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The First Record of *Microcodium* from Maastrichtian Kalat Formation, Kopet-Dagh Sedimentary Basin, NE Iran: Biostratigraphy and Microfacies

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Abstract
This paper is to present the biostratigraphy of the Maastrichtian Kalat Formation in Karnaveh area of the northeastern Iranian Kopet-Dagh sedimentary basin. Micropaleontological studies have led to the determination of micro-calcite structures, having *Microcodium* deposited in the stratigraphic section due to transgression and regression of the sea. On the basis of determined benthic foraminiferal taxa *Laffitteina mengaudi* (Astre), *Lepidorbitoides socialis* (Leymerie), *Omphalocyclus macroporus* (Lamarck), *Orbitoides apiculata* Schlumberger, *Orbitoides media* (d'Archiac), *Rotalia skourensis* Pfender, *Siderolites calcitrapoides* Lamarck, *Sirtina orbitoidiformis* Brönnimann & Wirz, *Sulcoperculina cosdeni* Applin & Jordan, *Sulcoperculina globosa* Cizancourt and *Sulcoperculina vermunti* (Thiadens), Kalat Formation in the studied stratigraphic section is assigned to the Maastrichtian. The current study represents the first record of *Microcodium* occurrence in Kopet-Dagh sedimentary basin in northeast Iran, expanding the current knowledge on its palaeogeographical distribution in Tethyan Realm.

Keywords
Microcodium, Maastrichtian, Kopet-Dagh, Kalat Formation, NE Iran.

Introduction

Kopet-Dagh (or Koppeh Dagh) mountain range represents a NE-trending, about 650 km long and about 200 km wide, active folded belt at the border between Iran, Turkmenistan and the Caspian Sea. It was formed on Hercynian metamorphosed basement in the SW margin of the Turan Platform. It is composed of about 10 km of mostly conformable Mesozoic and Tertiary sediments (e.g., Berberian and King 1981; Afshar-Harb 1994; Golonka 2004; Taherpour Khalil Abad et al. 2013; Raisossadat and Shokri 2011). After the Cimmerian orogeny event, corresponding to the closure of Paleo-Tethys Ocean in the Late Triassic/Early Jurassic, a post-collisional rifting event was associated with deposition of the first formation named Kashafrud Formation in Kopet-Dagh basin (Robert et al. 2014).
The aim of this paper is to report the first record and stratigraphic distribution of *Microcodium* in Maastrichtian of the Kalat Formation. On the basis of the benthic foraminiferal content and other associated organisms, an attempt was also made to provide the palaeoenvironmental interpretation of the sediment hosting the *Microcodium* infiltration.

Materials and Methods

The materials comprise eight samples which were collected from Karnaveh section. Eight thin sections were prepared and the microfossil content was identified using an optical microscope. The carbonate classification is in accord with the scheme of Dunham (1962), while the generic attributions of the benthic foraminifers are based on Rahaghi (1976), Kalantari (1987 and 1992), Khosrow Tehrani and Afghah (2004), Maghfouri-Moghadam et al. (2009), Vaziri-Moghaddam et al. (2013) and Azizi (2016). All samples are housed in the repository system of Geological Survey of Iran and Geosciences Research Center, NE Territory (M. Bahremand collection).

Geological Setting

The Kalat Formation has been named after the old fortress of Kalat-e-Naderi in eastern Kopet-Dagh. It was first introduced by geologists of the National Iranian Oil Company (NIOC) as a unit of coarse-grained detrital limestone occurring in the central and eastern parts of Kopet-Dagh sedimentary basin (Afshar-Harb 1994). In the type section in the Tang-e-Neyzar area, the formation consists of 277 m thick succession dominated by limestone interbedded with sandstones and shales.
The section is spotted near the Karnaveh village along Kalat-Dargaz road in Khorasan-e-Razavi province. It is located 60 km far from Iran-Turkmenistan border between 37°13'54'' N latitude and 59°26'21'' E longitude (Fig. 1). In Karnaveh section, Kalat Formation conformably overlies the Ab-Talkh and Neyzar formations and

underlies the Pestehligh Formation (Fig. 2). The lower 10 m of Kalat Formation consists of dark-gray, thin-bedded sandy limestone with benthic foraminifera. The following 15 m is composed of light-brown, thick-bedded limestone which yields benthic foraminifera, abundant *Microcodium* (sample k.3.31) and bivalve shell fragments, whereas the overlying 4 m is represented by brown to red, thick-bedded limestone. The upper part of the latter limestone yields abundant specimens of *Microcodium* (samples k3.35), benthic foraminifera and bivalve shell fragments (Fig. 3).

