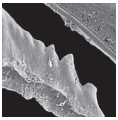


# New data on conodonts and ostracods of the Katkoyeh Formation (Lower–Upper Ordovician) at the Banestan Section of East-Central Iran: biostratigraphical and palaeobiogeographical significance

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Ordovician marine sedimentary sequences occur in several widely separated structural blocks in Iran, along the northern margin of Gondwana. In northern Kerman Province, the Ordovician sedimentary interval is known as the Katkoyeh Formation, which encompasses ~70–300 m of siliciclastic rocks with scarce carbonate and thick pyroclastic beds in its upper part. Previous studies provided several ages for the Katkoyeh Formation, puzzled by the limited number of palaeontological studies, mostly based on spot samples, the presence of regional important stratigraphic gaps, and the inherent structural complexity of the area. In order to adjust the depositional time of the Katkoyeh Formation, a systematic sampling for microfossils was conducted in the Banestan Section, located about 12 km northwest of the city of Zarand, in the vicinity of the Banestan village. Based on the occurrence of important biostratigraphic species, we recorded three conodont intervals in ascending order in the Katkoyeh Formation, namely the *Rossodus manitouensis*/*Paltodus deltifer* Concurrent Range Zone (Tremadocian, Lower Ordovician), the *Juanognathus variabilis* Range Zone (Floian, Lower Ordovician), and the *Icriodella superba* Range Zone (Katian–?Hirnantian, Upper Ordovician). The conodont biostratigraphy is discussed and analysed, improving the Ordovician intrabasinal correlation of Iran as well as correlation with distant palaeobiogeographic domains. The Upper Ordovician conodont assemblage is accompanied by two new species of ostracods: *Satiellina zarandensis* sp. nov. and *Ceratopsis persicus* sp. nov., both suggesting palaeobiogeographical affinities mainly with Gondwana and peri-Gondwanan regions. • Key words: biostratigraphy, microfossil, Tremadocian, Floian, Katian, Hirnantian, Gondwana.

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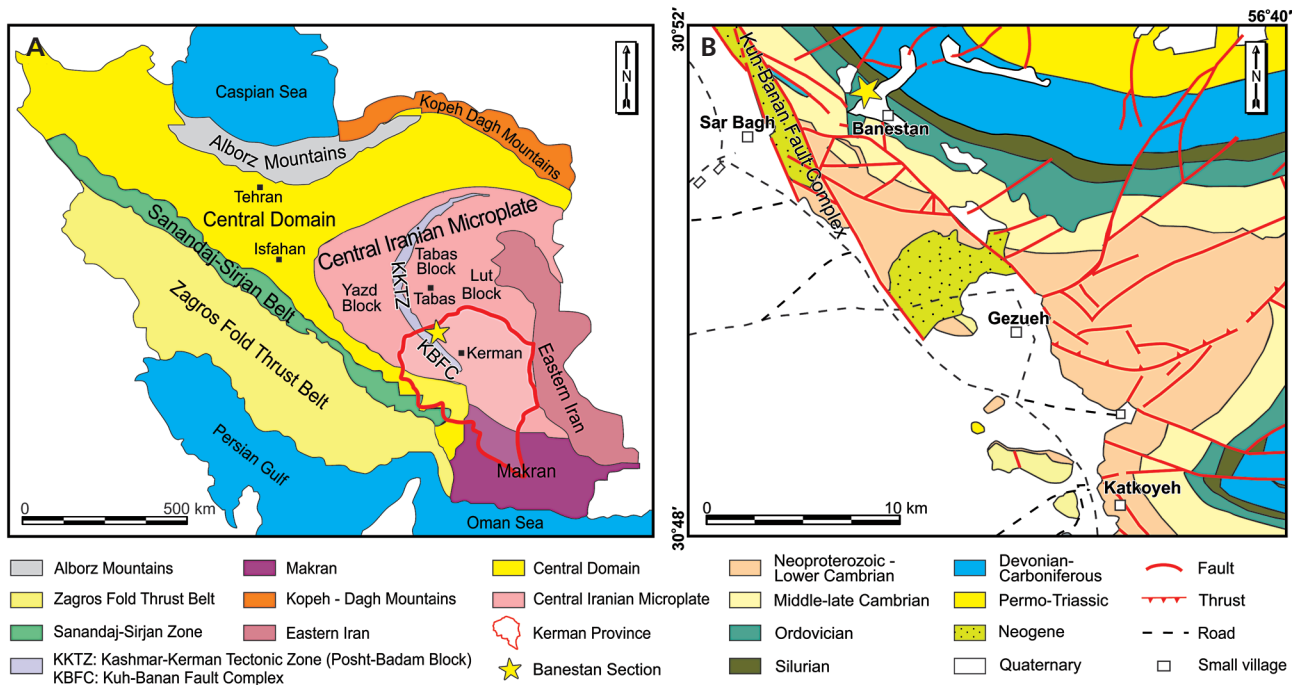
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Iran was a persistent single tectonic unit throughout the Ordovician, located somewhere on the northern margin of Gondwana (Cocks & Torsvik 2021). Its precise rifting time from mainland Gondwana is still not defined, but the very low diversity of Ordovician brachiopod faunas in the region by comparison with contemporaneous Mediterranean Province fauna of Morocco and Bohemia suggests that Iran was situated in a high latitude location throughout the Ordovician Period (Basset *et al.* 1999).

Ordovician marine sedimentary sequences occur in a number of widely separated structural units of Iran.

Mostly but not exclusively, they crop out in the Zagros area (Southwest Iran), and in the well-known outcrops of the Alborz Range (North Iran), Tabas and Kerman regions (East-Central Iran) (Fig. 1A). Parts of the sequences contain rich fossil faunas, such as conodonts, trilobites or brachiopods, but with a small number of notable exceptions there are few studies on taxonomy, biostratigraphy and biogeography of these biotas (*e.g.* Müller 1973, Basset *et al.* 1999, Bruton *et al.* 2004, Percival *et al.* 2009).

The presence of Ordovician sediments along the eastern margin of the Yazd Block and Kerman Province,



**Figure 1.** A – simplified tectonic map of Iran showing main tectonic domains and location of the Banestan Section, in NW Kerman Province (modified from Tadayon *et al.* 2017). B – geological map of the study area with location of the Banestan Section (modified from Vahdati-Daneshmand *et al.* 1995).

East-Central Iran, was first established during geological mapping of the area about sixty years ago by Huckriede *et al.* (1962), and later continued by Ruttner *et al.* (1968), Stöcklin & Setudehnia (1991) and Alavi-Naini (1993).

The Ordovician sedimentary succession in Central Iran (north of Tabas) was introduced as the Shirgesht Formation by Ruttner *et al.* (1968), for a series of about 800 metres of limestones, shales and partly sandstones. In the Kalmard Block, Yazd Block and Kerman Province to the south of Tabas, the Ordovician sedimentary interval includes siliciclastic rocks with scarce carbonate beds in the upper part. Hamed & Wright (1992) designated the latter succession as the Katkoyeh Formation for the sake of its best exposure in the nearby Katkoyeh village, east of Zarand, north-east Kerman Province (Fig. 1B). The Katkoyeh Formation was regarded as Arenigian to Ashgillian (Floian to Hirnantian of current usage) in its type area, although regionally it comprises also important stratigraphic gaps (Hamed *et al.* 1997; Rickards *et al.* 1994, 2001) (Fig. 2).

The oldest reference on Ordovician conodonts from Iran belong to Huckriede *et al.* (1962), who reported a Tremadoc–Arenig assemblage from the Katkoyeh Formation at the Dahu Section (Kerman region). In a landmark conodont contribution, Müller (1973) analyzed Cambrian–Early Ordovician conodonts from Northern Iran (Alborz region). However, conodonts from the Katkoyeh Formation in the central regions of Iran went out of research focus until

publications by Hamed (1995), Hamed *et al.* (1997), Zhen *et al.* (2001) and Hairapetian *et al.* (2017). Apart from a few conodont publications from the Shirgesht Formation in the Tabas area (Ghaderi *et al.* 2008, 2009), the application of conodonts to the lower Palaeozoic biostratigraphy in Central Iran has been limited. Only recently a more comprehensive investigation on late Tremadocian–Floian conodonts from the Katkoyeh Formation at the Kuh-e-Bonorg Section of the Kalmard Horst (west of Tabas) has been published (Nezhadabbas *et al.* 2020).

Ostracods in the Ordovician of Iran are scarcely documented, with only two contributions from the Central Iran Microplate and other two from the Alborz area (Fig. 1A). In the Central Iran Microplate, the fauna of the Shirgesht Formation is described from two localities. At Derenjal Mountains near Tabas, Ghobadi Pour *et al.* (2006) described eight species from the upper levels of the section; whereas Schallreuter *et al.* (2006) recorded more than 40 species from the lower levels of the formation in a section east of Anarak. In Alborz area, Ghobadi Pour *et al.* (2007) described a Middle Ordovician arthropod fauna of the Lashkarak Formation, among which, six are ostracod species. Finally, Ghobadi Pour *et al.* (2011) reported Tremadocian ostracod genus *Nanopsis* in a section 15 km southwest of the city of Shahrud in the Eastern Alborz Mountains.

In the present contribution, new conodont and ostracod collections from the Katkoyeh Formation at the

Banestan Section are analysed, providing new significant information for the biostratigraphy and intercontinental correlation of the Ordovician faunas of East-Central Iran.

