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The present book contains Contributions to the 13th International Symposium on the Ordovician System which was held from July 19th to 22nd 2019 at the Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia.

The main topics covered in short papers and abstracts include: chronostratigraphy, biostratigraphy and zonation, lithology, sedimentology and paleogeography, taxonomy of the various fossil groups, microbial assemblages, chemostratigraphy, ichnostratigraphy, event stratigraphy, basin analysis, complex studies of the Early Paleozoic history of biosphere, etc. They fully answer the broad interest of the global Earth science community in the Ordovician sedimentary basins research.

We hope that the publication of this volume of the contributions from researchers from different countries would be a remarkable advance in summarizing data on Ordovician stratigraphy collected by the international geological scientific society since the 12th International Symposium on the Ordovician System, USA (2015).

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CARBON ISOTOPIC COMPOSTION OF ORDOVICIAN CARBONATES IN BALTOSCANDIA: SHALLOW MARINE FACIES SHIFTING THE $\delta^{13}C_{carb}$ VALUES IN DIFFERENT WAYS

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Key words: *Ordovician, carbon isotopes, Baltoscandia, $\delta^{13}C_{carb}$ carbonate facies.*

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Secular trends in $\delta^{13}C_{carb}$ are mainly interpreted as changes in the global carbon cycle and principal processes of sequestration with straightforward implications to stratigraphy and palaeoclimatology. However, studies on several recent carbonate environments have described and explained cases where carbon isotopic composition of carbonates differ along onshore-offshore profile (e.g., Swart, 2015). This has led to discussion if secular $\delta^{13}C_{carb}$ changes in geological sections have been caused or influenced by changes in depositional settings and/or early diagenetic environment.

The facies (aquafacies) differences reflected in $\delta^{13}C_{carb}$ bulk-rock values in Ordovician carbonate basins have been recorded in some previous studies from North America (Holmden et al., 1998; Panchuk et al., 2006; Saltzman & Edwards, 2017). Similar depletion trend in $\delta^{13}C_{carb}$ values towards the shallower facies has been supposed for the Baltoscandian Basin by Saltzman & Edwards (2017) and Lindskog et al. (2019). These trends have been interpreted as an influence of local input of isotopically light carbon from various sources to the shallow restricted platform, including oxidation of organic matter in land or in water (Saltzman & Edwards, 2017). However, Brenchley et al. (2003) documented the opposite change – increasing $\delta^{13}C_{carb}$ values towards the proximal facies in the Hirnantian carbonates of Baltoscandia. Similar landward increasing $\delta^{13}C$ gradient has been described in Hirnantian interval (HICE) of North America by LaPorte et al. (2009). That was explained by local input of heavy carbon from weathered carbonates, increased photosynthetic activity, and restricted carbon exchange with surface ocean during the low sea level episode (LaPorte et al., 2009).

To map these trends more precisely and explain the different influence of platform facies to the carbon isotopic values we analysed a large $\delta^{13}C_{carb}$ dataset from Baltoscandian Middle and Upper Ordovician carbonates. This includes about 40 published and unpublished sections from Estonia, Latvia, NW Russia and Sweden (e.g., Kaljo et al., 2004, 2007; Ainsaar et al. 2010; Lehnert at al., 2014; and others). The sections were correlated using the best available biostratigraphic data and the Baltoscandian carbon isotope-chemostratigraphic correlation standard (Ainsaar at al., 2010), and projected to the global timescale. Ten $\delta^{13}C_{carb}$ curves from the deepest central part of the basin, the Livonian tongue, are very similar to each other by isotopic values in all stratigraphic levels and average curve of these sections was taken as composite standard, supposed to reflect the secular changes in the oceanic DIC. The curves of deviation of $\delta^{13}C_{carb}$ values from the standard curve were calculated for nearshore areas, compared with sea level changes and sequence stratigraphic units by Dronov et al. (2011).

The $\delta^{13}C$ curves of Darriwilian and Sandbian interval in northern and central Estonia are shifted about 1‰ and in islands of Saaremaa and Gotland 0.5 ‰ in negative direction compared to the standard curve of the basin. Still, the deviation of northern Estonian curves is not uniform: the interval of MDICE is shifted 0.7-1 ‰, whereas the interval of the Kukruse Stage (incl. Upper Kukruse Low) is shifted up to 1.5 ‰. Sections from NW Estonia with multiple gaps show the depletion of $\delta^{13}C$ values up to 2 ‰. There is a weak correlation between the deviation and sea level curve. The transgressive parts of the sequences (e.g., Aseri Stage) are slightly less depleted than late highstand parts or sequence boundaries (Kukruse Stage). The isotopic changes along the facies profile in the Sandbian-Katian transition interval are difficult to analyze. The well-known global GICE is missing in the shallower part of the basin because of a stratigraphic gap and. Other two isotopic excursions, Rakvere and Saunja, are strictly related to the micritic limestone facies and become hardly visible in the condensed sections of the deeper part of the basin. The origin and global correlation potential of these two excursions must be tested by using other geochemical methods.

The $\delta^{13}C$ curves of upper Katian-Hirnantian interval differ considerably in different facies zones. The $\delta^{13}C$ values from the interval of the Moe Excursion (BC12 isotopic zone; Ainsaar et al., 2010) are depleted by 0.5 ‰ in northern Estonia, but increased by 0.3 ‰ in the sections in Saaremaa island relative to the standard values. The following interval in the middle part of the Pirgu Stage (BC13) shows remarkable $\delta^{13}C$ depletion exceeding 2 ‰ both in northern and western Estonia. The uppermost Katian interval, including the Paroveja Excursion is obviously missing in northern Estonia. The HICE interval shows clearly an increasing trend of $\delta^{13}C$ values towards the nearshore sections. This shift reaches +1 ‰ in Saaremaa sections and +2 ‰ in the northern Estonian sections relative to the deeper part of the basin.

The general pattern of changes in $\delta^{13}C_{carb}$ values along the facies gradient shows stronger depletion in the marginal areas for the intervals with lower isotopic values in the standard curve, and weaker depletion or increase for the positive carbon isotopic excursion intervals. The weak correlation of the most depleted Darriwilian-Sandbian intervals to sea level lows suggests that depletion of $\delta^{13}C$ values in shallow marine facies is related to restricted seawater circulation and increased input of lighter carbon isotope during the episodes of lower sea level. This is not the case in Hirnantian interval, where obvious glacioeustatic sea level fall is corresponding to the onshore enrichment of carbonate in heavier carbon isotope. This means that sea level fall and increased restriction of carbonate platform from ocean waters have been led to opposite changes in isotopic composition of carbonate sediments, which might possibly be driven by different magnitude of sea level change or climatic differences. Further studies using different geochemical proxies are needed to fully understand this phenomenon.

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NEW ACRITARCH INVESTIGATIONS ON THE LOWER-MIDDLE ORDOVICIAN OF THE TAZEKKA MASSIF, EASTERN MOROCCO

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Key words: *Tazekka Massif, Ordovician acritarch, Eastern Meseta.*

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The Moroccan Ordovician played a major role in early acritarch research, with the establishment of numerous acritarch taxa firstly described during the 1960's and 1970's and subsequently widely recorded from many other localities around the world, such as *Barakella*, *Ericanthea*, *Marrocanium*, *Rugulidinium* (= *Striatotheca*), and others. Most of the Ordovician acritarch taxa that have first been described from Morocco are from the subsurface of Tadla, central Morocco, but additional studies in the 1980's also included first investigations from the Fezouata Formation (that includes the exceptionnally preserved biota of the Fezouata Lagerstätte) in southern Morocco and from different inliers in northeastern Morocco (eastern Meseta), such as the 'boutonnières' (inliers) of Zekkara (e.g. Fournier-Vinas, 1985) and of Tazekka (e.g. Marhoumi et al., 1982; Rauscher et al., 1982; Chakir, 1983). After the original monographical works in the 1970's, many of the subsequent studies were only short reports, and detailed investigations from the Ordovician of central and eastern Morocco have not been produced in the last three decades.

Here, we present first results of new investigations from the Tazekka Massif that is located in the western part of the eastern Meseta. The latter is also known as the Moroccan-Oranese Meseta because it extends from northeastern Morocco to northwestern Algeria, where further inliers occur, such as in the 'Monts de Traras' and in the 'Monts de Tlemcen,' that are currently also under investigation by the authors.

In the Tazekka Massif, most of the Ordovician to Devonian strata record low-energy, shale-dominated depositional conditions. The Ordovician succession is subdivided in (i) the Lower to Middle Ordovician fine-grained Bou Chfâa Fm., (ii) the Middle Ordovician sandstones of the Bou Jam-Jam Fm., the Upper Ordovician (iii) fine-grained Tehar el Brehl and (iv) sandstone-dominated Tifarouine formations. This succession was deposited along the most distal, north-western corner of a north-dipping passive continental margin that extended from Morocco to Egypt (e.g. Hoepffner 1987).

Our new investigations concern the 'schistes de Tazekka' at the base of the succession (lower part of the Bou Chfâa Fm). The acritarch assemblage recorded is typical of the peri-Gondwanan margin, including the palaeobiogeographical index taxa *Coryphidium* and *Striatotheca*. The investigated assemblage displays mostly taxa such as *Polygonium* and *Baltisphaeridium*, but also more age diagnostic genera, such as *Barakella* and *Arkonia*, pointing to a Floian age of the base of the succession, below the levels with 'Llanvirn' graptolites in the upper part of the Bou Chfâa Fm.

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PAROISTODUS HORRIDUS (BARNES AND POPLAWSKI), A TAXON THAT GIVES MUCH TO TALK ABOUT…: TAXONOMIC AND BIOSTRATIGRAPHIC PRECISIONS

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Introduction

Albanesi and Barnes (2000) recorded and interpreted the speciation process between *Paroistodus originalis* (Sergeeva, 1963) and *P. horridus* (Barnes and Poplawski, 1973) from the lower member of the Gualcamayo Formation, which is exposed on the western flank of the Potrerillo Mountain (Cerro Potrerillo, ca. 308009S–688369W), Central Precordillera of San Juan Province, Argentina. After the description of the morphological transitional taxa; i.e. *Paroistodus h. primus* and *P. h. secundus* by Albanesi (1998), the involved microevolutionary process was interpreted as "punctuated equilibria" by Albanesi and Barnes (2000), following the pioneer study of Eldredge and Gould (1972). The intermediate forms as well as the derived taxon, the originally well known species *P. horridus*, have numerous records through different localities and diverse paleoenvironments of the Middle Ordovician in the Precordillera, since its first report by Sarmiento *et al.* (1988) (e.g., Albanesi and Astini, 1994; Albanesi et al., 1995, 1998, 2013; Lehnert, 1995; Ortega et al., 1995; Ottone et al., 1999; Heredia et al., 2005; Voldman et al., 2008; 2018; Mestre and Heredia, 2013; Mestre, 2014; Serra et al., 2015; Feltes et al., 2016). From these records, Albanesi and Ortega (2002, 2016) published a consolidated biostratigraphic scheme for the Ordovician basins of Argentina, where *P. horridus* plays a key roll for a restricted time interval, as the upper subzone of the *Lenodus variabilis*, with a range that extends through the *Yangtseplacognathus crassus*, *Eoplacognathus pseudoplanus* and *E. suecicus* zones.

Discussion and conclusions

A recent paper by Mestre and Heredia (2019) deals with the taxonomy and biostratigraphy of *Paroistodus horridus*, and presents a different biostratigraphical interpretation for *P. horridus*, including an extended stratigraphical range. Mestre and Heredia (2019) also attempt to revise the multielemental taxonomy of the species *P. horridus* complex and its stratigraphic range. Unfortunately, their attempts are not supported by any of the previously detailed records of the species, even with much more precision, abundance and clearness of reports, including ecological and paleobiogeographical controls. The referred publication also shows inconsistencies in morphological features and sampling records, all of which makes a paper that intruduces errors in the biostratigraphy of the Middle Ordovician.

At first consideration, it is noticiable that the authors do not citate a series of contributions regarding the first reports of the species in the Argentine Precordillera (Sarmiento et al., 1988; Albanesi and Astini, 1994; Albanesi et al., 1995a,b), and the updated biostratigraphic chart of conodonts and graptolites for the Argentine basins (Albanesi and Ortega, 2016). Other important studies that involve *P. horridus* in the Precordilleran biostratigraphy (Ottone et al., 2007, Carrera et al., 2013, Voldman et al., 2013; Serra et al., 2015, Mango and Albanesi, 2018; Mango et al., 2018), isotope analyses (Albanesi et al., 2013; Henderson et al., 2018), paleocology and paleobiogeography studies (Albanesi and Bergström, 2004, 2010; Serra et al., 2017a,b, 2018), are ignored as well, which represents either a neglection or deficient research from the authors.

A number of mistakes in the paper of Mestre and Heredia (2019), which claim for corrections, are:

Page 1: *P. horridus* was firstly assigned to the genus *Paroistodus* Lindström by Albanesi and Astini (1994), and Albanesi et al. (1995a, b) and Lehnert (1995) (not only by this author) in the same year.

- The microevolutionary event of the *Paroistodus* lineage was documented in the upper part of the San Juan Formation and the Lower Member of the Gualcamayo Formation (Darriwilian) in the Precordillera by Albanesi and Barnes (2000), not at the base of this unit.

Page 2: The range of *Paroistodus horridus horridus* or *P. horridus sensu stricto* presents its FAD at the base of the *Yangtzeplacognathus crassus* Zone not in the middle of this unit, and the subspecies *Paroistodus horridus primus* Albanesi and *P. h. secundus* Albanesi characterize the upper subzone of the *Lenodus variabilis* Zone (Albanesi et al., 1998; Albanesi and Ortega, 2016). *Periodon gladysae* characterizes the lower subzone of the referred zone, where the ancestral form *Paroistodus originalis* (Sergeeva) is recorded. Regarding *P. gladysae*, it is deem to observe that the paper by Mestre and Heredia (2009) is wrong in several aspects when they neglect the taxonomy and distribution of this nominal species, not only because the authors do not know its widespread record (e.g., Sweet et al., 2004) but because its original taxonomy and range are confirmed in recent contributions (Stouge, 2012; Feltes et al., 2016).

- *P. horridus* presents its last appearance datum (LAD) at the *Pygodus anitae* Subzone of the *Eoplacognathus suecicus* Zone, as verified in diverse citated references above, after the first report by Albanesi et al. (1998). The supposed extension of the record of *P. horridus* through the *Pygodus serra*, *Pygodus anserinus*, and *Amorphognathus tvaererensis*, as referred to as by Mestre and Heredia (2019) is not verified by many studies about these biozones in the world, as well as in the Precordillera (e.g., Albanesi et al., 1998; Lehnert et al., 1999; Heredia, 2002; Ortega et al., 2008; Heredia et al., 2016; Feltes et al., 2018), which suggest a laboratory or sampling error of information by the authors. A similar mistake is introduced in the recently published range for *P. horridus*, in the synoptic compilation for the biozonation of South China (Wang et al., 2019), which significantly differs from those specific ranges published by diverse authors in China (e.g., Zhang, 1998; Chen et al., 2006) or Australia (e.g., Zhen and Percival, 2004) for the Australasian region.

Page 3: Conversely to the assertion of the discussed authors, there is no generation of biostratigraphic and nomenclatural problems given that *P. h. horridus* was referred to as *P. horridus* in Feltes et al. (2016). The latter authors just referred to the name of the upper subzone of the *L. variabilis* Zone (*sensu* Albanesi et al., 1998, and Albanesi and Ortega, 2002) and later confirmed by Albanesi and Ortega (2016). The mentioned subzone is diagnosed by the successive appearances of *P. horridus primus* and *P. h. secundus*, and is named to as *P. horridus* following the ICZN for a species name. Actually, the species *P. horridus* stabilizes its morphology with the aquisition of three or more denticles on the the posterior process of the P and S elements (*P. horridus horridus* or *P. horridus sensu stricto*), at the base of the *Y. crassus* Zone up to the top of the *E. suecicus* Zone so far. The application of the subspecies *P. h. primus* and *P. h. secundus* has been probed extremely useful and precise as biostratigraphic markers because of their typical forms, either bearing one or two denticles, respectively, with discrete overlapped ranges in the upper part of the *L. variabilis* Zone. The overlaping ranges occur before the entrance of *Y. crassus*, which is the nominal species for the succeeding zone, though representing an acute control for a short time interval (e.g. Ortega et al., 2007; Albanesi et al., 2013; Serra et al., 2015; Feltes et al., 2016; Mango et al., 2018).

Page 4: The referred biostratigraphic scheme of Heredia et al. (2017) is not supported by substancial and detailed records of first and last appearance data of conodont index species, particularly for the *Lenodus antivariabilis* and *Lenodus variabilis* zones.

- The synonymy list is far from being complete.

Pages 5-8: Mestre and Heredia (2019) claim for a quinquimembrate apparatus of *P. horridus* but they calculates the proportional ratio for 7 different morphotypes (cf. Löfgren, 1997).

- The different apparatus reconstructions, either by Dzik (1983), Stouge (1984), Löfgren (1995), Albanesi (1998), Zhang and Percival (2004), and the discussed apparatus by Mestre and Heredia (2019) are all based on isolated conodont elements given the lack of clusters and natural associations on bedding plane surfaces, which makes it not possible to verify its true architecture. The multielement conodont taxonomy by Albanesi (1998) is fundamented on the largest existing collection from a single section (over 14000 specimens) for the *Paroistodus horridus* complex.

Pages 9-10: The morphological features of *P. horridus s.s.* is variable through the ontogeny of the individuals, with variable amount of denticles, 3 to 10 denticles on the posterior process, in the different morphotypes, which is not a steady morphology for subdivisión of time intervals through its range that covers the *Y. crassus*, *E. pseudoplanus* and *E. suecicus* zones. Instead, *P. h. primus* and *P. h. secundus* show typical, discrete morphologies throughout the ontogeny, which are restricted to the upper part of the *Lenodus variabilis* Zone (i.e., the *P. horridus* Subzone).

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UNBRANCHED HOLDFASTS OF STALKED ECHINODERMS FROM THE ORDOVICIAN OF THE LENINGRAD REGION

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Key words: *Echinodermata, attaching, holdfast, benthos, Palaeozoic, Ordovician.*

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Important feature of the stalked echinoderms is larval attachment to substrate, with development of the calcite basal structure. That basal structure work as bearer and anchor for the stem, allows to rise theca with feeding organs above the seafloor. In some echinoderms (typical for Cambrian ones) this structure grows without morphological changes; some can lose it in adult stage (unattached Soluta). But in the most of Ordovician stalked echinoderms developed more complex attachment structures. Heavy increase of echinoderm holdfasts morphological diversity in the beginning of the middle Ordovician (Rozhnov, 2017a, b, 2019) reflects increase of the benthic echinoderms diversity in general and correlated with contemporary changes in marine substrate formation.

This diversity increase is obvious displaying in collection from Ordovician of the Leningrad Region, Russia. This collection were gathered by S. V. Rozhnov, V. B. Kushlina, P. V. Fedorov and other researches (include focused search by G. A. Anekeeva in 2017 – 2018) for many years. It contains more than 200 specimens of echinoderm holdfasts from the middle Ordovician and late part of early Ordovician.

Since we, usually, cannot attribute holdfasts accurately to the other skeletal parts of echinoderms – stems and crowns – classification of these structures is formal. Based on previous classifications and personal observations, authors divide all examined holdfasts in two large groups: «unbranched» (mostly structural aligned with «terminal discoidal holdfasts» by Carlton Brett (Brett, 1981)) and «branched». More detailed division of «unbranched» group, however, include the increased focus on internal morphology of these structures.

Unbranched holdfasts also divide in two groups: solid holdfasts (without internal structures, except for the narrow axial canal, that can go through all holdfast or has dead-end above the ground) and holdfasts with internal cavity (in that cavity we can see branched radial grooves, divided by septa; and sometimes other structures, as, for example, laying plates). Furthermore, there are transitional forms between unbranched and branched holdfasts, as well as between solid holdfasts and holdfasts with internal cavity.

Authors describe four morphotypes of the solid holdfasts (Fig. 1A – D; morphotypes C and D can be also considered as transitional forms between two groups) and seven morphotypes of the holdfasts with internal cavity (Fig. 1 E, F; Fig. 2 G – K).

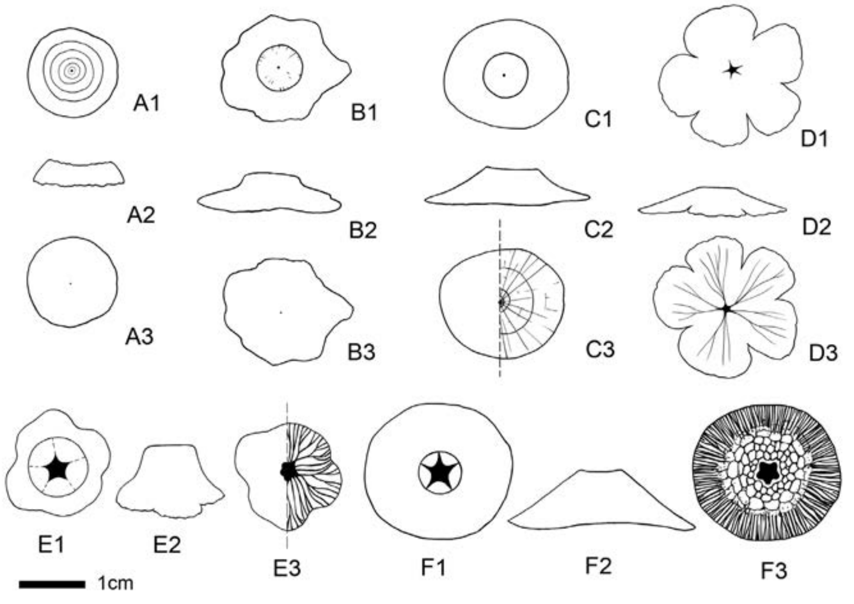

Fig. 1. Solid holdfasts (morphotypes A – D) and holdfasts with internal cavity (morphotypes E – F), see text for morphotypes description.

1 – proximal (upper) view, 2 – lateral view, 3 – distal (bottom) view. For holdfasts that have the basal layer, right part shown without this layer.

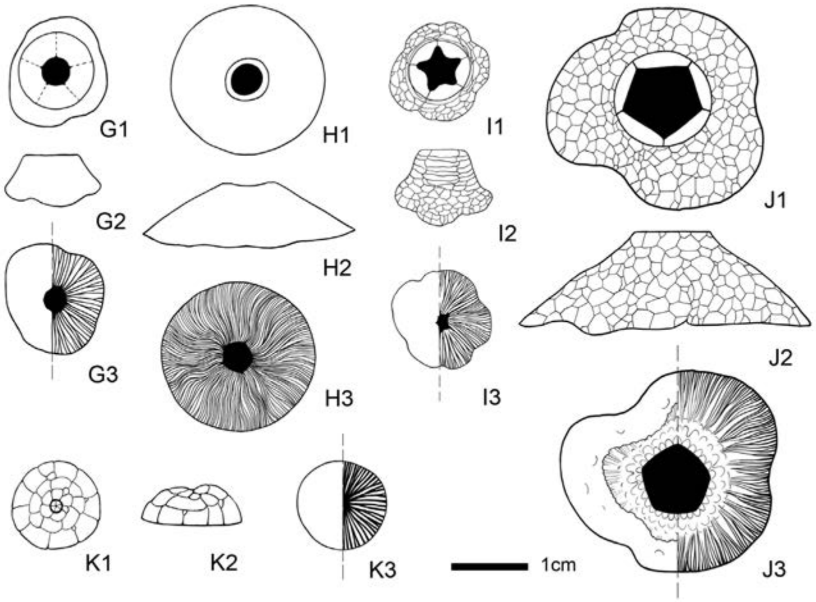

Fig. 2. Holdfasts with internal cavity (morphotypes G – K), see text for morphotypes description.
1 – proximal (upper) view, 2 – lateral view, 3 – distal (bottom) view. layer, right part shown without this layer.

The characteristics of the morphotypes:

1. Solid holdfasts.

A: Low holdfasts with rounded configuration, with slightly concave stem facet that has concentric sculpture in its surface. Axial canal is narrow, pentagonal.

B: Low holdfasts with irregular configuration and slightly separated discoidal proximal part. Axial canal is narrow, pentagonal.

C: Low holdfasts with rounded configuration, slightly sloping to the stem facet. Axial canal is narrow, rounded or rounded-triangular. There are may be margins of columnals in the proximal part, and traces of concentric sculpture in the stem facet surface. Distal surface has distinct basal layer and signs of radial relief (that may be compared with radial grooves of the hollow holdfasts) – that align this morphotype with those of second group, but it has not true internal cavity.

D: Low holdfasts with pentalobate configuration, slightly sloping to the stem facet. Axial canal is narrow (but significant wider than axial canal in morphotypes A – C), pentaradiate stellar. Distal surface slightly concave, with narrow branching radial grooves extending from the axial canal rays (that align this morphotype with morphotypes of second group), but there is no internal cavity. These holdfasts are without basal layer.

2. Holdfasts with internal cavity

E: Holdfasts with high proximal part, lobate basis and wide pentagonal or pentaradiate stellar axial canal. Have radial grooves and basal layer. Distal surface may be flat (but partially bend according to ground relief) or concave, with individual dome-shaped apophyses. Proportions of the axial canal and radial grooves width may vary.

F: Slightly sloping holdfasts with rounded configuration and wide pentaradiate stellar axial canal. Internal cavity inlayed by small plates. Radial grooves are narrow. Distal surface is concave, without basal layer.

G: Holdfasts with high proximal part, wide-lobate basis and wide rounded axial canal. Distal surface is concave, has radial grooves and basal layer. Axial canal may have five short narrow rays.

H: Slightly sloping holdfasts with rounded configuration, wide rounded axial canal and narrow, slightly meandrous radial grooves. Distal surface is concave, without basal layer.

I: Multiplated holdfasts with high lifted proximal part, lobate basis and wide pentagonal or pentaradiate stellar axial canal. Distal surface is flat, has wide radial grooves and basal layer. Some specimens have radial sculpture on the stem facet.

J: Multiplated dome-shaped holdfasts with high proximal part, trilobate basis and wide pentagonal axial canal. Distal surface is concave, partially covered by basal layer along the edges. Margins of the plates may be more or less distinct. Some specimens have apertures, mostly in sutures between the plates. One of such specimens has hollow apophyses in the internal cavity and on distal surface of the basal layer, that may be interpret as the result of infestation.

K: Multiplated (large convex plates that can detach independently) dome-shaped holdfasts with rounded basis.

Stem facet is rounded, small, lay in the depression. Internal cavity has well-developed septa and solid basal layer. Authors include with this morphotype structures that were firstly described as «Lichenocrinus».

All considered holdfasts types were adapted to the large firm objects, hardgrounds or consolidated detrite grounds. From one of the evolutionary trends in morphological development of this unbranched holdfasts were originated large variety of the branched holdfasts, adapted to attachment on the less consolidated carbonate detrit grounds.

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THE TRILOBITE AND CEPHALOPOD TAXONOMIC DIVERSITY FROM KUNDA STAGE DEPOSITS OF THE NORTHEASTERN PART OF THE BALTIC-LADOGA GLINT

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Key words: *Ordovician, Kunda Stage, trilobites, Asaphida, Corinexochida, Cephalopoda.*
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The Kunda Stage deposits are well represented in the northeastern part of the Baltic-Ladoga Glint by a number of natural outcrops (along the Lava and Volkhov rivers) and mines (the Putilovo and Babino quarries). These mud-carbonate deposits are well characterized with macrofossil remains. Among them, the trilobites (the orders Asaphida and Corinexochida) and cephalopods (the orders Endocerida, Actinocerida and Orthocerida) are well-distributed. The Kunda stage consists of four formations in this part of the glint and each lithological unit represents a different taxonomic diversity of the trilobite and cephalopod fauna.

The lower Sillaoru Formation is represented by clayey limestone, which usually abounds in oolites of various size. The characterristic Asaphid and Corinexochid trilobites here are *Asaphus expansus, Asaphus acuminatus lamanskii, Illaenus saarsi, Megistaspidella isvosica, Megistaspidella spinulata, Ptychopyge lesnikovae,* and *Dysplanus centrotus. Platillaenus ladogensis, Raymondaspis wittingtoni, Niobe karneevae, Nileus armadillo, Ampyx nasuta, Panderia ramosa, Pogerbovites volborthy,* and *Sculptaspis priscus* also exist but are relatively rare.

The overlaying Obukhovo Formation is composed predominantly of medium- and thick-bedded clayey limestone, sometime dolomitized, with scarce glauconite grains in the lower part of the unit. The formation characterized by a frequent occurrence of *Asaphus raniceps, Asaphus striatus* and *Illaenus insicus*, the more rare taxons *Ampyx nasuta* and *Megistaspidella convexa*.

The Sinyavino Formation is recognized by the lower boundary of tobacco-colored limestone which contains iron oolites up to 3 mm in diameter. The upper part of the formation is clayey limestone with small oolites occuring at individual levels. The taxonomic list of the trilobites includes *Asaphus minor, Illaenus chudleighensis*.

Simankovo formation consists from clayey lenslike limestone and marls with frequent interbeds where the widely common Asaphid and Corynexochid trilobites are *Asaphus pachyophthalmus, Asaphus sulevi, Asaphus ingrianus, Asaphus laevissimus, Illaenus dalmani, Illaenus wahlenbergi, Illaenus laticlavius. Volchovites simonkovensis, Homalopyge stacyi, Megistaspidella longicauda, Megistaspidella gigas* are rare.

The rich cephalopod fauna reported from the whole interval of the Kunda Stage. From the Sillaoru Formation to the Simankovo Formation the following taxons were studied: *Dideroceras amplum, Diderocersas incognitum, Paracyclendoceras canullatum, Estonioceras ariense, Planctoceras falcatum, Dideroceras pribalticum, "Endoceras" duplex, Eichwaldoceras volchovense, Schmidtoceras kundense, Dideroceras longispiculum, Dideroceras purtense, Lobocyclendoceras buschi,Lobocyclendoceras kundense, Proterocameroceras gdovense, Protocyclendoceras balticum, Ptotocyclendoceras cf. balticum,* and *Protocyclendoceras iriense.*

The reporterted tilobite and cephalopod fauna are important taxa for the Kundian Stage interval which provide additional characteristics for the regional stratigraphical units together with traditional orthostratigraphic groups.

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QUANTIFYING THE ROLE OF BIOTURBATION AND BIOEROSION IN ECOSPACE UTILIZATION AND ECOSYSTEM ENGINEERING DURING THE CAMBRIAN EXPLOSION AND THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT

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Key words: *trace fossils, evolutionary innovations, ichnology, paleoecology, macroevolution*.

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The Cambrian Explosion (CE) and the Great Ordovician Biodiversification Event (GOBE) are among the most important evolutionary breakthroughs in the marine biosphere during the Phanerozoic. There is an increased awareness about the role of bioturbation as a significant driving mechanism in macroevolution and its impact on geobiological feedbacks and geochemical cycles. In contrast, evolutionary patterns in bioerosion have rarely been addressed. A novel approach is used here to quantify ecospace utilization and ecosystem engineering during these evolutionary radiations based on a global dataset of bioturbation and bioerosion structures. Our analysis underscores the importance of the CE and the GOBE not only as phases of a marked increase in ichnodiversity, but also for the importance of significant changes in ecospace utilization in concert with modes of ecosystem engineering in marine environments. The increase in global ichnodiversity and ichnodisparity at the Ediacaran-Fortunian transition was accompanied by a marked diversification in modes of life and styles of ecosystem engineering, followed by a sustained increase in all metrics during the early Paleozoic. Major innovations took place first in siliciclastic offshore environments and later expanded into marginal-marine and nearshore settings as well as deeper-water and carbonate environments.

TECTONICS AND GEODYNAMICS OF THE SOUTHERN FRAME OF THE SIBERIAN CRATON IN ORDOVICIAN

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Most of the modern publications adopted the view presented in the article (Zonenshain et al., 1990) that at the end of the Ordovician, the Kazakhstan (Kazakhstan-Kirghiz) continent, which formed by accretion of island arcs and Precambrian continental blocks of Gondwana, divided the Paleoasian ocean into four oceanic basins: Ural, Turkestan, Junggar-Balkhash and Ob'-Zaisan. The Ob-Zaisan ocean was located between the Kazakhstan and the Siberian continents (blocks). On the border of the two collided continents (Kazakhstan and Siberia), the Ob-Zaisan (Zaisan-Junggar) orogenic belt was formed. It is believed that the Chara ophiolitic belt is its suture zone of the Ob-Zaisan ocean.

The basis of the new methodology of tectonic and geodynamic zoning of the Junggar-Altai-Sayan fold belt located in the southern framing of the Siberian craton the following tectonic units are highlighted (Buslov, 2011, 2014; Dobretsov, Buslov, 2007):

1. The Neoproterozoic-Paleozoic continental margin complexes on the Western margin of the Siberian continent (in the present coordinates), which include the Neoproterozoic – Early Ordovician Kuznetsk-Altai island-arc, Ordovician – Early Devonian passive margin and Devonian – Early Carboniferous active margin. The accretionary wedges of the island arcs contain only the oceanic crust fragments (paleoseamounts and ophiolites), which is typical of marginal complexes of Paleo-Pacific plate. New geochronological data on magmatic detrital zircons from Paleozoic sedimentary rocks of the Western margin of the Siberian craton (Chen et al., 2015; Dobretsov et al., 2017) suggest their provenance from the Mesoarchean – Paleoproterozoic basement of the Siberian craton and from the Neoproterozoic – Early Ordovician Kuznetsk–Altai island arcU-Pb ages of detrital zircons have been received from Paleozoic sediments of the Anui-Chuya zone in the Gorny Altai terrane which stores almost continuous record of the -200 myr from Cambrian to Carboniferous of the Siberian continental margins (Dobretsov et al., 2017). The Anui-Chuya zone, extending for more than 500 km and up to 200 km wide, is the largest structure in Gorny Altai bounded by major Late Paleozoic strike-slip faults

The passive margin deposits were dated using detrital magmatic zircons from sandstones of different ages: (1) the Middle-Upper Ordovician; (2) the Silurian; (3) the Early Devonian. The samples share similar age distributions of zircons within the ranges 530-470 Ma. At the Early Devonian level, there is quite a large population of Early-Middle Neoproterozoic (904-772 Ma) and Paleoproterozoic (2431-1879 Ma) zircons appear for the first time.

2. The composite Kazakhstan-Baikal continent has a basement that was formed in the Neoproterozoic – Ordovician time during the subduction of the Paleoasian oceanic plate, comprising the collage of Precambrian Gondwana-derived microcontinents and terranes (Tuva-Mongolian, Dzabhan, Kokchetav, Aktau-Moitin, Central Tianschan and others), beneath the Kazakhstan-Tuva-Mongolian island arc along the southeastern margin of the Siberian craton (in the present coordinates). For the Gondwana blocks, orogenic events of the Grenville age (1.4-0.9 billion years) are common. In the Ordovician time, the basement of the Kazakhstan-Baikal composite continent consisted of the accretionary-collisional arcs collage, microcontinents (cratonic terranes), continental-margin terranes, and accretionary complexes (flysch, olistostromes, fragments of oceanic crust and UHP and HP rocks of paleo-subduction zones derived from the deep subducted parts of continental and oceanic terranes). U-Pb ages of detrital zircons (Cai et al., 2016) have been received from Paleozoic sediments of the Altai-Mongolian terrane. The terrane is bounded by the North-East strike-slip fault in Rudny Altai, by the Erqis strike-slip fault in China, and by the Charysh-Terekta-Ulagan suture-shear zone in Gorny Altai. The terrane is dominated by rhythmically bedded quartz-feldspar or, to a lesser degree, polymictic sandstones, siliceous and phyllitic shales and slates. Those rhythmic flyschoid units are isoclinally folded, partially strongly metamorphosed and transgressively overlapped by Devonian volcaniclastic rocks.

The zircons from a quartz – plagioclase – biotite – chlorite schist give a quite wide age range from 480 to 2889 Ma (age peaks at 520, 780 Ma and 1950 Ma). The zircons from a paragneiss give also a quite wide age range from 425 to 2889 Ma (age peaks at 520 Ma and 800 Ma). The zircons from the sandstone give age cluster of 455 to 1940 Ma (age peak of 520 Ma and 800 Ma) (Cai et al., 2016).

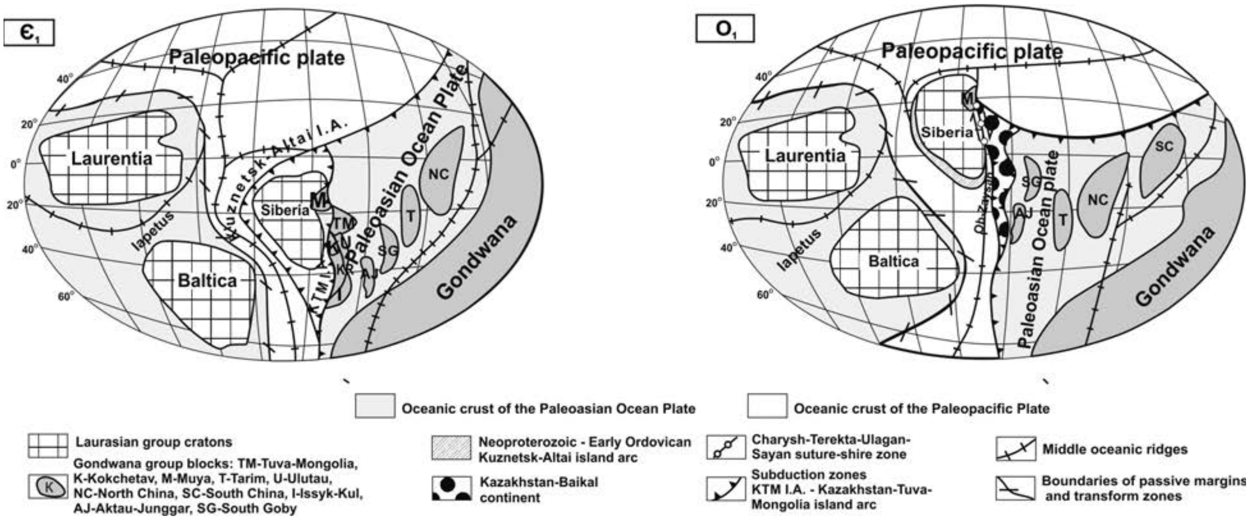

Fig. Paleotectonic reconstructions of the Central Asian folded belt in the early Cambrian and early Ordovician (compiled on the basis of the data presented in this article and paleoreconstructions according to (Didenko et al., 1994; Torsvik, T., Cocks, L., 2017)).

The majority of the Early Paleozoic sedimentary sequences on the periphery of Tuva-Mongolian microcontinent are commonly characterized by the major age populations at 520 Ma and 800 Ma and minor age populations of -1800 Ma and 2500 Ma (Rojas-Agramonte et al, 2011). With the above shown similarities it can be concluded that the Tuva-Mongolian microcontinent may have served as the relatively stable and common provenances for the sediment supply.

There are several lines of evidence to support the turbidites from Altai-Mongolian terrane as a subduction-accretion complex formed in the Early Paleozoic time (Cai et al., 2016).

3. The Middle Paleozoic Charysh-Terekta-Ulagan-Sayan suture-shear zone, which separates the continental-margin complexes of the Siberian and Kazakhstan-Baikal continents. This zone consists of fragments of Late Ediacarian – Early Ordovician oceanic crust of the Ob'- Zaisan oceanic basin, Ordovician blueschists and Ordovician-Silurian turbidites, Late Silurian – Devonian high grade metamorphic rocks and granites (Dobretsov, Buslov,2007; Buslov, 2011). The articles (Buslov, 2011; Cai et al., 2016; Chen et al., 2015; Buslov, Cai, 2017; Dobretsov et al, 2017) have shown that the subduction of the oceanic crust took place beneath the Altai-Mongolian terrane with the Northern. The fragments of paleosubduction zone preserved in the Charysh-Terekta-Ulagan-Sayan and in the East Kazakhstan and the Junggar were strongly separated by Late Paleozoic faults. The preserved total length of the paleosubduction zone exceeds two thousand km from the Chinese Altai to the Western Sayan. An integrated U–Pb and Hf-isotope study on detrital zircons from the early Paleozoic meta-sedimentary rocks from Altai-Mongolian terrane was conducted in order to trace their provenance and tectonic setting (Cai et al., 2016; Chen et al., 2016).

Based on the above data we conclude that, in the Ordovician, the southern frame the Siberian continent bordered the two margins of the Paleo-Pacific and Paleoasian ocean tectonic plates, which approached northwards and formed a complex structure similar to the modern structure of southeast Asia (Fig.).

The Paleo-Pacific plate was represented by the oceanic crust of the Ob-Zaisan basin with a passive margin with the Siberian craton. The oceanic crust of the Ob-Zaisan basin subducted under the Kazakhstan-Baikal continent, formed as a result of the evolution of the Paleo-Asian ocean plate. The fragments of the oceanic crust are preserved in the Middle Paleozoic Charysh-Terekta-Ulagan-Sayan suture-shear zone.