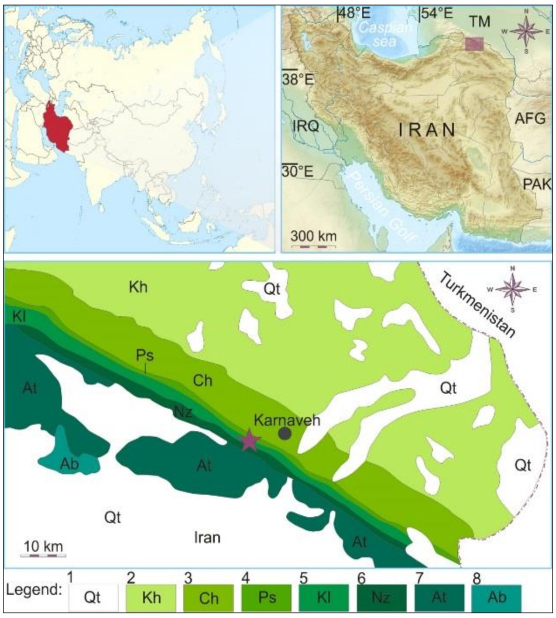


Fig. 1. Location of the Kalat Formation studied in the Karnaveh section (purple star). Quaternary: 1, alluvial deposits; Eocene: 2, Khan Giran Formation; Palaeocene: 3, Chehel Kaman Formation; 4, Pestehligh Formation; Maastrichtian: 5, Kalat Formation; Late Campanian/Maastrichtian: 6, Neyzar Formation; Santonian/Campanian: 7, Ab-Talkh Formation; Albian/Cenomanian: 8, Aitamir Formation.

Fig. 2. General view of the Kalat Formation section south of Karnaveh village, showing alternation of sandy limestone and shales with *Microcodium* levels (M).

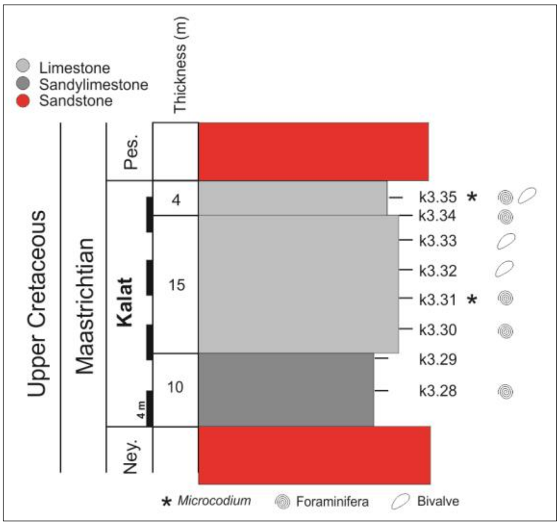


Fig. 3. Lithological column of the Kalat Formation in Karnaveh stratigraphic section.

Microcodium Record in the Kalat Formation

Microcodium is a calcified microstructure which is classified as the problematics. It resembles the problematic microfossil *Palaeomicrocodium* (Mamet and Roux, 1983; Kabanov et al., 2008). Although well preserved plates of both genera may be morphologically very similar, the most differences between *Microcodium* and *Paleomicrocodium* are as follows: a) *Palaeomicrocodium* has no central cavity and vacuoles; b) it does not occur in corrosive contacts with the host rock, and normally is not associated with distinct paleosol features and c) has been reported from the Cambrian up to the Permian (Mamet and Martinez-Garcia, 1995; Cherchi et al., 1997; Antoshkina, 2006). Also, Glück (1912) described aggregates of unusual calcite crystals in the marine Miocene of southern Germany as a limestone forming siphonaceous alga "*Microcodium elegans*", and placed the new entity in the Codiaceae of the Chlorophyta (Wood and Basson, 1972; Kabanov et al., 2008). Capeder (1904) described it as *Paronipora penicillata* and placed it in Gorgonacea. *Microcodium* prisms usually form a fan, spherical clusters or disks. The general shapes of these prisms are “Rosette” and “Isodiametric” in longitudinal and equatorial sections (Fig. 4).

