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# A new species of *Doraster* (Echinodermata: Asteroidea) from the lower Miocene of central Japan: implications for its enigmatic paleobiogeography

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**Abstract. A new species of well preserved zoroasterid asteroid was discovered from the lower Miocene Yamami Formation (approx. 16 Ma), Morozaki Group in Aichi Prefecture, central Japan. The specimens possess a small disc and long arms, and show clear stellate ossicles on the aboral disc surface, clearly supporting their placement within the genus *Doraster*. Currently *Doraster* is widely distributed in bathyal depths in the western Atlantic, represented only by one modern species, *D. constellatus*. The new discovery of fossil *Doraster* species not only extends the stratigraphic range of this genus but also suggests it was widely distributed in the Pacific before the closure of the Isthmus of Panama.**

**Key words: Asteroidea, *Doraster*, Japan, Miocene, Paleobiogeography**

## Introduction

*Doraster* is an asteroid genus of the family Zoroasteridae, distributed in the modern deep sea (upper bathyal zone) of the tropical and subtropical western coasts of the Atlantic, ranging from Massachusetts to French Guiana (Downey, 1970; Mah, 2007). The Zoroasteridae is characterized by a definite arrangement of primary enlarged disc plates and carinal plates along the mid-arm and longitudinal and transverse series of arm plates (Downey, 1970). Phylogenetic study of the Zoroasteridae, using both morphological (Mah, 2007) and molecular data (Mah and Foltz, 2011) has revised the previous classification of the zoroasterid genera and species. Fossil material is important for phylogenetic and biogeographic reconstructions, but so far very few records of fossil zoroasterids, especially those of the genus *Doraster*, have been available. *Zoroaster* aff. *fulgens* was described from the upper Eocene of Seymour Island, Antarctica (Blake and Zinsmeister, 1979). Occurrence of Miocene *Doraster* sp., the present species to be described herein, was reported by Yamaoka (1987), but the morphological details and its biogeographic implications were not fully discussed.

The purpose of this paper is to describe a new species of *Doraster*, which was discovered from the Yamami Formation of the Morozaki Group, central Japan, and to discuss the paleobiogeographic implications of this discovery.

## Geological setting

More than twelve specimens of *Doraster* were collected from a hill located south of Iwaya (Loc. 1 of Figure 1; 34°43′17.0″N, 136°54′41.0″E), Minamichita Town, Aichi Prefecture, central Japan. The beds are correlated with the lower part of the Yamami Formation (so-called “Odomari Bed”) of the Morozaki Group. Most of the fossils consist of intact specimens, but some of these are fragmentary. Although the original orientation of these specimens in the bed is unknown, since the block containing the material had already been dislodged when they were collected, four specimens show their oral surface, whereas the others show their aboral surface.

The Morozaki Group is distributed in the southern part of Chita Peninsula, Aichi Prefecture, central Japan. Small distributions are also found in two islands off Morozaki, Himaka and Saku islands. The Morozaki

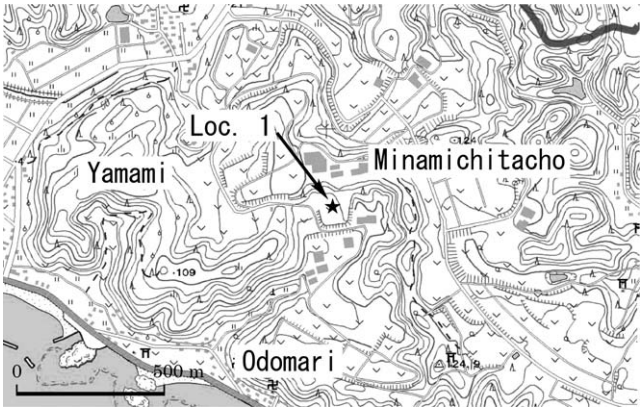


**Figure 1.** Locality of *Doraster mizunoi* sp. nov. (Loc. 1, 34°43′17.0″N, 136°54′41.0″E). The map was adopted from the Digital Japan Web System, Geospatial Information Authority of Japan.