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NEW DATA ON THE 'GIANT' OBOLID FAUNA (BRACHIOPODA) FROM THE ARMORICAN QUARTZITE FACIES (LOWER ORDOVICIAN) OF THE IBERIAN PENINSULA

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Key words: *Armorican Quartzite, brachiopods, giant linguliform, Portugal, Spain*.
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The Armorican Quartzite (=Armorican or Cruziana Sandstone) is a characteristic facies of mature quartzite, found throughout south-western Europe, present in the Lower Ordovician (Floian) of Brittany, Normandy, Portugal and Spain. In the United Kingdom, clasts from conglomerates of Triassic age near Budleigh Salterton, Devon (see Cocks & Lockley, 1981) are identified, with a high degree of confidence, as pebbles of Armorican Quartzite from the Armorican Massif in north-west France. In Bohemia and Morocco, chronological equivalent of the Armorican Quartzite do not develop Cruziana-sandstone facies. The Armorican Quartzite is characterised by the widespread presence of trace fossils deposited on a wide shelf in Ibero-Armorica (Gutiérrez-Marco et al., 2017), belonging to the *Cruziana* and *Skolithos* ichnofacies, which are representative of various settings in a range of wave-dominated to tide-dominated shallow-marine environments (Gutiérrez-Alonso et al., 2007). Body fossils are rare in the Armorican Quartzite, being most typically associated with concentrations of vertical burrows of *Daedalus* (= *Vexillum*, = *Humilis*), a common ichnogenus in the *Skolithos* ichnofacies. They represent post-depositional colonisation of storm deposits by wormlike bulldozers, maybe large polychaetes or enteropneusts. These vertical cone-shaped burrows are produced by animals that were opportunistically exploiting recently deposited storm-beds, harvesting for silt-size organic particles or meiofauna living in within the sand interstices (Neto de Carvalho et al., 2016). Such trace fossils are also recorded in the Lower Ordovician of Morocco (as *Vexillum*), SE France (Montagne Noire) and diverse places in North Africa, Middle East and the Arabian Peninsula (Seilacher, 2000). Trace fossils such as *Cruziana* and *Daedalus* (identified as *Heimdallia* but this genus is a junior synonym of *Daedalus* (see Fillion & Pickerill, 1990)) are recorded in what is regarded as an extension of the Armorican Quartzite facies in eastern Newfoundland, as well as large–sized *Lingulobolus* species (over 30 mm long; see Walcott, 1912) from Lance Cove, Bell Island, Newfoundland (Bell Island Group, upper Tremadocian, Lower Ordovician).

The brachiopod faunas are developed either as rare but extensive linguliform beds formed by centimetric to decimetric accumulation of highly fragmented taxa, usually difficult to identify (Emig & Gutiérrez-Marco, 1997), or by complete specimens (even including conjoined valves) preserved at the base of those storm sandstone sequences colonised by *Daedalus* (see Fig. 1.5). The faunas consist of low diversity assemblages (sometimes monotaxic) of 'giant' linguliform brachiopods including *Ectenoglossa lesueuri* (Rouault) (Fig. 1.4), *Lingulobolus brimonti* (Rouault), *L. hawkei* (Rouault), *Lingulepis crassipyxis* Havlíček (see *Lingulepis* sp. on Fig. 1.2), *Tomasina criei* (Davidson), *Pseudobolus*? *salteri* (Davidson), and a new bizarre 'giant' linguliform taxon (see Figs 1.1, 1.3) recognised so far in the Armorican Quartzite of northern Portugal only (Sá 2005). The brachiopods found in the Armorican Quartzite in France and Iberia were described and identified in works published since the middle of the 19th Century, a.o. by Rouault (1850) [later revised by Davidson (1880)], Guillier (1881), and Coke & Gutiérrez-Marco (2001). Cocks & Lockley (1981) reassessed the brachiopod fauna described by Salter (1864) from the Budleigh Salterton Pebble Bed. The distinctive elongated spatulate glosselline *Ectenoglossa lesueuri* is present in the Armorican Quartzite in England, Brittany, Normandy, Sarthe, Montagne Noire and the Central Iberian Zone of Portugal and Spain. Moreover, the two species of *Lingulobolus*, *L. hawkei* and *L. brimonti* have been identified from Brittany, Normandy and England; *L. brimonti* has been identified in the Lower Ordovician of the Montagne Noire (Courtessole et al., 1985, Havlíček, 1980) and also in the Lower Ordovician of Algeria (see Cocks, 2000), whereas *L. hawkei* is known from Portugal (see Perdigão, 1971; Coke & Gutiérrez-Marco, 2001, and Neto de Carvalho, 2006). This association of large linguliform brachiopods is represented in comparable lithostratigraphic successions restricted in south Gondwana, i.e. Ibero-Armorica, SW England, Algeria, Serbia and possibly Saudi Arabia (Gutiérrez-Marco et al., 2017). It is typical of the Gondwanan high-latitude inshore-shelf fauna. However, equivalent inner-shelf assemblages form Bohemia (*Leptembolon-Thysanotos* fauna) show palaeogeographical connections with the upper Tremadocian-lower Arenigian more temperate deposits of Baltica, south Urals, northern Iran and the central Andes (Gutiérrez-Marco et al., 2017). In

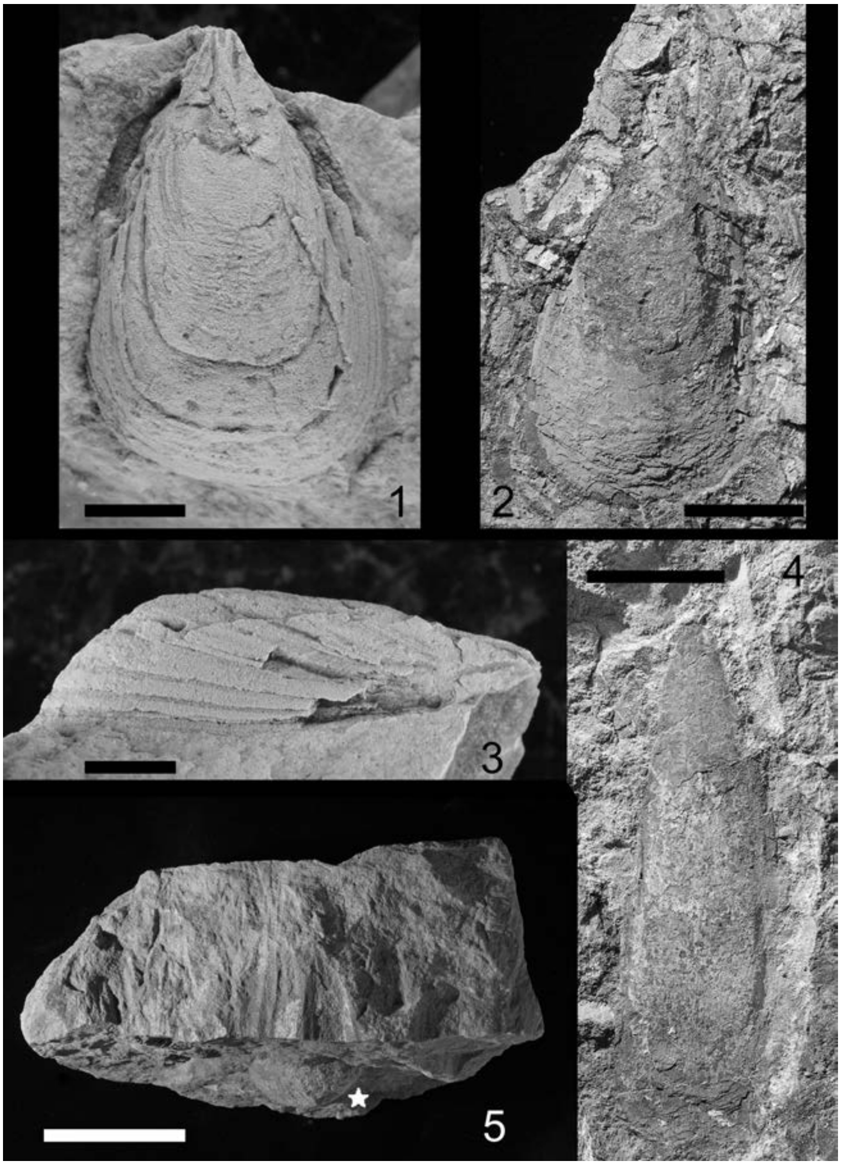

Fig. 1. 1, 3 – Obolidae gen. et sp. indet. from Guadramil, Portugal; 2 – *Lingulepis* sp. from El Pobo inlier, Guadalajara, Spain; 4 – *Ectenoglossa lesueuri* (Rouault), Guadarranque sincline, Cáceres, Spain; 5 – Specimen showing the relationship between the vertical burrows of ichnofossil *Daedalus* and the position of *Lingulobolus* sp. (see white star); Sierra Menera inlier, Guadalajara, Spain. Scale bars, 10 mm, except 5 (= 50 mm).

the Ranovac-Vlasina unit of eastern Serbia, Lower Ordovician sandstones have yielded the most inshore assemblage including ‘giant’ linguliform brachiopods such as *L. hawkei* and *P.*? *salteri* (Gutiérrez-Marco et al., 1999), both of which are recorded in the Armorican Massif and (as transported elements) in SW England.

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PALEOENVIRONMENTAL INTERPRETATION OF THE LOWER ORDOVICIAN *OEPIKODUS EVAE* ZONE IN THE PEÑA SOMBRÍA SECTION, PRECORDILLERA, ARGENTINA

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Key words: *paleoenvironments, Oepikodus evae Zone, Lower Ordovician, Argentine Precordillera*.
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Oepikodus evae (Lindström) is considered one of the most important index fossils of the Lower Ordovician because of its short stratigraphic range and wide geographical distribution. The *Oepikodus evae* Zone was defined by Sergeeva (1963) and Lindström (1971) for the upper part of the Billingen Stage in Baltoscandia, and it was corroborated and discussed by many authors from diverse paleoplates, such as the Argentina Precordillera (Albanesi and Ortega, 2016).

Recently, an increasing number of investigations have been accomplished about this biozone to define the Lower/Middle Ordovician boundary (e.g., Wang et al., 2005; Albanesi et.al., 2006; Bergström and Löfgren, 2009). This conodont zone has a wide distribution in the Argentine Precordillera, where it ranges through the middle part of the San Juan Formation, allowing an accurate regional correlation (Serpagli, 1974; Hunicken and Sarmiento, 1985; Albanesi et al., 1998, 2006; Soria et al., 2017; Mango and Albanesi, 2018). The San Juan Formation contacts diachronously with overlying stratigraphic units through the Dapingian-Darriwilian stages, with *O. evae* records in the upper strata of the San Juan Formation, close to the contact with the Gualcamayo Formation, in the northern Precordilleran localities (Hünicken, 1985; Albanesi et al., 1999). Five facies associations were identified through the San Juan Formation (Cerro La Silla and Niquivil sections), which are: sponge-algal reef-mounds and patch reef facies, skeletal-intraclastic facies, bio-intraclastic and oncolite grainstone facies, nodular limestones, and parted limestones (Cañas, 2002; Albanesi et al., 2006). These lithofacies represent environments from tidal and agitated shoal environments to deeper, sub-storm wave base, basinal settings, distributed along an open-shelf to the ramp. The main goal of this contribution is the description and interpretation of the carbonate microfacies at the Peña Sombría section, northern Precordillera, for the upper strata of the San Juan Formation that correspond to the *Oepikodus evae* Zone.

The section of Peña Sombría (Fig.) in the northern sector of the Precordillera exposes strata of the Lower/Middle Ordovician boundary interval. The Gualcamayo Formation mainly consists of black shales that paraconformably overlies the San Juan Formation. The presence of numerous species associated with the nominal species in the study interval, at the upper San Juan Formation, such as *Bergstroemognathus extensus* (Serpagli), *Cornuodus longibasis* (Lindström), *Drepanodus arcuatus* Pander, *Juanognathus variabilis* Serpagli, *Juanognathus jaanussoni* Serpagli, *Oepikodus evae* (Lindström), *Oistodus lanceolatus, Paroistodus parallelus* (Pander), *Periodon fabellum* (Lindström), *Protopanderodus gradatus* Serpagli, *Protopanderodus rectus* (Lindström), *Drepanoistodus forceps* (Lindström), *Drepranoistodus basiovalis* (Sergeeva), *Rossodus barnesi* Albanesi, *Microzarcodina flabellum* (Lindström), *Scolopodus rex* Lindström, *Tropodus sweeti* (Serpagli), *Decoriconus peselephantis* (Lindström), *Paltodus? jemtlandicus* Löfgren, *Gothodus* n. sp. suggests a low energy environment *below the storm wave base*. Likewise, we recorded scarce elements of *Oepikodus intermedius*, a typical species of shallower water paleoenvironments, associated with abundant elements of the more robust *Oepikodus intermedius* n. ssp., with similar requirements as *O. evae*.

Petrographic slides from 9 samples down the contact of the San Juan and the Gualcamayo formations, separated at 1 m intervals, are examined. The microfacies analysis of these strata determine thin to medium, nodular bedded, dark carbonate mud-dominated lithologies for the upper 10 meters of the San Juan Formation. All samples are burrowed skeletal/bioclastic wackestone, mostly composed of trilobites and pelmatozoan fragments. Articulate brachiopods and small gastropods are less common, and whole linguliform brachiopods, sponge spicules and ostracods are only occasionally present. Bioclasts and biomorpha range from 10 % to > 60 %. Micrite is usually very fine and homogeneous. Some samples present winnowed surfaces concentrating bioclasts that form pavements and very thin beds that can present shelter porosity. Bioclasts on these surfaces, as well as the surfaces themselves, can be phosphatized and stained with oxides. Mineralized bioclasts and oxidized glauconite are reworked within the wackestones by bioturbation. Many samples present solution seams concentrating insoluble argillaceous material and dolomite. These rocks are interpreted to have been deposited in a deeper, outer-ramp setting, bellow the storm wave base, as is evidenced by the dominance of carbonate mud deposition. The lack of evidence for storm deposition, the paucity of

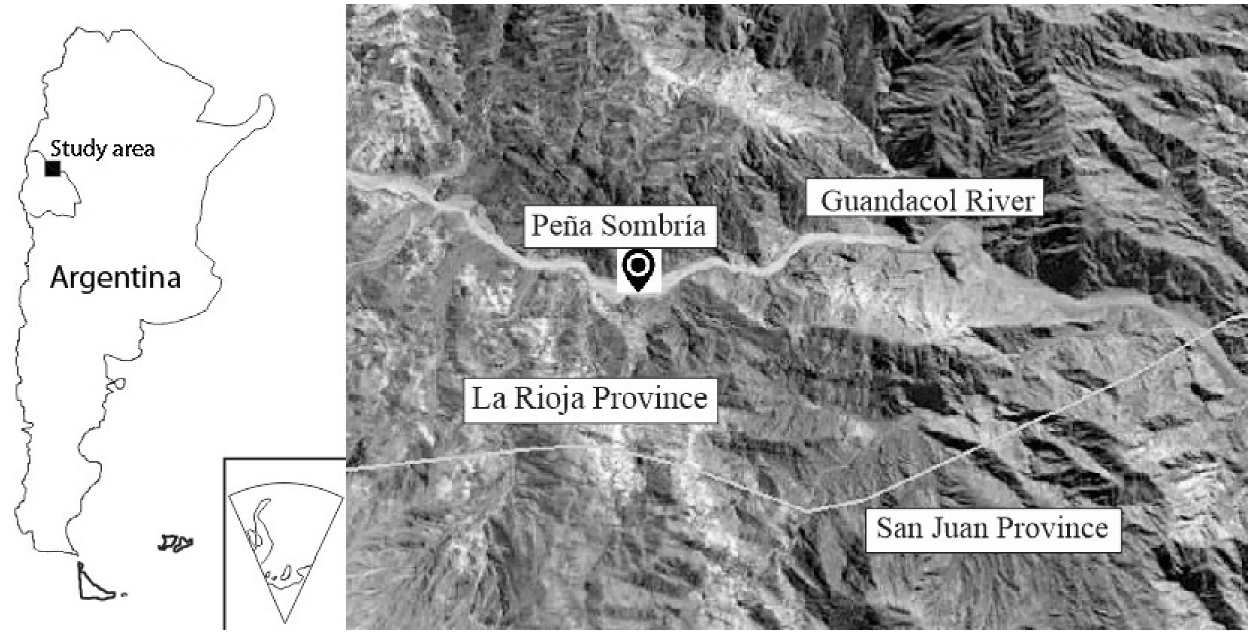

Fig. Location map and satelital image of the study area.

allochems other than bioclasts and biomorfa, and the absence of any organism indicative of the euphotic zone, common in the San Juan Formation, such as *Nuia, Girvanella, Halysis* and *Receptaculites*. Winnowed surfaces associated with phosphates, glauconite and oxide stains are indicative of low sedimentation rates. This facies was included by Cañas (1999) in the "Nodular wackestones and mudstone association" defined for the Guandacol area, interpreted to represent highstand shedding into an outer ramp setting. Identification of the upper *Huacoella*-lower *Niquivilia* biozones (Herrera and Benedetto, 1991) allowed to correlate this facies association with the "Lithoclastic-skeletal facies association" of the La Silla and Niquivil sections, a middle ramp or open platform facies association (Cañas, 1999) deposited in very shallow water, well within the photic zone and recurrently reworked by frequent storms. Microfacies analysis (Cañas and Aguirre, 2005) showed a highstand depositional pattern for this part of the San Juan Formation in the cerro La Silla section, supporting previous interpretation of the top strata of the San Juan Formation in the Peña Sombría section.

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MAJOR REGIONAL UNCONFORMITIES IN THE ORDOVICIAN OF THE TARIM BASIN, NW CHINA: IMPLICATION FOR OIL EXPLORATION

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The Tarim basin is one of the largest petroliferous basins in China. The Ordovician is extremely developed in the basin and is dominated by carbonate platform sediments. Generally speaking, the stratigraphic sequence of the Ordovician in the Tarim basin are completly developed. The lower part of the Ordovician consists of the Penglaiba Formation (O_1p) and the Yingshan Formation ($\mathrm{O}_{1\text{-}2}y$), which are characterized by thick carbonate rocks. The upper Middle and the Upper Ordovician can be divided into two lithostratigraphic sequences. One, in Kalpin area, is composed of the Dawangou Formation (O_2d), Saergan Formation ($\mathrm{O}_{2\text{-}3}s$), Kanling Formation (O_3k), Qilang Formation (O_3q), Yingan Formation (O_3y) and Tierekawati Formation (O_3t) in ascending order. The other one, developed in Taklamakan area, is divided ascendingly into the Yijianfang Formation (O_2y), Tumuxiuke Formation (O_3tm), Lianlitag Formation (O_3l) and Sangtamu Formation (O_3s). However, recent studies in this basin show that there are three major regional unconformities within the Ordovician. The first one occurs between the Penglaiba Formation and the Yingshan Formation (Ys/Pl) in both the Kalpin and Taklamakan area. It is represented by a large biostratigraphic gap of 3~4 conodont zones, equivalent to about 6~8 Ma in age. The second one is between the Yingshan Formation and the Lianlitag Formation (Ll/Ys) in the Taklamakan area. This unconformity results a biostratigraphic gap of 8~9 conodont zones, equivalent to 14~20 Ma. The third one below the Tierekawati Formation (Tr/O) and occurs mainly in the Kalpin area. The strata absent from this unconformity are varied greatly, representing intervals ranging from 2 Ma to 20 Ma. These unconformities are significant not only for the studies on the evolution of the Tarim Craton but also for the oil-gas exploration of the Tarim basin. Abundant oil resources have been discovered in the rocks under the Ll/Ys unconformity. Besides, recent drillings show that karst reservoirs are widely distributed in the Penglaiba Formation under the Ys/Pl unconformity. It reveals the Penglaiba Formation is an important oil exploration target. Furthermore, a series of carbonate formations are developed under the Tr/O unconformity, which can also be potential oil-gas reservoirs.

GLOBAL CORRELATION OF THE ORDOVICIAN DEPOSITIONAL SEQUENCES

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The detailed sea-level curve for the Ordovician based mainly on sequence stratigraphic studies of the North American platform was published almost 10 years ago (Haq & Shatter, 2008). Some refinements were introduced afterwards but no principal changes (Ogg et al., 2016). On the other hand, there were almost no attempts of direct global correlation of the Ordovician depositional sequences. It is usually suggested that Ordovician sea-level changes are of eustatic nature and could be traced all over the world. Comparative analysis of the Ordovician succession of the Siberian and North American platforms demonstrates a striking similarity in the long-term lithological changes and sea-level curve interpretation (Dronov, 2017). On both platforms, Ordovician succession starts with tropical stromatolite bearing carbonates, which abruptly changes to siliciclastic deposits and terminates with cool-water carbonates. (Ettensohn, 2010; Dronov, 2013). The sea-level curve for the Ordovician of North American platform assumes a prominent sea-level drop at the base of the Middle Ordovician and a long-term lowstand during all the Dapingian and Darriwilian (80-100 m lower than in the Lower and Upper Ordovician), (Ross and Ross, 1995). The sea-level curve for the Ordovician of Siberian platform looks roughly the same (Dronov et al., 2009; Kanygin et al., 2010).

On the other hand, sea level curves for the Ordovician of the Gondwanan platforms (North Africa, Yangtze platform, South America, Avalonia) seem to share different patterns (Videt et al., 2010; Su, 2007; Heredia and Beresi, 1995; Woodcock, 1990). The Middle Ordovician represents rather a highstand interval in these reconstructions. As for the Baltica, there are two different sea-level models for this palaeocontinent. The sea-level curve suggested by Nielsen (2004) demonstrates close similarity to the North American model while the sea-level curve presented by Dronov and Holmer (2002) seems to fit better to the platforms rifted from the Gondwana palaeocontinent (Munnecke et al., 2010). This contradiction reflects opposite opinions in the interpretation of limestone units within the deep-water setting of the Ordovician basin of Baltoscandia (Dronov, 2013). The invasion of carbonate facies into the black shale realm interpreted as a shallowing event in the deep-water model, assuming that limestone represents more shallow-water facies than the black shale (Nielsen, 2004). On the other hand, the same episodes in shallow-water areas characterized by the expansion of the relatively deep-water marine red bed facies into the shallow-water realm, suggesting deepening events.

Invasion of limestone facies into the deep-water black shale environment could be explained through the mechanism of "highstand shedding" (Schlager, 2007). According to this view, carbonates were transported from a shallow-water environment into a deep-water setting only at the time of maximum carbonate production in the shallow-water environment, i.e. during sea-level highstand. Based on this interpretation we suggest that Baltica also follow the Gondwanan sea-level patterns. As a result instead of one global sea-level curve for the Ordovician (Haq and Shutter, 2008) it would be probably more correct to suggest two semi-global curves for two big tectonic regions one of which includes Siberian and North American platforms and the other combine Baltica and Gondwanan platforms. This subdivision probably reflects position of the main Ordovician lithosphere plates (Dronov, 2017).

Based on developments of regional unconformities, shape of sea-level curves and long-term lithological changes in the Ordovician four groups of platforms could be displayed: 1) Siberia and Laurentia; 2) Baltica, Yangtze platform, Tarim and North China platform; 3) Africa, Arabia and European terrains; 4) Australia and Sibumasu. The other terrains could be usually attributed to one of those groups. Direct correlation of depositional sequences is better constrained within the groups and much more difficult between the groups. It is probably reflects regional tectonic and palaeogeography. Those depositional sequences that could be traced globally reflect eustatic events.

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K-BENTONITES IN THE ORDOVICIAN OF THE SIBERIAN PLATFORM

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Since 2008 twelve K-bentonite beds have been discovered in the Upper Ordovician of the Siberian Platform. Four of them have been identified in Baksian, six in Dolborian, one in Nirundian and one in Burian regional stages, which correspond roughly to the Upper Sandbian – Katian Global Stages (Bergström et al., 2009). The 4 lowermost beds from the Baksian regional stage were studied in detail. They are represented by thin beds (1-2 cm) of soapy light gray or yellowish plastic clays and usually easily identifiable in the outcrops. The beds were traced in the outcrops over a distance of more than 60 km along the Podkamennaya Tunguska River valley and its tributary Stolbovaya River. All twelve K-bentonite beds have been found within the Upper Ordovician cool-water carbonate succession. The four lowermost K-bentonite beds, which were sampled, have been studied by powder X-ray diffraction (XRD) and scanning electron microscopy (ESEM) together with energy dispersive X-ray analysis. Modeling of the XRD tracings using NEWMOD showed the samples consist of R3 ordered illite-smectite with 80 % illite and 20 % smectite plus a small amount of corrensite, which is a regularly interstratified chlorite-smectite. A minor amount of quartz is indicated by peaks at 4.21Å and 3.33Å. The presence of a chlorite phase indicates a primary magma rich in Fe & Mg. And the low percent of smectite in both mixed-layer phases reflects a high degree of burial metamorphism since the time of their origin. The K-bentonites provide evidence of intensive explosive volcanism on or near the western (in present day orientation) margin of the Siberian craton in Late Ordovician time (Dronov et al., 2011; Huff et al., 2014)..

The K-bentonite beds from the Baksian regional stage of the southwestern part of the Tungus basin in Siberia are thus derived from the alteration of volcanic ash falls. All four beds contain volcanogenic euhedral zircon and apatite phenocrysts. We analyzed zircon crystals from the K-bentonite bed succession within the Baksian regional stage and obtained the following series of 206Pb/238U ages: For the 1st (the lowermost) bentonite layer we have 3 ages from different sections: – B-1110-1 (453,9+-3,4 Ma), – B-1010-1 (453,5+-3,7 Ma) and – B-0510-1 (454,2+-3,3 Ma). The average age is 453,9 Ma. For the 2nd bentonite layer we also have 3 ages: – B-0410-1 (451,01+-3,2 Ma), – B-1010-2 (453,4+-3,7 Ma) and – B-1010-3 (455,1+-3,6 Ma). If we eliminate the most deviant age and take the two which are closer to each other the average age would be 452,2 Ma. That fits nice with the stratigraphic position of the Layer II which is younger than the Layer I. For the 3rd bentonite layer there is only one age (B-0510-3 – 453,8+-2,5 Ma) which does not fit with the stratigraphic position of the layer. However if we take 453,8 – 2,5 = 451,3 Ma it would make it consistent with the stratigraphic position of the Layer III. During the field work in the year 2017 we realized that the uppermost Baksian K-bentonite layer in the section 0308 (see Huff et al., 2014) miscorrelated. It was not the 3rd but the new one, the 4th (and younger) Baksian bentonite layer. The age of this bed is 450,58+-0,27 Ma (Huff et al., 2014) which fits very nice to the whole succession of four Baksian bentonite layers.

Layer I – 453,9 Ma
Layer II – 452,2 Ma
Layer III – 451,3 Ma
Layer IV – 450,6 Ma

The timing of volcanism is surprisingly close to the period of volcanic activity of the Taconic arc near the eastern margin of Laurentia. It looks like Taconic arc has its continuation along the western continental margin of Siberia and both of them constitute a single Taconic-Yenisei volcanic arc. Field studies of the Upper Ordovician succession along the Moyero River in the vicinity of the Anabar shield demonstrate an absence of K-bentonite beds along the eastern margin (in present day orientation) of the Siberian Platform. This contradicts popular palaeogeographic interpretations (www.scotese.com) and points to the position of a subduction zone along the western but not the eastern margin of the Siberian palaeocontinent at this time.

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BIOGEOGRAPHIC DELIMITATION OF THE TRANS-EUROPEAN SUTURE ZONE

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The tectonic units corresponding to the early Palaeozoic continents of Baltica are separated from those of Gondwana by several central European terranes located in-between. The most prominent geological discontinuity that exposes disparity of these tectonic units is the Tornquist lineament. It is usually interpreted as the Trans-European Suture Zone, a subject of repeated rifting, compression and strike-slip movement since the latest Precambrian. The only place in the central section of the Tornquist lineament where the possible suture is accessible at the surface, is the boundary between two tectonic units of the Holy Cross Mountains in southern Poland. A dislocation parallel to the SW margin of the Tornquist lineament separates there the northern Łysogóry unit of supposedly Baltic affinity from the southern Kielce unit, which represents the northern margin of the mostly subsurface Małopolska Massif. Based on a geochemical evidence it has been hypothesised that the Małopolska terrane migrated along more or less the same latitude from its original position near the South American part of Gondwana in the Cambrian to its present position near Baltica. This geotectonic scenario calls for a test. Usually, paleobiogeography is used for such purposes but few groups of early Paleozoic organisms include species distributed widely enough to show connections between former continents and restricted enough in their distribution to expose differences between particular terranes. The early Mid Ordovician pelagic conodonts are especially predisposed for such purposes because of their distinct provincialism. Unexpectedly, conodont assemblages of the earliest Mid Ordovician (early Darriwilian) age from the Łysogóry region and from the Kielce region show virtually identical species composition. One of the species dominant in both regions, of the genus *Trapezognathus* characterized by denticulated M elements, occurs elsewhere only in Morocco on the northern margin of Gondwana. Apparently, the separation of the Małopolska microcontinent from Baltica continued after the disappearance of *Trapezognathus* from there and an allopatric speciation process was initiated by a population of *Baltoniodus*. Also in this case, denticulation developed in the M elements of the apparatus but the process of speciation was truncated by re-appearance of the Baltic lineage of the genus in Małopolska. Later conodont faunas from the region are of mostly Baltic affinities, but remain distinct in showing a relatively high contribution from exotic species of *Sagittodontina*, *Phragmodus*, and *Complexodus*. The periodic North American Midcontinent tropical influences observable in the Baltic region did not reach the Holy Cross Mts. It appears thus that the Ordovician conodont faunas from the Holy Cross Mts. can be fit into a transect extending from Baltica to Gondwana, but an unexpected discontinuity in biogeographic gradients has been revealed between the Łysogóry region of the Holy Cross Mts. and the East European Platform. This new evidence disproves the long-held concept that the Łysogóry and Kielce regions had separate early Palaeozoic fates and that the Małopolska terrane was unified with Baltica already in the earliest Ordovician. This indicates that the Tornquist lineament marks a wide sea separating the Małopolska microcontinent (with Łysogóry at its northern tip) from Baltica in the early Palaeozoic.

RELATIONS BETWEEN CONODONTS AND U-PB AGES OF THE SANDBIAN AND KATIAN IN THE SOUTH AND WEST MARGINS OF THE NORTH CHINA PLATFORM

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Key words: *conodonts, K-bentonite, Pingliang Formation, Upper Ordovician, Ordos Basin.*
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The Upper Ordovician is absent totally in most of the areas of the North China Platform because of the uplift, while marine successions of the Sandbian and Katian widely develop from the south to west margins with great lithological changes. The changes evidently cause that the lithostratigraphic classification and correlation of the successions is rather confused and controversial especially in the south margin. Generally, the Sandbian mainly includes the well-known Pingliang Formation and its coeval strata, such as the most part of the Longmendong Formation in the west margin, the Jinsushan Formation, the Zhaolaoyu Formation, the Jinghe Formation and the Yaoxian Formation in the south margin. The Katian principally consists of the Taoqupo Formation, the Beiguoshan Formation and the top of the Longmendong Formation. K-bentonite beds are widely distributed especially in the Sandbian successions. Herein, conodonts and zircon U-Pb ages are attained together from the above formations at 5 outcrops located in Chunhua, Fuping, Yaoxian, and Pingliang respectively. It provides an opportunity to discuss the relations between the conodont biostratigraphy and zircon U-Pb ages. The results show that a U-Pb age of about 452.5Ma is got from the *Belodina compressa* conodont biozone in the interval between the Pingliang Formation and Beiguoshan Formation at the Tiewadian section in Chunhua, Shaanxi Province. A K-bentonite bed between the Pingliang Formation and Beiguoshan Formation attains an age of about 447.7Ma, which might be a little younger because it lies in the interval between the *Tasmanognathus multidentatus* conodont biozone and the *T. sishuiensis* conodont biozone at the Jiangjunshan section in Fuping, shaanxi Province. Three U-Pb ages are got from the Jinsushan Formation (also called as the Zhaolaoyu Formation by some authors) at the Zhaolaoyu section in Fuping, Shaanxi Province. The K-bentonite collected from the middle-upper part of this formation show ages of 445.2Ma and 453.2 Ma (data from the previous study), which approximately corresponds to the *Tasmanognathus multidentatus* conodont biozone. The ages are 457.5Ma and 452.1Ma at the levels 27.41m and 31.48m respectively above the bottom of the Jinsushan Formation according to the previous study, which should lie in the *T. sishuiensis* conodont biozone. The K-bentonite bed located between the Jinghe Formation (also called as the Yaoxian Formation by some authors) and the Taoqupo Formation attains an age of about 453.7Ma at the Taoqupo section in Yaoxian, Shaanxi Province based on the previous study. It corresponds to the top of the *Tasmanognathus multidentatus* conodont biozone. The K-bentonite samples we collected from the Pingliang Formation in Pingliang section in Gansu Province attain a set of discrete data. However, it shows that the ages of the bed lying 57.5m and 65m above the bottom of the this formation is are about 450 Ma and 451Ma based on the previous study at this section. According to the previous study, the horizons are close to or located in the *Erismodus quadridactylus* conodont biozone. It is obvious that the U-Pb ages presented here are subject to a margin of error, and thus seem inconsistent. However, they all keep within the range of the numerical ages of the Sandbian to Katian (458.4Ma~445.2Ma) shown in the latest International Chronostratigraphic Chart (201807).

A CLADISTIC APPROACH TO THE PALAEOBIOGEOGRAPHY OF LITUITID CEPHALOPODS IN MIDDLE AND LATE ORDOVICIAN

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Key words: *Lituitina, cephalopod, cladistic analysis, network analysis, South China*

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Lituitid nautiloids usually refer to the species belonging to Suborder Lituitina (King and Evans, 2019). Suborder Lituitina (= Suborder Lituitina Dzik, 1984) was proposed by Starobogatov (1983) who recognized an "Order Lituitiformes", which is characterized by the central or subcentral cylindrical siphuncle, longer septal necks, exogastric coiling of the apical part of shell with stable extension, and narrow and deep funnel sinus (Dzik, 1984). The suborder includes families Lituitidae and Sinoceratidae, and is assigned to Subclass Orthoceratia (King and Evans, 2019) or Order Orthocerida (Mutvei, 2002; Kröger, 2013). Family Lituitidae mainly includes *Lituites*, *Cyclolituites*, *Ancistroceras*, and Family Sinoceratidae includes *Sinoceras* and *Rhynchorthoceras*, which are common in the Middle–Late Ordovician of South China (Lai and Qi, 1977; Fang et al., 2015, 2017). The earliest record of lituitids, *Ancistroceras subcurvatum* Qi is likely from the middle part of Dawan Formation (Dapingian, Middle Ordovician) in Anhui Province of South China (Qi, 1980). From a slightly higher horizon of the Dawan Formation, *Sinoceras fengxiangense* Lai and Xu was reported (Xu and Lai, 1987).

Methods

A cladistic analysis is conducted herein for several significant species of Family Lituitidae and Sinoceridae aiming to elucidate the origin and phylogenic evolution of the group. Thirteen taxa, including lituitids, its related forms and two outgroups, and 16 characters were selected for the analysis. The cladistic analysis was undertaken using PAUP version 4.0 for PC. Heuristic parsimony searches were adopted, and the swapping algorithm carried out by TBR (tree bisection–reconnection). Network analysis was conducted with the software Gephi version 0.9.1 (Bastian et al., 2009), which also calculates the attributes to evaluate the network structures.

Phylogeny of lituitid nautiloids

The prevailing viewpoint on the origination of the lituitid nautiloids is probably that they evolved from species of Order Orthoceratida (Schindewolf, 1942; Dzik, 1984; Mutvei, 2002; Kröger, 2013; King and Evans, 2019). Accordingly, for the cladistic analysis, the taxa *Lituites lii*, *Lituites ningkiangense*, *Cyclolituites lynnensis*, *Ancistroceras subcurvatum*, *Ancistroceras undulatum*, *Rhynchorthoceras jurongense*, *Rhynchorthoceras yizanense*, *Sinoceras chinense*, *Sinoceras eccentric*, *Sinoceras fengxiangense*, *Sinoceras complexum* and two outgroups *Michelinoceras dayongense*, *Michelinoceras chaoi* were included. The results suggest that all the lituitids share a likely common ancestor, the orthocerids. The orthocerids gave rise to two lineages, one of which was the *Rhynchorthoceras* and *Ancistroceras* lineage, and the other was the *Lituites*, *Cyclolituites* and *Sinoceras* lineage. *Sinoceras* was the stem group from which *Lituites* and *Cyclolituites* were derived (Fig. 1).

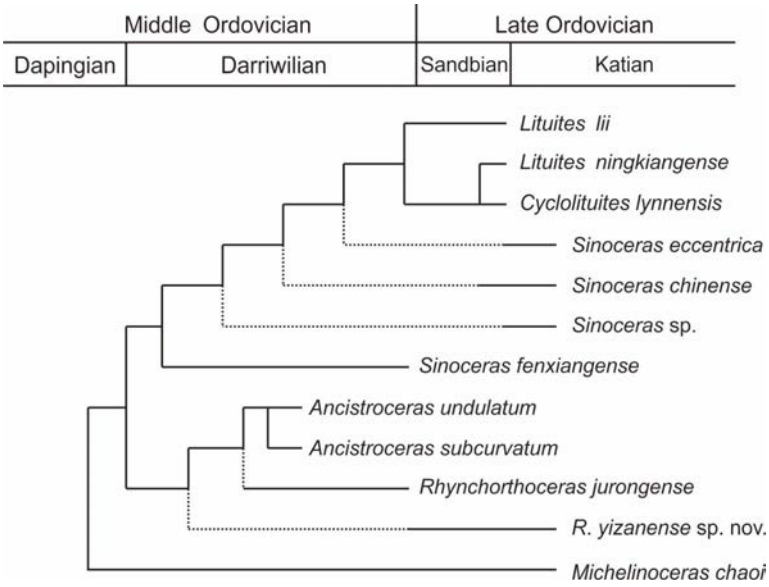

Fig. 1. Phylogenetic evolution of the lituitid nautiloids based on cladistics analysis (dashed lines indicate the "ghost lineage").

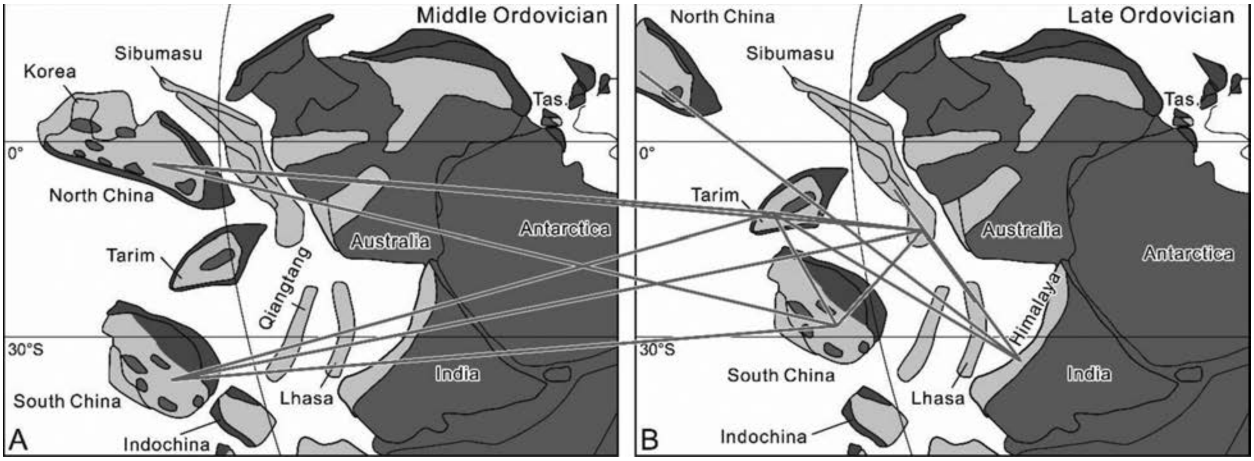

Fig. 2. Middle and Late Ordovician lituitid nautiloid network plotted on palaeogeographic maps (maps are modified from Fang et al., 2019; Yu et al., in press).

Lines indicate high similarity between lituitid nautiloid faunas distributing in plates during Middle and Late Ordovician.

Palaeogeographic analysis

Lituitid nautiloids were common forms in the Middle–Late Ordovician in the northeastern peri-Gondwanan regions (Fang et al., 2019), i.e., South and North China, Xinjiang (including Tarim and Altun), Baoshan of Yunnan, Thailand and Tibet (including Himalaya and Lhasa). Herein the palaeobiogeographic patterns of lituitid nautiloids have resulted from network approach (Newman, 2016). The network structures show the increasing complexity of relationship from Middle to Late Ordovician. The reconstructed palaeogeography maps plotted with network structures indicate that South China is probably the origination area of the lituitid nautiloids in Middle Ordovician, and after the origination, they immigrated to North China and possibly also Tarim (Fig. 2A). In the Late Ordovician time interval, many new types of lituitids made their appearances, e.g. *Lituites*, *Cylcolituites*, which spread rapidly to some other regions in the northeastern peri-Gondwana (Fig. 2B). It was proposed that the plate movements lead to the dynamic variation of cephalopod provincialism in the region during Middle and Late Ordovician (Fang et al., 2019).

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HIGH-LATITUDE UPPER ORDOVICIAN CANYONS: A RECORD OF PRE-HIRNANTIAN GLACIAL LOWSTANDS

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Kew words: *Ordovician, shelf stratigraphy, climate.*

The Upper Ordovician to Lower Silurian shelf stratigraphy in the Moroccan eastern Anti-Atlas is far more complex than the layer-cake sequence stack of the existing models. At least four main generations of downcuttings are identified. Incision widths and depths range from 0.5 to 20 km, and from > 50 to 500 m, respectively; infill thicknesses are of same order. Megaconglomerates are almost systematically observed in thalwegs (1 cm to > 2 m intrabasinal clasts). Above megaconglomerates, HCS-like beds have been deposited, which reflect supercritical flow conditions rather than storm events.