Microcodium is found in calcareous paleosols in carbonate shelves and margins of Tethys basin in Cretaceous and Paleocene sediments. There are many hypotheses on the origin of this microstructure. Some hypothesis support different levels of flora such as Lithothamnian, Codiacean, green, red and green-blue alga, corals, Stromatolites, bacterial filaments, fungi, etc. and some believe that *Microcodium* belongs to calcified roots of plants (Capeder, 1904; Gluck, 1912; Edwards, 1932; Jodot, 1935; Rutte, 1954; Cuvillier, 1955; Maslov, 1956; Kamptner, 1960; Guillaume, 1961; Durand, 1962; Klappa, 1978; Košir, 2004). The presence of *Microcodium* indicates terrestrial conditions and subaerial exposure, thus defining the termination of depositional cycles (Košir, 2004; Ahlborn and Stemmerik 2015).

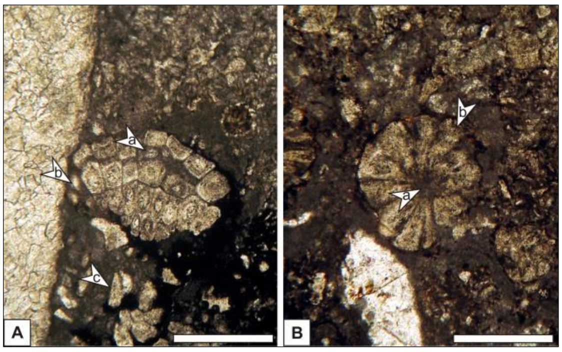


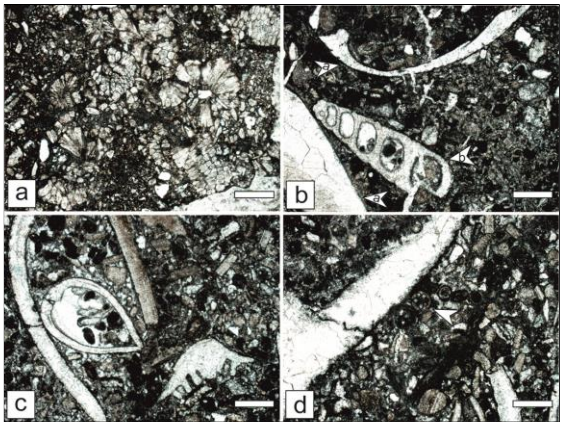
Fig. 4. A, Isodiametric form with intercellular spaces in the cortex (a), prism (b) and fragmented prisms (c) (equatorial section); B, Rosette form with axial canal (a) and petal-like prism (b) (tangential section). Scale bar: 250 µ.

