore, based on stratigraphic position, the Mila Formation has been assigned to the Middle and Late Cambrian (Afshar-Harb, 1979). The Lashkarak Formation has a very unique sedimentary facies consisting of dark gray shales, siltstones, and fine-grained sandstones that are interbedded with thin-bedded fossiliferous limestones (Fig. 2). In the study area, the Lashkarak Formation contains conodonts, brachiopods, and acritarchs, which have been assigned to the Tremadocian–Darriwilian (Ahmadzadeh-Heravi, 1983; Ghavidel-Syooki, 2001). The Ghelli Formation consists mainly of olive gray silty shales, micaceous siltstones and fine-grained sandstones that are cut by a 44 m thick igneous sill. The lower and upper boundaries of the Ghelli Formation are conformable with overlying and underlying formations (Fig. 2). Some intervals of this formation contain brachiopods, conodonts, and well-preserved chitinozoans, which suggests a Late Ordovician age as its type section (Ghavidel-Syooki and Winchester-Seeto, 2002). The Niur Formation, although well-developed in Central Iran, was first described by Afshar-Harb (1979) from the Northeastern Alborz Mountain Range. In the Pelmis Gorge area, this formation consists mainly of black shales, siltstones, and sandstones with intercalations of fossiliferous limestones (Fig. 2). In the Pelmis Gorge area, the Niur Formation contains abundant corals, brachiopods, crinoids, and palynomorphs (acritarchs and chitinozoans), which suggest an Early Silurian age (Ghavidel-Syooki, 2001; Ghavidel-Syooki and Vecoli, 2007).

3. Materials and methods

A total of 140 surface samples were collected from the whole stratigraphic interval of the Lower Palaeozoic strata (Mila, Lashkarak, Ghelli, and Niur formations) in the Pelmis Gorge area at the eastern part of Kuh-e-Saluk. The collected samples are designated herein by the National Iranian Oil Company code numbers preceded by prefixes MG-1 to MG-140 (Fig. 2). Palynomorphs were extracted from shale, siltstone, and fine-grained sandstone samples using standard palynological procedures, which included the removal of carbonates and silicates by hydrochloric and hydrofluoric acids and density separation of the organic residues in 30 ml of saturated zinc bromide solution. Organic residues were then sieved through 15 μm nylon mesh sieves. Palynological residues were mounted on glass slides for optical and scanning electron microscopy examinations. All samples proved to be palyniferous and yielded well-preserved and abundant palynomorphs with dominating acritarch assemblages and rare algal clusters in the Mila Formation; however, chitinozoans, scolecodonts, and chitinous graptolite remain in the Lashkarak and Ghelli formations. It is worth mentioning here that cryptospores and rare trilete spores are present only in the Ghelli Formation (MG-90 to MG-130). The palynomorph groups mentioned earlier were counted, and their percentages were calculated. These calculations indicate that samples MG-90 to MG-100 bear miospores and that their percentage is fairly higher than that of acritarchs and chitinozoans (Table 1 and Fig. 3). The chitinozoan group is common in samples MG-90 to MG-104 and is very rare to rare in the rest of the samples (Table 1 and Fig. 3). The results of the palynological study of the area, consisting of acritarch and chitinozoan assemblages of Lower Palaeozoic rock units (Lashkarak, Ghelli and Niur formations) were previously published by Ghavidel-Syooki (2001), Ghavidel-Syooki and Winchester-Seeto (2002), and Ghavidel-Syooki and Vecoli (2007). Therefore, this paper focuses on the terrestrial palynomorph group of the Ghelli Formation (Katian–Hirnantian), although diagnostic acritarch and chitinozoan taxa are discussed briefly herein. The miospores and acritarchs range in color from yellow to orange-brown, indicating an intermediate degree of thermal maturity (Plates I to VIII). All slides relating to this study are housed in the palaeontological collections of