The two older generations (late Sandbian/early Katian? middle Katian) show modest incision depths (<150 m). The infill consists of shale interval and thin-bedded turbiditic deposits grading upward into bioturbated sandstones. The third and fourth generations are penecontemporaneous with the end-Ordovician glaciation and display the largest amplitudes. One of them is seen to start abruptly (subvertical wall). They include glaciomarine plume deposits with striated dropstones, high-density turbiditic sands, channel conglomerates and subglacial soft-sediment shear zones. Downslope, in the deeper parts of the incision, km-scale lateral facies changes are identified from thick, massive megaconglomerates up to thin-bedded, bioturbated turbiditic sands. Deltaic sequences or tide-influenced sandwaves paradoxically prevail in their more proximal reaches. Interestingly, the initial infill does not show any glaciogenics but instead are depositional facies very similar to those of the older incisions. The infill of the fourth generation consists in early Silurian graptolitic shales and sandstones representing a 5-7 Myr time span, which is not represented outside the canyons. Last but not least, the younger incision(s) are commonly re-eroded into the infill of the older one(s).

Owing to the magnitude and extent of the downcutting, the resulting basal erosion surface may mimic regional unconformities. However, geometries, stratigraphic superimpositions and sedimentary infills suggest that Upper Ordovician incisions correspond to shelf canyons and associated shelf rivers. They were cut by retrogressive erosion during major sea-level falls that recurrently characterize the Late Ordovician, a period known to have been recurrently affected by the growth of large ice sheets. Only in the end-Ordovician, when ice-sheet fronts approached the shelf edge, inherited and underfilled canyons operated as accumulation zones for proglacial glaciogenics. Canyons are the missing link between the inner glaciated platform (Algeria, southern Morocco) and distal, thick (>400 m), turbiditic depocenters of northern Morocco. Similar features should be preserved in other lower-latitude clastic or mixed clastic-carbonate stratigraphic records including a shelf to slope transition. Over shallow carbonate platforms, canyon downcuttings are expected to be time-equivalent with karst horizons. Provided canyons are synchronous features worldwide, their identification in the rock record, which however need large exposure and/or seismic lines, contribute to decipher the patterns of the Late Ordovician glacially-impacted climate.

THE POSTGLACIAL TRANSGRESSIVE CONGLOMERATE IN THE HIRNANTIAN OF THE CENTRAL PRECORDILLERA

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Key words: *conglomerate, transgression, Hirnantian, Precordillera, Argentina.*

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INTRODUCTION

Hirnantian deposits of the Argentine Precordillera at the Talacasto area are represented by the conglomerate of the basal Salto Macho Member (Baldis et al., 1984) of the La Chilca Formation. The Ordovician-Silurian boundary is recorded in these deposits (Cuerda et al., 1988). The basal conglomerate of the La Chilca Formation represents a post-glacial Hirnantian transgression and this event is recognizable in other localities within the lower part of the La Chilca Formation. The deposition of the conglomerate took place before the graptolite-based *persculptus* Zone during a rapid post-glacial sea-level rise. It was first described at the Baños de Talacasto section by Marchese (1972). The conglomerate level is cover by black, greenish- grey and yellowish shale, whit graptolites of Hirnantian to Llandovery age (Cuerda et al., 1988; Lenz et al., 2003). The sedimentological and stratigraphic analysis of the conglomerate level has been carried out in three sections in the Talacasto locality: Quebrada Poblete Sur (PS), Quebrada Ancha (QA) and Baños de Talacasto (BT). The sedimentary sequence was interpreted on the basis of lithofacies, vertical stacking patterns, body geometry, vertical and horizontal strata relations and fossil content according to existing models.

The sections (Fig. 1) were correlated and analyzed with the transgression of the late Ordovician, according to proposed models (Clifton, 2003).

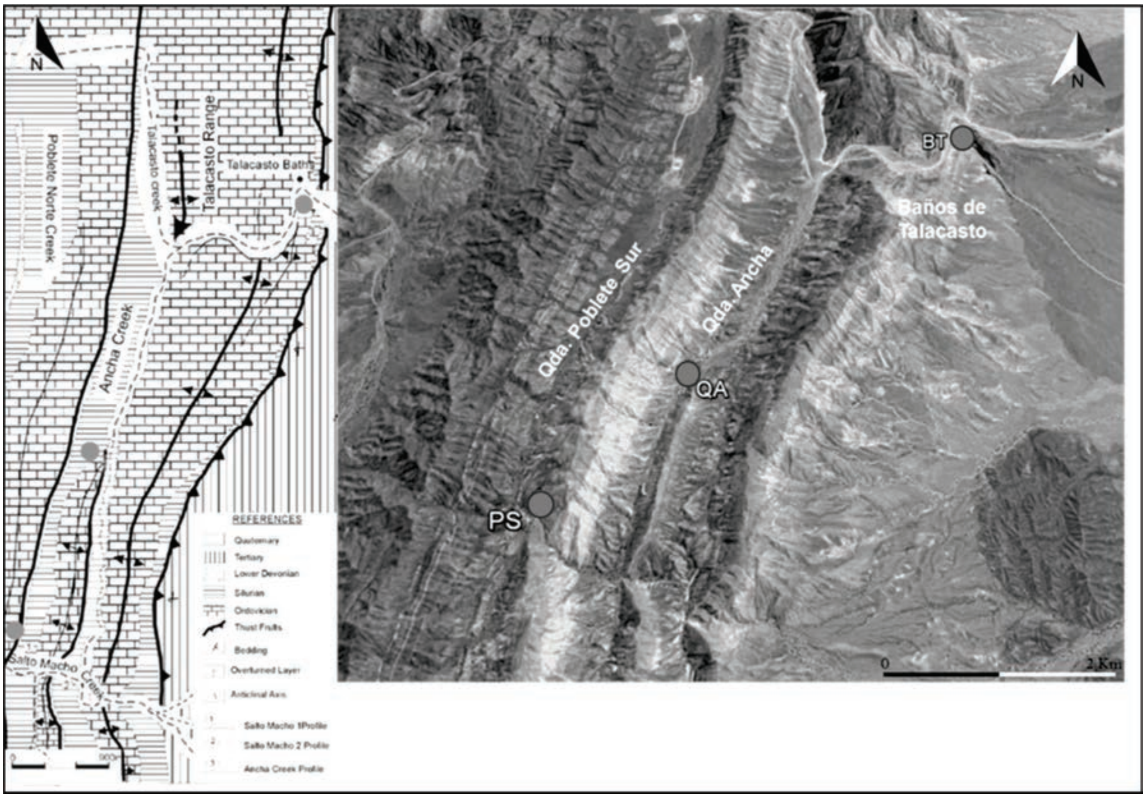

Fig. 1. a) Geological map of the Talacasto área, Central Precordillera according to Baldis et al., 1984). b) Google Earth image with localization of the studied sections.

STUDY SECTIONS

Poblete Sur section (PS): the conglomerate is represented by a tabular bed, with erosive base and greyish to reddish coloration. The thickness is 20 cm (approximately) and is overlying the limestones of the San Juan Formation. In the uppermost part, the oolitic sandstone passes into an oolitic level of 5 to 7 cm thickness, followed by the dark shales of the member Salto Macho (Fig. 2).

Quebrada Ancha section (QA): the conglomerate consists of a tabular bed, approximately 20 cm thick, with erosive surface, overlying the San Juan Formation. At the top, the conglomerate is in contact with oolitic sandstones, which shows a gradual transition to the oolitic level, followed by the silicilastic succession of the member Salto Macho of the La Chilca Formation (Fig. 2).

Baños de Talacasto section (BT): tabular conglomerate with a thickness of approximately 30 cm, in erosive contact with the underlying San Juan formation and in net contact with laminated shale-rich in Hyrnantian-Rhuddanian graptolites of the member Salto Macho. A distinctive characteristic in this section is the absence of the oolitic level (Fig. 2).

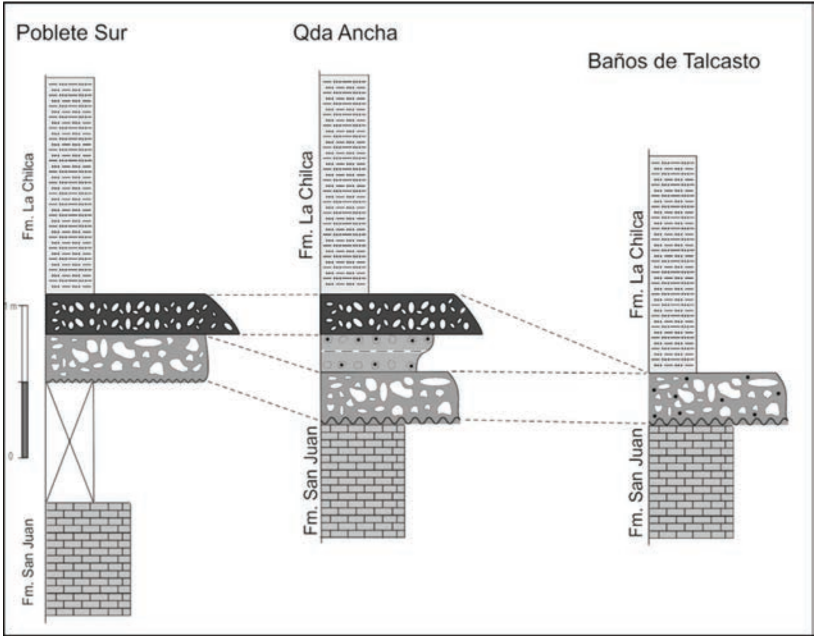

Fig. 2. Stratigraphic sections described in the Poblete Sur, Quebrada Ancha and Baños de Talacatos zones.

LITHOFACIES

The transgressive conglomerate at the base of Salto Macho exhibits two distinctive lithofacies:

Talacasto Conglomerate: this lithofacies corresponds to a sublithic orthoconglomerate, with more than 80 % of siliceous components (chert, chalcedony and monocrystalline quartz) and 20 % of limestone and organic fragments, which changes into an oligomictic orthoconglomerate. Presents a grain-supported fabric with clasts size ranging from granule to fine pebble (2-8mm). The sorting is variable in the West-East direction. The reddish to black sandy matrix is composed of monocrystalline and polycrystalline quartz, and fragments of limestone of fine to very fine sand grain size. The cement is calcareous with remnants of the original micrite with impregnations of oxides and iron hydroxides (Fig. 3).

Oolithic sandstone: this lithofacies with a grain-support fabric and inverse gradation consists of subangular to subrounded grains of siliceous composition (chert, chalcedony and monocrystalline quartz) and black oolites of chamositic composition. Calcareous components and lithic fragments are present in a smaller proportion. The reddish detrital matrix is rich in iron. In some parts, the micrite is dark gray, and with no fossiliferous content. Towards the top, it is enriched in oolitic elements, considerably reducing the siliceous and carbonates in a matrix rich in siltstone. At the topmost of the oolitic sandstone there is a ferruginous oolitic level of dark gray to black in color and with clast-support fabric. The ooids are distributed in high concentration and oriented packages, intercalated with dispersed ooid layers. The internal structure of the ooids is concentric, with chamositic and ferro-phosphatic layers. The ooids are rounded and ellipsoidal between 1 to 2 mm in diameter. The nuclei are siliceous grains, heavy minerals and organic fragments.

DISCUSSION

In transgressive successions, the conglomerate is presented as transgressive lags or accumulates in tidal systems (Clifton, 2003). The rapid transgression, caused by the post-glacial event and the wave agitation, causes the erosion of the exposed facies of the San Juan Formation. The carbonates were reworked and redeposited in two important psephitic levels in the coarse beach configuration (Arche, 1992). The first level corresponds to the sediments of the berm- the Talacasto conglomerate subfacies- closest to the contact with the San Juan Formation. It consists of discoidal and ellipsoidal forms, subangular to subrounded, polymictic composition and matrix-support fabric (Poblete Sur section). The second level occurs at the beginning of the berm, with subfacies corresponding to the top of the psephitic deposit. The clasts exhibit greater mineralogical (reduction of the carbonate components) and textural (clasts sub-rounded to well-rounded and high sphericity) maturity and clast-support fabric.

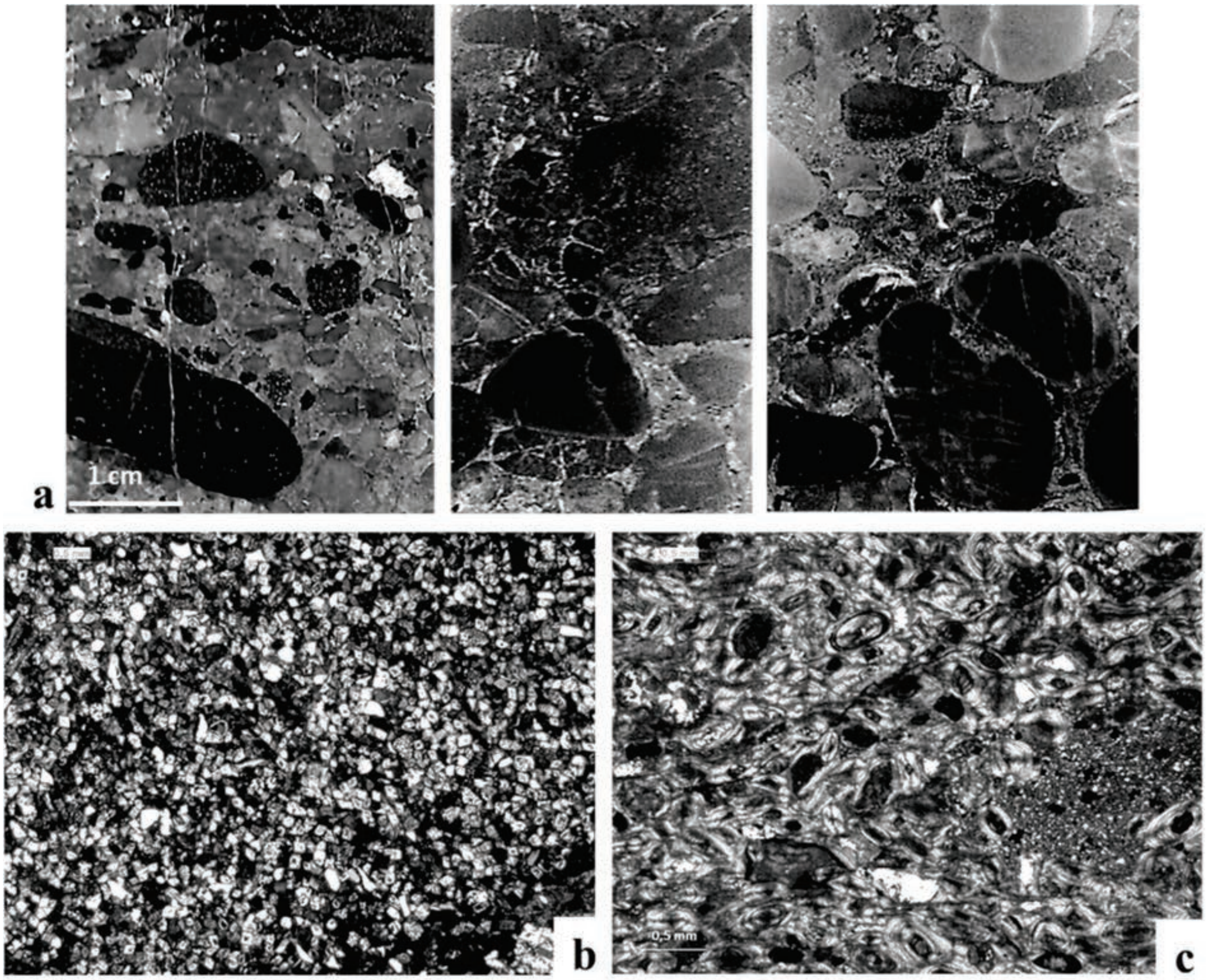

Fig. 3. a) Polished sections of the transgressive conglomerate in the three studied sections: (A) Poblete Sur, (B) Quebrada Ancha and (C) Baños de Talacasto. b and c – Oolithic sandstone facies and chamositic ooids in the Poblete Sur section.

The conglomerate deposit is the result of the transgressive post-glacial process of the Hirnantian, a register of the sea-level rise, and represents a continue mantle significant to regional correlations and to reconstruct the paleoenvironmental changes across the Ordovician-Silurian critical interval in the Precordillera. The increase of the available space during the final stage is represented by the oolitic sand facies, subjected to the action of the oscillatory processes of the wave, and which develop to ferruginous oolitic deposits, in a coastal land environment, associated with a regressive stage during the postglacial transgression.

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ORDOVICIAN TRACE FOSSILS FROM THE UPPER TIOURIRINE FORMATION OF MOROCCO: PRELIMINARY RESULTS

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In contrast to the high abundance of Ordovician invertebrate fossils in Morocco, which promotes a good part of the fossil trade worldwide (Gutiérrez-Marco and García-Bellido, 2018), there are only few references to the record of trace fossils in the thick siliciclastic units that compose the Ordovician sequence in the large region of the Moroccan Anti-Atlas, situated to the north of the Tindouf Basin and the West African Craton. The classic regional synthesis of Destombes (in Destombes et al., 1985) only mentioned the sporadic occurrence of *Skolithos* (identified as "*Tigillites*") in diverse Middle and Upper Ordovician formations, as well as of *Daedalus* (determined as "*Vexillum*") in the Guezzart Formation (upper Darriwilian) of the First Bani Group. The updated synthesis of Álvaro et al. (in press) neither paid attention to the trace fossils, and the more recent palaeontological literature dealing with the renowned Ordovician biotas of Fezouata and Tafilalt, just lists few ichnogenera without description or illustration. The only detailed ichnological contributions are from Gibb et al. (2010), dealing with Lower Ordovician *Rusophycus carleyi* (James) from the eastern Anti-Atlas, and from Azizi et al. (2017), who describe *Skolithos linearis* Haldeman from the Cambrian-Ordovician boundary of the central Anti-Atlas.

The purpose of our investigation is to provide a first evaluation of the ichnofauna from the Upper Tiouririne Formation of the Ktaoua Group, which is a trace-fossil rich unit in comparison with other units of the Anti-Atlas, and which is of Katian 2–3 age (for lithostratigraphy see Destombes et al., 1985 and Álvaro et al., in press). The only trace fossils cited from that formation are "*Tigillites*" (= *Skolithos*), mentioned by Destombes (in Destombes et al., 1985, p. 200) for a single section in the western Anti-Atlas, and large but undetermined 'cord-like' trace fossils, which appear rather widespread in the eastern Anti-Atlas (Van Roy 2006, p. 336; MacGabhann 2012, figs. 3.06a, 3.11a-b). The trace-fossil list from our work suggests a higher ichnodiversity and may contribute to the general knowledge of a large area of northern Africa and the Middle East, where Ordovician data are still scarce (see Seilacher 2007 and references therein).

The studied material comes from two sections located northeast of the town of Merzane that, together with the localities mentioned by Van Roy (2006) and MacGabhann (2012: M001 and M003), are located between 11.5 and 17.7 km east-southeast of the city of Erfoud (= Arfouf).

The Upper Tiouririne Formation mainly consists of ca. 50–140 m of medium- to coarse-grained, grey-brown sandstones, interbedded with sandy mudstones and some microconglomeratic horizons mainly of intraformational origin. It has been sedimentologically studied (a. o.) by Álvaro et al. (2007), Colmenar and Álvaro (2015) and Meddour (2016), and its most striking features are the record of slightly mineralised and soft-bodied fossils, including paropsonemid eldonioids, aglaspidid arthropods and problematic taxa (Van Roy 2006, MacGabhann 2012), which are exceptionally preserved in several of the massive sandstone beds (Tafilalt Biota). This 'Ediacara-type' preservation is linked to episodes of very rapid, possibly storm-influenced burial, of organisms with biopolymeric tissues preserved in special microbially bound substrates (MacGabhann et al., 2019).

Commonly associated with the extraordinary fossils of the Tafilalt Biota, and occurring in the same or adjacent strata, are prominent trace fossils of the Upper Tiouririne Formation, consisting of winding horizontal burrows that are composed of inclined, densely aligned knobby sediment aggregates, which appear along the upper bedding plane as characteristic beaded strings (Fig. 1A–G). These large burrows can be assigned to *Neoeione moniliformis* (Tate) and probably originated by the probing activity of a deposit-feeding animal. *N. moniliformis* was originally described from the Carboniferous of the UK (Boyd and McIlroy, 2018), and the occurrence from the Ordovician of Morocco is one of the oldest records of this ichnotaxon.

The trace-fossil association is diverse and pending detailed investigation. The following ichnotaxa could be identified: *Arenicolites* isp.; *Arthraria antiquata* Billings (Fig. 2C), *Arthrophycus brongniartii* (Harlan), *Asteriacites* cf. *lumbricalis* von Schlotheim (Fig. 2A), *Asterichnus lawrencensis* Bandel, *Cheiichnus* isp., *Cruziana problematica* (Schindewolf), *Cruziana* isp. (Fig. 2B), *Curvolithus simplex* Buatois *et al*., *Diplocraterion parallelum* Torell, *Gyro-*

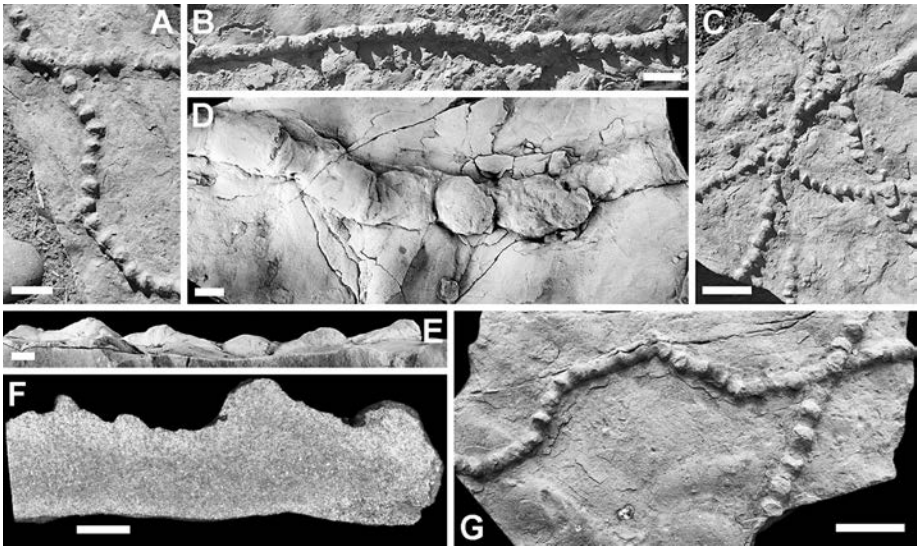

Fig. 1. *Neoeione moniliformis* (Tate) from the Upper Tiouririne Formation (Katian, eastern Moroccan Anti-Atlas).

A–C, G – photographs of some long specimens preserved in full relief and as convex epichnia. D–E – a wide trace in top (D) and lateral (E) views; F – longitudinal section between three consecutive knobs showing massive sand infill. Scale bars, 50 mm (A–C, G) and 10 mm (D–F).

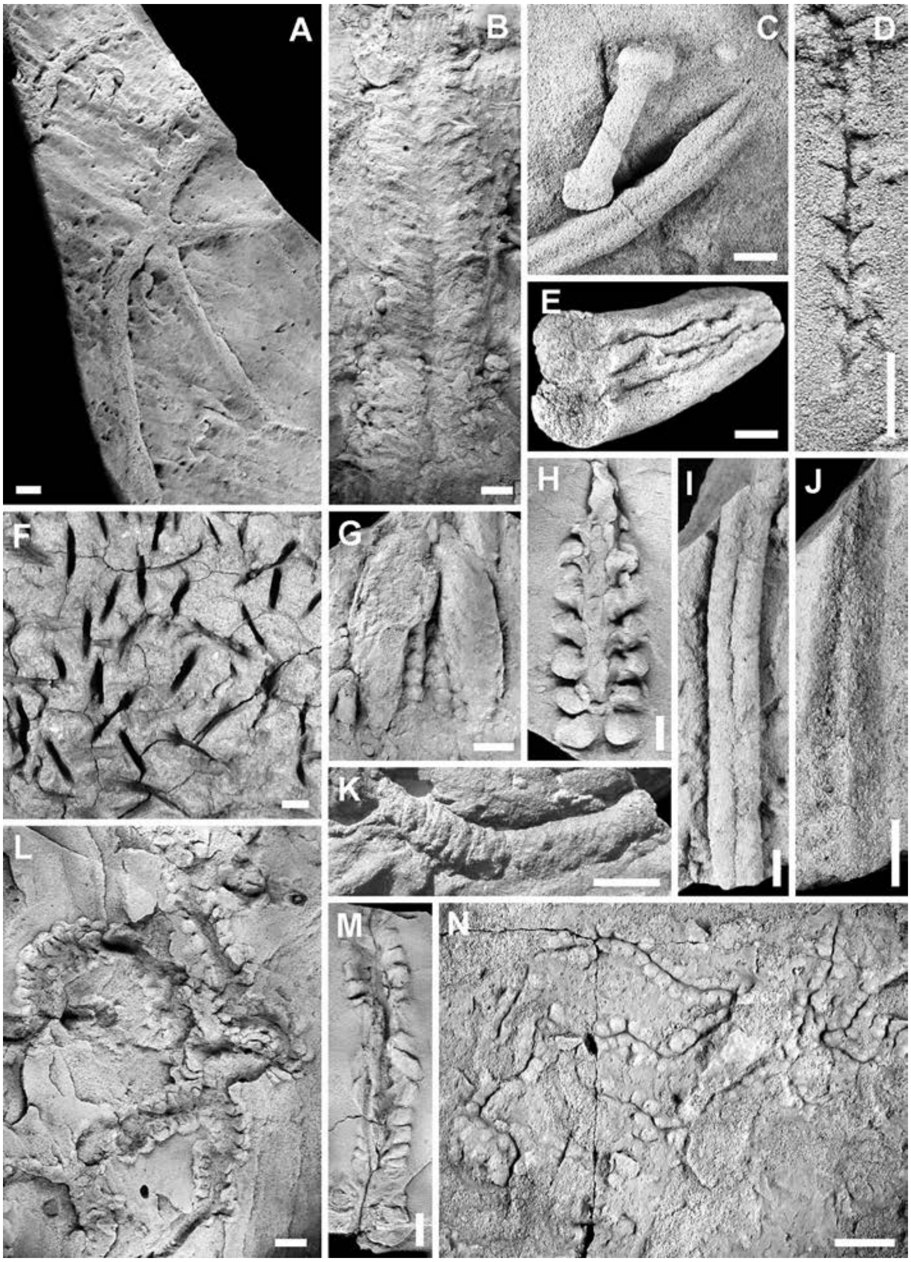

Fig. 2. Trace fossils from the Upper Tiouririne Formation (Katian, eastern Moroccan Anti-Atlas).

A – *Asteriacites* cf. *lumbricalis* von Schlotheim; B – *Cruziana* isp.; C – *Arthraria antiquata* Billings (upper left) and *Cruziana* isp.; D – *Protovirgularia dichotoma* M'Coy; E – *Teichichnus rectus* Seilacher, a burrow fragment in oblique-lateral view; F – *Heughia gregaria* Smith; G – *Rusophycus carleyi* (James); H – *Nereites* cf. *irregularis* (Schafhäutl) in hyporelief preservation; I-J – *Gyrochorte comosa* Heer in epi- (I) and hyporelief (J) preservation; K – *Taenidium barretti* (Bradshaw); L – *Nereites* cf. *irregularis* (Schafhäutl) in epirelief preservation; M – *Nereites pugnus* Emmons; N – *Nereites macleayii* (Murchison). Scale bars, 10 mm (A, B, F, G, K–N) and 5 mm (C–E, H–J).

chorte comosa Heer (Fig. 2I-J), *Heughia gregaria* Smith (Fig. 2F), *Nereites* cf. *irregularis* (Schafhäutl) (Fig. 2H, L), *N. macleayii* (Murchison) (Fig. 2N), *N. pugnus* Emmons (Fig. 2M), *Oravaichnium hrabei* Plička and Uhrová, *Protovirgularia dichotoma* M'Coy (Fig. 2D), *P. rugosa* (Miller and Dyer), ?*Ptychoplasma conica* Pieńkowski and Uchman, *Taenidium barretti* (Bradshaw) (Fig. 2K), *T. serpentinum* Heer, *Teichichnus rectus* Seilacher (Fig. 2E), *Rusophycus carleyi* (James) (Fig. 2G) and *Rusophycus* isp.

This trace-fossil association is characteristic for a shallow-marine, probably shoreface environment, and the relatively high ichnodiversity is indicative of favourable living conditions for the benthic organisms.

Acknowledgments

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FIRST RECORD OF LOWER ORDOVICIAN GRAPTOLITES FROM PERU

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Key words: *Central Andean Basin, Graptolite biostratigraphy, Correlation, Ordovician, Peru.*
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Ordovician graptolites from Peru were early described or illustrated by Newton (1901), Lapworth (1917), Steinmann (1929) and Bulman (1931), having later been reported from a number of localities of the Cordillera Oriental and a single place in the Amazonian Basin. Maletz et al. (2010) provided a review of all known occurrences and concluded that Ordovician faunas of Peru are restricted to a short interval in the Middle to basal Upper Ordovician (*Levisograptus austrodentatus* to *Nemagraptus gracilis* biozones). The only confirmed occurrence of Lower Ordovician fossils from Peru are the upper Floian conodonts and shelly faunas reported from the lower part of the San José Formation in the Inambari river section north of San Gabán (Gutiérrez-Marco et al., 2008), lacking graptolites. In a different area, the same formation recently provided interesting occurrences of Tremadocian and Floian graptolites, which we have identified as the oldest fossils from Peru. Preliminary information on this material is provided in this contribution.

The studied material originates from three nearby sections on the northeastern margin of the Apurímac River valley, ca. 80 km northeast of the city of Ayacucho. The San José Formation is here up to 700 m thick and lies unconformably upon a Neoproterozoic metamorphic complex. Its lower (but not basal) part has yielded Tremadocian to Floian graptolites. These are overlain by beds locally rich in shelly faunas documenting the existence of Darriwilian and lower Sandbian strata towards the middle and upper part of the formation. The sections here investigated are, from northwest to southeast, named Libertad (LIB), in the mountain trail between this hamlet and the city of Pichari; Catarata (CAT) and Nueva Alianza (NA), in the mountain trail between Oroya and the last hamlet; and Kimbiri (K), in the trail parallel to the Kashiroveni stream north of the village of Kimbiri Alto.

The oldest studied graptolites come from Km 8 of the trail from Catarata to Nueva Alianza (locality NA-1) and belong to the *Araneograptus murrayi* Biozone of the upper Tremadocian. The assemblage includes *Araneograptus murrayi* (Hall) (Fig. 1A), *Paradelograptus*? sp. 1 (with large proximal end and considerable webs, Fig. 1B), *Paradelograptus*? sp. 2 (small tubaria with slender stipes and low inclined thecae), *Paratemnograptus* sp., *Clonograptus* cf. *rigidus* (Hall), *Tetragraptus* sp. 1 (a three- to four-stiped reclined form, Fig. 1E), and ‘*Kiaerograptus*’ *supremus*? Lindholm (Fig. 1C–D).

The succeeding *Hunnegraptus copiosus* Biozone of the uppermost Tremadocian is still unidentified, but the *Tetragraptus phyllograptoides* Biozone of lowermost Floian age, is represented by the bed K0-A at Kimbiri. The assemblage comprises *Tetragraptus phyllograptoides* Strandmark (probably an early form with short part of fused stipes, Fig. 1I–J), *Paratetragraptus approximatus* (Nicholson) (Fig. 1F), *Clonograptus multiplex* (Nicholson) (a quite robust species with widely spaced branching, Fig. 1G–H), *Cymatograptus* cf. *demissus* (Törnquist) and undetermined expansograptids.

The *Cymatograptus protobalticus* Biozone is reported from beds K0-A/top and K0-B at Kimbiri, and is perhaps represented in the sample NA-2. The graptolite assemblage from Kimbiri includes *Cymatograptus protobalticus* (Monsen) (Fig. 1K–L), *Baltograptus geometricus* (Törnquist) (Fig. 1N), *Expansograptus* cf. *pusillus*? (Törnquist), *Corymbograptus v-fractus tullbergi*? (Monsen), *Clonograptus multiplex* (Nicholson) and *Tetragraptus amii* Elles & Wood. On the other hand, in the locality Nueva Alianza 2 the biozone is tentatively recognized by the occurrence of *C.* cf. *protobalticus*, *B. geometricus* (Fig. 1M), *B.* aff. *geometricus* (a slightly more robust form, with possibly a higher origin of th1^1), *Baltograptus turgidus* (Lee) (Fig. 2A–B), *Expansograptus* sp., *Acrograptus* sp. and *Clonograptus*? *subtilis* Törnquist. However, the record of *B. turgidus* and a poor specimen of *Expansograptus* resembling either *E. suecicus* (Tullberg) or *E. holmi* (Törnquist), leave open the possibility that NA-2 could span the boundary between the *C. protobalticus* and *B. vacillans* biozones.

The younger Lower Ordovician graptolites recorded from the studied area may be referred to the *Baltograptus minutus* Biozone of the middle Floian, which has been recognized in the Libertad and Kimbiri sections. Its lower assemblage is defined by the presence of *Baltograptus deflexus* (Elles & Wood) (quite typical specimens, Fig. 2H) plus other forms with a fairly long pendent proximal end, which in early stages can be confused with *B. minutus*, Fig 2C, D), *Didymograptellus bifidus* (Hall) (Fig. 2F–G), *E.* cf. *suecicus* (with somewhat reflexed proximal end and long vertical sicula), *T. amii*? (horizontal, slender stipes), *Tetragraptus* sp. 2 (horizontal, with strong proximal web), and

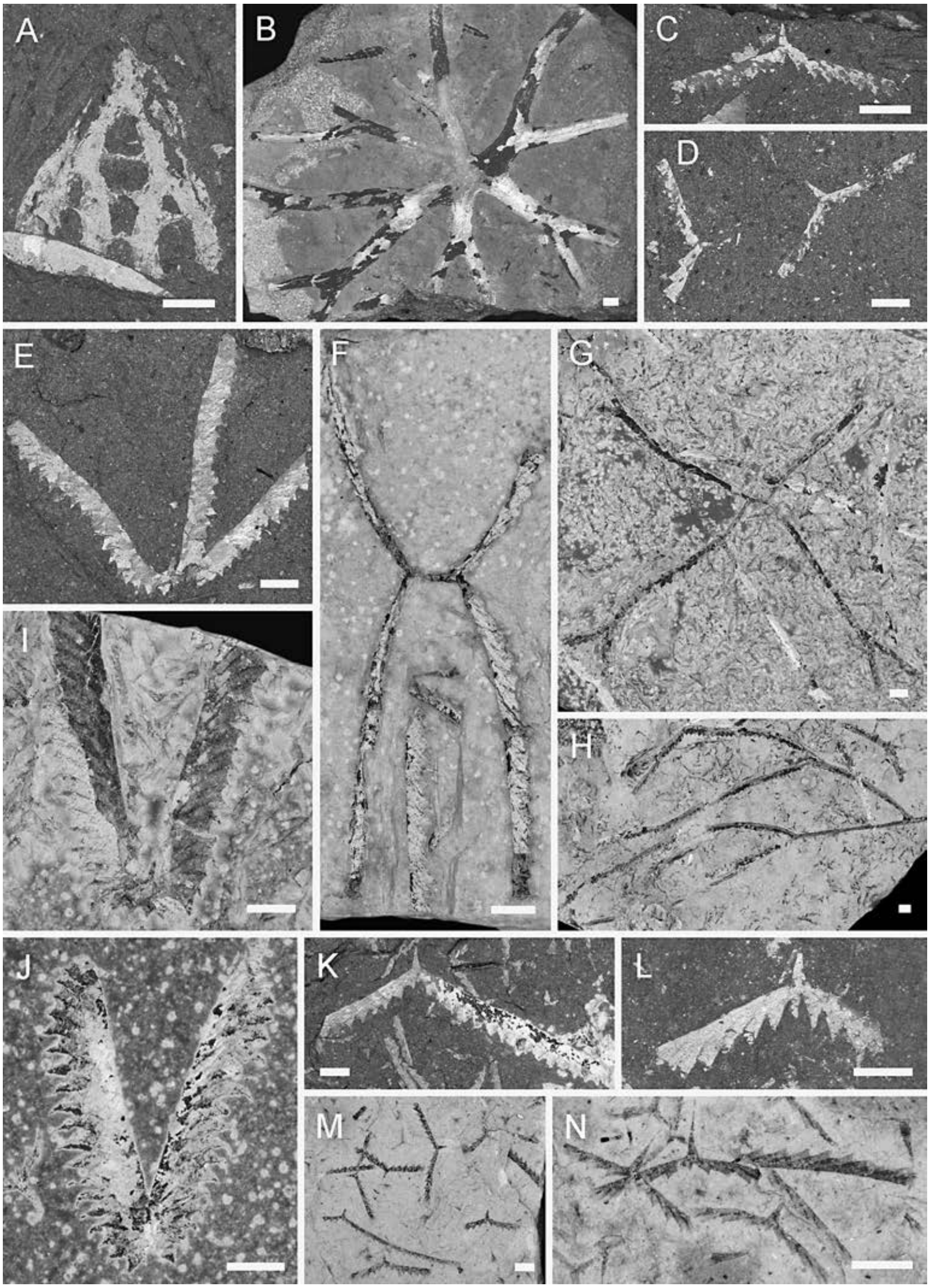

Fig. 1. A – *Araneograptus murrayi* (Hall); B – *Paradelograptus*? sp.1; C–D – *Kiaerograptus supremus*? Lindholm; E – *Tetragraptus* sp. 1; F – *Paratetragraptus approximatus* (Nicholson); G–H – *Clonograptus multiplex* (Nicholson); I–J – *Tetragraptus phyllograptoides* Strandmark; K–L – *Cymatograptus protobalticus* (Monsen); M–N – *Baltograptus geometricus* (Törnquist). A to E from locality NA-1; F to J from K0-A; K, L and N from K0-B, M from NA-2. Scale bars, 2 mm.

Dichograptus octobrachiatus (Hall) (specimens with 6-8 stipes and a strong proximal web, Fig. 2I). Above these beds, *B.* cf. *deflexus* is associated with *Pseudophyllograptus* gr. *densus* (Törnquist) (locality CAT-1, Fig. 1E) and higher up *B.* cf. *kurcki* (Törnquist) plus *B. minutus* (Törnquist) are recorded (K-2 and K-4 beds), then *B. kurcki* (bed K-6), and long specimens of *Pseudophyllograptus* sp. (beds K-3, K-8 and K-11). In the overlying strata no younger Floian or Dapingian graptolites have been recognized.

Besides the Apurímac River valley, in the Inambari River section where the Floian strata are largely dominated by shelly faunas, Lower Ordovician graptolites are represented by the single occurrence of *Tetragraptus amii*, which comes from shales directly above the limestone bed bearing conodonts of the *Oepikodus evae* Biozone (Gutiérrez-Marco et al., 2018).

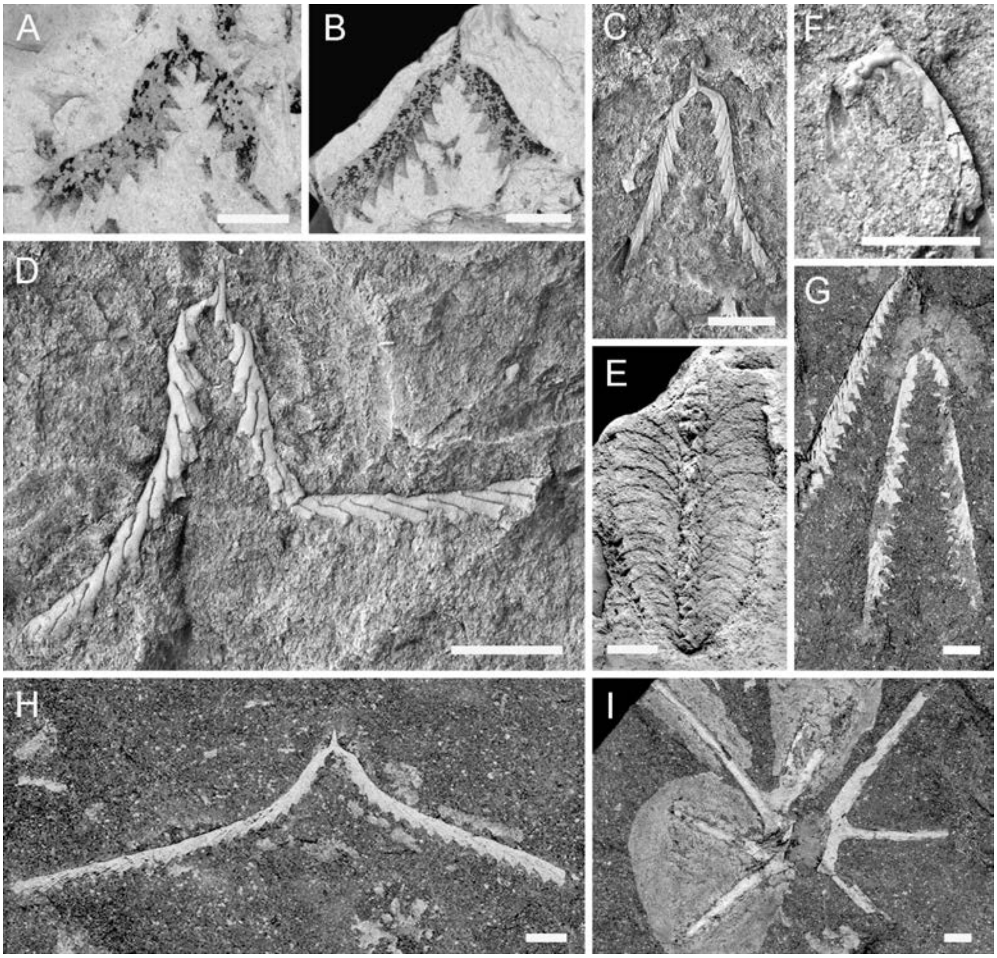

Fig. 2. A–B – *Baltograptus turgidus* (Lee); C–D – *Baltograptus deflexus* (Elles & Wood) pyritized, reverse and obverse views with long pendent part; E – *Pseudophyllograptus* ex gr. *densus* (Törnquist); F–G – *Didymograptellus bifidus* (Hall); H – *B. deflexus* (Elles & Wood); I – *Dichograptus octobrachiatus* (Hall). A–B from locality NA-2; C, D and H from LIB; E from CAT and F–G from K-1. Scale bars, 2 mm.