Benthic Foraminiferal Biostratigraphy

The fossiliferous biosparite and biomicrite microfacies of the Kalat Formation contain rich foraminiferal assemblages. Benthic foraminifera occur in the limestone and sandy limestone parts of the succession and represent significant biostratigraphic markers for Maastrichtian age widely present in the entire Tethyan region.
Laffitteina mengaudi (Astre) occurs for the first time in the Maastrichtian and has a wide distribution. It is known from the Maastrichtian-Paleocene shallow marine carbonate successions of Slovenia and Italy (Pugliese et al. 1995) and Turkey (Inan et al. 2005). It is common in restricted shelf area or lagoonal facies and subtidal-tidal environments (Goldbeck and Langer 2009). The other larger foraminifera such as *Lepidorbitoides* sp. (Fig. 7, d), *Lepidorbitoides socialis* (Leymerie) (Fig. 7, e,i), *Omphalocyclus macroporus* (Lamarck) (Fig. 7, f), *Orbitoides media* (d'Archiac) (Fig. 7, a-c), *Siderolites calcitrapoides* Lamarck (Fig. 7, j-k), *Orbitoides apiculata* Schlumberger, *Sirtina orbitoidiformis* Brönnimann & Wirz (Fig. 7, g), *Sulcoperculina cosdeni* Applin & Jordan, *Sulcoperculina globosa* Cizancourt and *Sulcoperculina vermunti* (Thiadens) are typical Maastrichtian species (e.g. Thiadens 1937; Meriç 1967; Weiss 1993; Premoli Silva et al. 1995; Caus et al. 1996; Mitchell 2005; Dieni 2010; Omaña 2013; Matsumaru 2016). The associated larger foraminiferal genera inhabit shallow waters of tropical to subtropical platforms (Caus et al. 1988; Goldbeck and Langer 2009; Robles-Salcedo et al. 2018). Smaller foraminifera are also present such as *Rotalia skourensis* Pfender (Fig. 7, h). This species is also found abundant in Maastrichtian beds (Brown and Bronnimann 1957). It is seen in restricted lagoon and tidal flat environments (Dragastan and Herbig 2007).