## Geological setting

### The Katkoyeh Formation

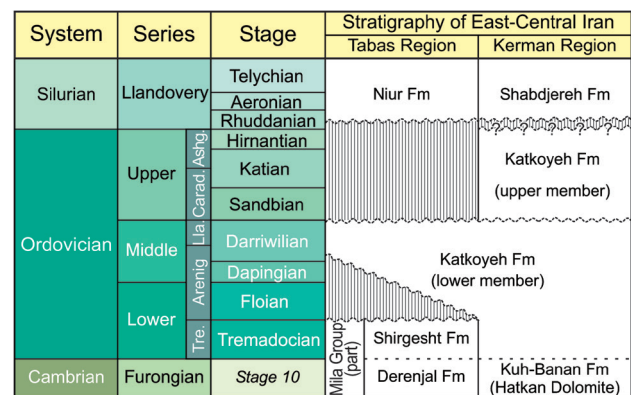
*Geology.* – The Katkoyeh Formation is well exposed in a number of isolated sections (Asyab, Banestan, Gezueh, Katkoyeh) along the eastern side of the Kuh-Banan Fault System to the east of Zarand, 65 km north-west of the Kerman Province (Huckriede *et al.* 1962, Rickards *et al.* 1994, Vahdati-Daneshmand *et al.* 1995, Hamedí 1995, Basset *et al.* 1999, Dastanpour *et al.* 2006) (Fig. 1B). Ordovician strata in the Kerman Province were also documented by Hamedí *et al.* (1997), who introduced biostratigraphic subdivisions and biogeographic data for the Cambrian to Silurian succession of East-Central Iran (Fig. 2).

The Katkoyeh Formation (Hamedí in Rickards *et al.* 1994) has a maximum thickness of 321 m and can be divided into two informal members. The lower member (Tremadocian–Darriwilian) is a lower transgressive shale-sandstone sequence that in some localities contains intervals of pillow basalts, followed up by a marine limestone-shale interval, and an upper pyroclastic interval. The upper member, of Late Ordovician age, consists of a lower red bed interval that grades upward into mixed marine and non-marine sediments (Hamedí 1995). In the Kerman region, the Katkoyeh Formation disconformably overlies the Furongian stromatolitic Hatkan Dolomite Member of the topmost Kuh-Banan Formation, and is overlain in turn by the basal fluvial deposits of the Silurian Shabdjereh Formation (Hamedí 1995, Zhen *et al.* 2001, Hairapetian *et al.* 2017).

*Previous biostratigraphic studies.* – Huckriede *et al.* (1962) first recognised the presence of Ordovician strata in the Zarand Area. In the Dahu Section, to the east of the Kuh-Banan Fault, they reported *Drepanodus arcuatus* Pander, *Drepanodus cf. subarcuatus* Pander, *Drepanodus sp.*, *Drepanodus homocurvatus* Lindström, *Distacodus sp.*, *Scandodus sp.*, *Gothodus sp.* and *Prioniodus sp.* from the first limestone horizon of the Katkoyeh Formation, along with hexactinellid sponge spicules, echinoderm remains and brachiopods that referred to the British Tremadoc or Arenig Series. From the overlying shale, the authors listed a fauna including *Didymograptus bifidus* (Hall) and trilobites, brachiopods and nautiloids which referred to the Llanvirn. In the Asyab Section to the north, Huckriede *et al.* (1962) yielded *Didymograptus sp.* and indeterminate ‘dendrograptids’, indicative of an

early Llanvirn age (Wolfart 1974). Rickards *et al.* (1994) described *Yutagraptus cf. mantuanus* Riva from a siliceous mudstone of the Katkoyeh Formation at the Banestan Section, indicative of a late Arenig age. The limestone low in the type sequence of the Katkoyeh Formation in Desuyeh Gorge yielded *Baltoniodus sp.*, *Drepanoistodus spp.*, *Bergstroemognathus extensus* (Graves & Ellison) and *Juanognathus variabilis* Serpagli (Hamedí 1995). Zhen *et al.* (2001) reviewed this fauna and reassigned *B. extensus* to *B. hubeiensis* An, and based on its biostratigraphic range and occurrences in the Honghuayuan and Dawan formations of South China and the Liangjiashan Formation of North China, they referred the Katkoyeh assemblage to the *Serratognathus diversus*–*Microzarkodina parva* zones (lower Floian–lower Darriwilian), though with emphasis on the older biozone (fig. 2). Subsequently, Zhen *et al.* (2006) regarded *B. hubeiensis* as a junior synonym of *B. extensus* based on new collections from the Honghuayuan Formation (Floian), and considered the possibility that the apparatus described under the name of *B. hubeiensis* from Iran may comprise Sa elements of *Rhipidognathus yichangensis* (Ni) as well.

A diverse graptolite assemblage recovered from the overlying clastic beds at the northern end of the Banestan Valley is indicative of the late Arenig and, probably, early Darriwilian age (Rickards *et al.* 2001). On western side of the Kuh-Banan Fault, in the Shabdjereh Section near Kerman, the lower carbonate horizon yielded conodonts identified by R.S. Nicoll (in Hamedí 1995) as *Erraticodon cf. balticus*, *Drepanoistodus sp.*, *Prioniodus sp.* and *Amorphognathus sp.*, indicating a ?Llanvirn age, though erroneously attributed to the Arenig by Bruton *et al.* (2004). Percival *et al.* (2009) reassessed those poorly preserved specimens and identified *Erraticodon cf. balticus* Dzik, *Scolopodus aff. princeps* Bagnoli & Stouge,



**Figure 2.** Stratigraphic correlation chart for the Ordovician of East-Central Iran (updated from Hamedí *et al.* 1997, with the time scale of Goldman *et al.* 2020). Ordovician United Kingdom regional series abbreviations: Abbreviations: Tre. – Tremadoc; Lla. – Llanvirn; Carad. – Caradoc; Ashg. – Ashgill.

*Drepanoistodus* sp., *Eoplacognathus?* sp. and *Prioniodus* sp. These authors interpreted an early Darriwilian age (*Lenodus variabilis* Zone) for the assemblage, based on the identification of the *Erraticodon* elements, and the general age accordance with the associated *Martellia* brachiopod fauna.

Bassett *et al.* (1999) recognised three distinct faunal units in the Katkoyeh Formation: a lower late Arenig graptolitic unit (A) at Banestan; a middle unit (B) characterised by the brachiopod *Rostricellula* and abundant bryozoan fauna that also occurs at Banestan, reported originally as possibly of Llandeilo age at the base but currently regarded as entirely Caradoc (Dastanpour *et al.* 2006, Ebbestad *et al.* 2008); and an upper (C) unit which crops out in the Gezueh Gorge, which Bassett *et al.* (1999) referred to the late Caradoc based on the record of brachiopod *Drabovia* aff. *crassior* (Barrande), though not excluding an Ashgill age for the uppermost beds based on the record of *Cryptothyrella?*, a genus otherwise common close to the Ordovician–Silurian boundary. A Late Ordovician (Caradoc–Ashgill) age for the upper unit is supported by Hamedi *et al.* (1997), who recovered *Icriodella* cf. *superba* Rhodes and the bryozoans *Hallopora* and *Diazipora* from a red muddy dolomitic limestone at the Dahu type locality. Recently, Hairapetian *et al.* (2017) determined conodont associations composed of *Amorphognathus* cf. *ordovicicus* (Branson & Mehl), *Icriodella* aff. *superba* Rhodes and *Panderodus* spp. from the “upper Katkoyeh” Formation in the vicinity of Kashmar, north-eastern Central Iran, which they referred to the Katian.

Ross *et al.* (2000) described Late Ordovician (Caradoc) bryozoan faunas from the Unit B at Banestan and from the Gezueh Gorge. Reitz & Davoudzadeh (1995) reported acritarch assemblages of Llandeilo to Caradoc age in two samples from Banestan, though their exact locality is unclear. From the palaeobiogeographical point of view, the acritarch assemblages belong to the warm water palaeoprovince.

In a recent contribution, Nezhadabbas *et al.* (2020) analysed the Katkoyeh Formation in a stratigraphic section located to the south of Kuh-e-Bonorg, eastern flank of Kalmard Anticline west of Tabas. They recognised three distinct lithostratigraphic members, consisting of a Lower Sandstone Member (mostly quartzarenite to litharenite), a Middle Shale Member (red to green shales interbedded with some dolomitic and calcareous sandstones, with wavy stromatolitic structures at the base) and an Upper Carbonate Member (limestones, dolostones and marls). After an extensive conodont sampling, Nezhadabbas *et al.* (2020) recovered seven productive samples, characteristic of the *Paroistodus proteus*, *Prioniodus elegans*–*Oepikodus evae* and *Trapezognathus diprion* zones, confirming an Early Ordovician (late Tremadocian–Floian) age for the uppermost part of the Katkoyeh Formation in the