The Tremadocian to Floian graptolite assemblages from the Cordillera Oriental of Peru constitute the northernmost record of Lower Ordovician graptolites in the Central Andean Basin of South America. Complete graptolite sequences from NW Argentina, the northern Chilean border and south Bolivia (e.g., Egenhoff et al., 2004, Vento et al., 2013, Albanesi & Ortega, 2016 and references cited therein) make a regional biostratigraphic correlation with the Peruvian assemblages possible. Thus, the upper Tremadocian *A. murrayi* and basal Floian *T. phyllograptoides* biozones have their counterparts both in Bolivia and Argentina. Above the latter, our *C. protobalticus* Biozone can be correlated with the homonymous biozone of Bolivia (Egenhoff *et al*. 2004) or with the rather equivalent *Tetragraptus akzharensis* Biozone of Argentina (Toro et al., 2015, Albanesi & Ortega, 2016), whereas the record of some taxa in the upper beds of locality NA-2 could be indicative of younger strata at the base of the *B.* cf. *deflexus* [= *B. jacksoni*] Biozone of Argentina/*E. holmi* Biozone of Bolivia. Finally, the *B. minutus* Biozone of Peru can be correlated with the *D. bifidus* Biozone of Argentina or with the *B. minutus* Biozone of Bolivia, where *D. bifidus* is however absent. The biostratigraphic scheme of the Lower Ordovician of Peru is also quite similar to the Baltic graptolite zones described by Maletz & Ahlberg (2011, 2018), even though *D. bifidus* has not been reported.

From a palaeoecological and palaeogeographical perspective, the studied assemblages are dominated by a mixture of deep water, pandemic (*Araneograptus, Paratemnograptus, Paradelograptus, Paratetragraptus, Clonograptus*) and shallower, endemic forms by the late Tremadocian and early Floian (*Baltograptus, Cymatograptus, Didymograptellus*). Starting from the *C. protobalticus* Biozone, graptolites are indicative of a general shallowing of the sequence, showing a decreasing percentage of pandemics (*D. octobrachiatus, T. amii, Expansograptus* spp.) and an abundance of endemic forms characteristic of cold to temperate inshore settings of Gondwana and Baltica, something similar to those observed in the southern part of the Central Andean Basin by Vento *et al.* (2014).

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MONSAGRO (SALAMANCA, SPAIN): AN 'ORDOVICIAN VILLAGE' BUILT WITH CRUZIANA AND OTHER TRACE FOSSILS FROM THE ARMORICAN QUARTZITE

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Key words: *trace fossils, Ordovician, Geotourism, Geological heritage, Urban geotrail.*

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There is an 'Ordovician village' in the world and it is in Spain (40° 30′ 12″ N, 6° 16′15″ W). It is called Monsagro and is located in the mountains of the province of Salamanca, not far (45 km) from the border with Portugal (Fig. 1).

Monsagro is a small municipality with a population of less than 150 inhabitants. It is part of the Natural Park of Las Batuecas – Sierra de Francia, a protected natural space of great environmental and tourist value, renown especially for the nearby Church-Sanctuary of Our Lady of the Peña (= rock hill) of France, built between the 15th and 18th centuries in the highest peak of the region (1,728 m). The foundation of Monsagro goes back to the repopulation instigated by the kings of León in the Middle Age. It was then that the original settlers began to build their houses using the abundant blocks of loose stones derived from the high peaks of Ordovician quartzites that surround the locality, mainly in the north.

Towards the middle of the 19th century, Madoz (1848) described the village as follows: 'Monsagro is in very rugged terrain surrounded by very steep rocky slopes [...] it consists of 112 houses poorly built, usually two-story, the lower level is used to gather the cattle […] communicated by paths with horseshoe curves […] 443 inhabitants'.

From generations, the loose blocks of Ordovician quartzite collected in the colluvial deposits that descend from the hillsides of the northern mountains have been used by the inhabitants of Monsagro to build their houses. But what makes this town different is that the presence of ichnofossils or nice sedimentary structures in many of these stones

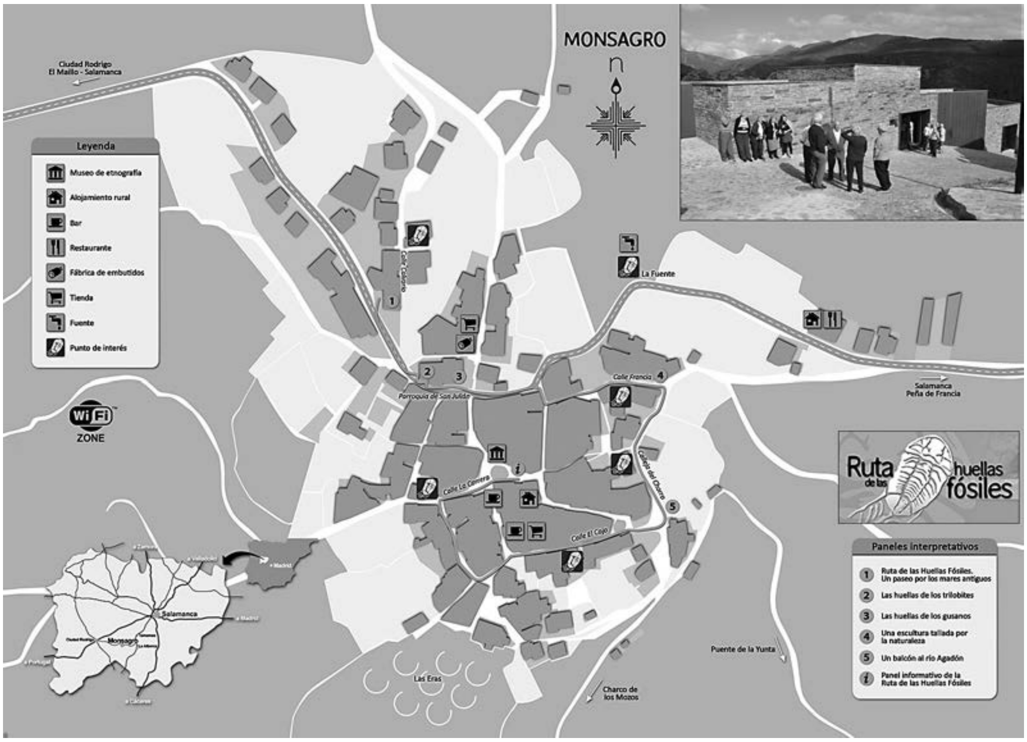

Fig. 1. Monsagro street map showing the official georoute of the trace fossils, with the location of the interpretive panels and other points of interest. In the upper right corner is a photograph of the exterior of the 'Museum of the Ancient Seas'.

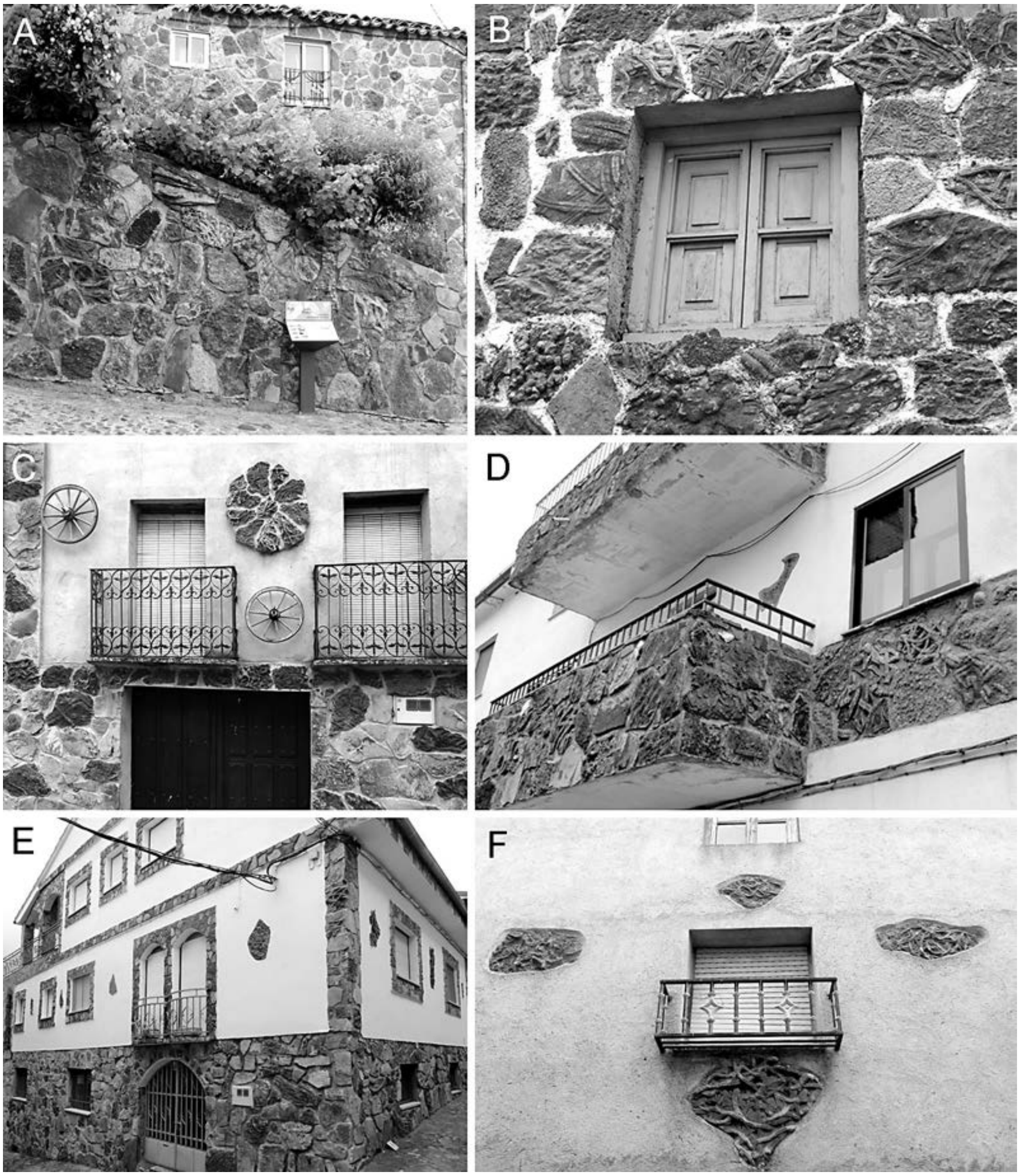

Fig. 2. A – interpretative panel of trace fossils recognized in the adjacent building stones. B–F – facades built in different epochs to show alternative modes or ornament with Armorican Quartzite blocks containing beautiful specimens of *Cruziana*.

did not go unnoticed and a selective search was launched for ornamental purposes. And, instead of building with the smooth and homogeneous parts of the stone blocks facing outwards, in Monsagro the trace fossils and the ancient ripple marks were set to be shown to the observer, in an attempt to embellish the facades, the streets, the communal fountains and even the walls of the church. Fig. 2 shows a selection of rustic architecture examples with different prominence of the trace fossils as ornamental elements on the facades of the houses. The result is an authentic 'ichnological festival' that is recently being implemented with great success by the authorities and has turned Monsagro into one of the most unique geotourism destinations in Spain.

From the geological point of view, the source of the fossiliferous blocks are the outcrops of the Armorican Quartzite sensu lato (units II and III of Bascones Alvira and Rodríguez-Alonso, 1990) that constitute the Sierra del Guindo immediately north of Monsagro. These correspond to the southern flank of the Variscan Peña de Francia syncline. The Armorican Quartzite is one of the most characteristic units of the Palaeozoic of southwestern Europe, being represented in the Lower Ordovician succession over most of the Iberian Peninsula (Gutiérrez-Marco et al. 2002). It comprises shallow marine deposits rich in trace fossils of the *Skolithos* and *Cruziana* ichnofacies, being representative of a mainly transgressive sequence developed during the Floian.

The first scientific mention about the presence of quartzites with *Cruziana* and *Skolithos* in Monsagro is due to Gil y Maestre (1880, p. 152), but almost all subsequent studies were concentrated in the area of the Peña de Fran-

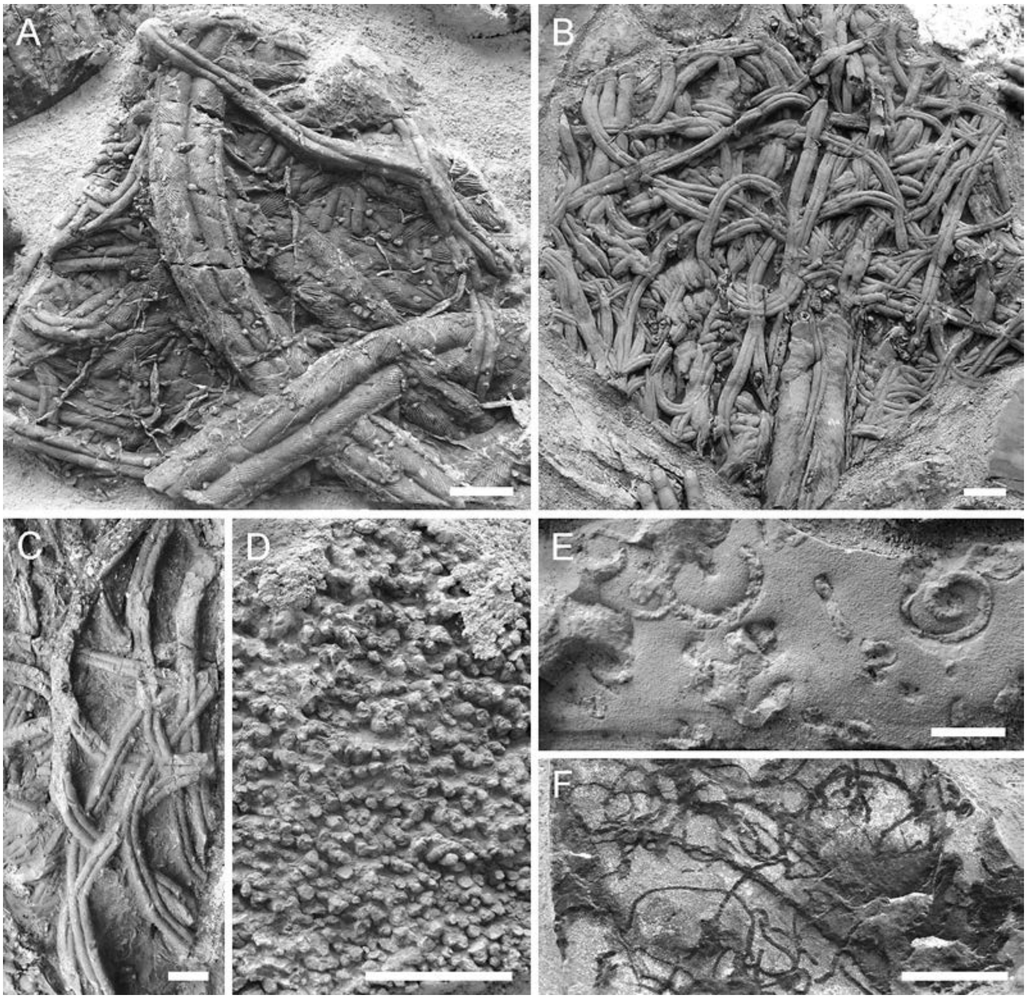

Fig. 3. Examples of Lower Ordovician trace fossils preserved on the walls.
A – overlapping specimens of *Cruziana goldfussi* and *C. furcifera*, cross-cut by *Skolithos*, *Palaeophycus* and *Lockeia*; B – Outstanding concentration of narrow elongated, ribbon specimens of *C. goldfussi* –partly with a scribble-like pattern, and in a single interaction with the large *C. rugosa/furcifera* of centre down; C – circling to sinusoidal behaviour of deep ploughing specimens of *C.* cf. *goldfussi*; D – 'pipe-rock' formed by *Skolithos linearis* Haldeman; E – transverse sections of *Daedalus desglandi* (Rouault); F – id. of *D. halli* (Rouault). Scale bars, 50 mm.

cia, in the continuity of the Sierra del Guindo about 8.5 km to the east (Hernández-Pacheco, 1910; Meléndez, 1954; Kindelán y Duany, 1957; Pickerill et al., 1984). The latter paper includes the description of representatives of a dozen ichnogenera, among which are described three ichnospecies of *Cruziana*.

Thanks to the use of blocks with ichnofossils as building material, the streets of Monsagro are a true open-air museum for tourists and also for scientists, often with well-preserved specimens that are very difficult to find in situ in the natural outcrops.

The most attractive blocks which were selectively collected by the inhabitants of Monsagro as building material are, by far, the surfaces of all sizes covered by *Cruziana* and few other elements of the *Cruziana* ichnofacies. We recognized among them the following ichnotaxa:

Cruziana furcifera d'Orbigny, *C. rugosa* d'Orbigny (Fig. 3B), *C. goldfussi* (Rouault) (Fig. 3A), *C. rouaulti* Lebesconte, *C. problematica* (Schindewolf), *Rusophycus* cf. *latus* Webby, *Rusophycus* ispp., *Didymaulichnus* isp., *Monomorphicnus* isp., *Diplichnites* isp., *Teichichnus* isp. and *Palaeophycus tubularis* Hall. The *Skolithos* ichnofacies is also represented in some blocks by the presence of *Skolithos linearis* Haldeman (both occurring as individual burrows or in dense clusters as 'pipe rocks', Fig. 3D), *Daedalus desglandi* (Rouault) (Fig. 3E), *D. halli* (Rouault) (Fig. 3F), *Monocraterion*? isp., *Rosselia*? isp., *Arenicolites* cf. *sparsus* Salter, *Bergaueria* sp. and *Lockeia* isp., which are preferably seen as transverse sections of vertical traces.

Besides the trace fossils, other surfaces of the blocks incorporated to the walls show a variety of wrinkle structures related to microbial mats, linguoid and interference wave and oscillation ripples, load structures, mineral crusts, etc.

In order to disseminate the geological heritage of Monsagro and the marine nature of the rocks forming the area, a 630 m long georoute across the village was created in 2015 (Martínez-Graña et al., 2017a, b). The aim of this activity is also to encourage the visit of tourists to a mountain region with serious problems of depopulation, and attempt to improve its local socio-economic development through geotourism and job creation. Under the logo of a *Cruziana* and the trilobite that made it, the georoute was called "Route of the Trace Fossils" (Fig. 1). It comprises six outdoor selected locations for setting various educational-interpretive panels written in both Spanish and English, 50 × 34 cm in size (Fig. 2A). Three of them are dedicated to the most spectacular trace fossils, two others of greater size (168 × 147 cm) to the beginning and ending points of the route, and one at a gazebo with a panoramic view of the surrounding relief and the remarkable tourist landmark that is the Peña de Francia. For optional visits, another additional six points of geological interest, outside the georoute, were indicated as landmarks at ground level, as well as a number of eye level directional signs indicating the correct sense of the visit. The classical methodology of signage and explanation was complemented with the publication of a pocket-sized folding brochure to facilitate the advertising of the georoute in tourist offices, community centres, etc., offering a guide of complementary tourist attractions and to publicize the village of Monsagro. Also a 'Museum of the Ancient Seas' was recently inaugurated to explain the marine past of the area (Fig. 1). But the digital technologies applied here to geotourism constitute one of the experiences with the widest impact, especially amongst the youngsters. Thus, every panel includes one or more QR codes that, using the free Wi-Fi of the village, provide complementary information in the form of videos, pdf documents and photographs. The other resources created for digital multimedia entertainment were an interactive Geoapp and two video games of paleontological content dealing with Ordovician seas, and also a virtual reality presentation in the museum.

As summarized by Martínez-Graña et al. (2017b) in Monsagro, in an entertaining way, we can take a journey into the past discovering traces of different marine organisms and processes on a cold-water sea-floor 475 million years ago, when the proto-Iberia was located at a high latitude in a different hemisphere, and we can imagine how it has journeyed to its current position due to continental drift.

Acknowledgments

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THE FOUNDING OF THE ORDOVICIAN SYSTEM: THE LEGACY OF CHARLES LAPWORTH FRS LLD FGS (1842–1920)

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Key words: *Ordovician System, Charles Lapworth, graptolites.*

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This year marks the 140th anniversary of the founding of the Ordovician System by Charles Lapworth, an action taken while assistant master at Madras College, St. Andrews, prior to his appointment as professor of geology in Mason Science College, Birmingham. Lapworth's contributions to palaeontology and stratigraphy are fundamental and lasting. These significant and substantial contributions were recognised by a Fellowship of the Royal Society, the Bigsby and Wollaston medals from the Geological Society, and the Royal Medal from the Royal Society, itself. In over 60 scientific papers, published between 1870 and 1910, Lapworth captured five main areas of contemporary 19th and early 20th century science. First, his detailed taxonomic work on graptolite (*Rhabdophora*) fossils, their classification, distribution and morphology, provided an unparalleled understanding of the evolution of this group, exposing changes in genera and species through successive strata, and their utility in constructing zonal sequences. Second, this focus on the classification and morphology of graptolites led to their use as a means of correlating strata, initially in the perplexing rocks of the Southern Uplands of Scotland (proving the inversion of strata in a complex tectonic belt), later in Wales, the English Lake District together with Northern Ireland and Scandinavia. His investigation of the stratigraphy of the thick Girvan Succession, highlighted the intercalation of the graptolite biofacies of the slope and the shelly biofacies of the deeper shelf, and thus provided a means to correlate strata deposited in basins (e.g. the graptolitic Moffat Succession to the south) and those on the platform through intermediate sections. Third, the use of fossils in tectonic belts such as the Northwest Highlands of Scotland (the Highland Controversy), allowed the recognition of repetition of strata by folding (although these repetitions were later ascribed to thrust duplexes) and the superposition of older rocks over younger strata, confirming horizontal movements within the Earth's crust, on an Alpine scale. Four, venturing out from Birmingham to Warwickshire and Shropshire, Lapworth established a Cambrian age for some of the strata previously referred to the Carboniferous, established the widespread distribution of the lower Cambrian *Olenellus* trilobite fauna and correlated these strata with coeval units in North America.

Arguably, however, his most enduring and influential paper introduced the tripartite classification of the Lower Palaeozoic, ending a long and bitter feud between the once good friends, Professor Adam Sedgwick and Sir Roderick Murchison. In short, the transitional belt between Sedgwick's Cambrian and Murchison's Silurian was assigned to Lapworth's Ordovician System.

North Wales itself – at all events the whole of the great Bala district where Sedgwick first worked out the physical succession among the rocks of the intermediate or so-called Upper Cambrian or Lower Silurian system; and in all probability much of the Shelve and the Caradoc area, whence Murchison first published its distinctive fossils – lay within the territory of the Ordovices. Here, then, have we the hint for the appropriate title for the central system of the Lower Palaeozoics. It should be called the Ordovician System, after this old British tribe. Lapworth, 1879.

The Lower Palaeozoic was thus described (Lapworth, 1879) as three chronostratigraphical units:

(c) SILURIAN SYSTEM:– Strata comprehended between the base of the *Old Red Sandstone* and that of the *Lower Llandovery*.

(b) ORDOVICIAN SYSTEM:– Strata included between the base of the *Lower Llandovery* formation and that of the *Lower Arenig*.

(a) CAMBRIAN SYSTEM:– Strata included between the base of the *Lower Arenig* formation and that of the *Harlech Grits*.

Initially the Ordovician was, actually defined in terms of basal stratotypes those between the base of the Lower Arenig and the Lower Llandovery, rather than on faunal content. This provided a framework that over the next few decades included, in ascending order the Arenig, Llanvirn, Llandeilo, Caradoc and Ashgill series, becoming the international standard for the system. This was a far cry from the truly global system we have today, including the Tremadocian as the basal of seven international stages (Bergström et al., 2008). In recent years, the International Subcommission on Ordovician Stratigraphy working closely with several IGCP projects has focused on biotic, climatic and environmental change (e.g. Harper and Servais, 2018; Munnecke et al. 2010; Servais and Owen, 2010) through the period together with its shifting palaeogeography (e.g. Harper and Servais, 2013). Lapworth's legacy lives on!

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EARLY PALAEOZOIC DIVERSIFICATIONS AND EXTINCTIONS IN THE MARINE BIOSPHERE: ONWARDS AND UPWARDS

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Key words: *Cambrian Explosion, Great Ordovician Biodiversification, palaeoecosystems, palaeoclimate, palaeoenvironments, single trajectory*

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A new interrogation of global biodiversity curves of marine organisms indicates that, despite fluctuations in amplitude, a single, continuous, large-scale, long-term radiation of life occurred during the Early Palaeozoic. This major biodiversification was initiated in the late Precambrian and was only finally concluded in the Devonian. The curve captures both the high-profile Cambrian 'Explosion' and the Great Ordovician Biodiversification 'Event' coincident with the establishment of modern climate and marine ecosystems. Both occurred during the continuous establishment of organisms and their ecological communities, developed during the 'Cambrian substrate revolution', the 'Ordovician plankton revolution', the 'Ordovician bioerosion revolution' and the 'Devonian nekton revolution.' At a smaller scale, different regional radiations are apparent and some have been identified and named (e.g. the 'Richmondian Invasion' during the Late Ordovician in Laurentia and the contemporaneous 'Boda Event' in parts of Europe and North Africa), in particular from areas that were in or moved towards lower latitudes permitting high levels of speciation in epicontintental seas. Datasets are incomplete for many parts of the globe, but also for particular time intervals (e.g. during the late Cambrian 'Furongian Gap'). The trajectory of Early Palaeozoic biodiversification appears thus to be a long-term, but single process where its progressive character will be better exposed and understood by more complete datasets and better analytical techniques.

LOWER-MIDDLE ORDOVICIAN GRAPTOLITE BIOSTRATIGRAPHY AND FUTURE CHALLENGES FOR THE CENTRAL ANDEAN BASIN (NW ARGENTINA AND S BOLIVIA)

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Key words: *Ordovician, Biostratigraphy, Graptolites, Argentina, Bolivia.*
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The aim of this work is to present an updated biostratigraphic framework based on Floian and Dapingian graptolites from the Central Andean Basin, with a regional and global correlation. The analysis of key graptolites, coming from seventeen stratigraphic sections exposed in northwestern Argentina and southern Bolivia (Fig. 1), also highlight remaining problems to solve.

Tetragraptus phyllograptoides *Biozone* (Lower Fl1). This biozone, previously known exclusively from Scandinavia, was first described in the Central Andean Basin at the Los Colorados area, Cordillera Oriental, Argentina. The geographic distribution of this interval was later expanded to the Santa Victoria, El Moreno, Cajas and Aguilar ranges, and probably to the La Ciénaga de Purmamarca section (Toro and Vento, 2013; Toro et al., 2015; Navarro et al., 2018 and references therein). The authors assigned the bearing levels with *T. phyllograptoides* (Fig. 2.1), *Paratetragraptus approximatus* (Fig. 2.10), *Clonograptus multiplex*, *Cymatograptus rigoletto* and *C. demissus* to the earliest Floian (Fl1), as occurs in Scandinavia (Maletz and Alberg, 2011). This biostratigraphic unit is regionally correlated with the *T. phyllograptoides* Biozone from the Cieneguillas1 section, at southern Bolivia (Egenhoff et al., 2004); while a global correlation with the *P. approximatus* Biozone of North America (Williams and Stevens, 1988) and South China (Zhang et al., 2019) is also proposed (Fig. 3).

Tetragraptus akzharensis = Cymatograptus protobalticus *Biozone* (Upper Fl1). This interval was first described at the Los Colorados area by the presence of the eponymous species (Fig. 2.6) associated with *Expansograptus constrictus*. Later, it was extended to the Santa Victoria area, in the Cordillera Oriental Argentina (Toro et al., 2015 and references therein). Afterward, Toro and Vento (2013) reviewed this unit at the Sierra de Aguilar, discussing in-depth its distribution in northwestern Argentina and global correlations. Further records of *Baltograptus vacillans* (Fig. 2.12), *B. geometricus* (Fig. 2.7) and *C. rigoletto* indicate a correlation between this interval and the *T. akzharensis* Biozone, recently identified at the La Ciénaga de Purmamarca section (Navarro et al., 2018 and references therein). The *T. akzharensis* Biozone is regionally correlated with the *C. protobalticus* Biozone from the Cieneguillas1 section, at southern Bolivia (Egenhoff *et al*., 2004). It is globally correlated with the eponymous Biozone of North America (Williams and Stevens, 1988), the *C. protobalticus* and *B. vacillans* biozones of Scandinavia (Maletz and Alhberg, 2011) and the *T. fruticosus*/*A. filiformis* Biozone of South China (Zhang et al., 2019) (Fig. 3).

Baltograptus cf. B. deflexus = Expansograptus holmi *Biozone* (Fl2). This unit was

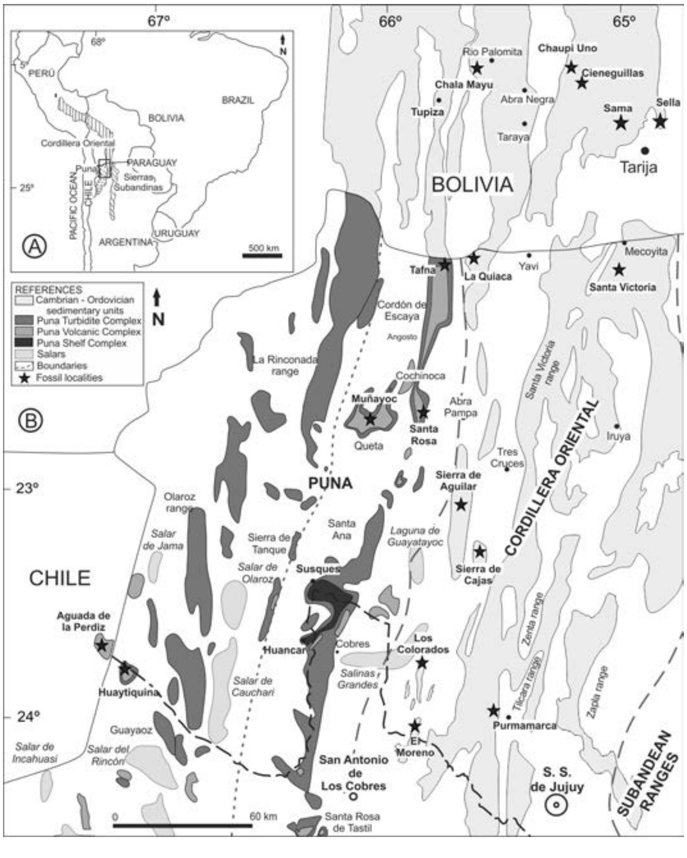

Fig. 1. A. Location map of the geomorphological provinces comprised in the Central Andean Basin. **B.** Location map of the Ordovician deposits and studied fossiliferous localities.

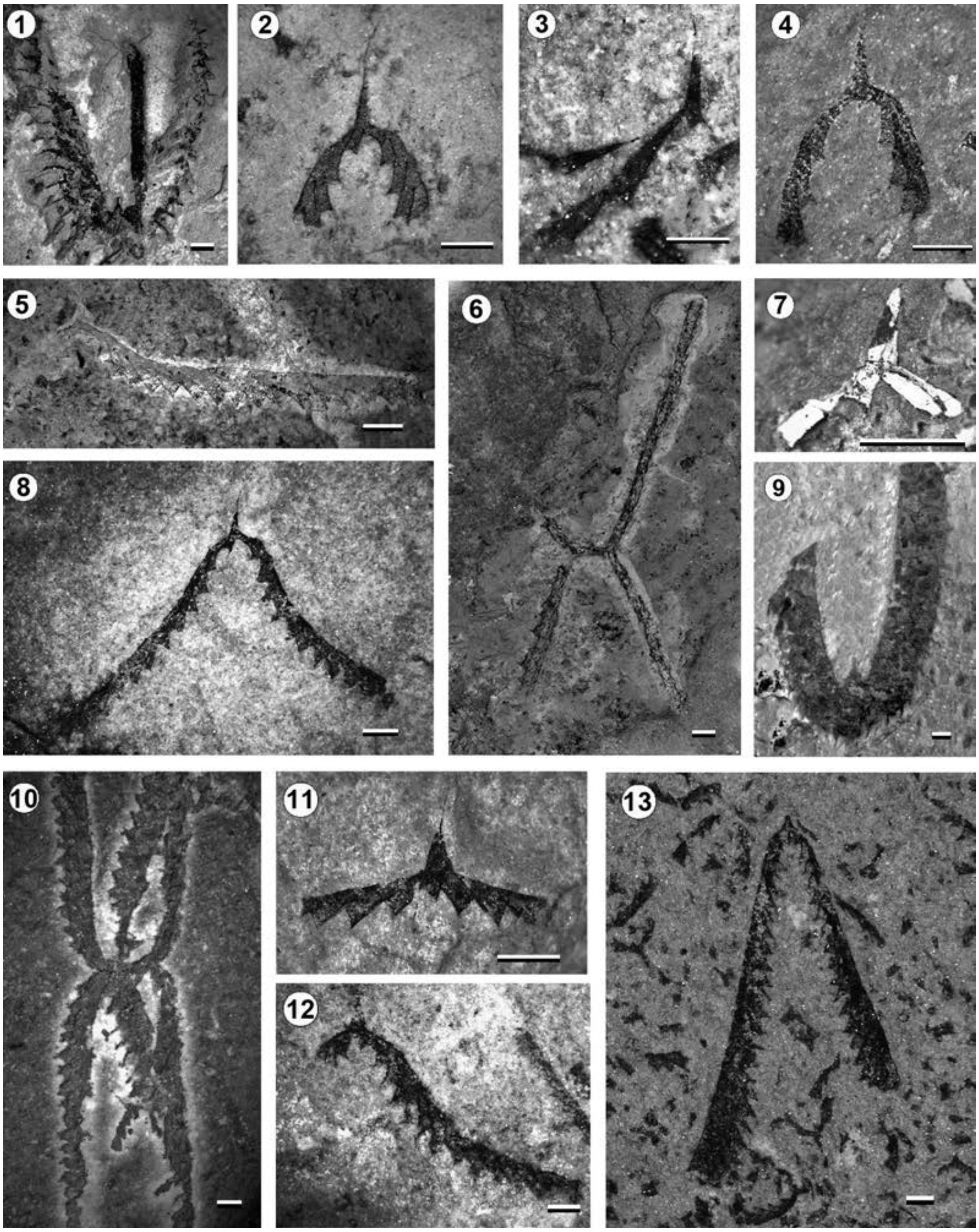

Fig. 2. Relevant graptolite taxa from the Early Ordovician (Floian) – Middle Ordovician (Dapingian) of the Central Andean Basin.

1. ***Tetragraptus phyllograptoides***, Los Colorados, CEGH-UNC 12571; **2, 8.** ***Baltograptus deflexus***. **2**. Los Colorados, CEGH-UNC 24893 **8**. Chamarra, CEGH-UNC 11570a; **3.** ***Azygograptus lapworthi***, Los Colorados, CEGH-UNC 24947; **4.** ***Baltograptus minutus***, Santa Rosa, CEGH-UNC 24894; **5.** ***Baltograptus* cf. *B. deflexus***, Los Colorados, IANIGLA-PI 1774; **6.** ***Tetragraptus akzharensis***, Los Colorados, CEGH-UNC 9358; **7.** ***Baltograptus geometricus***, Los Colorados, CEGH-UNC 24891; **9.** ***Isograptus* cf. *I. victoriae***, Tafna, CEGH-UNC 24892; **10.** ***Paratetragraptus approximatus***, Sierra de Aguilar, CEGH-UNC 12240; **11.** ***Xiphograptus lofuensis***, Los Colorados, CEGH-UNC 24943; **12.** ***Baltograptus vacillans***, La Ciénaga de Purmamarca, CEGH-UNC 24939; **13.** ***Didymograptellus bifidus***, Chamarra, CEGH-UNC 11535. Scale bar= 1mm.

widely known throughout the northwestern Argentina as "*B. deflexus"* Biozone until that Toro and Maletz (2007) revised the index species assigning it to *Baltograptus* sp. nov. (Fig. 2.5). They also emphasized that the first record of the true *B. deflexus* occurs in the overlying *Didymograptellus bifidus* Biozone. After that, Rushton (2011) included the new species as *B. jacksoni*, but Brussa et al. (2008), Toro and Vento (2013) and Toro et al. (2015) preferred renaming this biozone as *Baltograptus* cf. *B. deflexus* to avoid further confusions. We maintain the last propose, until the revision of the baltograptid species from the Central Andean Basin will be accomplished using statistical methods, as part of the PhD thesis of one of the authors (N. C. H. S.). The *Baltograptus* cf. *B. deflexus* Biozone is correlated with the *E. holmi* Biozone at southern Bolivia, recognized at the Cieneguillas1 section (Egenhoff et al., 2004).

GLOBAL Bergström *et al.* 2009 SERIES	STAGES	STAGES SLICES	CENTRAL ANDEAN BASIN: NW ARGENTINA Toro *et al.* 2015; Toro *et al.* 2018, in press	CENTRAL ANDEAN BASIN: BOLIVIA Egenhoff *et al.* 2004	SCANDINAVIA Maletz, 2005; Maletz and Ahlberg, 2011	SOUTH CHINA Zhang and Zhang, 2014; Zhang *et al.* 2019	NORTH AMERICA Williams and Stevens, 1988
MIDDLE ORDOVICIAN	DAPINGIAN	Dp2	? *"Isograptus victoriae"*	*Isograptus victoriae*	*Isograptus victoriae*	*Expansograptus hirundo*	*Isograptus v. victoriae*
		Dp1	*Azygograptus lapworthi*	*Azygograptus lapworthi*	*Pseudophyllograptus a. elongatus*	*Isograptus c. imitatus* *Azygograptus suecicus*	*Isograptus v. lunatus*
LOWER ORDOVICIAN	FLOIAN	Fl3	*Didymograptellus bifidus*	*Baltograptus minutus*	*Baltograptus minutus*	*Corymbograptus deflexus* *Didymograptellus eobifidus*	*Didymograptellus bifidus*
		Fl2	*Baltograptus* cf. *B. deflexus*	*Expansograptus holmi*	*Baltograptus* sp. cf. *B. deflexus*	*Tshallograptus fruticosus/ Acrograptus filiformis*	*Tshallograptus fruticosus*
		Fl1	*Tetragraptus akzharensis*	*Cymatograptus protobalticus*	*Baltograptus vacillans* *Cymatograptus protobalticus*		*Tetragraptus akzharensis*
			Tetragraptus phyllograptoides	*Tetragraptus phyllograptoides*	*Tetragraptus phyllograptoides*	*Paratetragraptus approximatus*	*Paratetragraptus approximatus*

Fig. 3. Biostratigraphic framework and global correlation proposed for the Central Andean Basin.

A global correlation with the *T. fruticosus* Biozone of North America (Williams and Stevens, 1988), the *Baltograptus* sp. cf. *B. deflexus* Biozone of Scandinavia (Maletz and Ahlberg, 2011) and the *T. fruticosus/A. filiformis* Biozone of South China (Zhang et al., 2019) is also proposed (Fig. 3).

Didymograptellus bifidus = Baltograptus minutus *Biozone* (Fl3). It was described for the first time in the western flank of the Argentine Cordillera Oriental, by the presence of the eponymous species (Fig. 2.13) associated with *B. minutus* (Fig. 2.4) and *B. deflexus* (Fig. 2.2, 8), at the Los Colorados area. Subsequently, it was recognized in a number of sections at the northwestern Argentina, such as Santa Victoria and La Quiaca, in the Argentine Cordillera Oriental (Toro et al., 2015 and references therein); Santa Rosa and Muñayoc, in the Argentine Puna, and also in the Aguada de La Perdíz Formation, at the Puna of Chile (Brussa *et al.,* 2008). This biostratigraphical interval can be regionally correlated with the *B. minutus* Biozone at southern Bolivia, which was recognized in the Sama-Chaupi Uno and Sella areas (Egenhoff et al., 2004). It is also correlated with the *D. bifidus* Biozone of North America (Williams and Stevens, 1988), the *B. minutus* Biozone of Scandinavia (Maletz and Ahlberg, 2011), the *D. eobifidus, C. deflexus* biozones, and possibly the lower part of the *A. suecicus* Biozone of South China (Zhang and Zhang, 2014) (Fig. 3).