Group consists of mudstone and alternating beds of sandstone and mudstone. Both sandstone and mudstone are highly tuffaceous, containing abundant volcanic glasses and pumices. The group consists of Himaka, Toyohama, Yamami and Utsumi formations in upward sequence, and all these formations are in conformable contacts.

Most of the Morozaki Group is not fossiliferous and consists primarily of deep-sea deposits of presumably bathyal depths. However, various invertebrate and vertebrate fossils, some of them beautifully preserved, are locally common and have been collected from turbiditic sandstone layers and from mudstones. So far, mollusks (Shikama and Kase, 1976; Shibata, 1977), echinothurioid echinoids (Amemiya *et al.*, 1994), and crinoids (Oji, 1990) have been reported or described from this group. The Tokai Fossil Society, an amateur group of fossil collectors in central Japan, has long been devoted to studying the deep-sea fossils from this group, after new outcrops were excavated when new farmlands were developed in the hilly area of southern Chita Peninsula in the 1980s. The society published a book on the fossils from the Morozaki Group in 1993, in which many groups of fossils, such as fishes, bivalves, gastropods, crinoids, asteroids, echinoids, ophiuroids, crustaceans, brachiopods, etc. were reported (Tokai Fossil Society, 1993). The asteroid fossils described herein were also reported in that book (as *Doraster* sp.).

Among these four formations, the Yamami Formation in particular is dominated by frequent intercalations of turbiditic sandstone into mudstone, and fossils are abundant in these sandstone layers. Well preserved, intact echinoderms and fishes are usually found in thin films in these sandstones. Abundant plant fragments are also present. This suggests that these fossils were transported and deposited by turbiditic flow activities. Transportation of the animal bodies did not apparently cause any disarticulation or fragmentation. Specimens of the new *Doraster* species, described herein, were collected by Mr. Mizuno of the Tokai Fossil Society from the upper part of the Yamami Formation.

The geologic age of the Morozaki Group is estimated to be approximately from 22 Ma to 15 Ma based on radiolarians (Sugiyama, 1994), planktonic foraminifers (e.g. Ibaraki *et al.*, 1984), diatoms (Ito *et al.*, 1999) and fission track dating (Doi, 1983). The upper part of the Toyohama Formation was estimated to be approximately 17 Ma according to radiolarian biostratigraphy (Sugiyama, 1994). The middle to the upper part of the Toyohama Formation was assigned to Zone N7 (17.3–16.4 Ma, Nathan and Leckie, 2003) in the foraminiferal zonation of Blow (1969). The fission track dating done for the Fukigoshi tuff bed in the upper part of the Yamami Formation shows an approximate age of 16 Ma. The present asteroid fossils occurred from the lower part of the Yamami Formation, and thus the age is here estimated as approximately 16–17 Ma.

## Paleobathymetry

Previous records of fossils from the Yamami Formation suggest that this formation was deposited at bathyal depths, namely about several hundred to over one thousand meters deep. The occurrence of *Teliocrinus ojii* (the specimens originally described as *T. springeri* by Oji (1990) were later treated as a new species by Roux *et al.*, 2009) suggests that the paleodepth should be several hundred to one thousand meters deep, because the extant species (*T. springeri*) has been reported from this depth interval. Also other echinoderms from the Yamami Formation, such as *Phormosoma* cf. *bursarium* and an undescribed species of *Hymenodiscus*, suggest that the Yamami Formation was deposited in the upper bathyal environment. The depth records of a modern species, *D. constellatus*, indicate a bathyal occurrence and are consistent with the bathymetric interpretation as estimated above.

The following abbreviations are used in the text: $R$ = length of major radius from center of disc to tip of ray; $r$ = length of minor radius from center of disc to interradial edge.