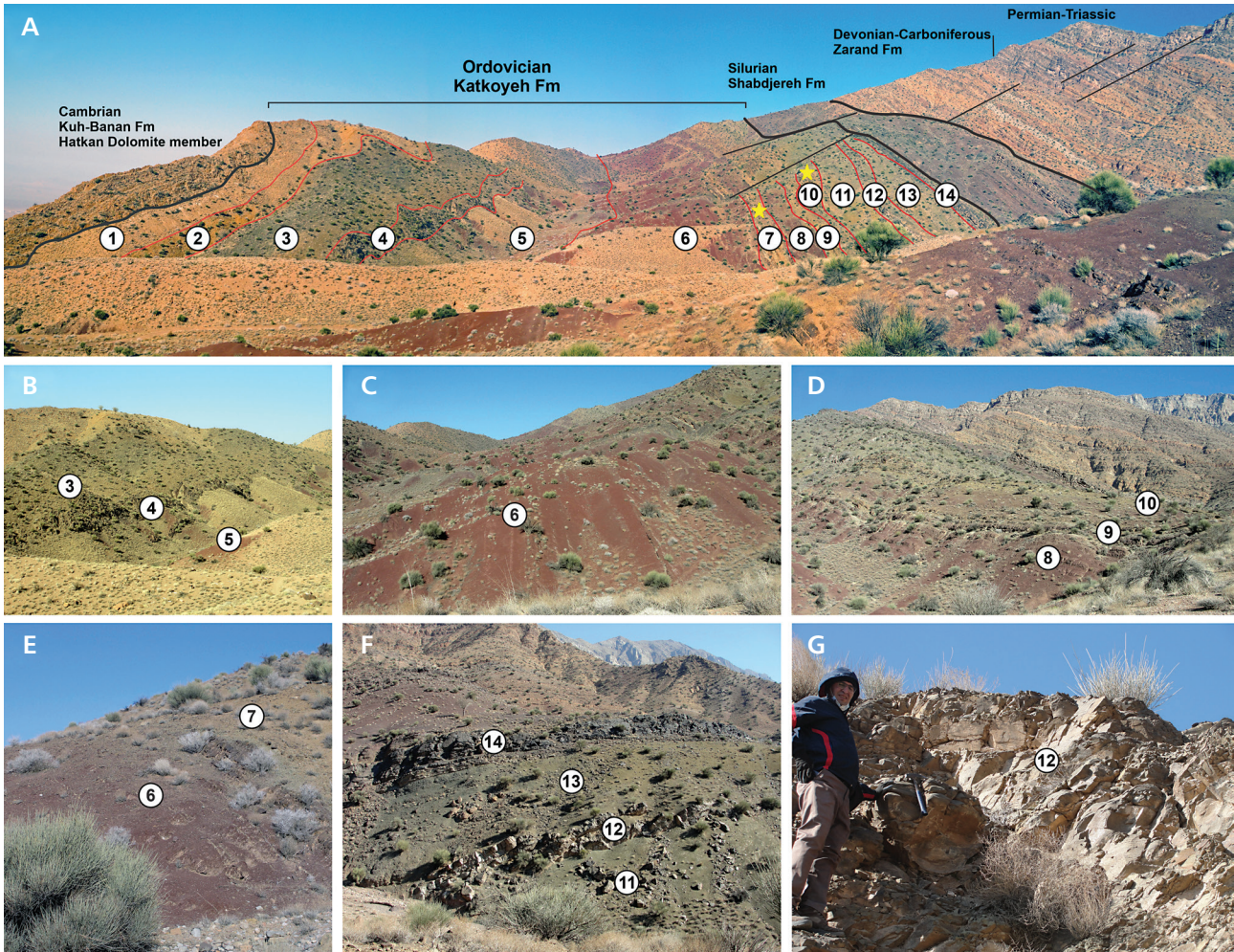
Kuh-e-Bonorg Section. In the same region, Jahangir *et al.* (2021) reported several species indicative of the *Trapezognathus diprion* Zone from a carbonate unit situated in the upper part of a mainly siliciclastic succession, provisionally referred to the Katkoyeh Formation.

## The Banestan Section

The Banestan Section is located in the Zarand area, northern Kerman Province, East-Central Iran, about 12 km northwest of the city of Zarand, in the vicinity of the Banestan village with its base at 30° 51' 48.18" N, 56° 39' 8.67" E; top: 30° 52' 6.33" N, 56° 39' 11.66" E; and 2350 m above sea level (Fig. 1). The sedimentary sequence crops out along both sides of a dry river bed, 300 m north of a track and adjacent to the small farmstead approximately 0.75 km NW of the Banestan village. The Kuh-Banan, Katkoyeh, Shabdjereh and Zarand formations, which involve Cambrian up to Devonian–Carboniferous sediments, form the northern flank of the km-scale Zarand Anticline in the Banestan area (Vahdati-Daneshmand *et al.* 1995). All the stratigraphic succession is deformed by the Alpine-Himalayan Kuh-Banan Fault, which generated several minor faults and folds with outstanding Palaeozoic outcrops in the area.

In the Banestan Section, the Ordovician Katkoyeh Formation consists mostly of silty shales, diabase, pillow lava, basaltic tuff, red sandstone, red silty claystone, marl, limestone and sandy limestone (Fig. 3). It rests above the upper dolomites of the Kuh-Banan Formation and is in turn overlain by the Shabdjereh Formation, a lateral stratigraphic equivalent to the Niur Formation (Figs 2, 3A). Traditionally, the Cambrian–Ordovician boundary in the Kerman province was situated between the upper Furongian Hatkan Dolomite member of the Kuh-Banan Formation and the basal shaly member the Katkoyeh Formation. However, the precise position of the lower Tremadocian boundary is still uncertain, because no fossil occurrences have been yet documented in the aforementioned interval.

The measured lithologic units (Figs 3, 4) of the Katkoyeh Formation from base to top at the Banestan Section are as follows: basement – Cambrian Dolomite Member (Hatkan) of the Kuh-Banan Formation; 1 – fine to medium sandy tuff, pale grey (1.2 m thick); 2 – sandstone and dolomite (2 m thick); 3 – pillow basalt (3 m thick); 4 – diabase (2 m thick); 5 – red siltstone and mudstone (40 m thick); 6 – red silty mudstone and shale (30 m thick); 7 – calcareous grey shale, with thin intercalations of limestone and dolomite including, brachiopods, gastropods, bivalves (samples B1–B6, 5 m thick section: sample B1 = from the base of unit 7, Sample B2 = 1.5 m, Sample B3 = 2.4 m, Sample B4 = 3.2 m, Sample B5 = 4.2 m, Sample B6 = 5 m



**Figure 3.** A – panoramic view of the Banestan Section with main lithostratigraphic subdivisions of the Katkoyeh Formation and sampled levels for microfossils (see text for number references). View to the East. • B – close view of pillow basalts (unit 3), diabase (unit 4) and red siltstones and mudstones (unit 5). • C – red silty mudstone and shale (unit 6). • D – red siltstone (unit 8), basaltic sandy tuff (unit 9) and argillaceous limestone (unit 10). • E – red silty mudstone and shale (unit 6) and calcareous grey shale interbedded with fossiliferous limestones (unit 7). • F – sandy tuff (unit 11), quartzitic sandstone (unit 12), sandy tuff (unit 13) and quartzitic sandstone (unit 14). • G – close view of quartzitic sandstone (unit 12).

from the base of the unit); 8 – red siltstones (18 m thick); 9 – basaltic sandy tuff (9 m thick); 10 – siltstones, calcareous mudstones and argillaceous limestones (Samples B7–B8, 6 m thick section: sample B7 = from the base of the unit, Sample B8 = 5 m from the base of the unit); 11 – pyroclastic green sandy tuff with green shaly interbeds (18 m thick); 12 – quartzitic sandstone (3 m thick); 13 – pyroclastic green sandy tuff with green shaly interbeds (20 m thick); 14 – quartzitic sandstone (3 m thick); overlying rocks – Silurian fluvial deposits of the Shabdjereh Formation.

## Material and methods

Eight conodont limestone samples, 5–6 kg each, were collected by A. Bahrami and F. Poursalehi from the Katkoyeh Formation at the Banestan Section. Samples

were fragmented and dissolved in diluted acetic acid (20%) following the standard conodont recovery techniques (Stone 1987), yielding 850 conodont elements. The conodont specimens are usually complete or only slightly fragmented, but they are very delicate and fragile; thus, many were broken during the recovery process. The specimens are glossy black (CAI 5 of Epstein *et al.* 1977) when observed in transmitted light. Associated with the conodonts, ostracod specimens were recovered in samples 6, 7 and 8. The ostracod valves show a good preservation and low diversity with only two identified species and at least two other unidentified ones. Images of the specimens were made using a scanning electron microscope at the Parto Electron ARD at University of Isfahan, Iran. Both conodont elements and ostracods are stored at the University of Isfahan under UIMC acronym numbers (University of Isfahan Museum Code).

## Conodont biostratigraphy and correlation (G.G. Voldman)

Based on the occurrence of important biostratigraphic species, we recorded three conodont range intervals, as putative biozones considering their boundaries can still not be established in the Katkoyeh Formation at the Banestan Section, namely *Rossodus manitouensis*/*Paltodus deltifer* Concurrent Range Zone (lower upper Tremadocian, Lower Ordovician), *Juanognathus variabilis* Range Zone (Floian, Lower Ordovician), and the *Icriodella superba* Range Zone (Katian–?Hirnantian, Upper Ordovician), in ascending order (Fig. 4). Representative conodont elements are shown in Figs 5, 7.

### *Rossodus manitouensis*/*Paltodus deltifer* Concurrent Range Zone (Tremadocian, Lower Ordovician)

The lower samples (B1–B3) from the Banestan Section contain a relative rich conodont fauna, including the index species *Rossodus manitouensis* Repetski & Ethington, *Paltodus deltifer deltifer* (Lindström) and *P. d. pristinus* (Viira), along with *Acanthodus lineatus* (Furnish), *A. uncinatus* Furnish, *Cordylodus angulatus* Pander, *C. caseyi* Druce & Jones, *Drepanoistodus costatus* (Abaimova), *Drepanoistodus* sp., “*Oneotodus*” cf. *variabilis* Lindström and *Paroistodus* sp. (Figs 5, 6).