Azygograptus lapworthi *Biozone* (Dp1). Maletz et al. (1995) documented for the first time this biozone in the Central Andean Basin in the Sama-Chaupi Uno area, southern Bolivia. After that, Egenhoff et al. (2004) described in more detail this interval, defining its base at the first occurrence of the eponymous species. Recent findings of *A. lapworthi* at Los Colorados (Fig. 2.3) and La Quiaca areas permit to extend the distribution of this biostratigraphic interval to the Argentine Cordillera Oriental, where related conodont records are documenting the early Dapingian (Dp1) age of the bearing deposits. The reassignment of the azygograptid specimens from the Huaytiquina section to *A. lapworthi,* and the occurrence of this species in the upper part of the Muñayoc section, indicate that this biozone is also present in the Argentine Puna. Recent findings of key conodonts from the overlaying levels at the Huaytiquina section, also indicate that this interval correspond to the early Dapingian (Toro et al., in press). Accordingly, a global correlation of this biozone with the upper part of the *A. suecicus* Biozone of South China (Zhang et al., 2019), the *P. angustifolius elongatus* Biozone of Scandinavia (Maletz, 2005) and the *I. v. lunatus* Biozone of North America (Williams and Stevens, 1988) is proposed (Fig. 3).

"Isograptus victoriae" *Biozone* (Dp2). This biozone was described for the first time in the Central Andean Basin at Chala Mayu area, southern Bolivia (Egenhoff et al., 2004). Monteros et al. (1996) described *Xiphograptus lofuensis* and *Pseudotrigonograptus minor* from the upper portion of the Huaytiquina section at the Argentine Puna. More recently, Toro et al. (in press) defined the base of this interval according with the presence of *Isograptus* sp. and the key conodont *Baltoniodus* cf. *B. navis*, and assigned an early Dapingian (Dp2) age to the bearer strata. These deposits are regionally correlated with equivalent green shales, that bears *X. lofuensis* (Fig. 2.11) and overlying the conodont-bearing levels of early Dapingian (Dp1) age, at the upper part of the Los Colorados section in the Argentine Cordillera Oriental (Toro et al., 2018), and with equivalent deposits with isograptids of the *I. victoriae* group (Fig. 2.9), from the Tafna area at western flank of the Argentine Puna (Toro et al., in press). Even though, the upper boundary of this interval remain uncertain for the Central Andean Basin, a global correlation with the *I. v. victoriae* Biozone of North America (Williams and Stevens, 1988), the *I. victoriae* Biozone of Scandinavia (Maletz, 2005) and the *E. hirundo* Biozone of South China (Zhang et al., 2019) may be suggested (Fig. 3).

Conclusions

The *Azygograptus lapworthi* and “*Isograptus victoriae*” biozones fills previous gaps for the high-resolution regional correlation of the Floian-Dapingian deposits in the Central Andean Basin. Further studies are conducted to precise the zonal boundaries and confirm the global correlation of the biostratigraphic framework here proposed.

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PAIRED ORGANIC AND CARBONATE CARBON ISOTOPE RECORDS THROUGH THE MIDDLE AND UPPER ORDOVICIAN OF ESTONIA

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Carbon isotopes have been in the standard toolbox for Earth history studies for several decades, helping to identify and interpret changes in carbon cycling, climate, environments and the biosphere. Carbon isotopic composition of Ordovician rocks has been documented from all major palaeocontinents, revealing a number of excursions with different magnitude and potentially different drivers. The largest of these is the Hirnantian Isotopic Carbon Excursion (HICE), which coincides with the end-Ordovician mass extinction. The Middle and Upper Ordovician succession of Baltoscandia has become a model area for studying carbon isotopes from bulk carbonates ($\delta^{13}C_{carb}$) and the Baltic standard curve (Ainsaar et al., 2010) serves as a basis for regional as well as intercontinental chemostratigraphic correlations. On the other hand, the carbon isotopic composition of organic matter ($\delta^{13}C_{org}$), is very poorly known from Baltoscandia and only few paired $\delta^{13}C_{carb}$ and $\delta^{13}C_{org}$ records from restricted stratigraphic intervals are hitherto available from the Ordovician (e.g. Young et al., 2010). On a global scale, too, $\delta^{13}C_{org}$ data sets are rare and some intervals, like the Katian, are yet very poorly covered (Edwards & Saltzman, 2016). However, paired organic and carbonate carbon isotope data provide valuable constraints for identifying changes in biological fractionation and atmospheric pCO_2 and pO_2 (Edwards et al., 2017), and could also aid understanding the nature of both globally and regionally driven carbon isotope anomalies.

In this study we provide a new high-resolution paired $\delta^{13}C_{carb} – \delta^{13}C_{org}$ data set from the Baltic Ordovician carbonate succession and examine if the $\delta^{13}C_{org}$ curve reveals the same features as the standard $\delta^{13}C_{carb}$ curve and explore if and how the offset between carbonate and organic matter trends varied in time. Another objective was to compare the new Baltic data with those recently published from other regions (e.g. Edwards & Saltzman, 2016) in order to assess the quality and chemostratigraphic potential of the new $\delta^{13}C_{org}$ records. We collected 211 samples for paired carbon isotope analysis from ca 200 m of Middle Ordovician to Llandovery strata of the Lelle (D-102) drill core, central Estonia. This section was selected for its representative palaeogeographic position on a carbonate platform setting within the Estonian shelf of the Baltic palaeobasin, as well as for its well-established biostratigraphy, sedimentology and geochemical context (e.g. Hints et al., 2007, Hints et al., 2017). The succession is represented mainly by limestones, which are partly dolomitic in the Darriwilian and Hirnantian, but otherwise of very low thermal maturity (CAI ~1).

The $\delta^{13}C_{carb}$ analyses were performed at the Department of Geology, Tallinn University of Technology, on a Thermo Finnigan Gasbench II coupled to a Delta V Advantage Isotope Ratio Mass Spectrometer. For $\delta^{13}C_{org}$ analysis, the insoluble residues were obtained by dissolving about 0.5 g of rock powder with 10 % HCl and were measured using elemental analyser Flash HT coupled with an isotopic ratio mass spectrometer Delta V Plus and Conflo IV at the Department of Geology, University of Tartu. Sample precision and calibration of data were performed using IAEA standards CH 3 and CH 6. TOC was less than 0.1 % in most samples, but exceeding 1 % in kukersite kerogen-rich basal Sandbian strata.

The bulk $\delta^{13}C_{carb}$ curve from the Lelle section exhibits variations between -1.5 and 4.5 ‰, revealing the main $\delta^{13}C_{carb}$ excursions known from elsewhere in the region: the Mid-Darriwilian excursion (MDICE), Kukruse low (LSNICE), Rakvere, Saunja, and Moe excursions and the prominent 4.5 ‰ HICE. Additionally, a positive excursion with an amplitude of c. 2 ‰ was identified in the lower part of the Nabala Regional Stage, middle Katian, and a brief negative excursion was observed in the Tõrremägi Member, basal Katian. The former was first reported from the Rapla section (Ainsaar et al., 2010) and the latter from several central Estonian sections (Bauert et al. 2017). Identification of the Guttenberg excursion (GICE) is only tentative, with bulk of this excursion missing due to a gap in the Lelle section.

The $\delta^{13}C_{org}$ values vary between ca -26 and -32.5 ‰. and the data are more scattered when compared to the $\delta^{13}C_{carb}$ curve, possibly due to variable sources of organic carbon. However, compared to data from other regions (e.g. Kozik et al. 2019, Li et al. 2018, Henderson et al. 2018), the Lelle $\delta^{13}C_{org}$ data set stands out by very little scatter and overall relatively low $\delta^{13}C_{org}$ values (long term average -30.3 ‰). In general, the $\delta^{13}C_{org}$ curve corresponds relatively well to the carbonate curve (Pearson correlation coefficient 0.65), and the above-mentioned $\delta^{13}C_{carb}$ excursions can all be recognized in the $\delta^{13}C_{org}$ data. MDICE and HICE are the most significant $\delta^{13}C_{org}$ events with slightly higher amplitude than the matching $\delta^{13}C_{carb}$ excursions. These can be used for global chemostratigraphy, but assessing the correlation of smaller excursions between continents needs additional high-resolution data. For purely chemostratigraphic purposes, the bulk carbonate curve remains nevertheless more robust tool.

The offset between carbonate and organic matter carbon isotope values ($\Delta^{13}C$, $=\delta^{13}C_{carb}$-$\delta^{13}C_{org}$) varies between 28.5 and 33.5 ‰. LOWESS smoothing of the Baltic data set revealed a time-constrained trend with $\Delta^{13}C$ values close to 30 ‰ through the Darriwilian and Sandbian, followed by ca 1.3 ‰ increase in baseline values near the expected position of GICE in the lowermost Katian. A decrease of similar amplitude occurs in the basal Silurian. Within this broad pattern some short-lived $\Delta^{13}C$ shifts may also be significant, for instance, in the upper Vormsi and lower Pirgu regional stages, where a rapid decrease and then increase in $\Delta^{13}C$ occurs; however, data from other sections are needed to confirm this. Young et al. (2010) documented a sharp 3 ‰ $\Delta^{13}C$ peak in the Hirnantian of the Kardla core, southern Estonia, but this feature was not revealed in the Lelle data set, where Hirnantian $\Delta^{13}C$ values are very similar to those in the Katian.

Based on data compilation mostly from Laurentia, Edwards & Saltzman (2016) documented a gradual long-term increase in $\Delta^{13}C$ values through the Lower and Middle Ordovician, which they attributed to changes in biological fractionation and increasing pO_2 levels. The new $\Delta^{13}C$ trend from the Lelle core also shows an increase, but in details the pattern is different – a major change in fractionation appears to be more abrupt and occurring later than suggested by Edwards & Saltzman (2016). It is possible that the Lelle $\Delta^{13}C$ trend carries a stronger imprint of regional or local drivers. First, during the same time interval the drift of Baltica towards tropical latitudes caused changes in climate and facies patterns in the Baltic palaeobasin and linked shifts in ecosystems, including the primary producer communities. This might have had impact on carbon isotopic fractionation through multiple scenarios. Second, even though the $\delta^{13}C_{org}$ and $\delta^{13}C_{carb}$ signatures appear to be well-preserved in the Lelle core, the effects of local depositional settings and minor diagenetic overprints should not be overlooked as shown by Richardson et al. (2019) working on an early Silurian succession from Estonia. An alternative explanation of the Lelle $\Delta^{13}C$ trend is that it reflects a more universal pattern associated with perturbation in the global carbon cycling, ocean-atmosphere system and climate that is marked by the early Katian Guttenberg $\delta^{13}C$ excursion and the following volatile interval of carbon isotope composition (Kaljo et al., 2007). At the same stratigraphic level several fossil groups show the beginning of a longer diversity decline that Kaljo et al. (2011) called the Katian prelude to the Hirnantian mass extinction.

In summary, the new paired carbonate and organic matter carbon isotope records from the Lelle core are the first stratigraphically long high-resolution data from Baltica and allow filling gaps also in the global data compilation. The revealed trends may be significant and suggest time-constrained changes in carbon fractionation close to GICE interval, but additional Baltic sections need to be studied in order to explore the spatial variability of $\delta^{13}C_{org}$ and $\Delta^{13}C$ trends across the basin.

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A LATEST ORDOVICIAN *HIRNANTIA* BRACHIOPOD FAUNA FROM WESTERN YUNNAN, SOUTH CHINA AND ITS SIGNIFICANCE

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Key words: *Hirnantia brachiopod fauna; latest Ordovician; western Yunnan; China; Sibumasu*
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A new, high-diversity, latest Ordovician brachiopod fauna including nearly 800 brachiopod specimens was collected from the Wanyaoshu Formation (Hirnantian) in the Shaodihe section, Mangshi City, western Yunnan, China. Altogether 22 genera and two undetermined taxa were identified; dominant are *Aegiromena*, *Anisopleurella*, *Fardenia*, *Dalmanella*, *Hirnantia* and *Hindella*, less common, *Paromalomena*, *Leptaena*, *Eostropheodonta*, *Cliftonia*, *Kinnella*, *Templeella* and *Plectothyrella*, together with some rare *Petrocrania*, *Xenocrania*, *Pseudopholidops*, *Palaeoleptostrophia*, *Skenidioides*, *Giraldibella*, *Draborthis*, *Dolerorthis* and *Toxorthis*. This is one of the most diverse of the typical *Hirnantia* faunas, associated with the Kosov Province. The paleobiogeographic relationships between western Yunnan (SW China), Myanmar, Yichang (Central China), Tibet (SW China) and Kazakhstan are clarified using network analysis and NMDS. The fauna studied is most similar to that of Myanmar; both reside on the Sibumasu terrane. However, a recalculated network diagram with data including the *Hirnantia* fauna from the Prague Basin indicates that the latter is more closely linked to that of western Yunnan, a testament to the very weak brachiopod provincialism during the Hirnantian, mainly due to the influence of dominant cosmopolitan taxa. The specimens from the western Yunnan were collected from seven fossil beds within about 6 m thick strata. Typical components of *Hirnantia* fauna, such as *Eostropheodonta*, *Dalmanella*, *Kinnella*, *Hindella* and *Hirnantia* itself are recorded in most of the fossil beds, even in the highest collection. With some deep-water index taxa such as *Aegiromena*, *Anisopleurella* and *Skenidioides* only found in top collection, a community turnover in the *Hirnantia* fauna corresponding to a major transgression is obvious. In this study, the ecological transitions within the *Hirnantia* fauna are discussed at the population and community levels. As a case study for a *Hirnantia* fauna at different bathymetric condition, it will be helpful for the interpretation of global datasets, and understanding the *Hirnantia* fauna in detail at a global scale.

SANDBIAN «SPONGE BEDS» OF THE EAST BALTIC – A BIOTIC OR DIAGENETIC EVENT?

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Key words: *Ordovician, sponges, bentonites, silicification, Russia, Estonia.*

Ordovician (Dapingian-Sandbian) carbonate succession of the East Baltic in the upper part of the Idavere Regional Stage (C_{III}b) includes several K-bentonite layers (Estonia), abundant siliceous remains of sponges, silicified bioclasts, patchy-silicified carbonate rocks (Estonia, NW Russia) and flinty nodules (NW Russia) (Asatkin, 1931; Männil, 1963). In the Russian sections, these deposits known as «sponge beds» due to the mass occurrence of the lithistid sponge bodies (Asatkin, 1931). This name can also be applied to Estonian sections containing abundant hexactinellid spicules of *Pyritonema subulare* Roemer. Jürgenson (1958) suggested the fossils with opal skeleton (sponges etc.) were a main source of SiO_2 for flinty nodules and bentonite layers – for shell/rock silicification. Põlma (1982) noted the association of silicified bioclasts/rocks with K-bentonite intervals (C_{III}, D_{II}, F_Ic) in the Ordovician of Estonia and suggested volcanic ash as the main source of silica. Rõõmusoks (1970) noted the remarkably simultaneous appearance of siliceous spicules *P. subulare* and numerous bentonite layers in C_{III}b of North Estonia. He did not interpret this observation, but, in fact, forced the reader to ask a question: is there a relationship between ash falls and the mass development of sponges? This short paper try to answer this question by considering distribution of sponges, bentonites and silicification in Dapingian-Sandbian part of the Ordovician carbonate succession (Fig.).

There are five variants for the «sponge beds» appearance at least. The «sponge beds» could be the result of the mass sponge development caused by ash falls (1) or another environmental changes (2). On the other hand, the «sponge beds» may only reflect the appearance of favorable burial conditions caused by an increase of pore water saturation state with respect to silica as a result of ash decomposition (3) or accumulation of a «critical mass» of siliceous sponges (4), or both (5).

The primarily siliceous sponges (hexactinellid and lithistid) in the Ordovician of East Baltic are presented by spicules and rare bodies. In Russian sections of B_Ib-C_{III}a and Estonian sections of B_Ib-C_{II} silicified bioclasts, silicified rocks and bentonite layers are absent. Sponge remains (spicules) are presented by glauconitic (B_Ib-B_{III}), goethitic (B_{III}, C_Ia), pyritic and calcitic (elsewhere) pseudomorphs.

1) The limestones of B_Ib-C_Ib usually contain rare spicules, most common *P. subulare*. At some level of B_Ib-B_{II} a local Hecker-type sponge-microbial mud mounds are observed, which are formed by hexactinellids (Fedorov, 2003).

2) A significant increase in the number of sponge spicules occurs in C_Ic of Estonia and C_Ic-C_{II} of NW Russia. According to Põlma (1982), the number of spicules in C_Ic in some Estonian boreholes reaches 30 % of the total number of bioclasts. Calcitized Pyritonema spicules are dominated. The most of calcitized spicules connected with relatively pure bioclastic wacke- and packstones. In contrast, pyritized spicules are most common in argillaceous limestones and marls.

3) Condensed and carbonate (0.7-1.2 m in North Estonia; Rõõmusoks, 1970) or thick and marly (12 m at Izhora plateau) C_{III}a deposits are transitional to the typical «sponge beds». The interval 1–1.5 m thick below the base of C_{III}b already contains rare silicified bioclasts and siliceous micronodules (which appear to be the result of the SiO_2 migration from the overlying C_{III}b). This interval in Estonian sections corresponds whole C_{III}a. In Russian Lisino borehole in upper part of C_{III}a numerous calcitized spicules of *P. subulare* are registered. Probably, this is «hidden» lower part of «sponge beds».

4) The main part of C_{III}b («sponge beds») in Estonia consists up to 18 bentonite layers (Männil, 1963). In these sections, we can see the changes in sponge fossilization – the hexactinellid and lithistid spicules become chalcedonic as well as more numerous. In NW Russia, the Shundorovo Formation contains frequent siliceous bodies of the lithistid sponges (Caryospongia, Carpospongia, Hindia etc.), early-diagenetic flinty nodules (around sponges and trace fossils) and silicified macrofossils. Both spicules and bodies are often characterized by traces of dissolution and re-precipitation (many spicules represents by chalcedonic pseudomorphs); re-precipitation has led to growth of the chalcedonic micro- and macronodules. The direct relationship between the number of sponges and the silicification rate formation can be noticed (Iskyul & Fedkovets, 2008); this confirms the viewpoint of Jürgenson, 1958). The extinction of the siliceous sponge remains (at NW Russia – gradual) is observed near the top of C_{III}b. Micronodules and silicified fossils continue to the overlying strata.

5) The D_I-D_{II} Stages characterize as a whole by rare hexactinellid spicules, flinty micronodules and only partly silicified macrofossils. In Estonian sections there are 1-2 bentonite layers within D_I Stage and 2 bentonite layers («d» and «e» after Jürgenson, 1958) bounding D_{II}a Substage. In East Estonia numerous chalcedonic spicules of *Pyritonema subulare* occur only between the layers «d» and «e» and, especially, above layer «e» (Männil, 1963).

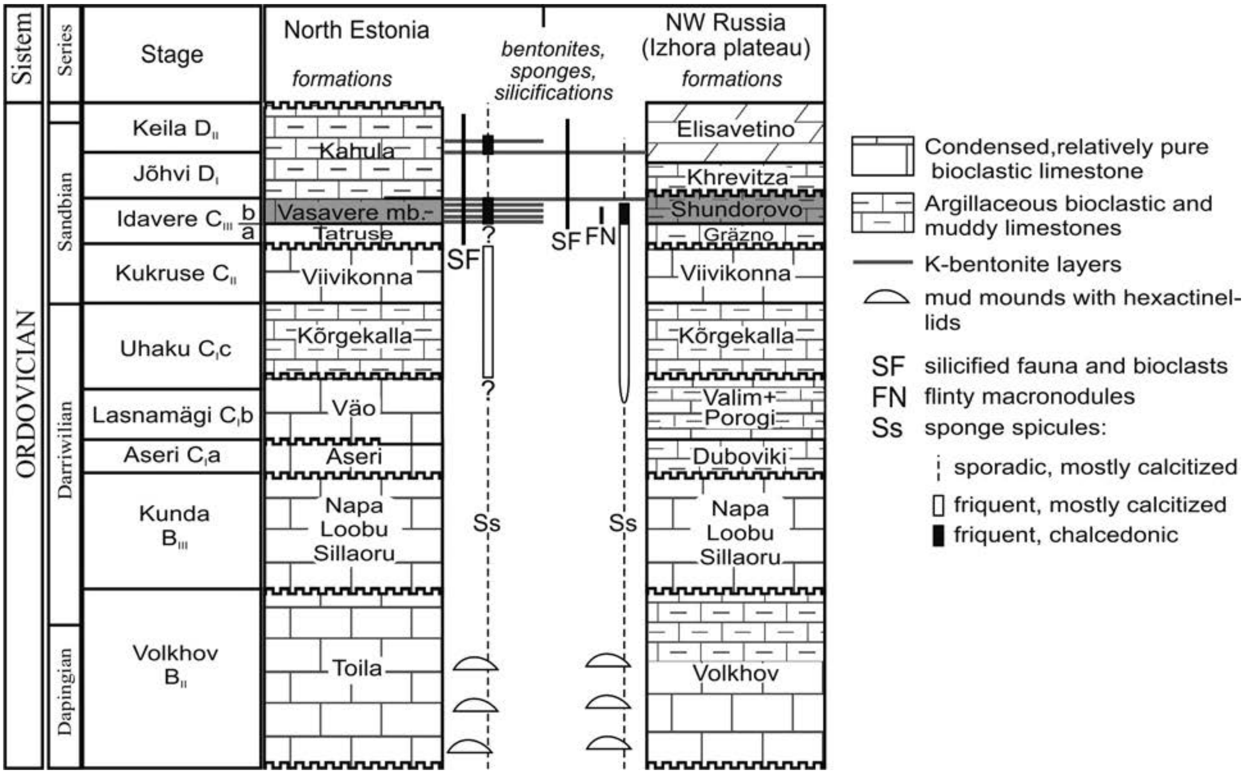

Fig. Stratigraphic scheme of the Dapingian-Sandbian part of Ordovician carbonate succession of the East Baltic with distribution of bentonite layers, siliceous sponges and associated siliceous formations (modified from Männil, 1963; Põlma, 1982; Fedorov, 2003; Dronov et al., 2005; Nõlvak et al., 2006).

The details of sponge distribution and depositional background of «sponge beds» suggest combination of biotic and diagenetic factors. In the B_Ib-C_{II} Stages there are no silicification and chalcedonic spicules even at the levels of their accumulation. This indicate unfavorable conditions for the biogenic silica burial. In other terms, the pore water of the lime sediments was not saturated with respect to silica. In C_{III}b and D_{II}a, mass development and burial of siliceous sponges coincided with the input of ash material, which served as an additional source of SiO_2. As the result, sediment water saturation with respect to silica has obviously increased and sponge remains kept their silica. Between these levels (in D_I), the rare bentonite layers facilitate silicification, but no mass accumulation of sponge remains was recorded. These data suggest: 1) the prevalence biotic and/or inner environmental factors of the development of sponge communities, 2) the importance of ash layers as an additional source of silica for sponge fossilization.

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MIDDLE-UPPER ORDOVICIAN CONODONTS OF TUVA AND WEST SAYAN

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Ordovician sequences are wide spread in Tuva and West Sayan (south of West Siberia). They are composed predominantly of terrigenous rocks with extremely rare limestones. Fauna was revealed mainly from Middle-Upper Ordovician (Decisions…, 1983). Only few brachiopods and gastropods were found from the Lower Ordovician strata. Conodonts are rare and were found from Middle-Upper Ordovician in the northern Tuva from Uyuk structural-facies zone (SFZ), and in West Sayan. Upper Ordovician conodonts were found in the western Tuva, from Kargy and Alash SFZs.

In the Uyuk SFZ, in vicinity of Malinovka Village (Central Tuva), lower subformation of the Tarlyk Formation is composed of rhythmic alternating gray sandstones and limestones, with rare mudstone layers. Limestones and mudstones yielded brachiopods, trilobites, bryozoans, crinoids and Middle Ordovician graptolites. From the upper part of limestone layer conodonts *Phragmodus* sp., *Scandodus* sp., *Semiacontiodus asymmetricus* (Barnes et Poplawski), *Drepanoistodus basiovalis* (Sergeeva) and *Drepanoistodus suberectus* (Branson et Mehl) were identified. This assemblage is characteristic for the Darriwilian *Eoplacognathus variabilis, E. suecicus* and lower part of *Pygodus serra* conodont zones.

Another Middle Ordovician conodont assemblage taxonomically more diverse and abundant was recovered from terrigenous-carbonate rocks of the Manchurek Formation, West Sayan. Along with brachiopods and bryozoans conodonts were obtained: *Phragmodus* sp. A., *Phragmodus* sp. B., *Phragmodus flexuosus* Moskalenko, *Panderodus* sp. A (sensu Nowlan, 1981), *Aphelognathus* sp. A, and *Drepanoistodus* cf. *suberectus* (Branson et Mehl) (Sennikov et al., 2000). Mentioned assemblage distinguish Darriwilian *Eoplacognathus variabilis, E. suecicus* and *Pygodus serra* conodont zones.

Upper Ordovician conodonts were revealed from Alash and Kargy SFZs, West Tuva. In the Alash zone, lower part of the Alavelyk Formation, Chergaky Group, conodont assemblages characteristic for upper Sandbian *compressa* and *undatus* zones were found (Decisions…, 1983; Izokh et al., 2012). Assemblage defined the *compressa* Zone was found from limestones cropped out on the right bank of Alash River, along with corals. It contained *Belodina compressa* (Branson et Mehl), *Icriodella* sp., *Panderodus* sp., and *Lonchodina* sp. Conodonts belong to *undatus* Zone were recovered from the sequences along Khondelen and Pichi-Shui rivers (Decisions…, 1983). The Khondelen River section contained *Icriodella* cf. *superba* Rhodes, *Panderodus gracilis* Branson et Mehl, *Phragmodus undatus* Branson et Mehl, *Belodina compressa* (Branson et Mehl), *Panderodus* sp. *Drepanodus* sp., *Distacodus* sp. and *Scandodus* sp. From section along Pichi-Shui River *Phragmodus* cf. *undatus* Branson et Mehl and *Oistodus* cf. *abundans* Branson et Mehl were found.

The Kargy Formation cropped out along the right bank of the Kargy River near Mugur-Aksy village, SW Tuva, is composed of alternating carbonate and terrigenous rocks. Conodonts were recovered from the four intervals of the section. They are represented by: *Amorphognatus* cf. *ordovicicus* Rhodes, *Belodina compressa* Branson et Mehl, *Panderodus gracilis* (Branson et Mehl), *Protopanderodus* sp., *Panderodus serratus* Rexroad, *Panderodus unicostatus* (Branson et Mehl), *Baltoniodus* sp. and *Aphelognathus* aff. *pyramidalis* Branson, Mehl et Branson. This assemblage characterize upper Katian-Hirnantian *Amorphognathus ordovicicus* Zone.

Middle-Upper Ordovician conodont assemblages are comprised of cosmopolite taxa and poses similarity with many regions worldwide including Siberian Platform. This allow to assume that Tuva paleobasin was opened during Middle and Upper Ordovician, in the periods of transgressions.

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ISOTOPIC GEOCHEMICAL PROXIES AND FACIES ACROSS SILURIAN–DEVONIAN BOUNDARY IN THE OBI-SAFIT GORGE (KITAB STATE GEOLOGICAL RESERVE, UZBEKISTAN)

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The Silurian–Devonian transition is globally marked by a significant positive δ^{13}C shift which is interpreted as recording primary seawater chemistry and representing a global oceanographic event (Salzman, 2002). In sections where index taxa for the Lochkovian GSSP are absent, chemostratigraphy can be an invaluable tool in defining the position of the Silurian–Devonian boundary. In the Zeravshan-Gissar Foldbelt, Uzbekistan the Silurian–Devonian boundary interval is represented by the Kupruk Formation of the Přídolían Series (Silurian) and the Madmon Formation of the Lochkovian Stage (Lower Devonian). The Kupruk Formation is part of the Arg Group that together with the Madmon and Khodzhakurgan formations constitute the southern flank of the Dzhindydarya Anticline cropping out in the left bank of the Dzhindy-Darya River. The studied section is located in the left bank of the Obi-Safit Gorge cutting through a thick carbonate succession. The Silurian–Devonian boundary here is confined to the lithological boundary between dolomitic crinoidal muddy limestones of the Kupruk Formation and detrital lumpy limestones of the Madmon Formation. The first occurrence of the conodont species *Ozarcodina eurekaensis* Klapper et Murphy and the tabulate coral species *Favosites* aff. *sociales* Sokolov et Tesakov in the section marks a biostratigraphic position of the Silurian–Devonian boundary, although it is rather provisional (Devonian sequences…, 2008). In terms of cyclostratigraphy, there is a maximum transgression surface of a major sedimentary cycle (sequence) and the massive occurrence of crinoids 35 m lower in the section. This surface is thought to be coeval with the maximum highstand on the eustatic curve and could be used for correlation of the Silurian–Devonian boundary strata across the Zeravshan-Gissar Ranges of South Tian Shan (Mikhailova et al., 2017).

The Obi-Safit section was sampled for carbon and oxygen isotope and geochemical studies in 2009 and 2016. Isotope-geochemical studies were carried out using whole-rock samples. The elemental analyses of carbonates were carried out on a high resolution Element II Finnigan Inductively Coupled Plasma Mass Spectrometer in the Analytical Center for Multi-Elemental and Isotope Research of the Siberian Branch, Russian Academy of Sciences at the Sobolev Institute of Geology and Mineralogy (Novosibirsk, Russia) by external calibration with internal standards to correct for instrumental and matrix induced drift. The most abundant isotopes free from elemental isobaric interference were selected. Measurements of Mn, Fe were conducted at medium resolution due to significant spectral interference; Al and Sr were measured at low resolution. Merck multi-element standards were used as calibration solutions. Analytical error is less than 10 % provided the concentration is at least 3-fold above the detection limit. The isotopic composition of oxygen and carbon was measured with mass spectrometer Finnigan MAT-253 in the Analytical Center with sample preparation on Gas Bench II line by standard methods. The accuracy of carbon and oxygen carbonate material measurements was controlled by NBS19 international standard (δ^{13}C = +1.9 ‰, δ^{18}O = -2.2 ‰) and amounted to 0.1 ‰ for δ^{13}C and δ^{18}O values.

The isotope-geochemical studies of the Obi-Safit section were accompanied by sedimentological studies. The section records transition from a shallow, semi-isolated marine basin (Kupruk Formation) to a relatively deeper, open shelf, normal marine basin (Madmon Formation) against several sea-level oscillations. Maximum transgressions are marked by the massive occurrence of bioherms; maximum regressions are defined by the presence of carbonate conglomerates and breccia. The Kupruk depositional environment was characterised by a variable hydrodynamic regime, the pulses of sedimentation were interspersed with episodes of subaerial exposure and desiccation (Mikhailova et al., 2017).

Geochemical studies were conducted to assess the terrigenous input, nutrient supply, and redox conditions in the sedimentary basin. The terrigenous input estimated by the amount of Al, Na, K, Si, Ti, Zr in carbonates varies widely in the section, with the maximum content reached in the lowermost part of the section gradually decreasing up the section. The Al content in the Obi-Safit section varies between 70 and 1900 ppm; Si, 430…7200 ppm; K, 50…900 ppm; Na, 70…440 ppm; Ti, 2.4…83 ppm; Zi, 0.1…4.6 ppm. The highest content of these elements is found in the Kupruk Formation, whereas the lowest values are measured for the Madmon Formation. The element distribution curves show two stratigraphic intervals where the content of these elements is highest, first at 50–160 m and second at 320–340 m above the base of the section, the latter interval corresponding to the boundary between the Kupruk and Madmon formations. Similar pattern is seen in U, Mo, and Co distribution suggesting anoxic conditions in bottom water and/or sediment. The lower part of the section is also characterised by elevated Fe and Mn values. The upper part of the section, in addition to relatively high U, Mo, and Co content, demonstrates high Ni and Cu concentrations and relatively elevated Ba content.

Carbon isotope composition in the studied section ranges between -4 ‰ and +4.7 ‰, with a trend towards increasing $\delta^{13}C$ values up the section. $\delta^{18}O$ values range between -2.3 ‰ and -14.8 ‰, and are -6.1 ‰ on average. Significant shifts in the $\delta^{18}O$ values down to -17.7 ‰ and -14.8 ‰ are seen, respectively, in the middle part of the Kupruk Formation (150 m from the base of the section) and at 100 m from the base of the Madmon Formation (430 m from the base of the section). Such decrease is usually attributed to post-depositional alteration of the carbonates.

Both petrographic studies of the analysed samples and examination of geochemical criteria (Fe and Mn content, with allowance for the terrigenous input) were conducted to assess preservation of the carbonates. The petrographic studies have revealed that the carbonates are predominantly mudstones, wackestones, and packstones, occasionally grainstones, although the latter is a result of recrystallisation of micritic matrix and dolomite grain (crystal) formation. The precipitation of the crystalline (dolomitic) cement is patchy in a form of irregular aggregates in the practically unaltered micritic matrix. The patchiness of the dolomitization is probably due to a varied degree of sediment bioturbation because the dolomite is almost always confined to burrow systems. The dolomitization is highest in the lower part of the section and decreases up the section. Values of Mn/Sr and Fe/Sr ratios are relatively low in the dolomitised intervals, occasionally increasing up to 1.8…2.1 and 0.2…1.0 against background values of 0.2…0.6 and 0.01…0.06, respectively. The increase in Mn/Sr and Fe/Sr values is accompanied by elevated Al content and could be attributed to the increased terrigenous input of iron and manganese. Covariation between $\delta^{13}C$, $\delta^{18}O$, Mn/Sr, and Fe/Sr values has shown that there are several stratigraphic intervals in the section where $\delta^{13}C$ and $\delta^{18}O$ decrease and Mn/Sr and Fe/Sr increase synchronously. Such a correlation speaks for significant alteration of primary isotope-geochemical characteristics of the carbonate material. Importantly, stratigraphic intervals where $\delta^{18}O$ values decrease down to -17.7 ‰ and -14.8 ‰ show evidence of neither increased Mn/Sr and Fe/Sr values, nor decreased $\delta^{13}C$ values; however, these intervals in petrographic thin sections consist of crystalline calcite aggregations. In this particular case we assume that only the oxygen isotope composition has been affected by the post-depositional alteration. Such variations in the $\delta^{18}O$ values along with the relatively constant $\delta^{13}C$, Mn/Sr, and Fe/Sr values are usually attributed to freshwater early diagenesis. This conclusion is in agreement with observed sedimentological features, specifically the occurrence of conglomerates and breccia at these stratigraphic intervals. Other than that, the produced $\delta^{13}C$ and $\delta^{18}O$ values in the section record primary variations of carbon and oxygen isotope composition in the sedimentary basin.

The Kupruk Formation is thought to represent a depositional environment with limited water circulation (Mikhailova et al., 2017) leading to episodic anoxia in the sediment and/or bottom waters as suggested by increased U/Al and Mo/Al values in the carbonates. This could favour the proliferation of sulfate-reducing and methanogenic microorganisms, which in turn could initiate precipitation of dolomite and formation of depleted carbon dioxide (Morrow, 1978; Baker & Kastner, 1981; Vasconcelos & McKenzie, 1997; Van Lith et al., 2003; Baniak et al., 2014). This mechanism explains the observed isotopically light composition of the carbonates.

The upper part of the Kupruk Formation records a change in the depositional regime, specifically the rise of sea level and the inflow of marine waters of normal salinity as suggested by a change in faunal composition (appearance of crinoids) and sedimentation (increased sediment sorting) (Mikhailova et al., 2017). These events are manifested in isotopic-geochemical characteristics of the carbonates: the observed decrease in U/Al and Mo/Al values suggests the establishment of normal redox conditions accompanied by the increase in $\delta^{13}C$ values approaching the isotopic composition of mean ocean water (0±2 ‰).

Deposition of the lower Madmon Formation was characterised by normal marine conditions and deepening of the sedimentary basin as evident from the widespread formation of microbial mud mounds. This was accompanied by isotopic geochemical perturbations because the observed increase in U/Al and Mo/Al values is coeval with the rise in Ni/Al and Cu/Al values and with the significantly elevated Ba and P values. The apparent increase in Ni, Cu, Ba, and P concentrations is thought to be indicative of an increased nutrient input in the sedimentary basin (Tribovillard et al., 2006). This in turn could ignite bioproductivity and lead to anoxic conditions in the sediment and/or bottom waters, as evident by the increased U/Al and Mo/Al values, providing high burial rate and preservation of the organic matter. Accelerated productivity and burial of the organic matter removes isotopically light carbon from the water and results in precipitation of carbonates with increased $\delta^{13}C$ values.

The isotope geochemical data are in agreement with facies variation and suggest the inflow of nutrient-rich oceanic water towards the epicontinental basin during the highstand. The observed isotopic geochemical perturbations is part of the global phenomenon seen in numerous coeval sections of the Silurian–Devonian boundary strata (Racki et al., 2012). It is important that the positive $\delta^{13}C$ shift in the studied section occurs ca. 30 m above the lower boundary of the Madmon Formation and ca. 65 m above the base of a maximum transgression surface. It remains to be seen whether the massive occurrence of microbial mud mounds that defines the base of the Madmon Formation or the sequence boundaries formed due to sea level oscillations can be used as chronostratigraphic markers for correlation of the Silurian–Devonian boundary across the Zeravshan-Gissar Ranges of South Tian Shan.

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EARLIEST KNOWN SPATIAL COMPETITION BETWEEN STROMATOPOROIDS: PALEOECOLOGICAL IMPLICATIONS FROM THE UPPER ORDOVICIAN XIAZHEN FORMATION OF SOUTH CHINA

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Key words: *stromatoporoid, Clathrodictyon, Labechia, Late Ordovician, spatial competition, growth behavior.*
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This study describes a rarely-recorded *syn-vivo* interaction between two genera of stromatoporoids, *Clathrodictyon* and *Labechia* from the Upper Ordovician Xiazhen Formation at Zhuzhai, Jiangxi Province, South China. The *syn-vivo* interaction is concluded on the basis of serial thin sections, which show distortions of skeletal elements on both stromatoporoids during their growth. *Labechia* exhibits highly distorted interskeletal elements including abnormally large, wide cysts and relatively thick cyst plates, while *Clathrodictyon* shows less distorted, *Ecclimadictyon*-like skeletal element. Based on their malformation, the *syn-vivo* interaction between *Clathrodictyon* and *Labechia* is interpreted to be spatial competition rather than commensalism or parasitism. It is the earliest known spatial competition between stromatoporoids, occurring in late Katian (Late Ordovician). This finding provides direct evidence for the growth behaviours of early stromatoporoids and indicates that clathrodictyids have broader ecological plasticity and play a more important part in the Late Ordovician coral-stromatoporoid reefs than labechiids.

TROPICAL ECOLOGICAL GRADIENT IN THE LATE ORDOVICIAN AND BRACHIOPOD FAUNAL EVOLUTION IN LAURENTIA

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Key words: *Ecological gradient, Brachiopoda, Late Ordovician, Laurentia*.

Within the ancient tropical shallow-marine depositional environments, especially in expansive epicontinental seas, the diversity and taxonomic composition of brachiopods and other shelly benthos can be effected by several factors, such as increased fluctuations in water temperature from the equator to the subtropics, a general lack of hurricane-grade storms and decreased circulation and oxygen at moderate water depth towards the equator, and equatorial cool-water tongue related to cold water upwelling. The large plate of Laurentia was inundated extensively by epicontinental seas during the Late Ordovician. The major rise in sea level resulted in displacement of the brachiopod faunas from continental-margin shelves to inland marine basins. The brachiopods that invaded and subsequently evolved in the epicontinental seas showed latitudinal differentiations and gradient, with several striking characteristics.

1. At the generic and species level, brachiopods started invading newly formed inland (epeiric) seas on a grand paleogeographic scale in the early Katian, and most taxa can be traced to their closely related forms in the pericratonic basins or shelves, such as the orthides *Plaesiomys* and *Paucicrura*, and rhynchonellide *Rhyntrotrema* and *Hiscobeccus*. By mid-Katian time, many brachiopod lineages in epicontinental seas developed shells that can be characterized as morphological extravagance and elaboration, such as a drastically larger size and globular shape, stronger shell growth lamellae or imbricating frills; pronounced muscle attachment structures (e.g., enlarged/deepened muscle scars, inflated and more strongly lobate cardinal processes), and increased shell perforations (endopunctae, epipunctae, aditicules). In some cases, a similar morphological trend can be observed in separate evolutionary lineages, such as the development of an enlarged trilobed cardinal process and increased shell perforation in the intracratonic forms of dalmanelloids (e.g. *Diceromyonia storeya*) and orthoides (*Plaesiomys occidentalis*), as compared to their closely related forms in pericratonic seas.

2. Faunal gradient along paleolatitudes. During the Late Ordovician, two of the largest inland, epicontinental basins (the Williston and Hudson Bay basins) in Laurentia straddled the paleo-equator, and another relatively large inland basin, the Michigan basin, was located at mid-tropical latitudes. Brachiopod-rich pericratonic shelves, such as the Anticosti basin and the Cincinnati Arch area, were located in relatively high tropics or subtropics (> 20°S paleolatitudes). During the Late Ordovician, the differentiation of an epicontinental brachiopod fauna from pericratonic faunas became manifest after the early Katian (Chatfieldian). Despite the morphological extravagance characteristic of many taxa of the epicontinental fauna that spread across a vast expanse of epicontinental seas, the total diversity at the generic level was relatively low (<16 genera per NA stage), in sharp contrast to the pericratonic Scoto-Appalachian brachiopod fauna that thrived along the southeastern margin of Laurentia during the Sandbian–early Katian interval, when the diversity was >60 genera per North American (NA) stage. This suggests that the large epicontinental seas had a relatively low carrying capacity of benthic shelly faunas, despite its commonly interpreted shallow, warm-water environment, in addition to the lack of severe storms in equatorially located seas, which would be favorable for such faunas. The limiting factors in epicontinental seas may have been related to fluctuating salinity due to sluggish circulation and high evaporation rate, relatively low oxygen content in the bottom water of some areas, or unstable nutrient supply due to disconnection with open-ocean upwelling.

