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Original article

Intriguing crinoid remains from the Rhaetian of Iran and their possible implications for the mid-Carnian crinoid extinction event☆

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ABSTRACT

It has been generally accepted that the representatives of holocrinid crinoids (Holocrinidae *sensu* Rasmussen, or Holocrinida *sensu* Hess and Messing) became extinct during the mid-Carnian extinction event. Until now, the youngest known, though not yet described, holocrinid representatives were specimens of *Holocrinus* nov. sp. from the early Tuvalian (Carnian). Here, we report dissociated but relatively well-preserved crinoid remains from the Rhaetian of central Iran resembling two taxa: *Holocrinus* sp. and *Isocrinus* sp. (both *sensu lato*). The holocrinid ossicles are represented mainly by internodals, but two nodals have been also reported. One of them (pluricolumnal consisting of nodal and infranodal) possesses undifferentiated symplectical lower facets which makes possible a reliable assignment to the genus level. The presented material constitutes the youngest known holocrinid crinoids to date.

1. Introduction

The Permian-Triassic extinction event is considered a major perturbation in crinoid history (e.g., Simms, 1999) in which only a single lineage derived from the Late Palaeozoic cladid ancestor (Ampelocrinidae) survived into the Early Mesozoic (Simms and Sevastopulo, 1993). After the end-Palaeozoic crisis, crinoids underwent a major evolutionary radiation during the Middle-Late Triassic that led to their rapid expansion through morphospace (Foote, 1995), as well as major morphological and behavioral innovations (Baumiller et al., 2010; Gorzelak et al., 2012). This radiation resulted in the appearance of new groups of crinoids, including holocrinids (Holocrinidae *sensu* Rasmussen or Holocrinida *sensu* Hess and Messing, 2011), encrinids (Encrinida), millericrinids (Millericrinida), isocrinids (Isocrinida), comatulids (Comatulida) and roveacrinids (Roveacrinida). Among these crinoids, *Holocrinus* is considered the stem group for all post-Paleozoic crinoids within the monophyletic subclass Articulata (Schubert et al., 1992; Hagdorn, 2011; but see also Webster and Jell, 1999). In the late Ladinian/early Carnian, crinoid diversification had reached its Triassic maximum (Simms, 1990; Hagdorn, 1995, 2011). It has been argued, however, that soon after, a global mid-Carnian extinction event affected many of the Early Carnian crinoid genera (Simms and Ruffell, 1990). It is widely accepted that all encrinids, ainigmacrinids, traumatocrinids, and probably all holocrinids went extinct during this time (e.g., Hagdorn et al., 2007).

Here, we report several well-preserved pluricolumnals and columnals of *Isocrinus* sp. and columnals of *Holocrinus* sp. from the Upper Triassic (Rhaetian) of central Iran. Holocrinid assignment at the generic level is certain due to presence of symplectial lower nodal facets (Hagdorn, 1983, 1993; Hagdorn and Głuchowski, 1993; Hagdorn et al., 1996). In contrast, cryptosymplexy or even smooth synostosis in case of 'true' isocrinids occur, though symplectial facets may also occur but on proximal nodals only (Simms, 1989). In this study, we use the methodology proposed by Hagdorn (see references cited above).

2. Geological and palaeontological settings

2.1. Geology

The thickness of the Upper Triassic Nayband Formation of Iran varies from 2000 to 3000 m (Schäfer et al., 2003; Fürsich and Hautmann, 2005). This formation consists of siliciclastic deposits with calcareous intercalations and frequent small patch reefs or biostromes composed of corals, sponges and bivalves in the upper part of the sequence (Seyed-Emami, 2003; Fürsich and Hautmann,

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2005). The age of this formation was dated mainly as Middle Norian–Rhaetian (Seyed-Emami, 2003; see discussion below). The stratigraphy of this formation is based on different groups of fossils, since conodonts and ammonoids are very rare and do not occur in all the members (Schäfer et al., 2003; Seyed-Emami, 2003). Thus, the age of some members or lower lithostratigraphic units was established based on foraminifers, hydrozoans (*Heterastridium*), bivalves, brachiopods and spores (Senowbari-Daryan and Hamedani, 1999; Buratti et al., 2001; Seyed-Emami, 2003). It has been generally argued that the sediments of this formation were formed in a shallow-water shelf environment (Buratti et al., 2001; Hautmann, 2001; Seyed-Emami, 2003). Particularly, the upper part of the Nayband Formation (the Howze-Khan Member) includes numerous fossils such as sponges, calcareous algae, corals, foraminifers, bryozoans (Schäfer et al., 2003), gastropods (Nützel et al., 2003), and bivalves (Hautmann, 2001). Crinoids, however, were never thoroughly described from this part of the section.

The Howze-Khan Member was mainly dated as mid-Rhaetian (Seyed-Emami, 2003). However, according to some authors the Rhaetian/Hettangian boundary is not well established and can be situated in other part of the section. For example palynological data by Buratti et al. (2001) placed the Triassic/Jurassic boundary within the middle part of the Howze Sheikh Member, which lies directly below the Howze-Khan Member. Also foraminiferal data suggest that the Howze-Khan Member (crinoidal limestones and sponge-bearing limestones) can be of Early Jurassic age (Senowbari-Daryan and Hamedani, 1999) in some localities. The locality (Chahriseh) under study herein, included in the Howze-Khan Member, is Rhaetian due to the presence of *Solenopora styriaca*, *S. zlambachensis* and *Parachaetetes rhaeticus* (species and their stratigraphic range according to Senowbari-Daryan et al., 2008), and Upper Triassic foraminifera assemblage (Senowbari-Daryan et al., 2008).