In the North American marginal and open shelf sequences, the *R. manitouensis* Zone (Landing *et al.* 1986) extends from the lowest occurrence of *R. manitouensis* up to its disappearance, which marks the beginning of the Low Diversity Interval (e.g. Ross *et al.* 1997, Pyle & Barnes 2002). The *R. manitouensis* Zone is equivalent to Fauna C among the five conodont intervals (A–E) in the Lower Ordovician of North America (Ethington & Clark 1971). *Rossodus manitouensis* is commonly present in the Tremadocian strata of British Columbia, Colorado, Nevada, Newfoundland, New York, Nunavut, Quebec, Texas, and Sonora of the Midcontinent Province (Repetski & Ethington 1983; Landing *et al.* 1986, 2012; Repetski 1988; Seo & Ethington 1993; Ji & Barnes 1994; Stewart *et al.* 1999; Pyle & Barnes 2002; Salad Hersi *et al.* 2007; Zhang 2020). In the Ibex Area of Utah, Miller *et al.* (2003) divided the *R. manitouensis* Zone into a lower, thin *Loxodus bransoni* Subzone and an upper, thick “*Paltodus*” *spurius* Subzone.

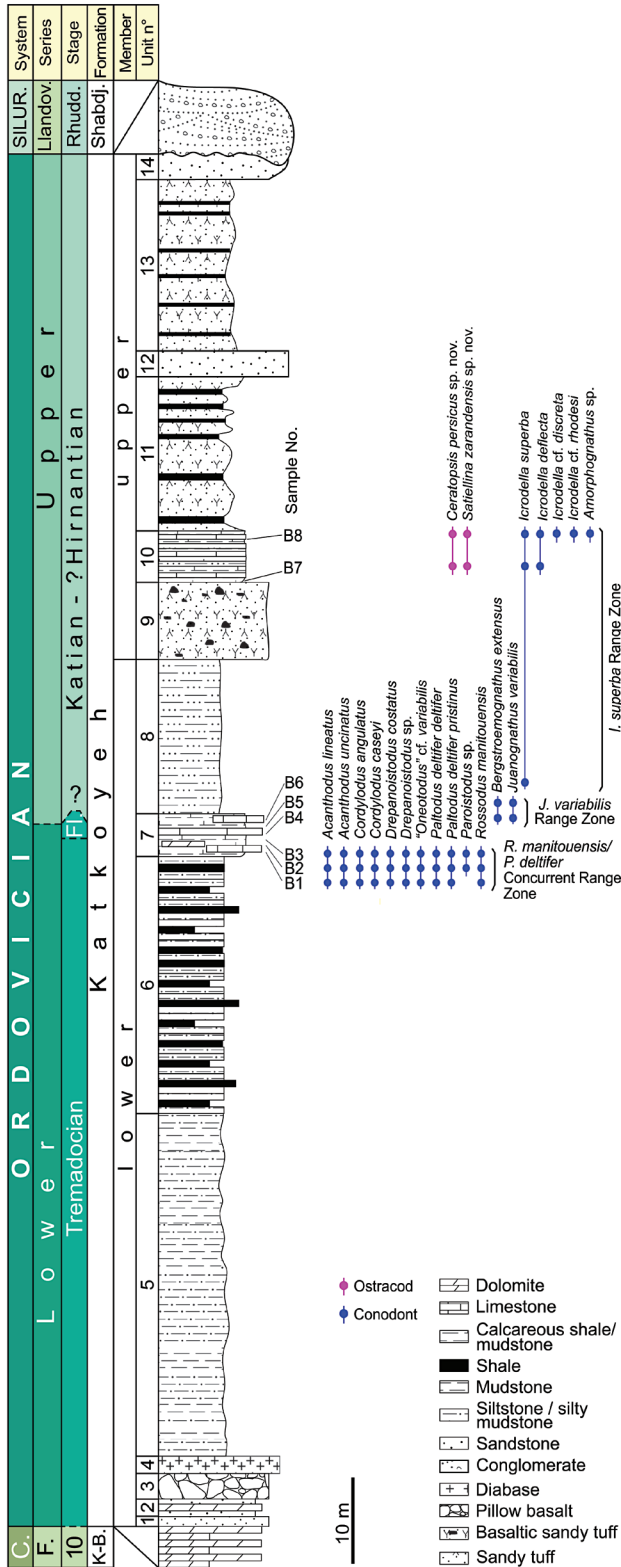
Lindström (1971) incorporated the *Paltodus deltifer* Zone into a Lower Ordovician conodont zonation for Europe, correlative to the *Ceratopyge* beds. In the chalcidony beds from the Holy Cross Mountains of Poland, Szaniawski (1980) divided the *P. deltifer* Zone into a lower *P. d. pristinus* Subzone and an upper *P. d. deltifer* Subzone. Löfgren (1996, 1997) implemented this subdivision for the

Tremadocian of south-central Sweden, where the lower subzone correlates approximately with the *Polycostatus falsionensis*–*R. tenuis* Zone and the upper subzone with the *R. manitouensis*–*P. sulcatus* Zone of the North American conodont zonation of Ji & Barnes (1994). Zhen *et al.* (2007) analysed the drepanodiform conodonts from the lower interval of the *P. deltifer* Zone in the Honghuayuan Formation, Guizhou, South China, observing that many specimens previously illustrated as *P. deltifer* from China actually do not correspond with the type material from Sweden. Additionally, the biostratigraphic value of *Cordylodus* in the studied conodont collection is unhelpful, as this genus disappeared at different times in different regions (Löfgren 1996).

*Rossodus manitouensis* is also known from several Gondwanan and peri-Gondwanan terrains. For instance, Seo *et al.* (1994) erected the *Chosonodina herfurthi*–*Rossodus manitouensis* Assemblage Zone in the upper Tremadocian Dumugol Formation of Korea, which also contains *Paltodus deltifer*. The importance of *R. manitouensis* for intercontinental correlation was emphasised by Löfgren *et al.* (1998), who reported it in very low numbers in the colder successions of Baltoscandia, within the *Paltodus deltifer* Zone (Fig. 6). Tolmacheva *et al.* (2008) first described *R. manitouensis* from Kazakhstan. Agematsu *et al.* (2008) adopted the *R. manitouensis* Range Zone, delimited by the FAD and LAD of the index species, in the lower Thung Song Formation of Tarutao Island, southern peninsular Thailand.

Wang & Wu (2009) summarised conodont stratigraphical ranges for the Lower Ordovician of the lower Yangtze Platform in South China, establishing in succeeding order the *Cordylodus angulatus*, *C. herfurthi*, *R. manitouensis*, *Glyptoconus quadruplicatus*, *P. deltifer* and *Serratognathus diversus* (*partim*) zones for the Tremadocian. Following Wang & Wu (2009), the lower boundary of the *Rossodus manitouensis* Zone is marked by the FAD of the eponymous species, whereas its upper boundary is marked by the record of *G. quadruplicatus* (Branson & Mehl), whose FAD marks the beginning of the overlying biozone. According to their observations, *R. manitouensis* range into the *G. quadruplicatus* Zone but not into the *P. deltifer* Zone. Wang *et al.* (2019) presented a new conodont biozone scheme for the Ordovician of South China, where *R. manitouensis* shortly overlap with *P. deltifer* in the *Colaptoconus quadruplicatus*–*P. deltifer* Zone. In the same contribution, the *R. manitouensis* Zone in the Yangtze platform correlates with the *C. herfurthi* and the overlying *P. deltifer* zones in the Jiangnan Slope.

In a conodont biozonation scheme for the Ordovician of North China, Wang *et al.* (2016, 2018) also interpreted that *R. manitouensis* ranges into the overlying *C. quadruplicatus* Zone. The latter can be broadly correlated with Fauna D of the North American Midcontinent succes-



**Figure 4.** Stratigraphic column of the Katkoyeh Formation at the Banestan Section with stratigraphical distribution of selected conodont and ostracod species. Abbreviations: C. – Cambrian; F. – Furongian; K-B. – Kuh-Banan Formation; Fl. – Floian; Llandov. – Llandoverly; Rhudd. – Rhuddanian; Shabdj. – Shabdjereh Formation.

sion (Ethington & Clark 1971). Alternatively, Yan *et al.* (2019) recovered the index species *G. quadruplicatus* from the upper carbonate unit of the Yeli Formation in the Jilin Province, North China, which still referred to the *R. manitouensis* Zone. Cho *et al.* (2021) updated the conodont biostratigraphy of the Dumugol Formation in Korea considering the revised North China scheme of Wang *et al.* (2016, 2018).

In the cold-water environments of the southern South American margin of Gondwana, *R. manitouensis* occurs in the lower *Paltodus d. pristinus* Subzone of the *P. deltifer* Zone in the Bordo Atravesado Formation of the Famatina System (Albanesi *et al.* 2005). The *P. deltifer* Zone is extensively documented in the Santa Formation of Cordillera Oriental, NW Argentina (*e.g.* Albanesi & Aceñolaza 2005, Voldman *et al.* 2013, Zeballo & Albanesi 2013). Lehnert *et al.* (1997) described “*Acodus*” *oneotensis* Furnish and *Oneotodus gracilis* Furnish from the carbonate platform facies of the La Silla Formation, in the Laurentian-related terrane of the Argentine Precordillera, which referred to the *R. manitouensis* Zone. From an overlying horizon, they obtained *Scolopodus* cf. *floweri* Repetski, *Aloxoconus* cf. *propinquus* (Furnish), *C. quadruplicatus* (Branson & Mehl), *Paroistodus numarcuatus* (Lindström) and *Rossoodus* aff. *manitouensis* Repetski & Ethington, which referred to the *P. deltifer* Zone of Baltoscandia and partly with the *Macerodus diana* Zone of the North American Ibexian Series (Ross *et al.* 1997). From the same stratigraphic unit, Albanesi *et al.* (2016) recovered the index fossils *Macerodus diana* Fähræus & Nowlan in the Umango Section and *P. d. deltifer* in the Portezuelo Jáchal Section. Additionally, Mango & Albanesi (2020) recovered *P. d. deltifer* along with species typical of the *Macerodus diana* Zone. In the western slope facies of the Argentine Precordillera, Voldman *et al.* (2018) collected few elements of *Rossoodus* cf. *manitouensis*, *Drepanodus arcuatus* Pander, *Paltodus* aff. *inaequalis* (Pander), *Scolopodus* cf. *subrex* Ji & Barnes from a stratigraphic succession containing *Macerodus diana*. In the Tiñu Formation of southern Mexico, situated between the Laurentian platform and the Gondwanan successions in Andean South America, Landing *et al.* (2007) recovered conodonts from the Río Salinas Member referable to the *P. d. deltifer* Subzone of Baltica, which correlated with the *R. manitouensis* Zone, in agreement with the records of Löfgren *et al.* (1998).