3. During the Late Ordovician, the low overall generic diversity of the epicontinental fauna was inversely related to its extinction rate, compared to the pericratonic faunas. Across the Sandbian-Katian boundary interval, the extinction rate peaked at 38 genera per NA stage for the continental-margin Scoto-Appalachian fauna. Throughout the relatively long Katian interval, the extinction rate decrease rapidly to about 10 genera per NA stage. The combination of a low generic diversity with low extinction rate (i.e. lower faunal turnover rate) suggests that the epicontinental fauna adapted to a set of relatively high-stress environmental conditions in the inland seas, becoming specialized and thrived in such settings. This pattern was not interrupted until the Katian-Hirnantian transition, when the rapidly intensifying Hirnantian glaciation decimated the epicontinental fauna.

BOUNDARIES AND POSITION OF THE SIBERIAN PALEOCONTINENT IN THE PALEOZOIC: PALINSPASTIC VERSUS PALEOGEOGRAPHIC RECONSTRUCTION

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Key words: *Paleozoic*, *Verkhoyansk-Chukotka Orogen*, *Siberian Platform*, *paleobiogeographic province*.
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Siberian paleocontinent in palinspastic reconstructions based on paleomagnetic data and from the perspective of plate tectonics has been traditionally depicted in modern configuration, i.e. excluding the surrounding fold-and-thrust belts. Major discrepancies are due to controversial interpretations of spatial position and origins of the Paleozoic terranes in the Mesozoic structure of the Verkhoyansk-Chukotka Orogen and Arctic islands. These tectonic blocks in most paleotectonic maps are referred to as wandering and exotic to the Siberian Platform (Zonenshain et al., 1990; Parfenov et al., 2003; Metelkin et al., 2012; Cocks et Torsvik, 2017). Several authors (Natapov et Surmilova, 1995; Oksman, 1998) regarded the Selennyakh, Tas-Khayakhtakh and Okhotsk Paleozoic inliers as autochthonous terranes of Siberian passive margin origin. The accumulated paleontological, lithological and other geological evidence allows substantial adjustments to be made in the paleomagnetic palinspastic reconstructions of the Mesozoic structure of the Verkhoyansk-Chukotka Orogen and Arctic islands for the Ordovician Period.

The Ordovician Period witnessed the maximum extension of epicratonic marine basins over the entire Paleozoic history (Ronov, 1993), as well as the large scale biodiversification and global expansion of pioneer taxonomic groups (ostracods, corals, bryozoans, echinoderms, brachiopods, etc.) leading to a three time increase in disparity of the marine biota compared to the Cambrian Period (Sepkoski, 1982; Kanygin, 2008). It is the Ordovician strata of the Siberian Platform and in the adjacent Paleozoic inliers that are represented by most complete and fossiliferous sections. We argue that these sections are restricted to the single Siberian epicratonic marine basin based on the available paleontological, stratigraphic, lithological and sedimentological evidence. The detailed database has been powered by a new methodological, chorological approach (i.e., typification of faunal associations and patterns of their distribution and migration at species level for the entire paleobasin taking into account specific ecological characteristics of different taxonomic groups) to reconstruct the Ordovician paleobiogeography (Kanygin et al., 2019).

Three most diverse and well studied groups of benthic fauna, ostracods, brachiopods, and trilobites have been used for the chorological analysis. These groups are reliable paleogeographic proxies given their ecological requirements with respect to abiotic and coenocytic conditions. As many as 260 ostracod species, 70 brachiopod species and over 60 trilobite species have been known from the Middle and Upper Ordovician of the Siberian Platform, Sette-Daban Ranges, Taimyr Peninsula, Selennyakh, Tas-Khayakhtakh, and Omulevka ranges, Chukotka Peninsula, and Kotelnyi Island. All the ostracod species appear to be endemic to the studied area suggesting an isolation of this particular paleobasin from other epicratonic basins by deep oceanic waters that could be anoxic and act as barriers to free migration of the benthic fauna. About 90 % of the brachiopod and trilobite species are endemic, the remaining species being common with North America.

The species composition of the fauna and the structure of the associations, with the dominance of the same species in all studied regions, indicate the absence of barriers to free dispersal of similar biocoenoses within the paleobasin extended from the west of Siberian Platform (Kulyumbe River Basin) to the Chukotka Paleozoic Inlier (in modern coordinates). This conclusion is supported by the data on other benthic faunal groups, including corals, bryozoans, echinoderms, gastropods, stromatoporates that were part of the same biocoenoses and had equally wide distribution in most of the regions. The Paleozoic terranes in the Mesozoic structure of the Verkhoyansk-Chukotka Orogen and the Siberian Platform arguably constituted a single megastructure in the Ordovician.

To explain the present day discontinuity of the regions, we used lithological, sedimentological, paleotectonic and geodynamic data characterising paleogeographic settings and their evolution in Paleozoic to support our reconstruction of the Siberian paleobiogeographic province (Kanygin et al., 2019). We demonstrated that the isolated Neoproterozoic and Paleozoic inliers constituted the passive margin of the Siberian Platform (shelf of the paleocontinent) in place of the modern day Verkhoyansk fold-and-thrust region. The shelf was deformed by post-Paleozoic tectonic processes, and fragments of this shelf are best preserved on the Taimyr Peninsula, in the Sette-Daban Ranges, and in a reduced form in the northern and southern flanks of the Verkhoyansk Ranges.

The affiliation of the terranes with the passive margin of the Siberian continent, in addition to faunal connectivity, can also be argued based on similarities in depositional environments, continued subsidence (expected from pericratonic settings), sea-level oscillations and sharp changes between carbonate and siliciclastic sedimentation. A 10-km-thick carbonate succession formed at the passive margin (five to seven times exceeding the thickness of coeval carbonate-siliciclastic strata in the interior parts of the platform) as a result of the continued sediment rich subsidence. The eastern passive margin became fragmented as a result of mid-Carboniferous rifting leading to separation of the terranes.

There is a vague faunal similarity, mostly at a level of high ranked taxa, and parallels in certain benthic genera and species distribution between the Siberian paleocontinent and the North America, which is in agreement with the majority of palinspastic reconstructions (Torsvik & Cocks, 2017). At the same time, the deficiency of common species of benthic faunal groups in the paleobasins of Siberia and Baltica could be interpreted as a manifestation of a larger distance between the two paleocontinents (Kanygin et al., 2010), although a possibility that there was a supercontinent consisting of Siberia, Arctida and Baltica in the Ordovician could not be excluded (Shatsillo et al., 2017).

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DARRIWILIAN GRAPTOLITES OF THE GUALCAMAYO FORMATION AT THE VILLICUM RANGE, EASTERN PRECORDILLERA, ARGENTINA

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Key words: *graptolites, Middle Ordovician, biostratigraphy, Precordillera, Argentina.*

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INTRODUCTION

The eastern flank of the Villicum Range, Eastern Precordillera (Ortiz and Zambrano, 1981) of the San Juan Province (Argentina) shows a well exposed Ordovician siliciclastic succession that overlies carbonate deposits of the San Juan Formation. It is composed of the Gualcamayo (lower – upper Darriwilian), La Cantera (upper Darriwilian-Sandbian), La Pola (Sandbian) and Don Braulio (Hirnantian) formations (Fig. 1).

In the La Pola and Don Braulio creeks sections the Gualacamayo Formation transitionally overlies the San Juan Formation and starts with an alternation of black shales and carbonate levels at the base (*transfacies sensu* Baldis and Beresi, 1981) followed by black shales with some nodules in the middle part of the succession. The upper beds consist of gray laminated/greenish-gray shales, which disconformably underlie the La Cantera Formation. The formation boundary is marked by an erosional surface (Baldis et al., 1982; Peralta, 1993).

Rich and abundant Darriwilian graptolite assemblages are present in this unit encompassing the *Levisograptus dentatus*, *Holmograptus lentus*, *Holmograptus spinosus* and *Pterograptus elegans* zones (Peralta 1993, 1995; Kaufmann and Ortega, 2016; 2017; Kaufmann, 2019). The graptolite faunas are uncommonly associated with conodonts, trilobites, phyllocarids and chitino-phosphatic brachiopods (*e.g.*, Baldis and Beresi, 1981; Baldis, González and Pires de Carvalho, 1984; Sarmiento, 1985, 1987, 1990; 1991; Heredia and Milana, 2010; Mestre, 2013; 2014, cited in Kaufmann, 2019).

The illustrated graptolite specimens are housed in the collections at the Instituto de Geología Emiliano Aparicio (INGEO), Universidad Nacional de San Juan (PI), and at the Museo de Paleontología, Universidad Nacional de Córdoba (CORD-PZ), Argentina.

STUDY SECTIONS

In the Don Braulio and La Pola creeks, which are separated from each other by ca. 500 m, outcrops of the Gualcamayo Formation exhibit some differences in composition and thickness that are attributed, in part, to tectonic effects (40 m thick in the Don Braulio Creek but only 20 m thick in the La Pola Creek). The basal levels of this unit consist of intercalated black shales and dark gray carbonate beds with numerous K-bentonite levels, and bearing a rich graptolite fauna corresponding to the *L. dentatus* Zone (*Arienigraptus angulatus* Subzone). The succeeding beds are composed of black shales with some carbonate nodules, and then by dark gray shales that are strongly deformed in the middle part of the succession and contain graptolites of the *L. dentatus* and *Holmograptus lentus* zones. Immediately above the levels with *H. lentus* Zone graptolites, a succession with black shales and sporadic carbonatic nodules, and yielding graptolites of the *H. spinosus* Zone is present in La Pola Creek. The apparent absence of the *H. lentus* Zone in the Don Braulio Creek section is probably linked to a sampling bias or tectonic effects.

The final meters of the Gualcamayo Formation correspond to laminated dark and light gray shales in the Don Braulio section or green gray shales in the La Pola section where graptolites of the *P. elegans* Zone and conodonts of the *Eoplacognathus suecicus* Zone were recorded.

GRAPTOLITE BIOSTRATIGRAPHY

A rich and diverse graptolite assemblage was recorded in the *L. dentatus* Zone, which is composed of ?*Etagraptus zhejiangensis*, *Acrograptus* cf. *A. ellesae*, *Anomalograptus*? sp., *Holmograptus bovis*, *Holmograptus* sp. 1, *Pseudobryograptus* sp., *Jiangshanites* sp., *Thamnograptus* sp., *Pseudophyllograptus* sp., *Pseudotrigonograptus ensiformis*, *Eotetragraptus quadribrachiatus*, ?*Tetragraptus reclinatus*, *Tetragraptus bigsbyi*, *Tetragraptus* sp., *Arienigraptus zhejiangensis*, *A. angulatus*, *Arienigraptus* sp., *Isograptus*? sp., *Parisograptus caduceus*, *Cryptograptus*

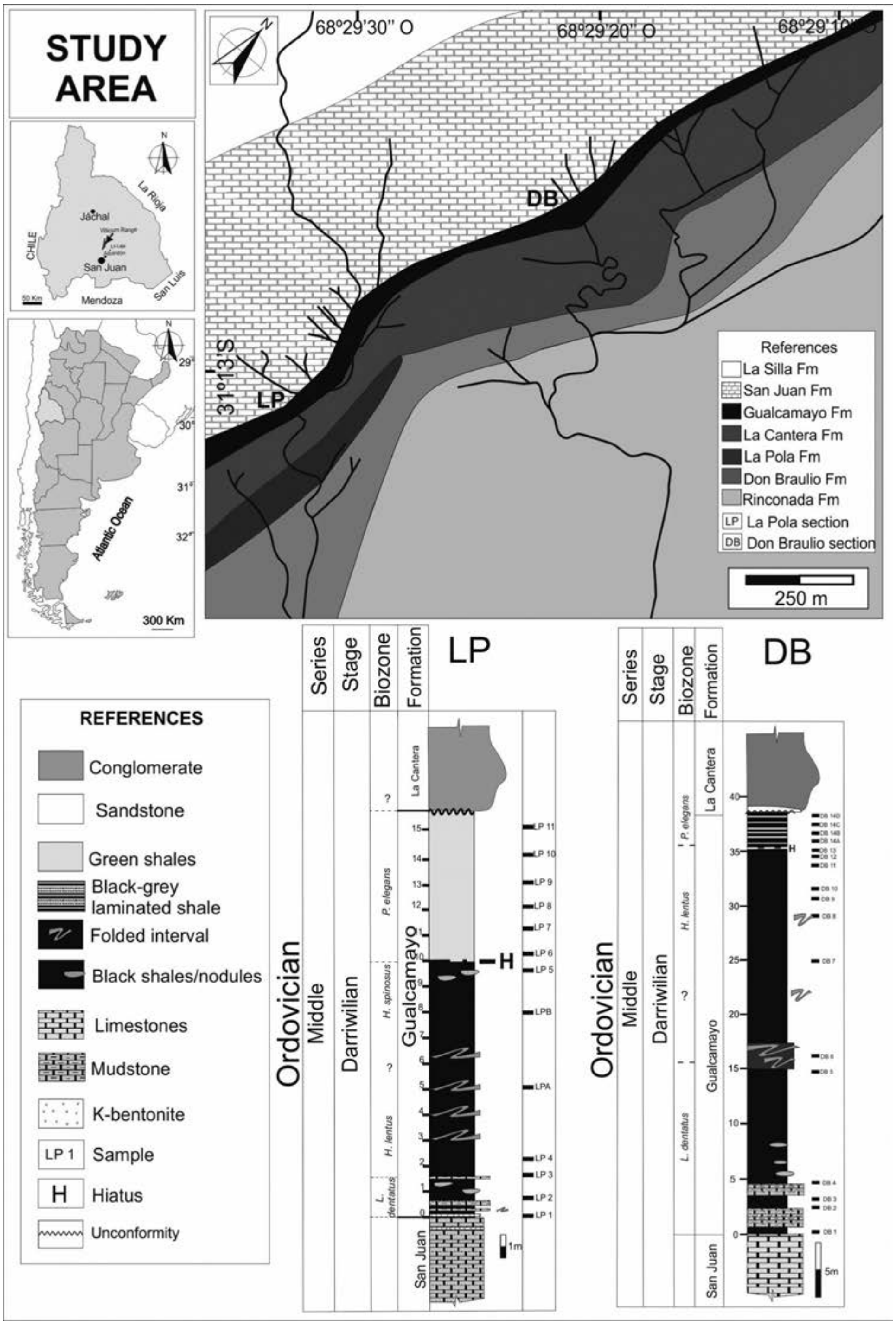


Fig. 1. Location map of the study sections and stratigraphic columns of the Gualcamayo Formation, Villicum Range, San Juan Province.

antennarius, *Glossograptus* sp., *Paraglossograptus tentaculatus*, *Levisograptus austrodentatus*, *Levisograptus* cf. *L. dentatus*, *Levisograptus primus*, *Levisograptus* cf. *L. mui*, *Levisograptus* sp. 1. The presence of the *Arienigraptus angulatus* in this graptolite assemblage allows us to refer it to the upper part of the *L. dentatus* Zone (*A. angulatus* Subzone) following the scheme of Albanesi and Ortega (2016) for the Argentine Precordillera.

Following previous works from the Central Precordillera (Brussa *et al*. 2003, among others) the first appearance of the genus *Archiclimacograptus* was used to recognize the *Holmograptus lentus* Zone in the Gualcamayo Formation due to the absence of the nominal taxon. This biozone includes *Anomalograptus*? sp., *Holmograptus bovis*, *Jiangshanites*? sp., *Thamnograptus* sp., *Eotetragraptus quadribrachiatus*, *Tetragraptus bigsbyi*, *Pseudophyllograptus* sp., *Pseudotrigonograptus ensiformis*, *Isograptus* sp., *Arienigraptus angulatus*, *Arienigraptus* sp., *Parisograptus*

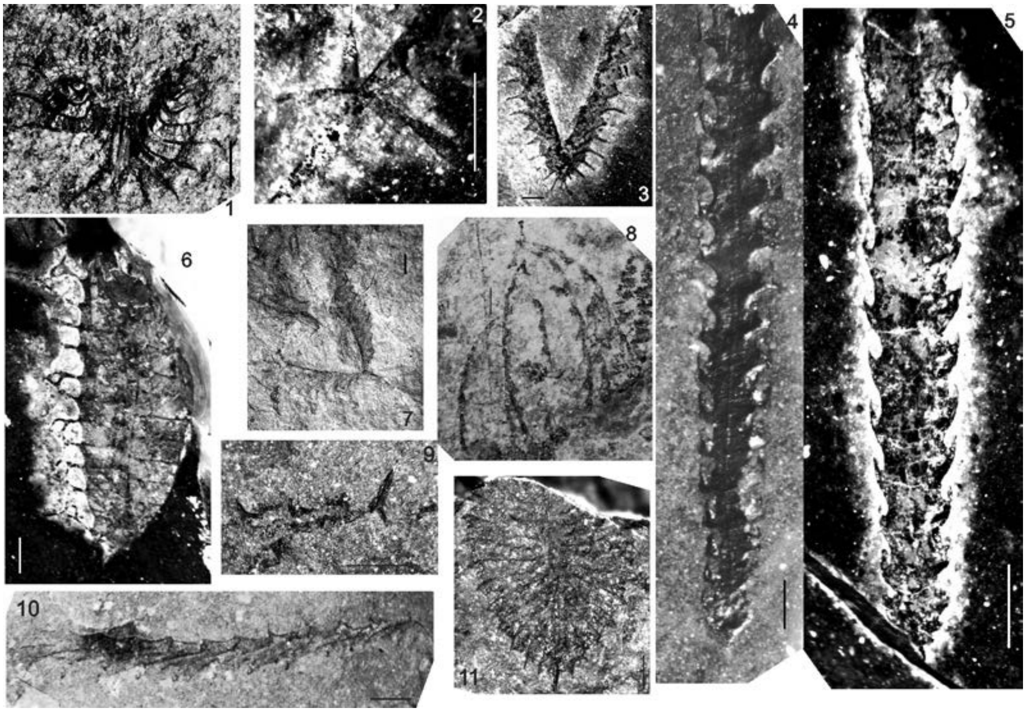


Fig. 2. Darriwilian graptolites from the Gualcamayo Formation at Don Braulio (samples DB) and La Pola (samples LP) Creek sections. PI Scale bar = 1mm.

1. *Arienigraptus angulatus* PI 1694, DB13, *H. lentus* Zone. **2.** *Holmograptus bovis* PI 1038A, DB3, *L. dentatus* Zone, *A. angulatus* Subzone. **3.** *Apoglossograptus* cf. *A. parallelus* PI 1417, LP11, *P. elegans* Zone. **4.** *Archiclimacograptus* cf. *A. marathonensis* PI 999, LP4, *H. lentus* Zone. **5.** *Levisograptus* cf. *L. dentatus* PI 1046, DB3, *L. dentatus* Zone, *A. angulatus* Subzone. **6.** *Paraglossograptus tentaculatus* PI 1052A, DB3, *L. dentatus* Zone, *A. angulatus* Subzone. **7.** *Tetragraptus bigsbyi* PI 1804, DB 3, *L. dentatus* Zone, *A. angulatus* Subzone. **8.** *Pterograptus elegans* PI 1318, LP8, *P. elegans* Zone. **9.** *Holmograptus* sp. PI 1073B, DB3, *L. dentatus* Zone, *A. angulatus* Subzone. **10.** *Holmograptus spinosus* PI 1198, LP5, *H. spinosus* Zone. **11.** *Bergstroemograptus crawfordi* CORD-PZ 25694, LP5, *H. spinosus* Zone.

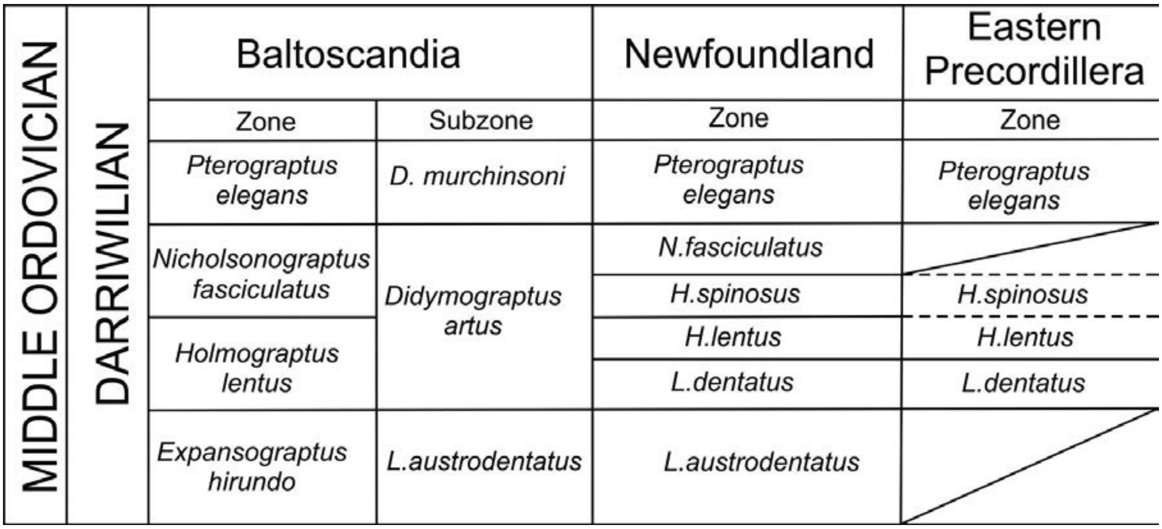
caduceus, *Cryptograptus antennarius*, *Glossograptus* sp., *Paraglossograptus tentaculatus*, *Levisograptus austrodentatus*, *Levisograptus* cf. *L. dentatus*, *Levisograptus primus*, *Levisograptus* sp. 1, *Archiclimacograptus* cf. *A. marathonensis Archiclimacograptus*? *ambiguus, Archiclimacograptus* sp. 1.

The *Holmograptus spinosus* Zone was only recognized in the Eastern Precordillera (Kaufmann and Ortega 2016). The graptolite assemblage is composed of *Atopograptus woodwardi*, *Holmograptus spinosus*, *Jiangshanites*? sp., *Thamnograptus* sp., *Pseudophyllograptus* sp., *Bergstroemograptus crawfordi*, *Paraglossograptus tentaculatus*, *Archiclimacograptus*? *ambiguus*, *Archiclimacograptus*? cf. *A.*? *pungens*, *Archiclimacograptus* cf. *A. marathonensis*, *Archiclimacograptus* sp. 2, and *Haddingograptus* sp. 1.

A diverse graptolite assemblage of the *P. elegans* Zone is present in the uppermost beds of the Gualcamayo Formation in the studied sections. It is composed of *Acrograptus* cf. *A. euodus*, *Wuninograptus* sp., *Thamnograptus* sp., *Jiangshanites*? sp., *Tetragraptus* cf. *T. erectus*, *Pterograptus elegans*, *Cryptograptus schaeferi*, *Glossograptus hincksii*, *Apoglossograptus* cf. *A. parallelus*, *Archiclimacograptus riddellensis*, *Archiclimacograptus angulatus*, *Archiclimacograptus* cf. *A. columnus*, *Archiclimacograptus* sp. 3, *Eoglyptograptus* sp., *Hustedograptus teretiusculus*, *Hustedograptus vikarbyensis*, *Hustedograptus* sp., ?*Hallograptus echinatus*, *Haddingograptus oliveri*, *Haddingograptus* sp. 2, *Reteograptus speciosus*, *Reteograptus geinitzianus*, ?*Normalograptus antiquus*, and *Pronormalograptus acicularis*.

Based on the studied graptolite collection is possible to recognize an unfossiliferous interval (H) in the upper part of the Gualcamayo Formation embracing at least the *N. fasciculatus* Zone. This unfossiliferous interval was also documented with graptolites in the Los Azules Formation, Cerro Viejo de Huaco, Central Precordillera (e.g., Brussa et al., 2003) where it is placed between the *H. lentus* and *P. elegans* zones.

Most of the biozones identified at the Villicum Range were also recorded in several sections of the Central Precordillera such as Río Gualcamayo area, Cerro Potrerillo, Cerro Viejo de Huaco, Oculta Creek, Las Aguaditas Creek, Cerro La Chilca, and La Invernada Range (Albanesi and Ortega, 2016; and references therein). A biostratigraphical scheme for the Middle Ordovician succession from the Villicum Range is proposed based on the studied graptolite assemblages (Fig. 3).



		Baltoscandia		Newfoundland	Eastern Precordillera
		Zone	Subzone	Zone	Zone
MIDDLE ORDOVICIAN	DARRIWILIAN	*Pterograptus elegans*	*D. murchinsoni*	*Pterograptus elegans*	*Pterograptus elegans*
		Nicholsonograptus fasciculatus	*Didymograptus artus*	*N.fasciculatus*	
				H.spinosus	*H.spinosus*
		Holmograptus lentus		*H.lentus*	*H.lentus*
				L.dentatus	*L.dentatus*
		Expansograptus hirundo	*L.austrodentatus*	*L.austrodentatus*	

Fig. 3. Biostratigraphic chart showing Darriwilian graptolite zones from Baltoscandia, Newfoundland and Eastern Precordillera (modified from Albanesi and Ortega, 2016; Kaufmann, 2019).

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UPPER ORDOVICIAN TABULATE CORALS FROM GORNY ALTAI

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Key words: *tabulate corals, Ordovician, Katian Stage, Gorny Altai.*

Ordovician and Silurian sediments of Gorny Altai are represented by generally rhythmic and often regularly alterating terrigenic and carbonate rocks. Alternation of terrigenic and volcanic benches is extremely rarely observed. Limestone lenses are reported in predominantly terrigenic sections. Different facial sediments with significantly varying thickness can be found in various parts of the paleobasin (Sennikov et al., 2008).

Tabulate corals are widespread in Ordovician sediments of Gorny Altai. For the first time they were described in early 50-60s of the last century (Sokolov, Mironova, 1959; Dzyubo, 1960, 1962, 1965; Mironova, 1960; Barskaya, 1963). In 1959 B.S. Sokolov and N.V. Mironova described a new genus *Amsassia* and two its species. N.V. Mironova also identified two new genera from Altai: *Mesosolenia* and *Hillaepora* (Mironova, 1960). P.S. Dzyubo identified new genera *Karagemia* Dziubo and *Bajgolia* Dziubo in Gorny Altai in 1960 and 1962, respectively. In 1966 the monographic description of Ordovician tabulate corals from Gorny Altai was done (Dzyubo, 1966).

We studied Ordovician tabulate corals from the collection that was collected from the section near Lake Teletskoye, on the right bank of Verkhniy Turochak River (left tributary of Iogach River). Sediments cropped out by the Verkhniy Turochak Section belong to Samysh Body aligned with Darriwilian and Sandbian Stages (Sennikov et al., 2018). The Samysh Body is characterized by sandstone, siltstone, limy sandstone and limestone, gray, green-gray to red colored.

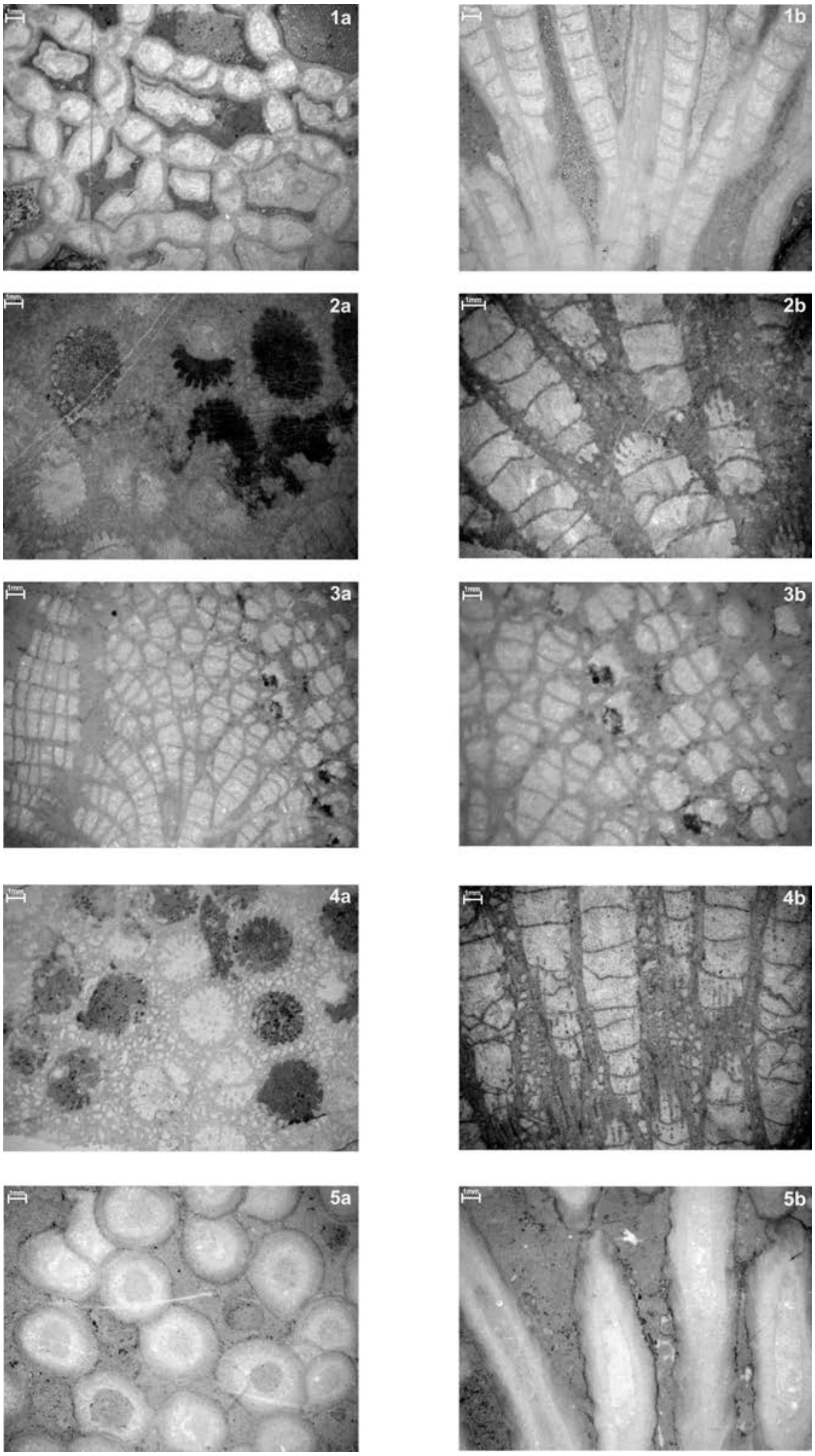
Tabulate corals were found in massive clayey limestones. This layer of the section yielded multiple gastropods, ostracods, crinoids, stromatoporoids, rugose and tabulate corals. Tabulate coral colonies exceed 50 cm and comprise a major part of the layer (Fig.). Tabulates are mostly represented by massive and fasciculate corals with very rare cateniform corals.

The following typical tabulate complex of Upper Ordovician was identified in studied collection: *Reuschia aperta* Kiär, *Rhaphidophyllum ellipsoidalis* Preobrazhensky, *Nyctopora denticulate* Sokolov et Tesakov, *Cyrtophyllum bargastensis* Dziubo and *Catenipora* sp. (Plate). Genera *Reuschia*, *Nyctopora*, *Cyrtophyllum* and *Catenipora* were previously found from Ordovician of Gorny Altai. Genus ?*Rhaphidophyllum* was never discovered in Gorny Altai

Fig. 1. Giant tabulate coral colonies (up to 50 cm) in a layer of massive clayey limestone from the Verkhniy Turochak Section.

Plate

Species of tabulate corals from the Verkhniy Turochak Section



1a,b – *Catenipora* sp., transverse and longitudinal section; 2 a,b – *Rhaphidophyllum ellipsoidalis* Preobrazhensky, transverse and longitudinal section; 3a,b – *Nyctopora denticulate* Sokolov et Tesakov, transverse and longitudinal section; 4 a,b – *Reuschia aperta* Kiaer, transverse and longitudinal section; 5 a,b – *Cyrtophyllum bargastensis* Dziubo, transverse and longitudinal section.

before. Species *Reuschia aperta* identified for the first time in Gorny Altai, was reported from Upper Ordovician of Norway (Kiär, 1929). Species *Rhaphidophyllum ellipsoidalis* and *Nyctopora denticulate* were identified in Altai collection for the first time. *Rhaphidophyllum ellipsoidalis* was previously found in Iryudy Formation, Upper Ordovician Northeast Russia (Preobrazhensky, 1968).

Species *Nyctopora denticulate* were previously found in Dolborian Regional Stage (Middle part of Katian Stage) of Siberian Platform. Species *Cyrtophyllum bargastensis* is typical for Tekhten' Regional Stage (middle and upper parts of Katian – lower part of Hirnantian) of Gorny Altai.

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DIANULITES (BRYOZOA, ESTHONIOPORATA) FROM LATE ORDOVICIAN (SANDBIAN) OF THE TELETSKOE LAKESIDE IN GORNY ALTAI

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Key words: *Late Ordovician, bryozoans, Teletskoe Lakeside, Gorny Altai.*
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Esthonioporate bryozoans of genus *Dianulites* Eichwald, 1829 has been identified from the Late Ordovician (Sandbian) of Gorny Altai. These bryozoans occur on north-western Lake Teletskoe (Teletskoe Lakeside in Gorny Altai) from the Tozodov Section – outcrop located on right bank of the Tozodov Creek, which is right tributary Iogach River, in 1 km from the mouth. Bryozoans were found in Member 8 (Tozodov Unit) (Sennikov et al., 2018), which has a thickness of 8-10 m and represents siltstones in alternation with fine sandstone, slightly carbonate, steel-grey and greenish grey.

The studied bryozoans have massive hemispherical colonies different shape, 0.8-3.5 mm wide at their base; secondary overgrowth occurs. Autozooecia long with polygonal autozooecial apertures; maculae consisting of larger autozooecia present, but weakly expressed; diaphragms in autozooecia straight, abundant.

Previously only one species of genus *Dianulites* Eichwald – *D. ramosoformis* Jaroshinskaja, 1967, has been described from the Late Ordovician of Gorny Altai, which was discovered in Chebor Formation (Hirnantian) on Iogach River. The studied species differs from *D. ramosoformis* in having hemispherical colonies instead of ramose and abundant diaphragms instead of rare. Moreover three species of genus *Dianulites* Eichwald – *D. fastigiatus* Eichwald, 1829, *D. petropolitanus* (Pander, 1830), *D. janischevskyj* Modzalevskaya, 1953 – with wide stratigraphical and geographical distributions are known from the Late Ordovician (Modzalevskaya, 1953; Astrova, 1965; Pushkin, Popov, 2001; Pushkin, 2002; Nekhorosheva, 2003). The studied species differs from *D. fastigiatus* in having hemispherical colonies instead of rugose-shaped and abundant diaphragms instead of rare, from *D. petropolitanus* in having weakly expressed maculae and very small apertures of autozooecia, from *D. janischevskyj* lacking maculae composed of exilazooecia. The studied species differs from most other species of genus *Dianulites* Eichwald described from the Early to Middle Ordovician of the East European Platform by Pushkin, Popov, 2001, in having abundant diaphragms instead of rare or absent. Also studied species differs from *Dianulites borealis* Astrova, 1965 described from Early Ordovician of Arctic Russia by Astrova (1965) and Ernst et al. (2014) in having abundant diaphragms and lacking cystopores. According to Ernst et al. (2014) *Dianulites borealis* comes from the uppermost Tremadocian and therefore is the oldest known member of the genus *Dianulites* Eichwald. However, Nekhorosheva (2015) believes that the age of these bryozoans cannot be older than the Floian.

Based on the data presented, it can be concluded that bryozoans of the genus *Dianulites* Eichwald from the Tozodov Section are a new species. This is consistent with the data of A.M. Jaroshinskaya (1960a, 1960b, 1962, 1967, 1973), who described many new species both from the Chebor Formation in Teletskoe Lakeside and from the Gur’yanov Formation (Sandbian) of the northeast part of Gorny Altai.

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STRATIGRAPHIC SIGNIFICANCE OF FIRST DISCOVERY OF FAUNAL REMAINS IN THE ORDOVICIAN OF THE CENTRAL TUVA STRUCTURAL-FACIAL ZONE

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Key words: *Ordovician, Tuva, inarticulate brachiopods.*

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Tuva is a region with the complex folded geological structure (Vladimirskaya, Blagonravov, 1966; Geological..., 1974, 1983; V. Sennikov, 1977). In the Ordovician stratigraphic chart of Tuva adopted by the MSC Russia in 2015 (Decisions..., 2016) there are defined several structural-facial zones (SFZ): Karga, Alash, Khemchik, Central Tuva, Uyuk and Sistig-Khem. Structural-facies zones differ from each other in a characteristic set of local stratons – formations and series.

The Central Tuva structural-facies zone is the only zone of Tuva where no faunal remains have been found until recently in Ordovician sediments. This zone is bordered on the West by the Khemchik SFZ**,** on the North – by the Uyuk SFZ, and on the North-East – by the Sistig-Khem SFZ.

According to previous studies Ordovician sequences of the Central Tuva are represented by Tebek terrigenous series, divided into seven lithological bodies: 1) multicolored conglomerate-sandstone, 2) multicolored siltstone, 3) multicolored siltstone – sandstone, 4) gray-colored conglomerate-sandstone, 5) red-colored sandstone, 6) red-colored conglomerate, 7) multicolored sandstone (Decisions .... 1983).

In 2018 we studied the Ordovician outcrops of the Central Tuva zone in the upper reaches of the Bayan-Kol River (the right tributary of the Upper Yenisey River) and confirmed the presence of the “second” multicolored siltstone member in Ordovician section (see above). In the third member composed of multicolored siltstone and sandstone cropped out in the Ortaa-Khem River Section (right tributary of the Bayan-Kol River), Lingulida brachiopods were discovered in three locations for the first time. The found fossil collection includes more than three dozens of dorsal and ventral shells of different state of preservation. Morphological features of the structure of shells are typical for representatives of two brachiopod genera: *Ectenoglossa* Sinclair, 1945 and *Leontiella* Yadrenkina, 1982, belong to family Obolidae (Treatise..., 2000).

Different species of the *Ectenoglossa* are know in many regions (Europe, Baltic States, Siberian platform, etc.). Basically, all findings are confined to the Lower and Middle Ordovician. Popov, Cocks (2014) reported *Ectenoglossa* from the lower part of Katian Stage in Kazakhstan. Representatives of *Ectenoglossa* cf. *derupta* Yadrenkina, 1977 were found in the Borlug Formation of the Malinovskaya series, in the Uyuk SFZ (Sennikov et al., 2001, 2006).

Our collection includes *Leontiella gloriosa* (Yadrenkina, 1982), which were previously found in Middle Ordovician of the Kulyumbe River Section (Northwest of the Siberian Platform) (Kanygin et al., 1982).

The new lithological and paleontological data allow us to assign the Ordovician deposits of the Central Tuva SFZ to the undifferentiated deposits of the Malinovskaya Series. The lower part consist of the first three members yielded Lingulids brachiopods can be aligned with the Borlug Formation of the Malinovskaya Series of the Uyuk SFZ (Sennikov et al., 2001, 2006).

The middle part of the section of the Central Tuva SFZ, the fourth and the fifth bodies (gray-colored conglomerate-sandstone and red sandstone members) can conditionally be attributed to Tarlyk Formation of the Malinovskaya Group (Sennikov et al., 2006). The upper part of the section – the sixth and seventh bodies (red conglomerate and multicolored sandstone members) can be conditionally aligned with the Tamzyr Formation of the Malinovskaya Group (Vladimirskaya, 1967, 1973; V. Sennikov, 1977; Decisions ..., 1983; Sennikov et al., 2006).

A hiatus in sedimentation is assumed for the Tremadocian interval in the Central Tuvan SFZ, as well as in the neighboring Khemchik and Uyuk SFZs. The total thickness of Ordovician sediments in the Central Tuva zone is more than 2000 m according to previous studies, which requires updating.

Conclusions

1. Ordovician sediments of the Central Tuvan structural-facies zone cropped out along the Bayan-Kol River should not be regarded as an independent Tebek Series, as it was adopted until recently (Decisions..., 1983).

2. In spite of close location of Ordovician sections of the Central Tuva SFZ to the Shemushtag Group of the Khemchik SFZ, cropped out in the middle reaches of the Eylig-Khem River, we believe that they should be assigned to the Malinovskaya Group of the Uyuk SFZ. In the 50-ies of the last century Ordovician sediments of the right bank

of the Upper Yenisei River (Ulug-Khem River) has already been designated as undifferentiated Malinovskaya Group of Uyuk zone on the geological maps.

3. The subdivision of the Malinovskaya Group of the Central Tuva SFZ into mapped local stratigraphic units (formations) requires further investigation.

4. The lower part of the Ordovician section of the Central Tuva SFZ can be aligned with the Borlug Formation of Malinovskaya Group of Uyuk SFZ due to the findings of Lingulid brachiopods in the lower part Ortaa-Khem River section (right tributary the Bayan-Kol River).