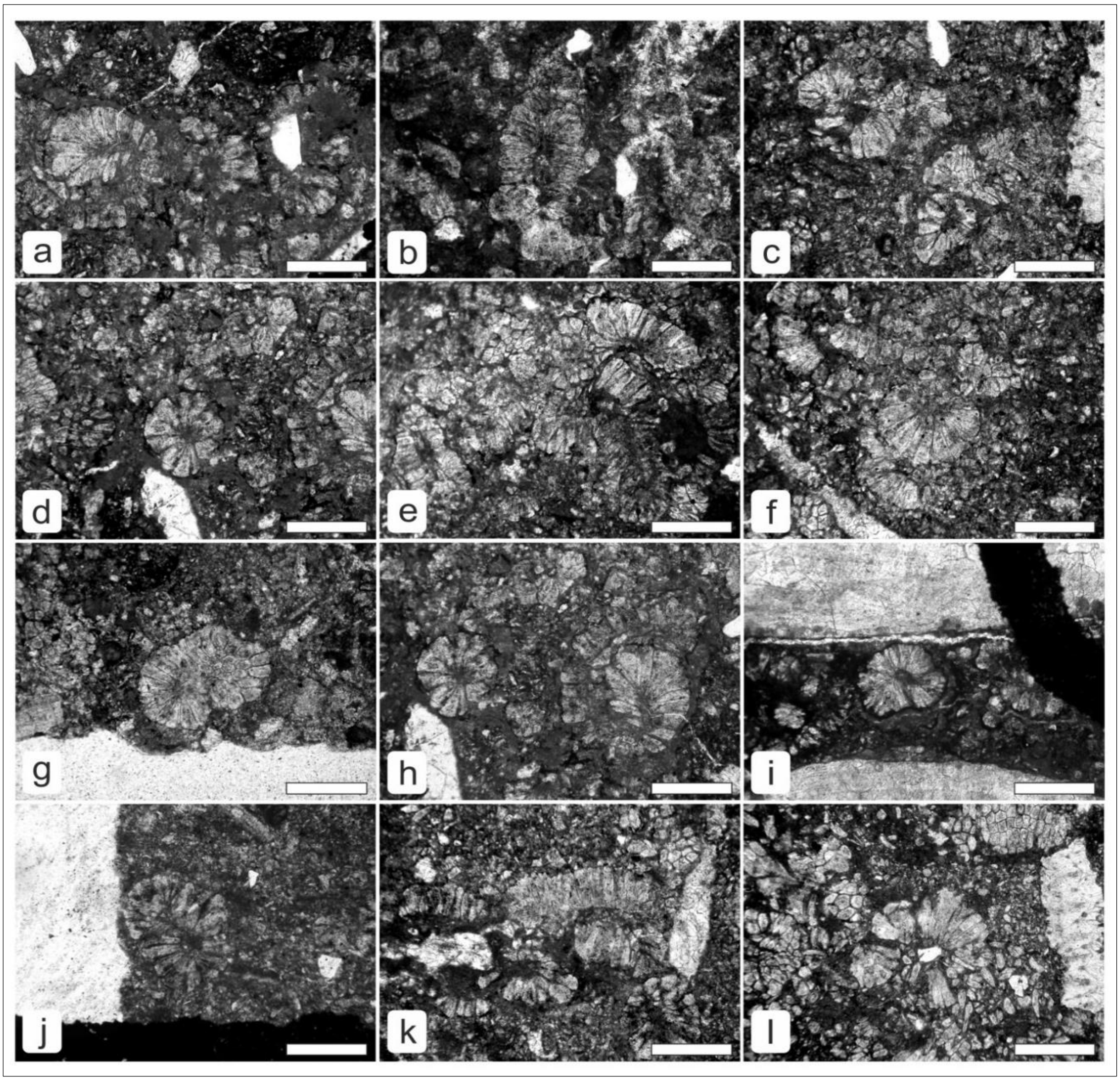
Palaeoenvironments and Age Reports

Depositional environment of the Kalat Formation suggests low-energy restricted inner platform and shallow intertidal to supratidal with the episodes of subaerial exposure. Two microfacies were recognized: sandy bioclastic peloidal packstone and sandy bioclastic peloidal wackestone. The main characteristic of sandy bioclastic peloidal packstone is the presence of *Microcodium* in a micritic matrix (Fig. 8, a). The occurrence of *Microcodium* is indicative of paleosoils developed in the shallowest areas of the platform during periods of subaerial exposure (Grajales-Nishimura et al. 2003). Various broken skeletal grains including bivalves and gastropods in a micritic matrix with common geopetal fabric are characteristic of sandy bioclastic peloidal wackestone (Fig. 8, b-d) originated in a restricted inner platform.
From the occurrence and age reports of *Microcodium*, it is well described by Košir (2004): "The fossil record of *Microcodium* is unusual, with its peak occurrence in the early Paleogene (especially the Paleocene and early Eocene), and later in the Miocene (Wright and Tucker 1991; see also review of geographical and stratigraphical distribution in Klappa 1978). Smit (1979) and Bignot (1994, 1995) stated that *Microcodium* did not appear before the early Paleocene, arguing that its appearance in Cretaceous rocks resulted from a deep penetration of *Microcodium* into the older rocks from the overlying Tertiary formations. However, there are numerous unambiguous and well-documented reports on *Microcodium* from the Upper Cretaceous carbonate successions of the Peri-Tethyan region".



Pl. 5 Thin-section photomicrographs of the determined microfacies types from the Maastichtian Kalat Formation in Karnaveh section. a, sandy bioclastic peloidal packstone with micritic matrix and Microcodium, samples No. k3.35; b, sandy bioclastic peloidal wackstone with large bivalve shell fragments (a) and gastropod shell (b) in a micritic matrix; geopetal deposition of peloids in a gastropod shell can be seen, samples