In Iran, the *Paltodus deltifer* Zone has been previously recorded with both the *P. d. pristinus* (Viira) and *P. d. deltifer* subspecies in several sections to the north of the Kerman Province. It is known from Simeh-Kuh and Deh-Molla in Eastern Alborz (Ghobadi Pour *et al.* 2011, Jahangir *et al.* 2015), the Derenjal Mountains (Ghobadi Pour & Turvey 2009), and the Kalmard Mountains to the southwest of Tabas (Ghaderi *et al.* 2009). On the other

hand, Repetski & Ethington (1983) pointed out that the coniform elements described by Müller (1973) as *Acodus oneotensis* Furnish from the Shirgest Formation in the Derenjal Mountains are actually junior synonyms of *R. manitouensis*.

Based on the cooccurrence of the index species *R. manitouensis* and *P. d. deltifer* in the absence of *C. quadruplicatus* in the studied assemblage, the lower conodont samples from Banestan can be correlated with the upper part of the *R. manitouensis* Zone and the lower part of the *P. d. deltifer* Subzone of the *P. deltifer* Zone.

### *Juanognathus variabilis* Range Zone (Floian, Lower Ordovician)

Samples B4–B5 from the Banestan Section yielded a typical Floian assemblage from temperate water areas, such as the Argentine Precordillera and other parts of Laurentia. It is characterised by a few elements of *Bergstroemognathus extensus* (Graves & Ellison) and *Juanognathus variabilis* Serpagli (Figs 5, 6). This interval approximately correlates with the Acoite Formation at the Aguas Blancas Creek, in the Ordovician cold-water domain of the Cordillera Oriental of Argentina (Albanesi *et al.* 2020).

*Bergstroemognathus extensus* has a biostratigraphic range extending from the latest Tremadocian *Triangulodus bifidus* Zone in South China (*e.g.* Zhen *et al.* 2009) up to the latest Floian *O. intermedius* Zone in the Argentine Precordillera (*e.g.* Mango & Albanesi 2020, Mestre *et al.* 2020, Moreno *et al.* 2020). Zhen *et al.* (2001) described as *B. hubeinensis* (An) the specimens from the Katkoyeh Formation, though the species was later synonymised with *B. extensus* (Zhen *et al.* 2006).

On the other hand, *J. variabilis* ranges from the lower Floian *Serratognathus diversus* Zone also up to the latest Floian *O. intermedius* Zone (*e.g.* Zhen *et al.* 2009, Mango & Albanesi 2020). Both *B. extensus* and *J. variabilis* are common components in the late Floian of Australia, the Argentine Precordillera, Greenland, Western Ireland, United States, Newfoundland, Quebec, and North-South

China (*e.g.* Serpagli 1974; Stouge & Bagnoli 1988; Smith 1991; Albanesi *et al.* 1998; Pyle & Barnes 2002; Zhen *et al.* 2001, 2003, 2009; Wang *et al.* 2005; Landing & Westrop 2006; Stouge *et al.* 2016).

Albanesi *et al.* (1998) nominated as *J. variabilis* the lower subzone of the *O. evae* Zone based on its high relative frequency in the Cerro Potrerillo of the Precordillera. Mango & Albanesi (2019) defined the *Juanognathus-Bergstroemognathus* biofacies, characteristic of middle to outer ramp deposits of the Precordillera. Pyle & Barnes (2002) reconstructed the apparatus of *J. variabilis* to include a compressed *e* element previously assigned to *Reutterodus andinus* Serpagli, 1974. This assignment resulted in a mayor modification to the Midcontinent Realm zonation, by erecting a *J. variabilis* Subzone within the *O. communis* Zone to replace the ?*R. andinus* Zone proposed by Ross *et al.* (1997). This distinctive element was also recovered in beds with *J. variabilis* from the Banestan Section (Fig. 5Z).

### *Icriodella superba* Range Zone (Katian–?Hirnantian, Upper Ordovician)

Sample B6 from the Banestan Section yielded a monospecific assemblage characterised by abundant *Icriodella superba* Rhodes. The genus *Icriodella* is common in the Late Ordovician, ranging up to the Llandovery–Wenlock boundary interval (*e.g.* Mabillard & Aldridge 1983). In particular, *I. superba* is well-known from the Katian of North America (Leslie 2000), Europe (Savage & Bassett 1985), and the Argentine Precordillera (Ortega *et al.* 2008). Its first appearance occurs in the uppermost part of the *A. tvaerensis* Zone, just below the base of the Katian Stage (*I. cf. superba*, Goldman *et al.* 2007), and its range continues up to pre-Hirnantian levels (*e.g.* Savage & Bassett 1985). From the Boghu Section of Central Iran, Hairapetian *et al.* (2017) illustrated *Icriodella aff. superba* Rhodes in association with *Amorphognathus cf. ordovicicus* (Branson & Mehl), which referred to the Upper Ordovician Katian Stage. The Pa elements of *I. superba* from the Banestan

**Figure 5.** Lower Ordovician conodonts from the Katkoyeh Formation at the Banestan Section, East-Central Iran. • A, C–D – *Paltodus deltifer deltifer* (Lindström, 1954); A – M element, sample B2, UIMC 1011; C – M element, sample B2, UIMC 1012; D – P? element, sample B2, UIMC 1013. • B, E – *Paltodus deltifer pristinus* (Viira, 1970); B – Sc element, sample B2, UIMC 1014; E – M element, sample B2, UIMC 1015. • F “*Oneotodus*” cf. *variabilis* Lindström, 1954, sample B1, UIMC 1016. • G–L – *Rossodus manitouensis* Repetski & Ethington, 1983; G – M element, sample B1, UIMC 1017; H – Sa element, sample B1, UIMC 1018; I – Sba? element, sample B1, UIMC 1019; J – Sbb? element, sample B2, UIMC 1020; K – Sbb? element, sample B2, UIMC 1021; L – Sc element, sample B2, UIMC 1022. • M–O, Q – *Cordylodus angulatus* Pander, 1856; M – P element, sample B3, UIMC 1023; N – S element, sample B3, UIMC 1024; O – S element, sample B3, UIMC 1025; Q – S element, sample B2, UIMC 1026. • P – *Cordylodus caseyi* Druce & Jones, 1971, S element, sample B3, UIMC 1027. • R–T – *Acanthodus lineatus* (Furnish, 1938); subrounded element, sample B1, UIMC 1028; S – subrounded element, sample B1, UIMC 1029; T – compressed element, sample B1, UIMC 1030. • U – *Acanthodus uncinatus* Furnish, 1938, P? element, sample B1, UIMC 1031. • V, W *Drepanoistodus* sp.; V – M element, sample B2, UIMC 1032; W – Sa element, sample B1, UIMC 1033. • X, Z – *Juanognathus variabilis* Serpagli, 1974; X – Sa element, sample B5, UIMC 1034; Z – M? element, sample B5, UIMC 1035. • Y, AA – *Bergstroemognathus extensus* (Graves & Ellison, 1941); Y – Pb element, sample B4, UIMC 1036; AA – broken P? element, sample B4, UIMC 1037. • AB – *Parioistodus* sp., M element, sample B2, UIMC 1038. All scale bars represent 100 µm.





Lower Ordovician Conodont Biozonation							
Stage	Baltica	North China	South China	N. America Midcontinent	Central Iran		
					Derenjal Mts	Banestan	
Floian	Oepikodus evae	Jumudontus gananda	Oepikodus evae	Reutterodus andinus	Juanognathus  variabilis		
		Paraserrat. obesus / Paraserrat. paltodiformis		Oepikodus communis			
	Prioniodus elegans	S. extensus	Prioniodus honghuayua- nensis				
		Serratognathus bilovatus	Serratognathus diversus				
Tremadocian	Paroist. proteus	Scalpellodus tersus – Tr. aff. bifidus	Triangulodus bifidus	Acodus deltatus / Oneotodus costatus	Paroistodus proteus		
		Colaptoconus quadruplicatus	Paroistodus proteus	M. diana S. subrexi			Drepanodus- P. deltifer
			Colaptonocus quadruplicatus				
	Paltodus deltifer	Rossodus manitouensis	Chosonodina herfurthi – Rossodus manitouensis	Rossodus manitouensis	Cordylodus angulatus	P. deltifer / R. manitouensis	
	Cordylodus angulatus	Chosonodina herfurthi	Cordylodus angulatus	Cordylodus angulatus			
			Cordylodus angulatus	Cordylodus angulatus			
I. fluctivagus	Iapetognathus jilinensis	Iapetognathus fluctivagus	Iapetognathus fluctivagus	Cordylodus lindstroemi			

Figure 6. Lower Ordovician conodont biostratigraphic scheme showing the regional correlation of the Katkoyeh Formation at the Banestan Section with the Derenjal Mountains of Central Iran (Ghaderi et al. 2009), and its global correlation with conodont successions established in other palaeogeographic domains (Wang et al. 2018, Goldman et al. 2020). Abbreviations: I. – Iapetognathus; Paraserrat. – Paraserratognathus; S. – Serratognathus; Tr. – Triangulodus; M. – Macerodus; S. – Scolopodus; P. – Paltodus; R. – Rossodus.