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ALPHA, BETA AND GAMMA DIVERSITY CONTROLS ON ORDOVICIAN-SILURIAN BRACHIOPODS OF THE BALTIC BASINS

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Brachiopods are a major component of the fossil record of the early Palaeozoic sediments of the Baltic Basin, their skeletons have a high preservation potential and they are comparatively well studied. Brachiopods underwent a major diversification during the Great Ordovician Biodiversification Event (GOBE). The role of spatial and environmental heterogeneity for the diversification process is discussed controversially among scholars.

We estimated alpha, beta and gamma diversity of the brachiopods of the Baltic basin and compared them with sediment thickness estimates and proxies of sediment heterogeneity in order to find dependencies. We used a combined dataset from the Database of Geoscience Collections of Estonia (SARV) and the Paleobiology Database (PBDB), comprising c. 13.000 occurrences from more than 800 localities, binned the occurrences into time bins of c. 4-8 Myr length, ranging from the Early Ordovician – Late Silurian and placed them into standardized 0.3° latitude-longitude squares. Additionally, we compiled localized bed thicknesses and counts of lithological and stratigraphical units.

We found dependencies of the gamma diversity with the number of lithological units and of the beta diversity with our proxy of lithological heterogeneity. We conclude that the massive brachiopod diversification was locally associated with an increase in the heterogeneity of the depositional environment.

ORDOVICIAN TRACE FOSSILS OF THE SIBERIAN PLATFORM

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Key words: *Trace fossils, Ordovician, Siberian Platform.*
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In recent years new data on distribution of trace fossils in the Ordovician succession of the Siberian palaeocontinent have been obtained. Giant *Rusophycus* traces (32x20 cm) were reported from the Baykit Sandstone (Vikhorevian and Mukteian regional stages, Darriwilian) for the first time from the outside of the Gondwana palaeocontinent (Kushlina & Dronov, 2011). Rich and diverse *Cruziana/Rusophycus* ichnocoenosis was found in quartz sandstones of the upper part of the Moyero formation (Kirensko-Kudrinian regional stage, uppermost Darriwilian) on the northeastern margin of the Tungus basin (Dronov & Kushlina, 2014). Appearance of these typical Gondwana trace fossils come together with typical Gondwana lithology and accompany the wide distribution of the “Nubian facies” in the Tungus basin. Invasion of these facies marks destruction of previously existed warm-water carbonate platform and sea-level lowering probably coinciding with the beginning of cooling event (Dronov, 2013; 2014). Lithology and position of the Baykit Sandstone and its counterparts (between the warm-water and cool-water carbonate series) strongly remind one of the lithology and position of the Upper Ordovician (Katian) Eureka Quartzite of Laurentia (Dronov, 2014). Morphology of the Siberian *Cruziana* and *Rusophycus* traces, their size and claw formula suggests that they belong to a new ichnospecies probably endemic for the Siberian palaeocontinent (Dronov et al., 2016). Trace fossils assemblages from the Darriwilian of the Irkutsk basin on the south of the Siberian platform also demonstrate closer affinity to Gondwana than to Baltica. The assemblages include *Polycladichnus* and *Teichichnus* for shallow-water settings and *Palaeophycus*, *Arthrophycus*, *Megagrapton*, *Phycodes* and *Cochlichnis* for relatively deep-water settings (Dronov & Mikuláš, 2008). Massive thick-bedded *Thalassinoides* ichnofabric identified in limestone of the Volginian regional stage (Upper Darriwilian) in the northern part of the Tungus basin is very similar to that described in Laurentia (Jin et al., 2012). That could be regarded as an independent evidence for near equatorial position of this part of the basin in the Darriwilian time. From the Upper Ordovician of the Tungus basin traces of boring activity like *Trypanites* and *Balanoglossites* reported for the first time. In the Ordovician of Baltica such traces appears much earlier in Floian and Dapingian but disappears when the palaeocontinent migrated into tropics. In Siberia boring traces probably reflects onset of the cool-water conditions (Dronov, 2013). Numerous conical-shaped trace fossils similar to *Conichnus conicus* Männil, 1966 but usually larger (10-35 cm high and about 7-20 cm in diameter) were found in the Upper Ordovician (Katian) cool-water carbonate succession of the Tungus basin on Siberian platform. Calcite tubes of stromatoporoid *Aulacera tenuipunctata* Yavorsky, 1955 were found in an axial or slightly tilted position in the cones. The cones were interpreted as stromatoporoid trace fossils and could be attributed to fixation/anchoring traces or Fixichnia (Dronov et al., 2016). Finding of *Rusophycus carleyi* in the Middle Ordovician deposits of the Siberian Platform near its boundary with Baikal-Vitim folded belt probably indicates the same tectonic event as at the eastern (in present-day orientation) margin of Laurentia and manifest Taconic orogeny. On both palaeocontinents (Siberia and Laurentia) invasion of Gondwanan ichnospecies *R. carleyi* in the Middle Ordovician marks docking of some Gondwanan microcontinents to these landmasses (Dronov et Kushlina, 2018).

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KERATOSE-LIKE SPONGES AND THEIR IMPORTANCE IN EARLY REEF EVOLUTION

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Keratose-like sponges, now occur as sparitic fibrous network embedded within micritic matrix, are recently reported from carbonates worldwide. Earliest record of keratose-like sponges is from early Cambrian archaeocyath-microbial reef, though their record may date back to the Ediacaran considering first record of fossil sponges in the late Precambrian. Their records occur throughout the Phanerozoic, but many of them are concentrated in the early Paleozoic reefs, especially those of the mid-Cambrian to the mid-Ordovician. It may suggest importance of keratose-like sponges in early reef evolution, especially in pre-Darriwilian reefs when Paleozoic-type reef builders such as stromatoporoids, bryozoans, and rugose and tabulate corals are not abundant yet. Many keratose-like sponges are reported from reef cavities, and interpreted to be cryptic dwellers. On the other hand, there are some examples of keratose-like sponges occupying main portion of the reef, suggesting their importance as framework-builder and/or binder in reef building. One of the most intriguing phenomena is their occurrence within “stromatolites”, intercalated with microbial layers and formed “tight laminar frame reefs”. Together with other early Paleozoic reef-building sponges – archaeocyaths in the early Cambrian, lithistid sponges in the mid-Cambrian to the mid-Ordovician, pulchrilaminids in the early Ordovician and stromatoporoids in the mid-Ordovician to the end-Devonian, keratose-like sponges may suggest a new story in reef evolution.

STROMATOLITE ABUNDANCE ANOMALY IN EARLY ORDOVICIAN: THE RISE OF SPONGE-MICROBIAL ASSOCIATION?

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Key words: *microbialites, Tarutao Islands, keratose sponges, Ordovician radiation, Sibumasu.*

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With a prominent disparity in the morphology and the microfabric, stromatolites occur widely in the fossil record of the Precambrian. Noticeably, they show a long-term decline in abundance throughout the Proterozoic. The decline tendency continued in the Phanerozoic (Riding, 2011), while the Cambrian and Early Ordovician record a resurgence of microbialites (Riding, 2006). By the Early Ordovician, the abundance of stromatolites achieved Neoproterozoic- to Mesoproterozoic-like prevalence, based on the latest rock record–normalized occurrence analyses (Peters et al., 2017).

Sponge-microbe association also began to occupy shallow reef communities during the Cambrian. A few recent studies reveal that sponge-microbial communities built laminated 'stromatolites' in Cambrian, Carboniferous, and Triassic (Luo and Reitner, 2015; Coulson and Brand, 2016). During the Cambrian-Early Ordovician, it is unclear whether the peak of stromatolite abundance is apparent, due to the emergence and rapid increase of these sponge-related bioconstructions, or associated with unique and fluctuating environments and extreme climates. The reassessment of the microfabrics of those Cambrian-Early Ordovician stromatolites holds consequences for a better understanding of the crucial transition from microbial to metazoan reefs in the earth history (Li et al., 2015, 2019; Shen and Neuweiler, 2018).

Here we explore some Lower Ordovician reefs from the Tarutao Islands, off the coast of Satun Province of southern Thailand. The reefs occur in the late Tremadocian Pa Nan Formation, Thungsong Group. There are at least three reef horizons which are made up of massive boundstone with a distinct laminar texture in the outcrop. Individual reef bodies are domical or lenticular in shape with a thickness of 2.8–11.5 m, surrounded by bioclastic limestones. The reefs were previously regarded as stromatolites (Wongwanich et al., 1983), however detailed microfacies analysis demonstrates intricate sponge-microbe association in the laminated deposits (Fig. A).

With high porosity, the 'stromatolites' are partly dolomitized and characterized by undulated laminations which consist of dark and light laminae of automicrites (Fig A). Anastomosing microtubules (probably keratose sponges) are conspicuous within the light laminae (Fig. B), whereas the dark ones are largely composed of tubiform calcimicrobes (Fig. C). Fenestral features and halite pseudomorphs (Fig. D) usually occur on the interface between the dark and light laminae, which indicate a partly evaporitic environment. A cyclic fluctuation in sea-level and in salinity probably facilitated the construction of alternating thin microbial layers and sponge-rich micritic laminae.

In Ordovician and Cambrian carbonates, there are increasing reports of anastomosing microtubules (Hong et al., 2012; Larmagnat and Neuweiler, 2015; Li et al., 2017) with morphology and preservation similar to those described above, but we herein provide the first case of Ordovician 'stromatolites' made up of sponge-microbe alternations. It requires further excavations to assess how common these sponge-related bioconstructions are in the Cambrian-Early Ordovician microbialites, which would lead to a better understanding of the Great Ordovician Biodiversification Event (GOBE) in terms of reef evolution.

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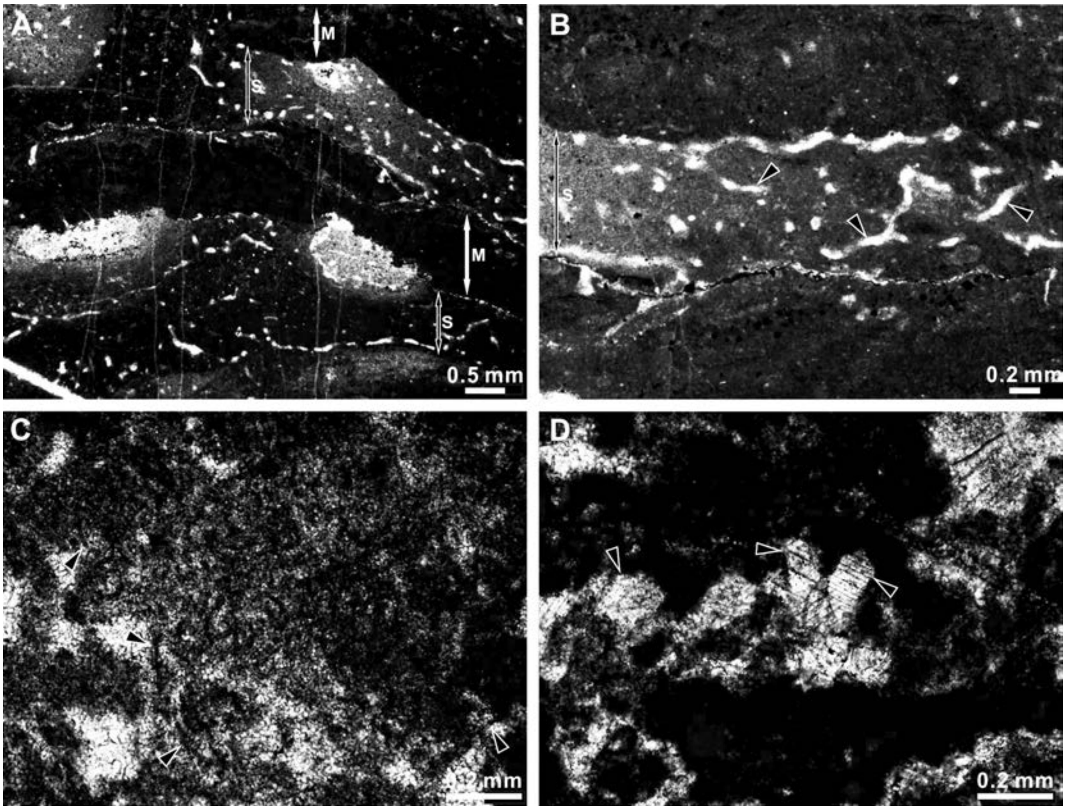

Fig. Photomicrographs of the 'stromatolites'.

A – Vertical surface of the 'stromatolites', showing interbedded accumulation of light laminae (S) and dark laminae (M). B – Zoomed-in view of the light laminae (S) illustrating the anastomosing microtubules (black triangles). C – Enlargement of the dark laminae, showing filamentous calcimicrobes (black triangles). D – Halite pseudomorphs (black triangles) surrounded by dark microbial fabrics.

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A SYNOPSIS OF THE DIVERSITY HISTORY OF THE LATE CAMBRIAN AND ORDOVICIAN GASTROPODS OF THE MAJOR BLOCKS OF CHINA

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Key words: *gastropods, Ordovician, distribution, diversity, China*.

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1. Introduction

Gastropods have a long stratigraphic range through the entire Phanerozoic, with their first appearance in the early Cambrian, and a wide geographical range over many distinct facies (Cox, 1960; Yü, 1979; Yü and Rong, 1991). After initial low diversity through the entire Cambrian, gastropods underwent a significant, step-wise diversification in the Ordovician, probably promoted by origination events in the Floian, early Darriwilian and early Sandbian (Frýda and Rohr, 2004). Previous global biogeographical summaries of Ordovician and Silurian gastropods (Frýda and Rohr, 2004; Ebbestad et al., 2013) incorporated few data on gastropods from China. However, diverse gastropod faunas are known to occur in China, which may significantly alter the global diversity curve. Herein we compile the Ordovician gastropod records of South China, North China and Tarim, as well as other occurrences from all blocks of China (Fig. 1) to analyze the diversity history of gastropods in China during the late Cambrian and Ordovician, to assess the role that gastropods played in the Great Ordovician Biodiversification Event (GOBE). A composite generic diversity curve of the late Cambrian and Ordovician gastropods of China is produced, and compared to the curve of Frýda and Rohr (2004).

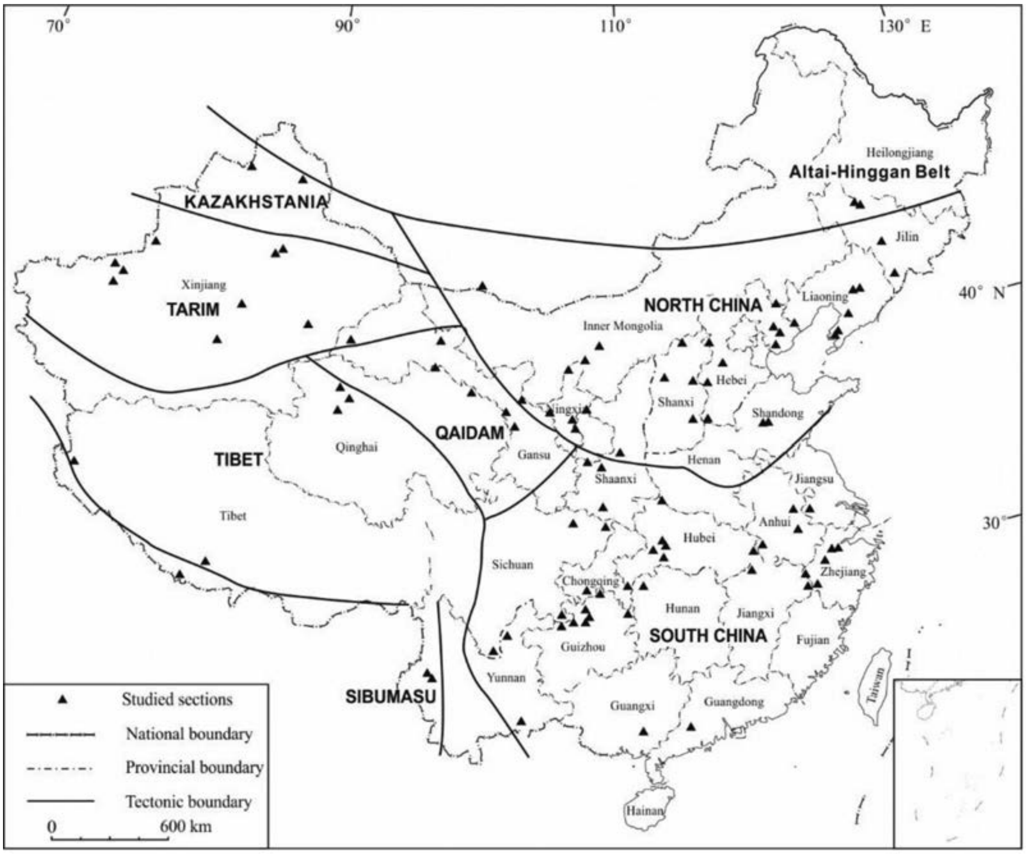

Fig. 1. The main paleogeographic blocks of China and the geographical distribution of upper Cambrian and Ordovician Chinese sections that have yielded gastropod records. The base map is after bzdt.nasg.gov.cn/.

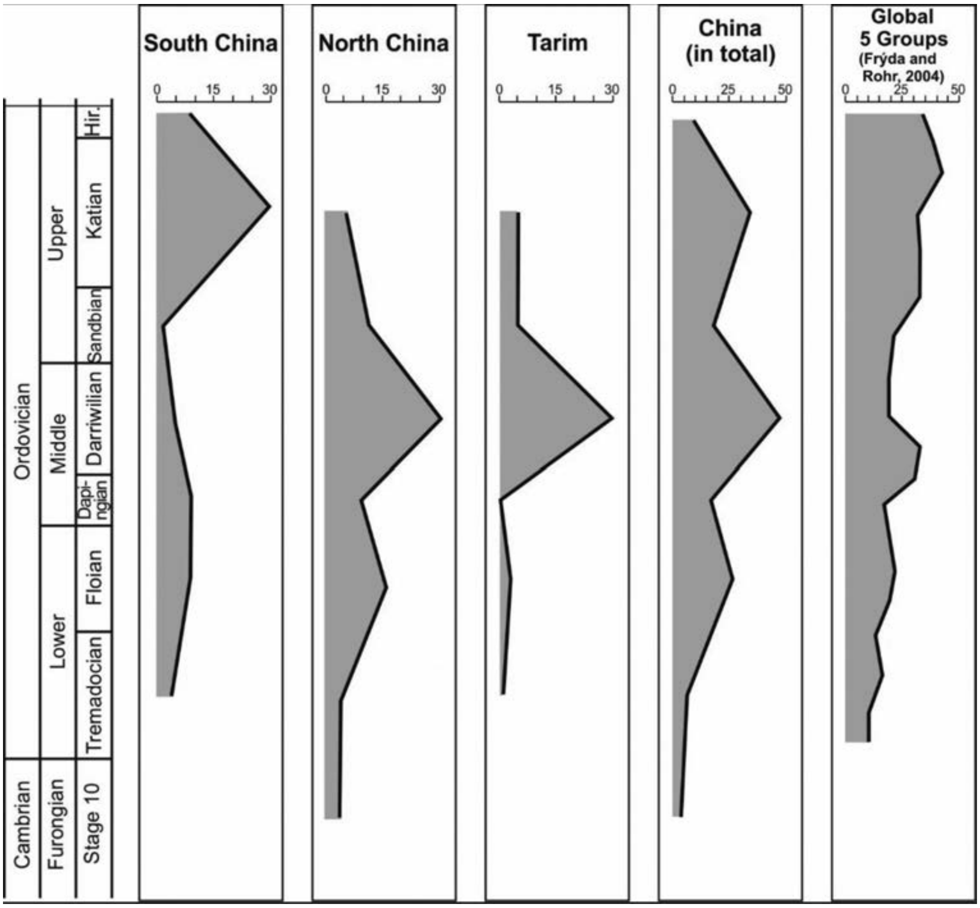

Fig. 2. Total generic diversity of gastropods in upper Cambrian to Ordovician strata of China. Note the curve for China is based on occurrence data from all blocks of China.

2. Material and Methods

Occurrences of gastropods in upper Cambrian and Ordovician strata of China were obtained from all available publications and internal reports, including published papers, monographs, regional paleontological atlases, regional stratigraphic charts, geological survey reports and online databases (e.g., the Paleobiology Database and the Geobiodiversity Database). The present diversity analysis focuses on gastropods at the genus level, rather than the species level, because restudy of some recorded species is required to clarify their synonymies and validity. All the generic occurrences were binned to chronostratigraphic stages, and the total number of genera occurring within each stage was calculated. Herein we use total taxic diversity as a proxy of mean standing diversity (Fig. 2). For occurrences of gastropods in certain regions, plates or terranes for which direct chronostratigraphic assignment was not possible, we followed the latest trans-regional correlations proposed by Zhang et al. (2019).

3. Results and Discussion

3.1 Late Cambrian

For the upper Cambrian strata of China, four genera have been recorded from the Jinan area, Shangdong Province (*Pelagiella* by Walcott, 1913), and from the Wuhuzui and Benxi areas, Liaoning Province (*Maclurites*, *Matherella* and *Lytospira* by Yü & Yochelson, 1999). No gastropods have been reported from this interval in other blocks of China, probably due to the dominance of dolostones which could be a taphonomic bias against aragonitic fossils, e.g., in South China and Tarim.

3.2 Ordovician

In general, North China yielded the most diverse Ordovician gastropods within China. In this block, there is an initial increase of generic gastropod diversity from 4 in the Tremadocian to 16 in the Floian, followed by a slight decrease to 10 in the Dapingian (Fig. 2). A diversity peak in North China is reached in the Darriwilian, with 30 genera recorded; thereafter, the diversity decreases gradually to 12 in the Sandbian and 6 in the early Katian. As no upper Katian to Hirnantian rocks are preserved in North China, due to the Huaiyuan Epeirogeny (Zhen et al., 2016), gastropod diversity cannot be assessed for this time interval.

In South China, for most of Ordovician time, gastropods exhibited a relatively low generic diversity of no more than 9 (Fig. 2). A low generic diversity of 5 is recorded for the Darriwilian of South China, in contrast to the contemporaneous burst of 30 in North China. After a significantly low diversity of 2 genera (*Phragmolites* and *Ecculiomphalus*) in the Sandbian, a diversity peak of 29 genera was observed in the Katian of South China. From the Darriwilian to the Katian, the gastropods of South China show a substantial increase from 5 to 29 genera, in contrast to the sharp drop from the peak of 30 to 6 in North China. These two contrasting diversity trajectories may reflect the effects of the changing geographical patterns of the two blocks in the Middle and Late Ordovician, which also resulted in the changing provincialism of cephalopods over this time interval (Fang et al., 2019). It is noteworthy that 9 genera of Hirnantian age are recorded in South China, mostly from the Kuanyinchiao Bed (carbonate) on the top of the Wufeng Formation (black shale), in association with the dominant *Hirnantia* Fauna.

The Ordovician gastropod diversity curve for Tarim shows a low generic diversity of one genus in the Tremadocian and three genera in the Floian (Fig. 2). It is puzzling that no gastropods have been found in the Dapingian strata of the block, an interval dominated by alternations of dolomitic limestone and limestone (Zhang and Munnecke, 2016). This is in sharp contrast to the obvious peak of 29 genera in the Darriwilian. From the Darriwilian to the Katian, the diversity decreases to 5 genera and is followed by a Hirnantian hiatus, a trajectory resembling that of North China.

The total generic diversity curve of all the blocks comprising China (Fig. 2) shows three diversity peaks between the late Cambrian and the Hirnantian, a history similar to that of the composite curve of many groups produced by Sepkoski (1995). The first diversity peak of 26 genera occurs in the Floian, the second (47 genera) in the Darriwilian, and the third (34 genera) in the Katian. The two earlier peaks are mainly contributed by North China and Tarim, whereas the third peak is contributed by South China.

3.3 Comparison with other continents

Compared to the diversity curves of other regions or continents, the Chinese gastropod diversity history shows several distinct features. The diversity curves of Ordovician gastropods from North China and Tarim largely resemble the global composite of Frýda and Rohr (2004), except for the Darriwilian segment, where the peak appears to be slightly delayed in South China relative to the global curve. This could be an artefact caused by the lower time resolution of the Chinese curve, or a true diversity signal. The low Katian gastropod diversity in North China may result from the extensive stratigraphic hiatus spanning the late Katian to early Carboniferous (Zhen et al., 2016). The lack of a Darriwilian gastropod peak in South China may be caused by insufficient sampling of gastropods from the Darriwilian Kuniutan Formation, or an unfavorable environment. The prominent diversity peak of gastropods in the Katian of South China coincides with one of the main diversity episodes of the GOBE (Sepkoski, 1995), and also approximately the Ordovician gastropod peak of the global composite curve (Frýda and Rohr, 2004), in contrast to the low diversity in North China and Tarim.

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EARLY DIVERSIFICATION OF CHITINOZOANS ON BALTICA: NEW DATA FROM NORTHERN ESTONIA AND LATVIA

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Key words: *chitinozoans, Middle-Late Ordovician, North Estonia, Latvia.*

Cryptic chitinozoans originated and diversified during the Great Ordovician Biodiversification Event (GOBE). They are abundant and diverse in the Ordovician and Silurian succession of Baltoscandia – the region where they were first reported by Alfred Eisenack in 1930s. Chitinozoans from eastern Baltoscandia, including Estonia, are generally well-known by excellent and often three dimensional preservation in the late Middle and Late Ordovician limestones. Due to the abundance and biostratigraphic utility, chitinozoans from this interval are extensively studied and their diversification history is rather well documented (Paris et al., 2004; Hints et al., 2018). However, the early diversification of chitinozoans from Tremadocian to Dapingian is rather poorly known in Baltoscandia, and the previous diversity estimates for these stages are notably lower compared to the values from other regions (Achab and Paris, 2007; Liang and Tang, 2016; Liang et al., 2018). Hints and Nõlvak (2006) reported a diverse late Tremadocian chitinozoan assemblage from a single sample, suggesting that the previously reported low diversity during the Early and early Middle Ordovician of Baltica was primarily due to sampling bias and lack of studies. In order to fill this gap and more fully document the early diversification of chitinozoans on Baltica, we collected new samples and re-studied older, hitherto unpublished collections, in total 80 samples. The bulk of new data were recovered from two sections, the Jägala waterfall section, northern Estonia (Nõlvak et al., 2019), and the Baldone drill core, central Latvia. Combining these data with additional new samples from northern Estonia and previously published reports, allows better understanding of the early diversification of chitinozoans in Baltoscandia and assessing their biogeographic affinities. The studied sections are briefly characterized as follows.

The Jägala waterfall section in northern Estonia represents a shallow-shelf part of the Baltoscandian basin. In total, 11 genera and 47 species of chitinozoans were identified from the 7.5 m succession of sandstones, marls and carbonates. The fossiliferous strata range from the Hunneberg to Kunda regional stages, corresponding to the upper Tremadocian to lower Darriwilian. A barren interval in the Floian is largely due to poor preservational conditions, but may also indicate a low diversity period after the late Tremadocian diversity peak. Full details on this section are provided in Nõlvak et al. (2019).

The Baldone borehole, central Latvia, represents a deeper shelf mud-supported facies comprising marls and argillaceous limestones. Compared to northern Estonia, the upper Tremadocian to the lower Darriwilian succession is ca ten times thicker; however, the Floian and Dapingian strata are represented by redbeds which are barren of organic-walled microfossils. Twenty samples, 100–500 g each were processed from the section and 12 yielded chitinozoans. Altogether, 13 genera and 37 species were identified. Two species, *Conochitina raymondii* and *Clavachitina grandicula* were obtained from the lowermost part of the Zebre Formation, corresponding to the upper Tremadocian or lower Floian. Diverse chitinozoan assemblage was recovered from the Šakyna and Baldone formations, lower Darriwilian.

The Uuga and Leetse cliffs, Pakri peninsula, northern Estonia, were studied by eight new samples from the Türisalu, Varangu and Leetse formations, Tremadocian to Floian. Two species, *Pellichitina*? sp. and *Rhabdochitina* sp., were identified from the Varangu Formation at Uuga, reminding the lower productive samples from the Jägala section (Nõlvak et al. (2019). In Leetse cliff, the uppermost sample from the Varangu Formation yielded a different chitinozoan assemblage from that in Uuga, including *Conochitina* cf. *raymondii*, *Eremochitina* sp. A aff. *baculata*, *Lagenochitina esthonica* and *Lagenochitina* cf. *longiformis*. The Leetse Formation at the Uuga cliff contained *Conochitina decipiens*, *Desmochitina* sp. gr. *minor*, *L. esthonica*, *L.* cf. *longiformis*, *Conochitina* sp., *E.* sp. A aff. *baculata* and *Euconochitina* sp.

The Mäeküla outcrop in Tallinn, northern Estonia, was studied by two samples from the Leetse Formation and both of them yielded chitinozoans, including *Conochitina decipiens* and *Desmochitina* sp. gr. *minor*, *Eremochitina* sp. A aff. *baculata*, *Lagenochitina* cf. *longiformis* and *Lagenochitina ovoidea*, which are quite similar to the assemblage in the same formation at Uuga. One new species, *Desmochitina* sp. n., which is characterized by an ovoid chamber and lack of neck and collar was recovered and a questionable form resembling *Cyathochitina calix* was observed in the upper part of the formation roughly corresponding to the middle part of Floian.

The results based on the above five sections shed new light on the chitinozoan diversification during the Early and early Middle Ordovician (Tremadocian to Dapingian) in Baltoscandia. During this interval, strata from the stratigraphically more complete deeper shelf sections of the Baltic palaeobasin are mainly occupied by redbeds, which are devoid of chitinozoans (Nõlvak, 2002). Thus the condensed strata in northern Estonia are more promising for studying the early diversification of chitinozoans in Baltoscandia.

As illustrated in Nõlvak et al. (2019), the chitinozoans recovered from the middle and upper Floian at Jägala waterfall increased the diversity value significantly, about a three-fold to five-fold compared to the previous estimates for Baltica (Paris et al., 2004), whereas the data from the Floian and lowermost Dapingian are still rare. However, the additional samples from northern Estonian outcrops added some supplementary data to this interval. The late Tremadocian assemblage of *Desmochitina* sp. gr. *minor*, *Lagenochitina* cf. *longiformis*, *Lagenochitina esthonica* and *Lagenochitina ovoidea*, recorded from the Jägala waterfall section, is now known to occur in the Floian too, if the correlations are correct. In addition, four species, *E*. sp. A aff. *baculata*, *Conochitina* sp., *Euconochitina* sp. and *Desmochitina* sp., are newly identified from the Floian. Thus, at least 8 species, excluding the questionable *Cyathochitina calix*, were present in the Floian interval. Furthermore, three species, *Conochitina* cf. *raymondii*, *Pellichitina*? sp. and *Rhabdochitina* sp. can be added to the interval of late Tremadocian. These data, combined with the report of Hints and Nõlvak (2006), suggest that chitinozoans experienced a short and distinct bloom in the late Tremadocian with more than 20 species present. Notably, a similar late Tremadocian diversity acme has also been recognized in South China (Liang and Tang, 2016), and the regions share a number oIn summary, chitinozoan diversity in the Early and early Middle Ordovician appears to have been notably higher on Baltica than estimated in previous works. Although the biodiversity estimates during this interval are still low, with the only exception of late Tremadocian, the trend is still in rise through the Floian to Dapingian and then reaches its acme in the early Darriwilian. Further studies focusing on this interval, particularly the Floian, are still required to fully understand the chitinozoan diversification on Baltica.

This is a contribution to IGCP 653 project.

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DROWNING EVENT AND YANGTZE RAMP DURING EARLY TO MIDDLE ORDOVICIAN IN SOUTH CHINA: IMPLICATIONS FOR THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT (GOBE)

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The ramp model was introduced by Read (1985), in which there is a low-angle slope (generally less than 1°). During Early-Middle Ordovician in South China, the Yangtze Platform was changed from a shelf to a ramp due to drowning event, coincided with biodiversity acmes of many taxa, also known as the Great Ordovician Biodiversification Event (GOBE) in South China (Luan et al., 2017). The GOBE is one of the most significant and rapid radiations of marine organisms during geological history, especially at lower taxonomic levels, associated with ecological revolutions indicated by the replacement of Cambrian evolutionary fauna by Paleozoic evolutionary fauna (Sepkoski, 1979, 1981). Both the biotic and abiotic factors (i.e. intrinsic and extrinsic factors) are taken into considerations in order to explain the origin of GOBE. The extrinsic factors, however, should be more important at larger scale (i.e., paleocontinental scale) (Servais and Harper, 2018). In South China, numerous researches focused on the GOBE, showing the earliest biodiversity acme of brachiopods during Early-Middle Ordovician and other unique features (Zhan et al., 2010, and references therein). Although some corresponding sedimentary responses have been observed (Liu, 2009; Liu et al., 2010; Liu et al., 2011), the correlations with ramp background have never been discussed in detailed.

Thus five sections in the Yangtze region and one section in the Jiangnan region have been selected, including Daoba in Guizhou Province (GPS, 28°16'13.8″N, 108°36'12.3″E), Xiangshuidong in Hubei Province (GPS, 29°59'7.2″N, 111°26'57.6″E), Daling in Anhui Province (GPS, 30°16'29. 5″N, 117°39'23. 1″E), Gudongkou in Hubei Province (GPS, 31°21'48.7"N, 110°45'34.9"E), Honghuayuan in Guizhou Province (GPS, 28°04'01.8"N, 106°51'20.8"E), Nanba in Hunan Province (GPS, 28°23'59.38"N, 112°15'12.04"E). And they can be correlated with each other based on the detailed biostratigraphical framework (Li et al., 2017; Luan et al., 2019).

The mixed siliciclastic and carbonate deposits of the Meitan, the Dawan and the Zitai formations are widely distributed in the Yangtze Platform after drowning (Luan et al., 2017, 2019). More specifically, in this research, four siliciclastic lithofacies and fifteen carbonate lithofacies are identified, i.e., LF1 cross-bedded sandstone, LF2 sandstone, LF3 siltstone, LF4 mudstone, LF5 bioclastic grainstone, LF6 bioclastic grain-packstone, LF6R bioclastic rudsotne, LF7 bioclastic packstone, LF7B bioturbated bioclastic packstone, LF8 bioclastic wackestone, LF8B bioturbated bioclastic wackestone, LF9 argillaceous bioclastic wackestone, LF9Q quartzose bioclastic wackestone, LF10 open-marine bioclastic wackestone, LF10S spiculite wackestone, LF10G gastropod wackestone, LF11 calcimudstone, LF11A argillaceous calcimudstone and LF11Q quartzose calcimudstone.

The results show that the topography of ramp after drowning are high northwest and southeast low, dipping downward from north to south, with the terrigenous sediments coming from western platform, being controlled by eustatic sea-level and tectonic movements. The brachiopods, moreover, attains its first diversity peak in South China or even around the world during Ordovician, and this diversity peak comprises three onshore migrations (Zhan and Jin, 2014), which is probably facilitated by a series of new niches provided by the gentle topography of ramp. Since the brachiopods occupied the shallow-water environment, the Whiterock fauna (trilobites) migrated toward deep water (Zhou et al., 2007), have been suggested as avoiding the competitions with brachiopods, and gradually replaces the Ibex fauna (trilobites) in the process of migration. Thus the episodic radiations of organisms in South China are more or less controlled by the palaeoenvironmental background.

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ISOGRAPTUS MOBERG AND *PSEUDISOGRAPRUS* BEAVIS AND MIDDLE ORDOVICIAN ZONAL STRATIGRAPHY OF THE GORNY ALTAI (SW SIBERIA, RUSSIA)

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Key words: *Ordovician, graptolites, zonal stratigraphy, Gorny Altai*.

Numerous Ordovician graptolites were collected by N.V. Sennikov and first regional graptolite zonation for the Gorny Altai was proposed (Sennikov, 1976; Obut, Sennikov, 1984; Obut, Sennikov, 1986; Sennikov, 1996; Sennikov et al., 2008). After ratification of the new Ordovician stages of ICS International Commission on Stratigraphy (Ogg et al., 2008), the updating of the graptolite zonation for the Ordovician of the Gorny Altai become important.

The studied section is located in a quarry and roadside pits on the left bank of the Lebed River (Fig. 1). In a quarry, interbedding of clayey argillites, siltstones and sandstones is observed, with a total thickness of about 140 m. In this section, numerous well preserved graptolites belong to the genus *Isograptus* and the genus *Pseudisograptus* have been found. Analysis of ranges of the graptolite species in the Pridorozhny Section allowed specify the lower boundaries of graptolite zones in the Dapingian interval. The *I. gibberulus* Zone was subdivided into two Subzones: the lower *C. deflexus* Subzone and the upper *I. maximo-divergens* Subzone. Also in this section, the stratigraphic position of the lower boundary of the *E. hirundo* Zone (the lower boundary of the *I. caduceus imitatus* Subzone) is recorded.

The *C. deflexus* Subzone for stratigraphic division of the Altai Ordovician sections was defined in 2011 by the author (Bukolova, 2011) covering the lower part of the *I. gibberulus* Zone. The stratotype of the *C. deflexus* Subzone for the Ordovician of Gorny Altai is proposed in the Pridorozhny Section. The *C. deflexus* Zone is outlined in the Ordovician of South China (Webby et al., 2004), which allows a correlation with international levels. In Russia, the zonal subdivision of *C. deflexus* is allocated only in the Ordovician of Gorny Altai. The lower boundary of the considered subzone was defined by the First Appearance Data (FAD) of *Isograptus gibberulus* (Nicholson) (zonal index-species for *I. gibberulus* Zone) and *Corymbograptus deflexus* (Elles et Wood) (zonal index-species for *C. deflexus* Subzone). *C. deflexus* Subzone besides the index-species includes *Pseudisograptus manubriatus* (Hall), Expansograptus sp., *Acrograptus nicholsoni* (Lapworth), *Isograptus paraboloides* Tzaj, *Pseudisograptus* sp., *Corymbograptus deflexus* (Elles et Wood), *Isograptus* aff. *walcottorum* Ruedemann, *Isograptus* sp., *Corymbograptus* sp., *Paradelograptus* sp.

The *I. maximo-divergens* Subzone in the Altai Ordovician sections was first identified by Bukolova (2011) in the volume of the upper part of the *I. gibberulus* Zone. For the *I. maximo-divergens* Subzone stratotype a part of the Pridorozhny Section was proposed – the top 1 meter of the 4th unit and partially the 5th unit (without the top 1.8 metres). The *I. maximo-divergens* Zone was defined in the Ordovician of Australia, New Zealand and North America

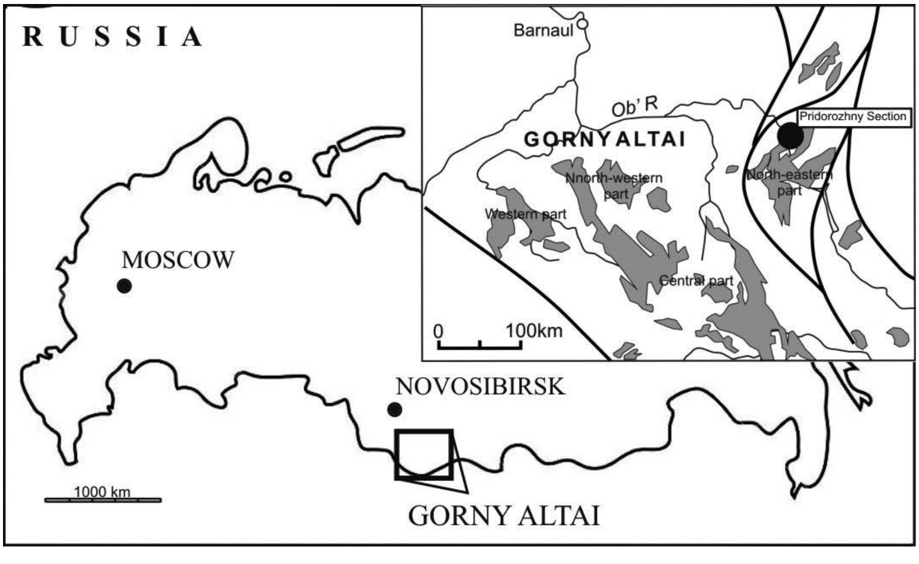
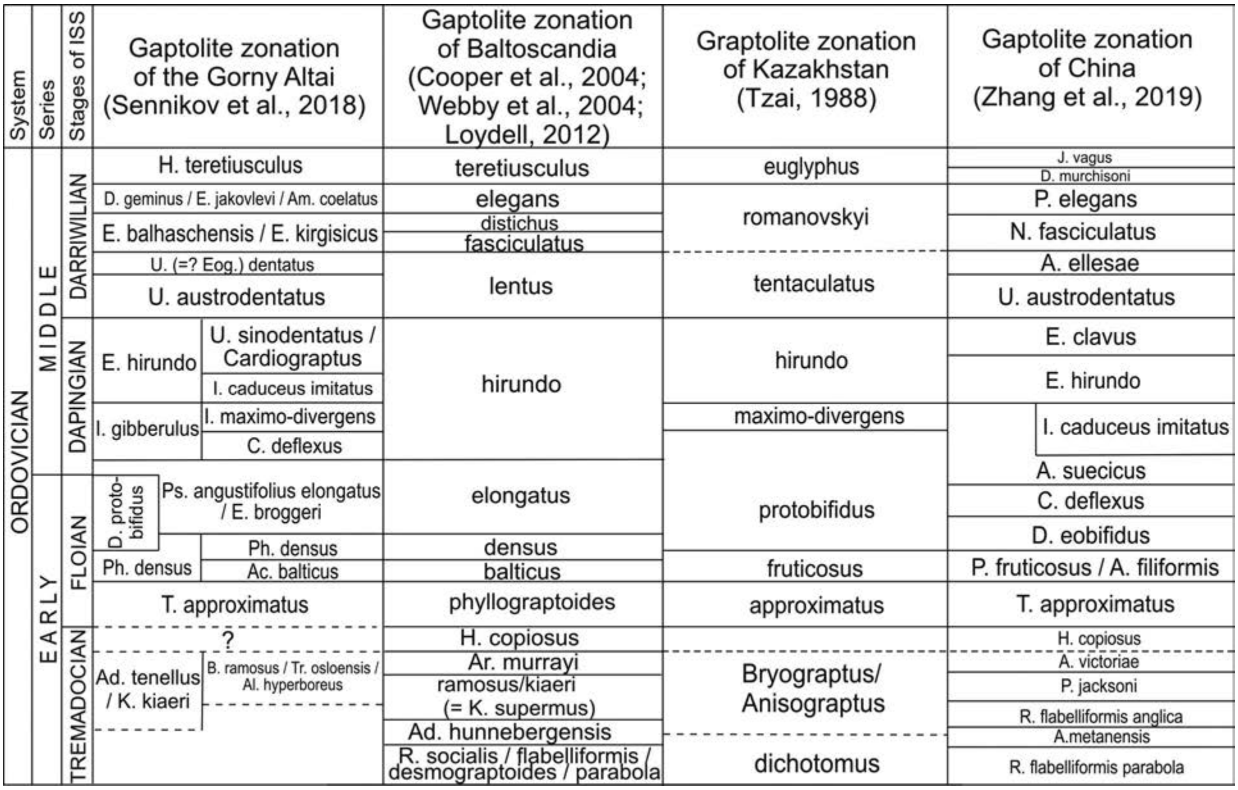


Fig. 1. Sketch map of locations of the Altay Ordovician deposits with main structural-tectonic elements (after Sennikov et al., 2018).