## Systematic description

Family Zoroasteridae Sladen, 1889
Genus *Doraster* Downey, 1970

*Remarks*.—The morphological characters of this

genus are described in detail in Mah (2007). This genus is represented by a single modern species, *D. constellatus*. *D. qawashqari*, originally described as a species of *Doraster* by Moyano and Larrain Prat (1976), was transferred to a different, closely related genus, *Myxoderma* of the Zorasteridae (Mah, 2007).

*Doraster mizunoi* sp. nov.

Figure 2A–F

*Diagnosis*.—*Doraster* with small disk, large stellate aboral plates, especially the central one which is typically pentastellate, and long and slender arms.

*Material and repository*.—Four specimens were available for this study. Holotype (NUM-Fa 0175) and three paratypes (NUM-Fa 0176a, 0176b, 0177 and 0178) are kept in the Nagoya University Museum, Nagoya University. All the specimens were collected by Mr. Yoshiaki Mizuno from the upper part of the Yamami Formation in Iwaya (Loc. 1 of Figure 1).

*Etymology*.—The specific name comes from Mr. Yoshiaki Mizuno who found these fossil asteroids, along with numerous well preserved fossils, from the Morozaki Group.

*Description*.—Rays are five in number, long and slender. Disc is small and slightly rounded, and interbrachial arcs are sharp. Abactinal disc plates are large, stellate and flat. $R$ = 60–65 mm (average: 63.3 mm); $r$ = 4–8 mm (average: 5.9 mm); $R/r$ = 10–12 (average: 11.2).

Surrounding the central aboral surface are five primary interradial plates, and all these plates are large and conspicuously stellate. Distal to the primary interradial plates are five radial plates that are smaller than the interradials, but their shapes are not clearly visible. The other ossicles and details of structures such as the anus and the madreporite on the disc are not observable. Originally the aboral surface was probably covered with skin-like scales or tiles from the central area of the disc to at least the middle part of the arms. Papulae were not observed.

On the arms, there are five rows of plates on the aboral side; the carinal plates and two rows of plates, adradials and marginals, on either side. The marginal plates are inconspicuous and not so much developed. In all specimens examined in this study, the first carinal plates seem to be large but they are not clearly separated from the radial plates. None of the arms show any spines or spinules.

The ventral aspect is not well preserved, and therefore it is difficult to observe adambulacral and ambulacral plates. Only a small part of the adambulacral plates can be observed; they consist of two alternating carinates and noncarinates. Pores for the tube feet are not observed.

*Discussion*.—The specimens from Morozaki have a definite arrangement of primary enlarged disc plates and carinal plates along the mid-arm and longitudinal and transverse series of arm plates. They also have primary disc plates with a conspicuous star shape (Figure 2B–C). These characteristics are shared with the living species *Doraster constellatus* (Figure 3A).

The specimens from Morozaki and the genus *Cnemidaster* (= *Mammaster*) are similar in the arrangement of plates on the disc, but the disc plates of *Cnemidaster* are more swollen and larger than in *Doraster mizunoi*. Additionally, *Cnemidaster* does not have adradial plates, while the specimens examined clearly have these plates. Mah (2007, p. 184) mentioned that the specimens from Morozaki are assignable to *Myxoderma* Fisher, 1905 (Figure 3B) based on the primary spines on all plates, and reticulate feature of disk and arm plates. However, primary spines of *Doraster mizunoi* are hardly observable on any of the preserved plates and its plates are tightly arranged. Large-sized specimens of *Myxoderma qawashqari* (USNM 1084273, $R$ is more over than 100 mm) have a reticulate skeleton but the spines are not as conspicuous as in small-sized specimens of *M. qawashqari*, and the primary spines may well become undeveloped during ontogeny. Considering the small sizes of the Morozaki specimens, the absence of primary spines strongly suggests that they are assigned to the genus *Doraster*, not *Myxoderma*. Recent species belonging to the genus *Doraster* consist of only one species, *Doraster constellatus*. *Doraster mizunoi* from Morozaki, however, has sharper stellate primary disc plates, a smaller disc and slenderer arms than *D. constellatus*. Therefore *Doraster* from Morozaki is considered as a new species.