Section present a great variability in the aboral margin shape, ranging from slightly bent (Fig. 7C, D) to strongly arched (Fig. 7E, F), consistent with the plasticity of shapes illustrated in literature (e.g. Rhodes 1953, Bergström & Sweet 1966).

The upper set of productive samples is dominated by more advanced forms of *Icriodella*, though with *I. superba* still present, and few indeterminate species. Samples B7–B8 contain *I. deflecta* Aldridge, characterised by a strong deflection of the anterior platform with respect to

Figure 7. Upper Ordovician conodonts from the Katkoyeh Formation at the Banestan Section, East-Central Iran. • A–P, AB – *Icriodella superba* Rhodes, 1953; A – M element, sample B6, UIMC 1039; B – Pa element, sample B6, UIMC 1040; C – Pa element, sample B7, UIMC 1041; D – Pa element, sample B6, UIMC 1042; E – Pa element, sample B6, UIMC 1043; F – Pa element, sample B6, UIMC 1044; G – Pb element, sample B2, UIMC 1045; H – Pb element, sample B6, UIMC 1046; I – Pa element, sample B6, UIMC 1047; J – Sb element, sample B6, UIMC 1048; K – Sb element, sample B6, UIMC 1049; L – Sb element, sample B6, UIMC 1050; M – Sb element, sample B6, UIMC 1051; N – Sd? element, sample B6, UIMC 1052; O – Sa? element, sample B6, UIMC 1053; P – Sb element, sample B6, UIMC 1054; AB – Pa element, sample B8, UIMC 1055. • Q–S – *Icriodella* cf. *discreta* Pollock et al., 1970, Pa element, sample B8; Q – UIMC 1056; R – UIMC 1057; S – UIMC 1058. • T – *Icriodella* cf. *rhodesi* Bergström & Ferretti, 2014, Pa element, sample B8, UIMC 1059. • U–X, AA – *Icriodella deflecta* Aldridge, 1972, Pa element; U – sample B7, UIMC 1060; V – sample B7, UIMC 1061; W – sample B8, UIMC 1062; X – sample B8, UIMC 1063; AA – sample B8, UIMC 1064. • Y – *Amorphognathus?* sp., Pb element, sample B8, UIMC 1065. • Z, AC–AK, AQ – indeterminate *Icriodella* elements; Z – M? element, sample B7, UIMC 1066; AC – M element, sample B7, UIMC 1067; AD – M element, sample B7, UIMC 1068; AE – M element, sample B8, UIMC 1069; AF – Pb element, sample B7, UIMC 1070; AG – Pb element, sample B8, UIMC 1071; AH – Sa element, sample B8, UIMC 1072; AI – Sb element, sample B8, UIMC 1073; AJ – Sb element, sample B8, UIMC 1074; AK – Sa element, sample B7, UIMC 1075; AQ – Sd? element, sample B8, UIMC 1076. • AL – gen. et sp. indet. 1, sample B7, UIMC 1077. • AM–AP – gen. et sp. indet. 2; AM – P? element, sample B8, UIMC 1078; AN – Pb element, sample B7, UIMC 1079; AO – Sc? element, sample B8, UIMC 1080; AP – Sa? element, sample B7, UIMC 1081. • AR – gen. et sp. indet. 3, sample B7, UIMC 1082. All scale bars represent 100 µm.



Upper Ordovician Conodont Biozonation					
Stage	Baltoscandia	North China	South China	North America Midcontinent	Central Iran (Banestan)
Hir.	<i>O. hassi</i> <i>Noixodontus</i>			<i>O. hassi</i> Fauna 13	
	<i>Amorph.</i> <i>ordovicicus</i>		<i>Amorph.</i> <i>ordovicicus</i>	<i>Aph. shatzeri</i> <i>Aphelognathus divergens</i> <i>Aphelognathus grandis</i>	<i>Icriodella superba</i>
Katian	<i>Amorph.</i> <i>superbus</i>	<i>Y.yaoxianensis</i> <i>Yaoxianognathus neimenguensis</i> <i>Belodina confluens</i>	<i>Protop. insculptus</i> <i>Hamarodus brevirameus</i>	<i>Ou. robustus</i> <i>Oulodus velicuspis</i> <i>Belodina confluens</i>	
	<i>Amorph. tvaerensis</i>	<i>B. alobatus</i>	<i>Ph. undatus</i> <i>Belodella compressa</i>	<i>Baltoniodus alobatus</i> <i>Belodella compressa</i>	
		<i>B. gerdae</i> <i>B. variab.</i>	<i>E. quadrydactilus</i> <i>Pl. aculeata</i> <i>P. anserinus</i>	<i>Baltoniodus variabilis</i> <i>P. anserinus</i>	
Sandbian	<i>P. anserinus</i>			<i>Cah. sweetie</i>	

Figure 8. Upper Ordovician conodont biostratigraphic scheme showing the regional correlation of the Katkoyeh Formation at the Banestan Section with conodont successions established in other palaeogeographic domains (Wang *et al.* 2018, Goldman *et al.* 2020). Abbreviations: Hir. – Hirnantian; *O.* – *Ozarkodina*; *Amorph.* – *Amorphognathus*; *B.* – *Baltoniodus*; *P.* – *Pygodus*; *Y.* – *Yaoxianognathus*; *Ph.* – *Phragmodus*; *E.* – *Erismodus*; *Pl.* – *Plectodina*; *Protop.* – *Protopanderodus*; *Aph.* – *Aphelognathus*; *Ou.* – *Oulodus*; *Cah.* – *Cahabagnathus*.

the posterior blade (~35°), with both anterior and posterior processes of similar length, and a ridge running on the outer lateral flange (Fig. 7AA).

Among the icriodelforms, sample B8 also yielded Pa elements (Fig. 7Q–S) that resemble *I. discreta* Pollock, Rexroad & Nicoll but with slight morphologic differences. The Banestan specimens are similar to those described by Cooper (1975) from the Silurian Brassfield Limestone of southern Ohio, and differ from the holotype in that they are narrower, the platform is poorly developed, and have minor lateral deflection or offset of the blade. Additionally, some of these elements present icrions with bifurcating tips at the platform (Fig. 7R).

A broken anterior platform with the nodes laterally elongated, even fused in the anterior portion of the platform was also obtained from sample B8 (Fig. 7T). A similar ornamentation characterises the late Katian–lower Hirnantian *I. rhodesi* Bergström & Ferretti from the Keisley Limestone of northern England (Bergström & Ferretti 2014). However, in *I. rhodesi* the transversal ridges are developed throughout the platform, and not limited to its anterior part. On the other hand, the Llandovery *I. inconstans* Aldridge also carries laterally elongated nodes on the platform, though they do not tend to coalesce (Aldridge 1972). The species *I. dicrana* Zhang & Barnes from the Llandovery of the Anticosti Island also shows ridges by lateral fusion of the platform nodes; however, its blade bears denticles with laterally bifurcated tips (Zhang & Barnes 2002).

Aldridge (1972) defined the *I. discreta*–*I. deflecta* Assemblage Zone with an unknown lower limit in the lower Llandovery (Aeronian) of Britain, which approximately correlates with the *Dystomodius kentuckyensis* Zone of North America (e.g. Cooper 1975, McCracken & Barnes 1981, Idris 1984). The *D. kentuckyensis* Zone has traditionally been interpreted to begin at the Hirnantian/Rhuddanian boundary (e.g. Dahlqvist & Bergström 2005, Cramer *et al.* 2011, Melchin *et al.* 2012). In the fossiliferous sequence of Anticosti, the base of the Silurian was defined using conodonts as the first appearance of *Ozarkodina hassi* and/or its regular associate *O. oldhamensis* (McCracken & Barnes 1981). There, *I. discreta* and *I. deflecta* appear slightly higher stratigraphically in the lowest Llandovery *Ozarkodina hassi* Zone (Zhang & Barnes 2002), before the *Distomodius kentuckyensis* interval. Following the latter study, Wang & Aldridge (2010) proposed to use *O. aff. hassi* as a local zonal fossil for the uppermost Ordovician–lowest Silurian interval in South China. In general, *Icriodella* used to habit in shallow shelf, relatively high energy environments (e.g. Sweet & Bergström 1984, Barnes 2020).

Bergström *et al.* (2011) introduced a major revision to the conodont biostratigraphic position of the Ordovician/Silurian boundary, situating the *O. hassi* Zone from the middle Hirnantian to the Rhuddanian of the North American scheme. As shown by Bergström *et al.* (2014), the base of the *O. hassi* Zone in western Anticosti Island is within the HICE interval, within the lower part of the *Metabolograptus persculptus* Zone (stage slice Hi1 of

Bergström *et al.* 2009). Based on the aforementioned studies, specimens of *Icriodella* ex gr. *discreta* may range from the latest Ordovician to the Silurian. Taking into account the stratigraphic position of the samples B7–8, *i.e.* below the Shabdjereh Formation, and the associated ostracod biostratigraphic data, we consider highly probable that the analysed specimens correspond to the Upper Ordovician (Fig. 8). As no other index conodont species were recovered from these samples, further collecting will certainly help refining the position of the Ordovician–Silurian boundary at the Banestan Section.