2.2. Triassic crinoids from Iran and adjacent areas

Ruttner (1984) first mentioned Triassic crinoids from Iran. This crinoidal material collected by Ruttner from the Middle Triassic (uppermost Ladinian) Sina Formation (Aghdarband Group) of NE Iran was thoroughly described later by Kristan-Tollmann (1991). The latter author described numerous crinoid taxa, including roveacrinids: *Osteocrinus aghdarbandensis* Kristan-Tollmann and *O. saklibelensis* Kristan-Tollmann; traumatocrinids (Traumatocrinidae, Encrinidae and Ainigmacrinidae belong to order Encrinida; see Hess and Messing, 2011): *Traumatocrinus caudex* (Dittmar); isocrinids: *Balanocrinus* sp., *Holocrinus*? *quinqueradiatus* (Bather) and *Entrochus* sp. (for its systematics see comments below).

Crinoids from adjacent areas (Afghanistan, southern Russia and former Soviet republics of Central Asia, Turkey, Ukraine [Crimea]) were illustrated and described in the following papers: Kristan-Tollmann and Krystyn (1975), Klikushin (1982, 1983, 1986, 1988, 1992 and references therein), Simms (1990), Kristan-Tollmann (1991), Baumiller and Hagdorn (1995), Hagdorn (1995 and references therein), Hagdorn and Göncüoglu (2007).

3. Material and methods

Fieldwork was carried out in 2008–2010 by Babak Aghababalou in the central Iran, slightly SW from Chahriseh Mountains in the village of Chahriseh near town Komshecheh, *ca.* 40 km to NE from Esfahan (Fig. 1). In this locality, described also by Senowbari-Daryan et al. (2008), part of the Howze-Khan Member with a thickness of 130 m is exposed, consisting of dark grey shales with intercalations of lenticular limestones and sandstones. All crinoids were collected from the upper part of the Howze-Khan Member, *ca.* 13 m below the Triassic/Jurassic boundary described by Senowbari-Daryan et al. (2008). Above, Lower Jurassic sandstones without macrofossils and Cretaceous grey limestones with *Orbitolina* are exposed (Senowbari-Daryan et al., 2008). In the investigated part of the Howze-Khan Member, calcareous algae (solenoporaceans, Senowbari-Daryan et al., 2008), sponges and corals occur frequently.

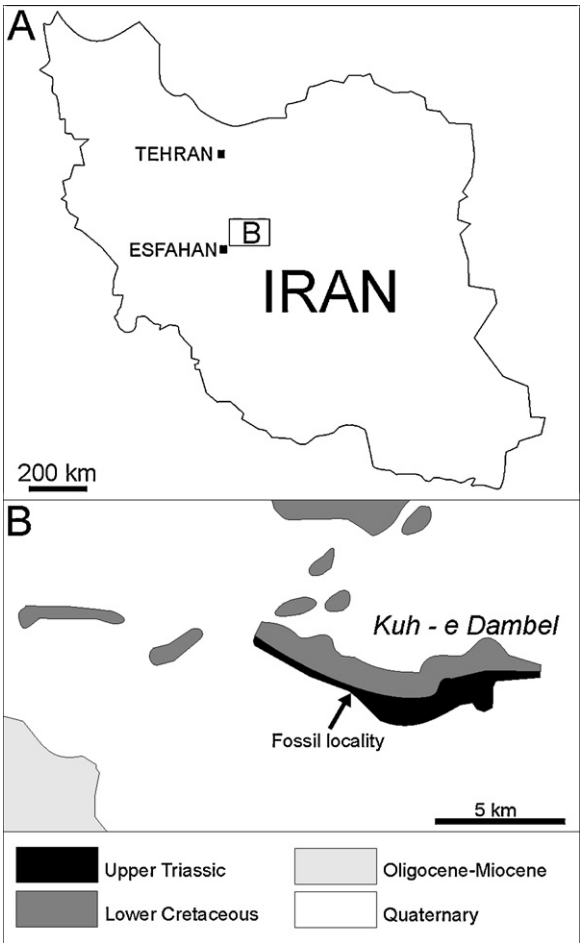

Fig. 1. Map of Iran (**A**) and location of the fossil locality (**B**); taken from Zahedi (1978), modified.

Crinoids were collected primarily from the weathered sediments as well as the surfaces of the bedding planes. Additional material was collected in 2011 from the chemical maceration (glauber salt) of the rock slabs at the Laboratory of Paleontology and Biostratigraphy of the University of Silesia. Apart from numerous foraminifers, echinoderm ossicles including columnals and pluricolumnals of crinoids (*Isocrinus* sp.: 72 remains; *Holocrinus* sp.: 23 remains) were found. The collection is housed at the Laboratory of Paleontology and Biostratigraphy of the University of Silesia (Catalogue abbreviation: GIUS).

4. Systematic palaeontology

Systematics follow the revised Treatise (Hess and Messing, 2011).

Order HOLOCRINIDA Jaekel, 1918
Family HOLOCRINIDAE Jaekel, 1918
Genus **Holocrinus** Wachsmuth and Springer, 1886
Holocrinus sp.
Fig. 2(A–F)