## Paleobiogeography of *Doraster* and its related taxa

*Doraster* from Morozaki was collected with other starfish species, *Anthenoides* sp., *Hymenodiscus* sp., and two sea urchin species, *Brissopsis makiyamai* and *Phormosoma* cf. *bursarium* (Amemiya *et al.*, 1994). Most of these species are considered as inhabitants of the bathyal zone, occurring between 200–1000 m depth, based on data from the Smithsonian National Museum of Natural History database. Thus, the associated taxonomic assemblage suggests that *Doraster mizunoi* is a member of the upper bathyal fauna. Considering that the modern *D. constellatus* occurs between 73–2601 m (Smithsonian database as above) with its primary abundance at 300–700 m (Mah, 2007) suggests that *Doraster*'s bathymetric occurrence has remained unchanged from the Miocene to now.

Mah (2007) discussed the paleodepths of Zoroasteridae including the genus *Doraster*. According to the record of *Zoroaster* sp. aff. *fulgens* from the upper Eocene, the

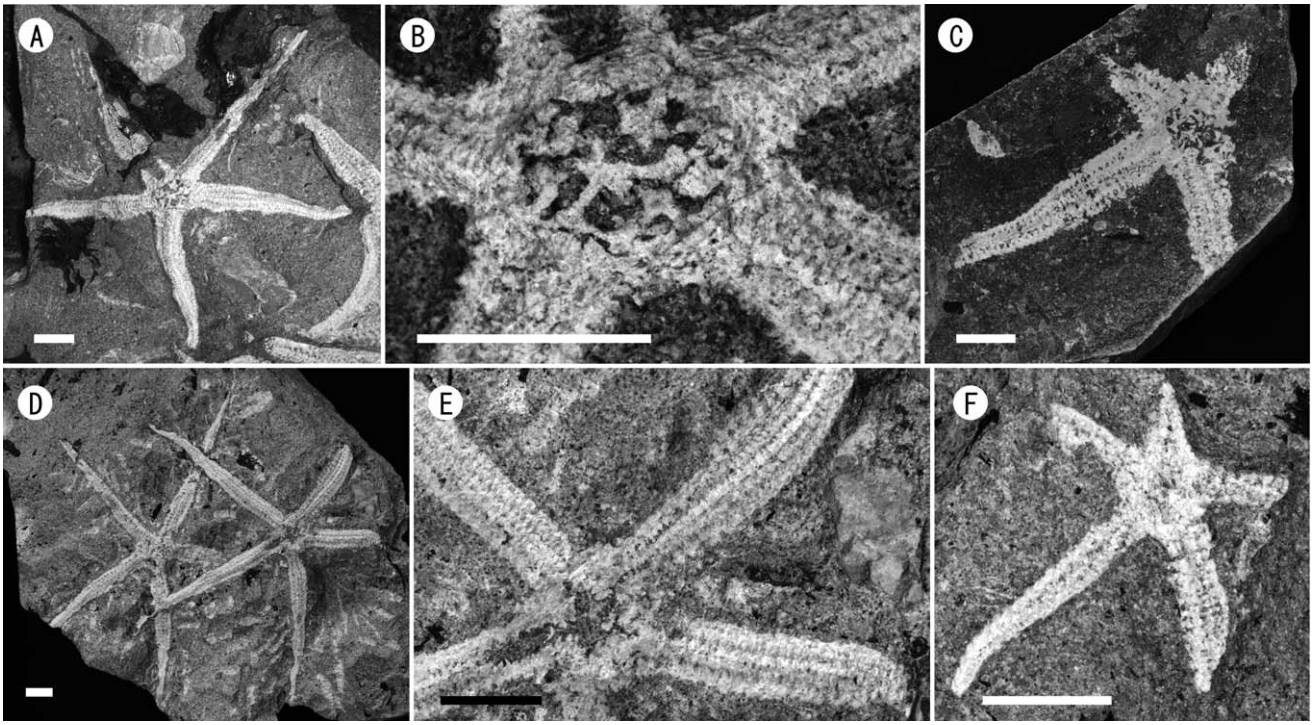


**Figure 2.** *Doraster mizunoi* sp. nov. from Iwaya, lower part of the Yamami Formation, Morozaki Group. **A**, Holotype (NUM-Fa 0175); **B**, enlarged view of dorsal disk of the holotype, with stellate ossicles; **C**, paratype (NUM-Fa 0177) with stellate ossicles in the disk; **D**, left, paratype (NUM-Fa 0176a), right, paratype (NUM-Fa 0176b); **E**, enlarged view of paratype (NUM-Fa 0176b), showing carinal plates and adjacent two rows of plates; **F**, paratype (NUM-Fa-0178). All scale bars are 10 mm.

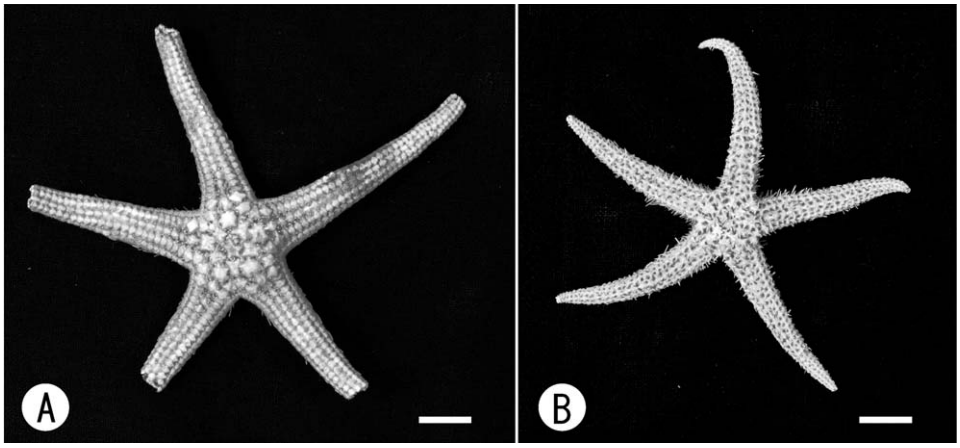