### Systematic palaeontology – Ostracoda (M.J. Salas)

The taxonomic classification adopted herein follows that proposed by Mohibullah *et al.* (2014) and the references therein. Abbreviations: L<sub>max</sub> – maximum length of the valve; L<sub>max</sub>:H<sub>max</sub> – maximum length/maximum height ratio; L1–L4 – lobes from the anterior to posterior; S1–S3 – sulci from anterior to posterior.

Class Ostracoda Latreille, 1802  
 Subclass Podocopa Sars, 1866  
 Order Beyrichiocopida Pokorný, 1954  
 Suborder Palaeocopina Henningsmoen, 1953  
 Superfamily Hollinoidea Swartz, 1936  
 Family Tetradellidae Swartz, 1936  
 Subfamily Tetradellinae Swartz, 1936

#### Genus *Ceratopsis* Ulrich, 1894

*Type species.* – *Beyrichia chambersi* Miller, 1874, by original designation (Ulrich 1894).

#### *Ceratopsis persicus* sp. nov.

Figure 9A–E

*Holotype.* – UIMC 1001, heteromorph right valve (Figure 9E).

*Type horizon and locality.* – 83.2 m above the base of the Katkoyeh Formation, (sample B6), Katian–Hirnantian, Upper Ordovician. Banestan Section, Zarand area, northern Kerman Province, East-Central Iran.

*Material.* – About twenty valves, between left and right, selected from the residues and investigated in SEM. Illustrated material, paratype UIMC 1002 (Fig. 9A); paratype UIMC 1003 (Fig. 9B); paratype UIMC 1004 (Fig. 9C); paratype UIMC 1005 (Fig. 9D).

*Etymology.* – For Persia, the ancient name of Iran.

*Diagnosis.* – *Ceratopsis* species with a lamellar, short and posteriorly curved speral process. Without S3, the posterior half of the valve has a unique large, globose and swollen lobe (L3 + L4). Ventral lobe rounded and poorly defined. Velar dimorphism relatively developed, with a wide velum.

*Description.* – Valves subelliptical to subrectangular in lateral view, mainly amplete to slightly preplete in some tecnomorph specimens. Anterior margin curved, posterior margin acuminate towards the dorsal half of the valve, ventral margin gently curved to straight. Hingeline straight and long; maximum length slightly dorsal of midheight, L<sub>max</sub> = 1.29 mm. Cardinal angles obtuse. Lateral surface of valves quadrilobate (L1, L2, L3 + L4). Lobe L1 developed as flattened semicircular speral dorsal process, it is projected posteriorly as a curved lamella. It very slightly overreached the dorsal margin. The base of the lobe L1 is located in the anterior cardinal angle, is robust and occupies a small area. Fimbriate along lateral edge. Lobe L2 short, straight, inclined posterodorsally, not reach dorsal margin. Dorsal end of the lobe spherical and well-defined. The posterior half of the valve bears a large globose, swollen unique lobe (L3 + L4), in only some specimens the lobe is separate by a sulcus Sulcus S3 very poorly defined and sloped towards anterior. Posterior lobe (L3 + L4) separated from L2 by a well-defined, long, deep and inclined posteriorly sulcus. S2 is slightly curved with the convexity towards posterior. S1 short, inclined posteriorly, poorly defined and deep. The lobes are connected ventrally by a subdued connecting histial lobe. The lobe is rounded, narrow and poorly defined. Velum extends from anterior cardinal angle to postero-ventral margin. In tecnomorph exemplars the velum is narrow, separated from the ventral lobe abruptly by a fine, well-defined groove; in heteromorph velum wide, mainly anteroventrally, and the contact with the ventral lobe is gradual.

*Remarks.* – The described species is assigned to *Ceratopsis* Ulrich, 1894 on the basis of the quadrilobate lateral surface, the morphology of its anterodorsal process, the presence of a histial connecting lobe, and the presence of a velar dimorphism. The genus is recorded in Middle to Upper Ordovician levels of North America and Europa (British Isles, Ibero-Armorica and Bohemia), having been recognised 16 species so far. The genus was reviewed in detail by Warshauer & Berdan (1982), Jones (1986) and Vannier (1987) who described all the species of these three regions. Due to its original combination of characters, the described material is considered a new species: absence of S3, ventral lobe rounded and poorly developed and dimorphism velar relatively developed. The new species differs from all the Laurentian species mainly in the

absence of S3, due to the presence of a single posterior lobe (L3 + L4). In addition, in the Laurentian species the ventral connecting histial lobe is ridge-like. Respect to the British Isles species, the greatest similarities are with *C. inflata* Jones, 1986, from the upper Darriwilian of Shropshire, by their broad and swollen histial flange and with *Ceratopsis* n. sp. 1 (see Jones 1986, Vannier 1987), from Sandbian levels of Dyfed, by their lamellar and short speral process. However, unlike *C. persicus* sp. nov., *C. inflata* has the lobes L3 and L4 separated by a shallow S3, and L1 often has a very long, slender speral process; and *C. n. sp. 1* has a poorly defined lobes, L2 is nearly a small rounded node. *Ceratopsis persicus* sp. nov. shows greater similarities with Ibero-Armorican and Bohemian species, they are similar in the fusion of L3 and L4 and in its rounded and poorly defined ventral lobe. However, each has a special combination of characters. Between these, *C. persicus* sp. nov. seems to *C. krutai* Vannier, 1987, from Sandbian levels of Bohemia, in its lamellar, short and posteriorly curved speral process, however the velar dimorphism is more developed in the new species and the rounded node of the dorsal end of L2 is less defined. With respect to *C. calatravensis* Vannier, 1987 from the early Katian of Spain, the new species have a similar lobesulcus structure but differs in their speral process, which is spinous in *C. calatravensis* and in the more developed velar structure in heteromorph valves of the new species. The velum is wider and extends to the postero ventral region of the valve. Finally, the *C. persicus* sp. nov. differs from *C. hastata* (Barrande, 1872) from Sandbian levels of Bohemia and *C. normandensis* (Příbyl, 1975) from Sandbian levels of Ibero-Armorica in its speral process, which is short and lamellar, whereas in the other two species it is spinous, long and vertical.

**Occurrence.** – Known only from the upper levels of the Katkoyeh Formation at the Banestan Section (Upper Ordovician), Central Iran.

Suborder Binodicipina Schallreuter, 1972  
Superfamily Drepanelloidea Ulrich & Bassler, 1923  
Family *uncertain*

### Genus *Satiellina* Vannier, 1986

*Type species.* – *Bollia delgadoi* Vannier, 1983.

#### *Satiellina zarandensis* sp. nov.

Figure 9F–L

*Holotype.* – UIMC 1006, left valve (Figure 7F).

*Type horizon and locality.* – 83.2 m above the base of the Katkoyeh Formation, (sample B6), Katian–Hirnantian,

Upper Ordovician. Banestan Section, Zarand area, northern Kerman Province, East-Central Iran.

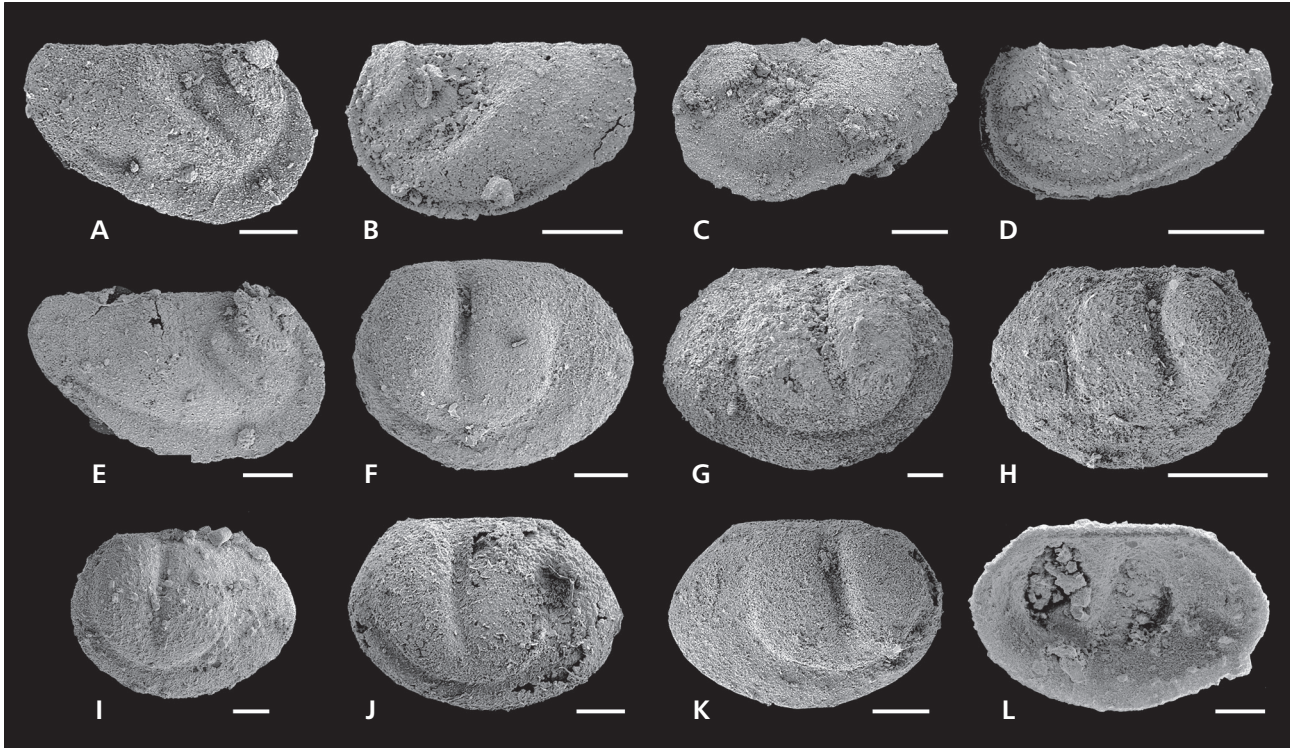
**Material.** – Nearly thirty left and right valves, selected from the residua and investigated in SEM. Figured material, paratype UIMC 1007 (Fig. 9G); paratype UIMC 1008 (Fig. 9H); paratype UIMC 1009 (Fig. 9I); paratype UIMC 1010 (Fig. 9J).