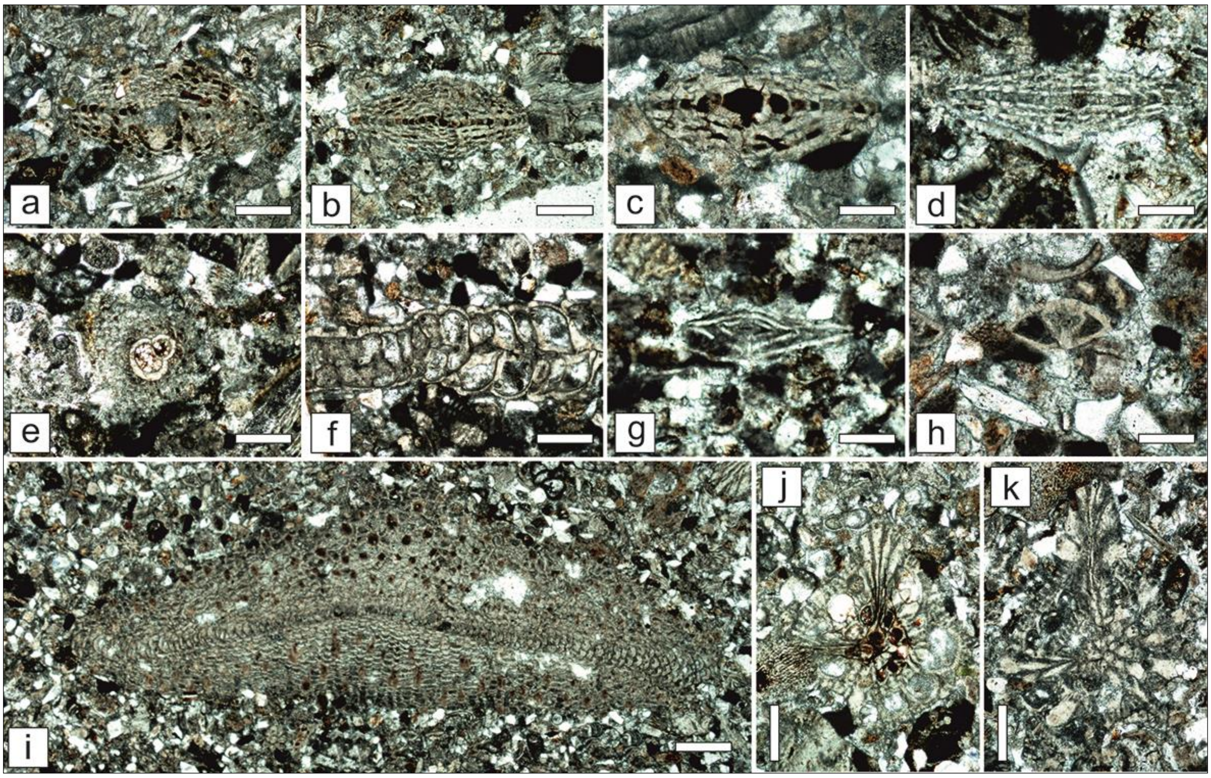
No. k3.35; c, sandy bioclastic peloidal wackstone with micrite matrix and geopetal deposition of peloi ds and fine quartz grains in a gastropod shell, samples No. k3.31; d, sandy bioclastic peloidal wackstone with Terquemella sp. (white arrow) in a micritic matrix, samples No. k3.31. Scale bar: 30 µm.



Pl. 1. Thin-section photomicrographs of the Microcodium (a-l) from the Maastichtian Kalat Formation in the Karnaveh section.

Conclusion

Microcodium has been recorded for the first time in Iran. It is found in sandy limestone of the Kalat Formation associated with larger Maastrichtian benthic foraminifera. This study presents important implications for extending the palaeogeographical distribution of Maastrichtian foraminifera taxa and *Microcodium* aggregates along the northern Tethyan margins. The depositional texture and foraminiferal assemblage from the Kalat Formation indicate deposition in an environment that represents a shallow carbonate ramp with *Laffitteina* in lagoonal facies types characterized by the sporadic input of open shelf genera *Lepidorbitoides, Orbitoides, Omphalocyclus, Siderolites* and *Sirtina*. The levels at which *Microcodium* occurs in the Kalat Formation are probably broadly corre lative with the Meaninsk Suite in Soviet Turkmenistan (Stöcklin and Setudehnia, 1991).



Pl. 2. Thin-section photomicrographs of the benthic foraminifera associated with *Microcodium* from the Maastichtian Kalat Formation in the Karnaveh section. a-c, *Orbitoides media* (d'Archiac), samples No. k3.35; d, *Lepidorbitoides* sp. samples No. k3.31; e, i, *Lepidorbitoides socialis* (Leymerie, 1851), samples No. k3.35; f, *Omphalocyclus macroporus* (Lamarck), samples No. k3.35; g, *Sirtina orbitoidiformis* Brönnimann & Wirz, samples No. k3.35; h, *Rotalia skourensis* Pfender, samples No. k3.31; j-k, *Siderolites calcitrapoides* Lamarck, samples No. k3.35.

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