**Figure 3.** Recent zoroasterids. **A**, *Doraster constellatus* Downey from north of Valiente Peninsula, Panama (USNM E18505); **B**, *Myxoderma qawashqari* (Moyana and Larrain Prat) from southwest of Paita, Piura, Peru (USNM E1080458). Scale bars are 10 mm.

habitat of the genus *Zoroaster* at that time would be at shallow depths (Blake and Zinsmeister, 1979). If we consider the paleodepth of the habitats of zoroasterids as a whole, the new record of the Miocene *Doraster mizunoi* suggests that zoroasterids in the Miocene were probably deep-water inhabitants, and that they migrated from a shallow to a bathyal environment prior to the Miocene, probably during the late Eocene and the early Miocene.

It seems premature for us to discuss the paleobiogeography of the Zoroasteridae because there are only sporadic fossil records of this family. Aside from the genus *Doraster*, its closely related genus *Myxoderma* is widely

distributed in the Pacific (Mah, 2007). The present record of *Doraster* from the Miocene of the northwestern Pacific, as well as the modern distribution of *Doraster* and *Myxoderma*, suggests that the two genera or their common ancestor were once widely distributed both in the Pacific and the Atlantic, whereas the genus *Doraster* has been restricted only to the western Atlantic since the early Miocene. The enigmatic distribution pattern of *Doraster* may be explained by the closure of the Isthmus of Panama, which isolated modern *Doraster* to the Atlantic.

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