**Etymology.** – For Zarand area, type locality of the species.

**Diagnosis.** – *Satiellina* species with the two lobes similar, both are globose, rounded, perpendicular to the dorsal margin and parallel to each other. The lobes are close to each other, S2 is straight and narrow.

**Description.** – Valves complete to very slightly postplete and subelliptical in outline, measuring between 1.71 and 0.67 mm in length and 1.28 and 0.55 mm in height. The average  $L_{max}:H_{max}$  ratio is ca. 1.37.  $L_{max}$  is situated at the level of the valve mid-height. The dorsal margin is straight and short, nearly  $2/3$  of the  $L_{max}$ . The anterior outline is curved, and the posterior one is angular or sharp, with the angle at the mid-height. The ventral margin is evenly rounded. The cardinal angles are both obtuse and well defined. The valves bear two well-developed lobes, they are globose, long, straight, almost parallel and extend perpendicular from the dorsal margin. The lobes reach the dorsal margin, but not overreach it, and they extend to the ventral half of valves. The lobes are similar to each other, only in some specimens L1 is slightly swollen in its median sector. Lobe L1 is near the anterior margin and L2 is almost coincident with the mid-length. Lobes are confluent below the adductorial sulcus by a prominent connecting lobe in U-shape. Sulcus S2 is nearly straight and very narrow. Lateral surface convex. Posterior extralobular surface wide.

**Remarks.** – The new species is assigned to *Satiellina* Vannier, 1986 by its two well developed, elongated and ventrally connected lobes, and by its convex lateral surface without pseudovelum. Until now the genus had four species mainly distributed in the Middle to Upper Ordovician of Peri-Gondwana and Gondwana (Ibero-Armorica, north of Africa and South America, Brazil) and one in the Baltic region (Vannier 1986, Vannier *et al.* 1989, Adorno *et al.* 2016, Gonçalves *et al.* 2022). *Satiellina zarandensis* sp. nov. differs from the other species of the genus mainly in its lobes, they are broad and globose, similar to each other and are very close together, so S2 is too narrow and straight. The most similar species to the new material is *S. henningsmoeni* (Nion, 1972) in Robardet *et al.* (1972) from Sandbian levels of Normandy in the Armorican Massif, however in this species the



**Figure 9.** Upper Ordovician ostracods from the Katkoyeh Formation at the Banestan Section, East-Central Iran. • A–E *Ceratopsis persicus* sp. nov.; A – lateral view of heteromorph right valve, paratype UIMC 1002; B – lateral view of tecnomorph left valve, paratype UIMC 1003; C – lateral view of heteromorph left valve, paratype UIMC 1004; D – lateral view of tecnomorph left valve, paratype UIMC 1005; E – holotype UIMC 1001, lateral view of heteromorph right valve. • F–L – *Satiellina zarandensis* sp. nov.; F – holotype UIMC 1006, lateral view of left valve; G – lateral view of right valve, paratype UIMC 1007; H – lateral view of right valve, paratype UIMC 1008; I – lateral view of left valve, paratype UIMC 1009; J – lateral view of left valve, paratype UIMC 1010; K – lateral view of right valve, UIMC 1011; L – internal view of right valve, UIMC 1012. All scale bars represent 200  $\mu$ m.

nodes are narrower, more separated from each other and curved forward; the outline of the valves is more rounded, whereas in the new species it is more elliptic, with the posterior outline acuminate at the mid-height. In addition, the new species is bigger,  $L_{\max}$  reaches 1.71 mm. Respect to *S. jamairiensis* Vannier, 1986, from the Djefara Formation (Upper Ordovician) of Libya, the new material differs mainly in the ventral connection lobe, which is very poorly defined in the Libyan species.

**Occurrence.** – Known only from the upper levels of the Katkoyeh Formation at the Banestan Section (Upper Ordovician), Central Iran.

### Ostracod palaeobiogeographic and biostratigraphic implications

Although only two ostracod species were recorded in the studied section, we can provide some preliminary considerations with respect to palaeobiogeographical affinities of the fauna. The genus *Satiellina* Vannier, 1986 comprises five species of Middle–Upper Ordovician

distribution throughout Ibero-America, Gondwana and Baltica: *Satiellina delgadoi* (Vannier, 1983), from the Sandbian of France and Portugal, *Satiellina henningsmoeni* (Nion, 1972) in Robardet et al. (1972), from the Sandbian of France, *Satiellina biloba* (Troedsson 1918), from the Upper Ordovician of Sweden, *Satiellina jamairiensis* Vannier, 1986, from the Upper Ordovician of Lybia, and *Satiellina paranaensis* Adôrno & Salas, 2016 in Adôrno et al. (2016), from the Hirnantian of Brazil. Instead, *Ceratopsis* Ulrich, 1894 shows a wider geographical distribution with 16 species recorded in the Middle to Upper Ordovician of North America, British Islands, Ibero-Armorica and Bohemia. However, the genus shows two clearly different groups in terms of their morphological features, one recorded in Laurentia and the other in the peri-Gondwanan region. Vannier (1987), based on a detailed morphological comparison, carried out the phylogenetic analysis of the genus assuming that, two forms of the Darriwilian of British Islands would have given rise to two different phylogenetic lines, on the one hand the North American species and on the other the Bohemian and Ibero-Armorican species. As was discussed in the definition of *Ceratopsis persicus* sp. nov.,

the species shows strong similarities to the Bohemian one. So, the presence of *Satiellina* and *Ceratopsis* in the upper levels of the Katkoyeh Formation indicates a palaeobiogeographic affinity with Gondwana and peri-Gondwanan terranes.

None of the ostracod genera recorded in the studied section was identified in the Shirgesht Formation of Central Iran. However, the Middle Ordovician ostracods described by Ghobadi Pour *et al.* (2006) from a section at Derenjal Mountains also suggests peri-Gondwanan affinities, mainly with the Ibero-Armorica region. On the other hand, Schallreuter *et al.* (2006) suggested Thuringian affinities for an upper Ordovician assemblage recorded in the Anarak outcrops of the Shirgesht Formation. The fauna of the Lashkarak Formation at Alborz Mountains, northern Iran, shows affinity with the ostracods of the Shirgesht Formation (Central Iran), peri-Gondwanan and Baltic regions (Ghobadi Pour *et al.* 2007). Based on the Upper Ordovician ostracods described from the Shirgesht Formation, Schallreuter & Hinz-Schallreuter (2009) placed Central Iran in a Thuringian province with Thuringia and Sardinia. However, *Satiellina zarandensis* sp. nov. and *Ceratopsis persicus* sp. nov., along with the fauna described by Ghobadi Pour *et al.* (2006), suggest peri-Gondwana affinities.

Although ostracods have lower biostratigraphic resolution than conodonts, from the previous discussion it is clear that both genera present in Katkoyeh Formation were recorded until now in Middle–Upper Ordovician stages. The more similar species to *Ceratopsis persicus* sp. nov. are *C. krutai* and *C. calatravensis* both from the Sandbian–Katian of peri-Gondwana, while *Satiellina* has two species from the Sandbian in peri-Gondwana and the other three are from Hirnantian levels of Gondwana and Baltic region. Therefore, the ostracods would agree with the Late Ordovician age suggested by conodonts together with the stratigraphic position of the sampled levels, below the Shabdjereh Formation.

## Conclusions

(1) Systematic sampling for microfossils of the Katkoyeh Formation at the Banestan Section has allowed recognition of three conodont assemblages, ranging from the Lower to the Upper Ordovician.

(2) The *Rossodus manitouensis*/*Paltodus deltifer* Concurrent Range Zone (Tremadocian, Lower Ordovician) is well represented by the eponymous species along with *Acanthodus lineatus*, *A. uncinatus*, *Cordylodus angulatus*, *C. caseyi*, *Drepanoistodus costatus*, *Drepanoistodus* sp. and *Paroistodus* sp. Most of these species are well known from the North American marginal and open

shelf sequences as well as from the colder successions of Baltoscandia, and South America, among other places.

(3) A typical Floian (Lower Ordovician) assemblage from temperate water areas is recognised after the record of *Bergstroemognathus extensus* and *Juanognathus variabilis*.

(4) The Upper Ordovician in the Katkoyeh Formation is represented by at least four species of the conodont genus *Icriodella* (*I. superba*, *I. deflecta*, *I. cf. discreta*, *I. cf. rhodesi*), which allow to constrain the upper sampled levels to the Katian–?Hirnantian stages. However, we are not able to discard a younger age due to the absence of other index species.

(5) Two new species of ostracods, *Satiellina zarandensis* sp. nov. and *Ceratopsis persicus* sp. nov. occur in the Upper Ordovician *Icriodella superba* Range Zone. These suggest palaeobiogeographical affinities mainly with Gondwana and peri-Gondwana.

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