System	Series	Stages of ISS	Gaptolite zonation of the Gorny Altai (Sennikov et al., 2018)		Gaptolite zonation of Baltoscandia (Cooper et al., 2004; Webby et al., 2004; Loydell, 2012)	Graptolite zonation of Kazakhstan (Tzai, 1988)	Gaptolite zonation of China (Zhang et al., 2019)
ORDOVICIAN	MIDDLE	DARRIWILIAN	H. teretiusculus		teretiusculus	euglyphus	J. vagus
							D. murchisoni
			D. geminus / E. jakovlevi / Am. coelatus		elegans	romanovskyi	P. elegans
			E. balhaschensis / E. kirgisicus		distichus		N. fasciculatus
					fasciculatus		
			U. (=? Eog.) dentatus		lentus	tentaculatus	A. ellesae
			U. austrodentatus				U. austrodentatus
		DAPINGIAN	E. hirundo	U. sinodentatus / Cardiograptus	hirundo	hirundo	E. clavus
				I. caduceus imitatus			E. hirundo
			I. gibberulus	I. maximo-divergens		maximo-divergens	I. caduceus imitatus
				C. deflexus		protobifidus	
							A. suecicus
	EARLY	FLOIAN	D. protobifidus	Ps. angustifolius elongatus / E. broggeri	elongatus		C. deflexus
							D. eobifidus
			Ph. densus	Ph. densus	densus	fruticosus	P. fruticosus / A. filiformis
				Ac. balticus	balticus		
			T. approximatus		phyllograptoides	approximatus	T. approximatus
		TREMADOCIAN	?		H. copiosus		H. copiosus
			Ad. tenellus / K. kiaeri	B. ramosus / Tr. osloensis / Al. hyperboreus	Ar. murrayi	Bryograptus/ Anisograptus	A. victoriae
					ramosus/kiaeri (= K. supermus)		P. jacksoni
							R. flabelliformis anglica
					Ad. hunnebergensis		A.metanensis
					R. socialis / flabelliformis / desmograptoides / parabola	dichotomus	R. flabelliformis parabola

Fig. 2. Correlation of regional stratigraphic subdivisions for the Ordovician of the Gorny Altai, China, Baltoscandia, and Kazakhstan.

(Cooper, 1979; Webby et al., 2004; Loydell, 2012), as well as in the Ordovician of Kazakhstan (Tzai, 1988). In Russia, the zonal subdivision *I. maximo-divergens* is allocated only in the Ordovician of Gorny Altai. The lower boundary of the considered subzone was defined by the FAD of the index-species – *Isograptus maximo-divergens* (Harris). Graptolite association of the *I. maximo-divergens* Subzone besides the index-species includes *Expansograptus* sp., *Acrograptus nicholsoni* (Lapworth), *Corymbograptus deflexus* (Elles et Wood), *Isograptus* sp., *Isograptus* aff. *walcottorum* Ruedemann, *Expansograptus extensus* (Hall), *Pseudotrigonograptus ensiformis* (Hall), *Isograptus reduncus* Tzaj, *Isograptus primulus* Harris, *Isograptus* aff. *schrenki* Obut et Sobolevskaya, *Pseudisograptus manubriatus janus* Cooper et Ni, *Isograptus elegans* Tzaj.

The *I. caduceus imitatus* Subzone was allocated by a team of researchers, including the author (Bukolova, 2011), covering the lower part of the *E. hirundo* Zone. The *I. caduceus imitatus* Zone was defined in the Ordovician of China (Webby et al., 2004). In Russia, the zonal subdivision is allocated only in the Ordovician sections of the Gorny Altai, one of which is the Pridorozhny Section. The lower boundary of the considered subzone was defined by the FAD of the index-species- *Isograptus caduceus imitatus* Harris. *Caduceus-imitatus* Subzone besides the index-species includes graptolites *Pseudisograptus manubriatus* (Hall), *Expansograptus* sp., *Isograptus* sp., *Isograptus elegans* Tzaj, *Isograptus divergens* (Harris), *Isograptus caduceus* (Salter), *Expansograptus suecicus suecicus* (Tullberg), *Corymbograptus* sp.

Substantial supplements have been made to the zonal graptolite scale of the Middle Ordovician of Gorny Altai at the level of the Dapingian stage (Zones *I. gibberulus* and *E. hirundo*). The *I. gibberulus* Zone is subdivided into two: lower *C. deflexus* Subzone and upper *I. maximo-divergens* Subzone, both of them were established in the Pridorozhny Section. New *I. caduceus imitatus* Subzone was defined, as a lower part of *E. hirundo* zone. As a result, the possibility of direct correlation with the Ordovician zones of China, Australia, New Zealand, North America and Kazakhstan appeared (Fig. 2).

This is the contribution to IGCP 653 project.

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NEW DATA ON THE ORDOVICIAN DEPOSITS OF SIBERIA

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Key words: *Ordovician, Siberian Platform, West Siberian Plate, Gorny Altai, microfossils, algae.*
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The degree of the Ordovician deposits studying in Siberia is extremely uneven. Changes in the Ordovician part of the International Stratigraphic Chart (ISC): three-term division, 7 new stages, the lower Ordovician boundary on the appearance of *Iapetognathus fluctivagus* conodonts, etc., led to a new understanding of the stratigraphic position of the Ordovician rocks in Siberia (Kanygin et al., 2017; Makarenko et al., 2014; Decisions .., 1999; Sennikov et al., 2008, 2013, 2018; Sobolevskaya, Nekhorosheva, 2017). As a rule, sediments of the Lower Ordovician do not always contain fossil organic remains, which would allow comparisons with the General and International stratigraphic scales. For the identifying and correlation of the Ordovician deposits in new regions, paleontological material is important, such as nano-, micro-, macrofossils, and bioclastic with the involvement of geological and geophysical data.

The well-studied Ordovician deposits within the Igarka-Norilsk structural-facial zone (SFZ) of the Siberian platform occur according to the Upper Cambrian and overlap with a large stratigraphic disagreement by the Lower Silurian (Kanygin et al., 2017; Sobolevskaya, Nekhorosheva, 2017). Kystyktakhskaya 1p borehole, drilled in this SFZ (valley of the Kystyktakh river), had crossed Ordovician deposits in the interval 2715.6–2600 m, according to GIS and lithology. The underlying Cambrian sediments characterized by archaeocyates to the depth 3410.05 m, have been overlapped by 987-meter strata of layered varicolored dolomites, with interlayers and anhydrite lenses, with an abundance of sulphides and lenses of clayey limestone. Above the strata of variegated dolomites, a thin (about 20 m) microbiostatic interlayer was traced, containing few bioclasts of ostracods, brachiopods, trilobites, crinoids, and skeletal fauna. In thin sections (samples with depth 2623 m), the thalli sections of the alga *Nuia sibirica* Maslov (Plate, Fig. 1) and the grubs of *Girvanella problematica* Nich. et Ether were found. The Ordovician section ends with a 28-meter pack of gray dolomites, marls without definable fauna. According to regional stratigraphic schemes, layers with *Nuia sibirica* Maslov have been traced in the upper part of the Taimyr Grustninskaya sequence, in the upper subformation of the Ust-Kut Formation on the Siberian Platform, in the Taimen Formation of the Tremadocian Takoshkin horizon of the Zolotokitat and Martayga zones of the Kuznetsk Alatau (Kanygin et al., 2017; Sennikov et al., 2018; Sobolevskaya, Nekhorosheva, 2017).

Beds with algae *Nuia sibirica* Maslov (Plate, Fig. 2), combined into the Nyarga Formation, were also traced to the East of the West Siberian Plate (right bank of the Ob River) (Makarenko et al., 2014; Sennikov et al., 2013). Bioclastic strata with fragments of ostracods, trilobites, brachiopods, mollusks, crinoids, with shrinking cracks, lenses of relict clotted-lumpy texture and an admixture of aleuritic quartz grains was transverse by the borehole Nyarginskaya 1 in the interval 2948.7–2756.4 m. It was discordant overlapped by tuffs and effusive rocks of the Devonian Dunaevskaya strata. Taking into account changes in the ISC, the layers with *Nuia sibirica* trace the lower boundary both of the Ordovician and the Tremadocian stage in certain facies and can be established in new researching areas.

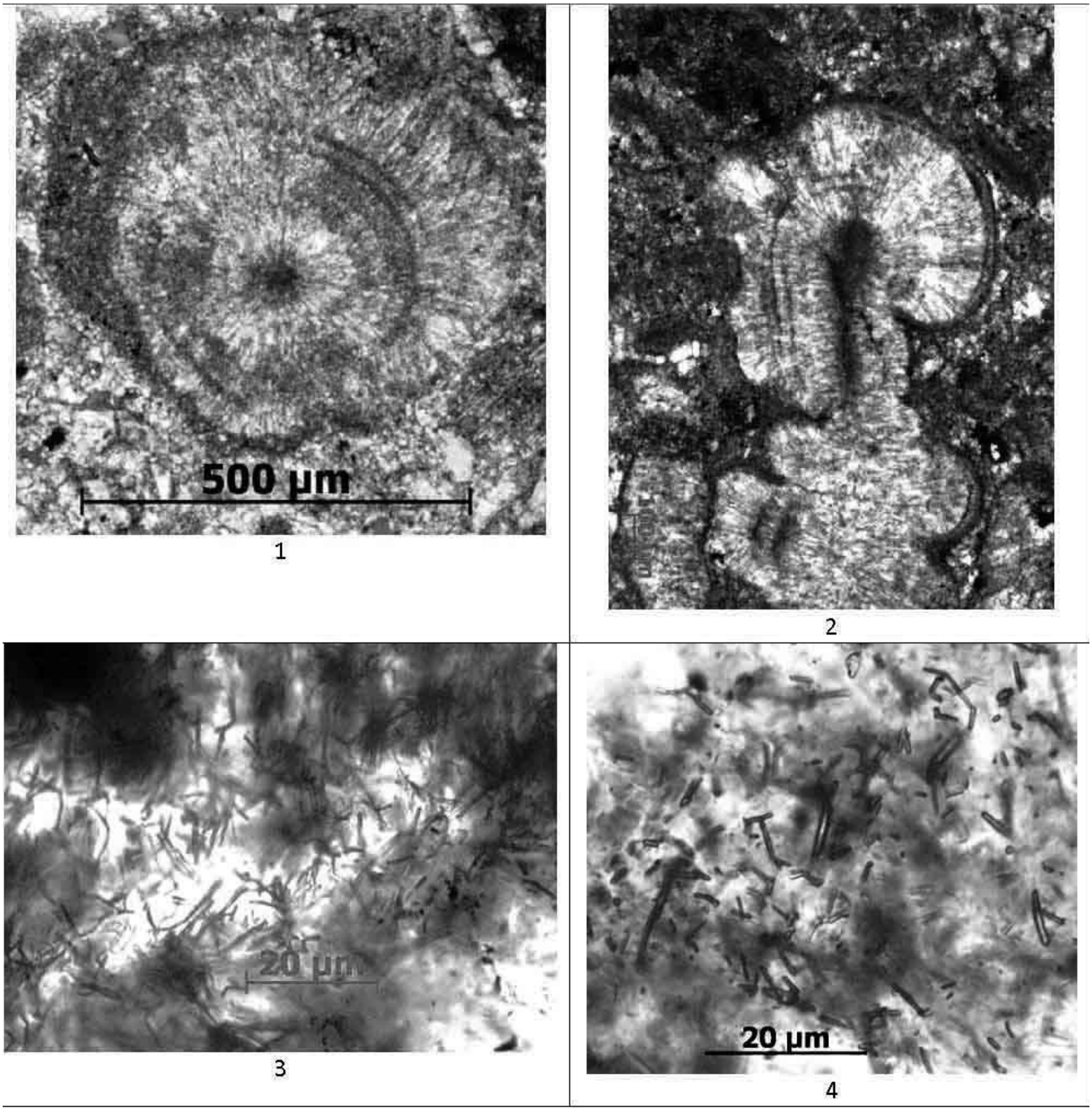
The weak faunal characteristic of the Upper Cambrian and Lower Ordovician deposits, especially in areas of a strong rocks dislocation, obliged to establish the poorly defined Cambrian-Ordovician formations. On the West Siberian plate such deposits are identified by G. Isaev in the Sobolinaya strata and traced in borehole sections in Sobolinaya, Polonskaya, Golovnaya and other areas (Isaev, 2007). The stratigraphic position of the strata is analogous with the Gorno-Altaiskaya series of the Altai-Sayan folded region. By the study of carbonate-chlorite schists with a curved structure from the Polonskaya 1 borehole in thin sections, microfossils were found that we found later in the schist aleurolites of the Cambrian-Ordovician Maralikhinskaya Formation of the Charyskaya SFZ of Altai Mountains (Plate, Figs 3–4) (Makarenko et al., 2014).

The Middle and Upper Ordovician deposits were studied in the borehole 56 of the Myldzhinskaya area (the stratotype of Pavlovskaya Formation) (Decisions .., 1999). Presumably, deposits of this level are traced in sections of the borehole 118 (it is practically alternate of the borehole 56, at 700 m to the north), in the borehole 208, located 4.5 km from it to the east and in the borehole 104, at 7.7 km to the north-northeast.

In the borehole 104 from interval 2635.4–2644.0 m dark gray micritic limestones were raised with Ordovician algae and relics of calcareous netting fragments. In the interval 2742–2739 m deeply sandy silicified calcarenites were lifted by the borehole 118, similar to those of the borehole 56 section. In the borehole 208, the lower part of the section (about 70 m) is represented by brecciated altered dolomites, and microphytolite dolomitized recrystallized limestones were lifted from the upper part of the section. Their age is conventionally designated as Cambrian-Ordovician.

Plate

Paleontological remains in thin sections of the Ordovician deposits of Siberia



Figs 1, 2 — *Nuia sibiri*ca Maslov algae section (Fig. 1 — Kystyktakhskaya borehole 1p, sample 2905-1, depth 2623.0 m; Fig. 2 — Nyarinskaya borehole 1, sample 5876, depth 2944 m); Figs 3, 4 — micro remains in shale (Fig. 3 — Polonskaya borehole 1, sample 23, interval 2916.2–2920.0 m; Fig. 4 — Maralikhinskaya Fm, sample 2136/3a, Gorny Altai).

The results of the thin sections study of the deposits comparable to the Ordovician ones show their sharp difference from the deposits of all other Phanerozoic systems and weak identification, especially in new regions, in the absence of the studying methods complexity.

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BRACHIOPOD ZONATION OF THE UPPER ORDOVICIAN DEPOSITS OF THE TUNGUSKA SYNECLISE (SIBERIAN PLATFORM)

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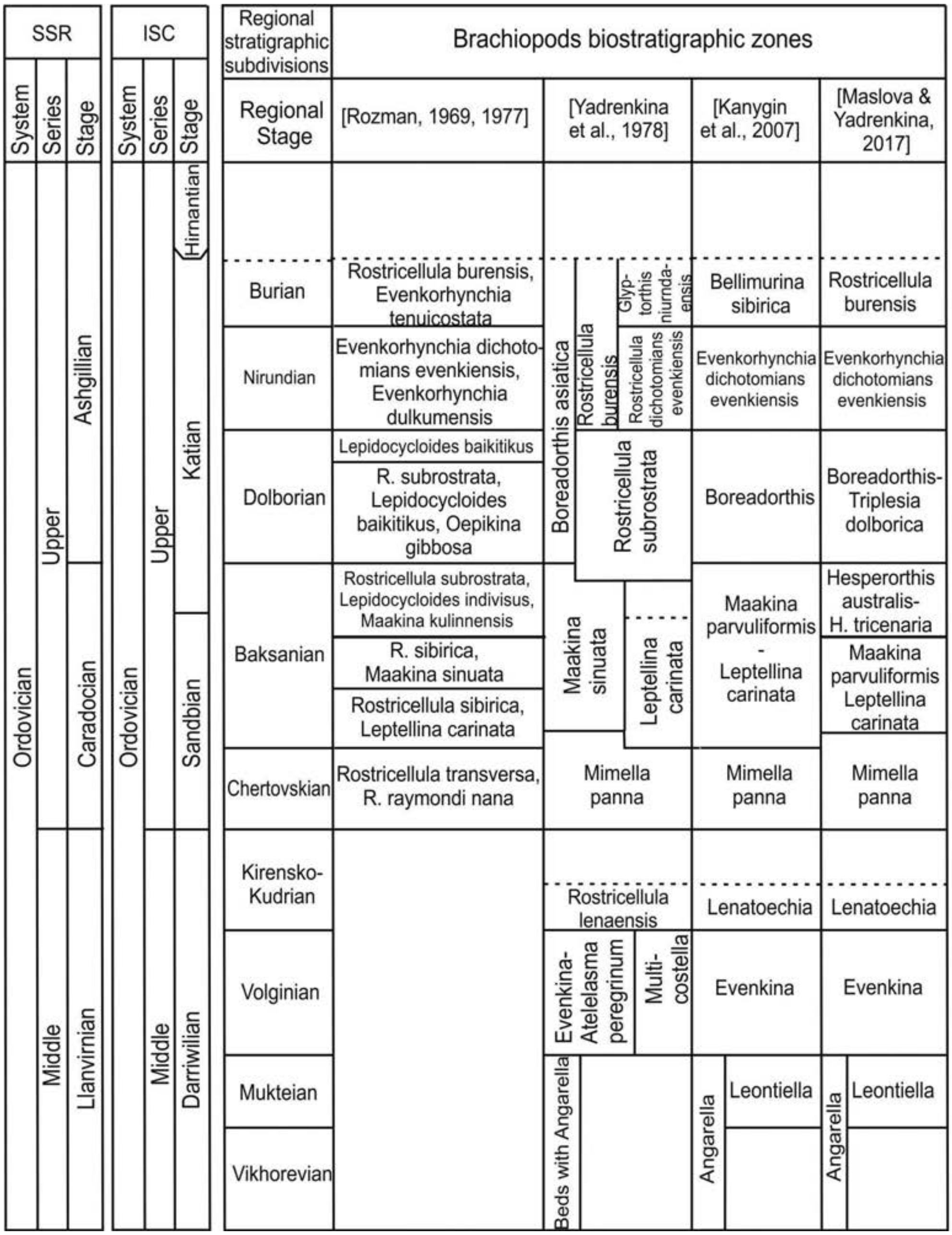
Key words: *brachiopods, Ordovician, biostratigraphic zones.*

Brachiopods are one of the most widespread group of macrofauna in the Ordovician deposits of the Siberian Platform. A fundamental basis for zonation of the Ordovician of the Siberian Platform was introduced by O.I. Nikiforova and O.N. Andreeva (1961). They described the most important brachiopod taxa for stratigraphy and used them as guidelines for establishing the first versions of regional stratigraphic schemes. Brachiopod complexes characterizing regional stages typified the defined later biostratigraphic zones. In 1969 Kh.S. Rozman (1969) in the valleys of the



SSR			ISC			Regional stratigraphic subdivisions	Brachiopods biostratigraphic zones			
System	Series	Stage	System	Series	Stage	Regional Stage	[Rozman, 1969, 1977]	[Yadrenkina et al., 1978]	[Kanygin et al., 2007]	[Maslova & Yadrenkina, 2017]
Ordovician	Upper	Ashgillian	Ordovician	Upper	Hirnantian					
					Katian	Burian	Rostricellula burensis, Evenkorhynchia tenuicostata	Boreadorthis asiatica Rostricellula burensis Glyptorthis niurundaensis	Bellimurina sibirica	Rostricellula burensis
						Nirundian	Evenkorhynchia dichotomians evenkiensis, Evenkorhynchia dulkumensis	Rostricellula dichotomians evenkiensis	Evenkorhynchia dichotomians evenkiensis	Evenkorhynchia dichotomians evenkiensis
						Dolborian	Lepidocycloides baikitikus R. subrostrata, Lepidocycloides baikitikus, Oepikina gibbosa	Rostricellula subrostrata	Boreadorthis	Boreadorthis-Triplesia dolborica
		Caradocian				Baksanian	Rostricellula subrostrata, Lepidocycloides indivisus, Maakina kulinnensis	Maakina sinuata	Maakina parvuliformis - Leptellina carinata	Hesperorthis australis-H. tricenaria
					Sandbian		R. sibirica, Maakina sinuata	Leptellina carinata		Maakina parvuliformis Leptellina carinata
							Rostricellula sibirica, Leptellina carinata			
						Chertovskian	Rostricellula transversa, R. raymondi nana	Mimella panna	Mimella panna	Mimella panna
	Middle	Llanvirnian		Middle	Darriwilian	Kirensko-Kudrian		Rostricellula lenaensis	Lenatoechia	Lenatoechia
						Volginian		Evenkina-Atelelasma peregrinum Multicostella	Evenkina	Evenkina
						Mukteian		Beds with Angarella	Angarella Leontiella	Angarella Leontiella
						Vikhorevian				

Fig. 1. Brachiopod zones distinguished on the Siberian Platform by different authors.

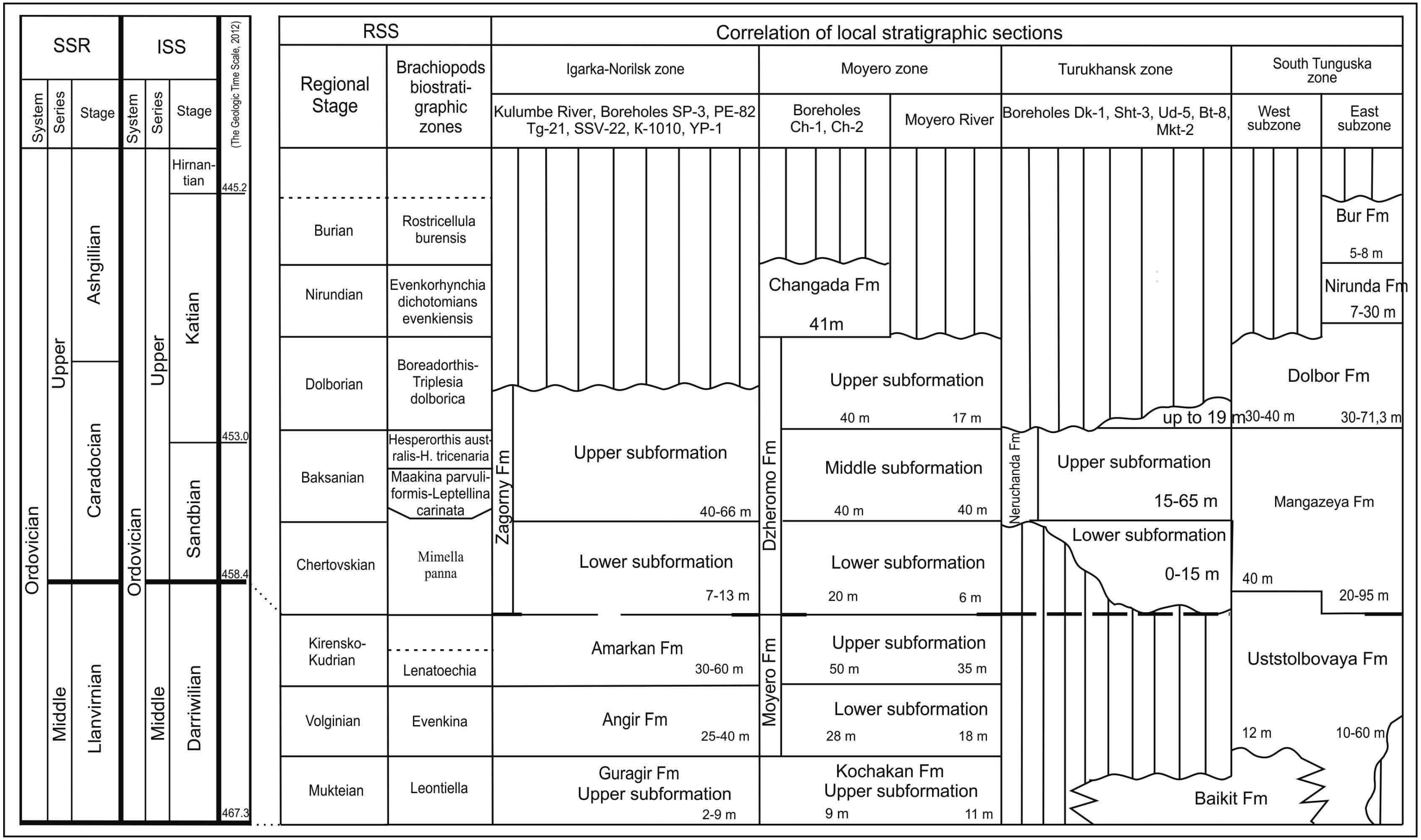


Fig. 2. The correlations of biostratigraphic zones by brachiopods with subdivisions of the regional and local stratigraphic scale.

Nizhnyaya Chunku and the Bolshaya Nirunda rivers distinguished two zones, which corresponded to the Nirundin and Bursk horizons – *Evenkorhynchia dichotomians evenkiensis* и *Rostricellula burensis – Evenkorhynchia tenuicostata*. In 1974 A.G. Yadrenkina (1974) after studying the entire territory of the Siberian platform, distinguished 11 brachiopod complexes characterizing all the regional stages of the Ordovician. In 1977 Kh.S. Rozman further divided the Upper Ordovician to eight zones. Subsequently, a team of specialists developed a system of parallel biostratigraphic scales by different groups of fauna (Rozman, 1977; Yadrenkina et al., 1978). Yet later with the appearance of new data from further studies A.G. Yadrenkina developed three biostratigraphic zones for the Middle Ordovician: *Leontiella*, *Evenkina*, *Lenatoechia*, corresponding to Mukteian, Volginian and the lower part of the Kirensko-Kudrian regional stages. The Upper Ordovician was divided into five zones by the volume of corresponding regional stages (Kanygin et al., 2007, 2013) (Fig. 1). Zones by brachiopods were first included into the new version of the regional stratigraphic scheme of the Ordovician of the Siberian Platform, which was officially accepted in 2014 by the Interdepartmental Stratigraphic Committee of Russia and published (Kanygin et al., 2017).

Author conducted analysis of the stratigraphic and spatial distribution of the brachiopod complexes of the Tunguska Syneclise. This allowed to refine and detail the division and correlation of Ordovician deposits (Fig. 2). Full characterization of the distinguished brachiopod zones was published (Maslova & Yadrenkina, 2017). The lower boundaries of the zones correspond to the first appearance of the index-species, the upper boundaries – to the first appearance of the index-species of the overlying zone. The proposed biostratigraphic zones correspond to assemblage zones. In the developed zonal biostratigraphic scheme, the boundaries and volumes of the zone of *Mimella panna* and *Maakina parvuliformis-Leptellina carinata* were specified. In the Upper Ordovician, the zone of *Hesperorthis australis-Hesperorthis tricenaria* is established, corresponding to the upper part of the Baksanian regional stage. The index-species of this zone are cosmopolites and can serve as a reference level for global correlations.

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BRACHIOPODS OF ORDOVICIAN AND SILURIAN BOUNDARY DEPOSITS IN THE ARCTIC

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Arctic sections in which Ordovician-Silurian brachiopods were studied include those on Novaya Zemlya, Vaigach, Pai-Khoi, Taimyr Peninsula, Siberian Platform, Severnaya Zemlya, Novosibirsk Islands, and in Northeast Russia. Brachiopod taphotopes confined to carbonate deposits differ in all the sections mentioned above in taxonomic composition. In sections of the southern part of Novaya Zemlya, Vaigach and Pai-Khoi, the Late Ordovician brachiopods are endemic and probably due to the isolation of the basin, which started in the Late Ordovician (Bondarev, 1968). Among them are representatives of such genera as *Ancystorhyncha, Vellamo, Platystrophia, Oxoplecia*, and at the very top of the section, *Proconchidium muensteri* (St. Joseph) (Ugra and Varnek horizons). Related species of these genera, except for the Novaya Zemlya-Vaigach-Pai-Khoi region and the Urals, are known in the Late Ordovician (Katian) sediments of Baltoskandia. The oldest Rhuddanian (Llandovery) brachiopod assemblage was studied in the reference section of the Khatanzeya Peninsula (Perseisky Horizon). There, optimal conditions of shallow water caused by the Llandovery transgression contributed to the diversity of the brachiopod assemblage (Modzalevskaya, 1985). Occurrence in the assemblage of representatives of such genera as *Stricklandia, Clorinda*, which are close to the species of the Llandovery stratotype region, helped to specify the age of the host sediments (A_4) (Cocks et al., 1984).

Two types of Ordovician-Silurian sections identified in Taimyr for the north and south are characterized by continuous occurrence of boundary sediments. The northern section (Lower Taimyr River basin) is considered to be transitional to carbonate strata exposed in southern Taimyr. The Late Ordovician carbonate-terrigenous Barkovskaya Fm. includes a specific set of brachiopod taxa including species similar to brachiopods from the Boda Limestone (Dalarna, Sweden), and they cannot be identified with brachiopods of the same age from the sections of the Siberian platform. The data suggested that during the Katian, the Taimyr Peninsula belonged to the Baltic paleocontinent (Cocks, Modzalevskaya, 1997). In organogenic detrital limestone from *Holorhynchus giganteus* Kiaer and *Tcherskidium unicum* (Nik.), there are interlayers of siliceous shale with graptolites from the Climacograptus supernus zone. The Dvoininskaya rock sequence with graptolites of analogues of the Parakidograptus acuminatus zone, which lies conformably on the Barkovskaya Fm., is poorly characterized by sporadic *Meifodia recta* (Nikif.) brachiopods from the Moyerokan Horizon, the Siberian Platform. In southern sections (basins of the Zhdanova and Tareya rivers), the brachiopod assemblage of the Povorotninskaya Fm. is, on the contrary, typical of the Bursky and Nirundinsky horizons of Siberia. It is characterized by limited taxonomic composition with representatives of the orders Orthida, Strophoménida and Rhynchonellida. The lower boundary of the overlying Andreevskaya Fm. lies with graded stratigraphic unconformity or with a lack of the Rhuddanian part of the section. Its most complete section (Tareya River) is represented by stromatoporoid-coral limestone, and limestone with brachiopoid banks. The presence of the Rhuddanian stage in the sections is indicated by the findings of pentamerids of the Borealis and Virgiana genera, known in the Moyerokan Horizon of the Siberian Platform (Modzalevskaya, 2003b).

In the Upper Ordovician Stroininskaya Fm., the Severnaya Zemlya Archipelago (October Revolution Island), brachiopods have not been found. The overlying Vodopadnaya Fm. (Matusevicha River) is characterized by an endemic, but taxonomically diverse assemblage of Silurian brachiopods with strophomenids, pentamerids, atripids, rinhonellids and spiriferids. Similar to Novaya Zemlya, the pentamerids community, taphonomically represented by accumulations of *Borealis cristiformis* (T.Modz.), is the oldest of them (lower subformation of the Perseiskaya Fm.) (Modzalevskaya, 2003a).

In Kotelny Island (New Siberian Islands), the two studied types of Ordovician-Silurian sediments differ in types of rock and fauna. The Teryutekhskaya Fm. (interfluve of the Nicola and Tyuor-Yuryakh rivers) along with brachiopods (*Hesperorthis, Glyptorthis, Rostricellula, Oxoplecia, Mimella*), typical of the Dolborsky, Nurundinsky and Bursky horizons of the Siberian Platform, in the middle part hosts *Holorhynchus* ex gr. *gigantea* Kiaer and *Tcherskidium unicum* (Nik.), characteristic of the upper Ashgillian of the Omulev Mountains (Modzalevskaya, 2018). In the conformably lying Urasinskaya Fm., the brachiopods have not been found. In the northeastern section of the island, the Siberian species *(Strophomena lithea* Nikif.) was recorded in the Late Ordovician Anisinskaya Fm., but in the underlying Malodirinsky-Ainanskaya Fm., the brachiopod assemblage of Eastern Siberia typical of the Chertovskoy, Baksansky and Dolborsky horizons, was identified. The boundary Silurian interval is poor in brachiopods and is dated from other groups of the fauna.

In the Omulev Mountains (Mirny Creek), a full section was studied with a gradual transition from the Ordovician to the Silurian. The alternation of layers with shelly and graptolite fauna is a distinctive feature of the Tirekhtyakhsky Horizon, which contributed to the exact dating of the *Tcherskidium unicum* (Nik.) and *Holorhynchus* ex gr. *gigantea* Kiaer brachiopods (Climacograptus longispinus supernus zone level). Pentameridas give way to a typical Hirnantian fauna: *Hirnantia* aff. *sagittifera* (McCoy), *Dalmanella* cf. *testudinaria* (Dalman), *Girardibella* aff. *bella* (Bergström) (Oradovskaya, Sobolevskaya, 1983). Above, together with the graptolites of the Rhuddanian zone of Akidograptus ascensus and Parakidograptus acuminatus, there is diverse brachiopod assemblage with typical Silurian genera *Protozeuga, Zygospiraella, Protatrypa, Draborthis, Skenidioides*, which existed throughout the Llandovery.

Conclusion. Brachiopods are important for biofacies constructions and substantiation of biogeographic models of paleocontinents' evolution. In addition to individual stratigraphic levels used for intraregional and interregional correlations, their biostratigraphic significance increases due to joint findings with graptolites or conodonts.

This is contribution to IGCP 653 project.

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QUANTIFYING EARLY CAMBRIAN DIVERSITY PATTERN OF SMALL SHELLY FOSSILS ON THE YANGTZE PLATFORM, SOUTH CHINA

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Key words: *CONOP; subsampling; shareholder quorum; taphonomic bias; phosphatization*
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The early Cambrian is characterized by a rapid increase of both biodiversity and morphological disparity (Knoll and Carroll, 1999; Erwin and Valentine, 2012). The emergence and diversification of small shelly fossils (SSFs) during the earliest Cambrian (e.g. Li et al., 2007; Maloof et al., 2010) are generally considered to be the beginning of the Cambrian Explosion. SSFs widely occur on the Yangtze Platform, South China, but most of the previous studies focus on systematics and biostratigraphy (Steiner et al., 2007; Yang et al., 2015). The diversity pattern of small shelly fossils on the Yangtze Platform remains obscure.

We chose 15 well-studied sections (Li and Xiao, 2004; Na, 2011; Qian and Zhang, 1983; Steiner et al., 2004; Yang et al., 2013, 2015) from the Fortunian to the Stage 3 for this study. The dataset contains 235 collections and 161 species of SSFs on the Yangtze Platform. Two approaches are applied to assess fossil diversity patterns. Firstly, we use the Constrained Optimization (CONOP9, Sadler and Cooper, 2008) to create a best-fit composite correlation model and diversity curve, based on the detailed information of FADs and LADs of species. With occurrence-based dataset, we assess diversity by counting taxa actually sampled in a biozone, and use shareholder quorum subsampling (Alroy, 2010) with a quorum of 60 % to estimate sampling-standardized diversity.

The CONOP-derived taxonomic richness curve exhibits a strong increase in the first two SSF biozones (Fig. 1). After the peak of biozone 2, taxonomic richness gradually drops to its lowest level in biozone 4 and achieves

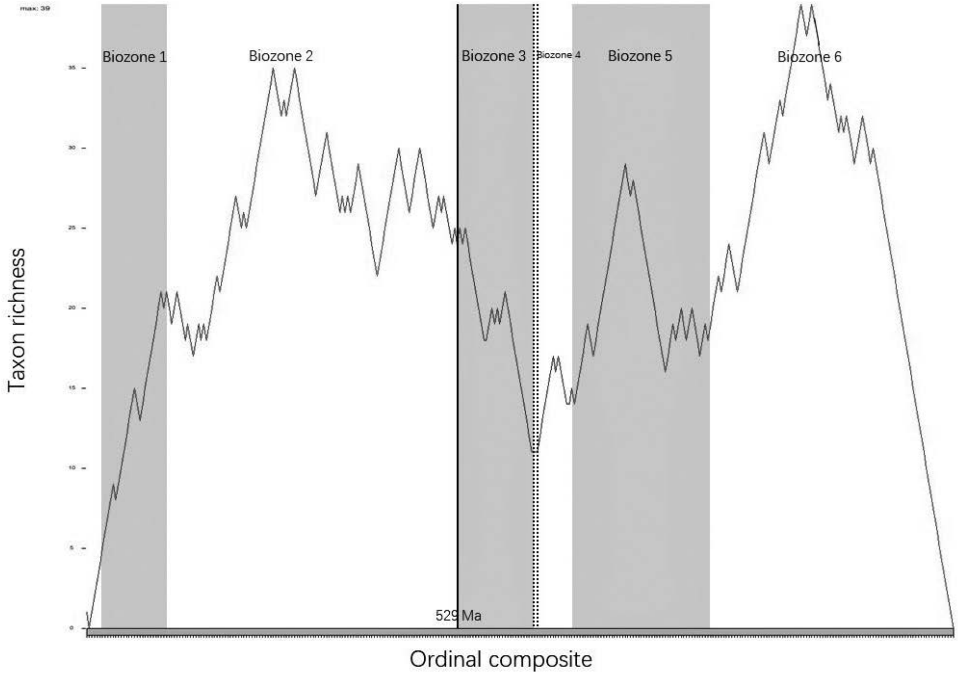

Fig.1. Taxon richness based on CONOP correlation among 15 sections and 161 species.
Biozones denote *Anabarites trisulcatus-Protohertzina anabarica* Assemblage zone, *Siphogonuchites triangularis-Paragloborilus subglobosus* Assemblage zone, *Watsonella crosbyi* Assemblage zone, *Sinosachites flabelliformis*-T*annuolina zhangwentangi* Assemblage zone, *Ninella tarimensis-Cambroclavus fangxiangensis* Assemblage zone, and *Rhombocorniculum cancellatum* Taxon range zone from no. 1 to no. 6 respectively. Solid vertical line marks the FAD of *Watsonella crosbyi*, indicating the beginning of Cambrian Stage 2. Dash lines mark the poorly fossiliferous interzone between biozone 3 and biozone 4.

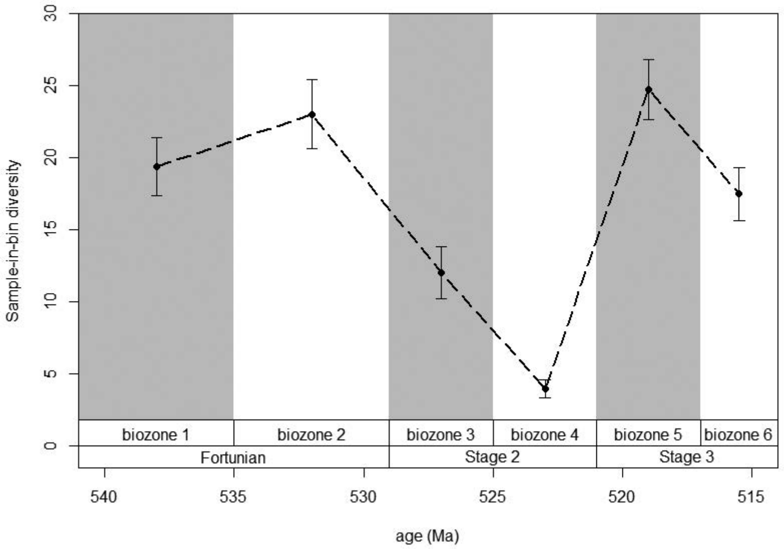

Fig.2. Sampling-standardized species-level diversity (sample-in-bin) from Fortunian to Cambrian Stage 3 based on shareholder quorum subsampling with 60 % frequency coverage per zone. Error bars are standard deviations of 100 subsampling trials. Ma, millions years ago.

a climax again in biozone 6. In contrast, sampling-standardized diversity doesn't show any notable rise throughout the first three stages of Cambrian, but it confirms a significant decline of SSF diversity in the Stage 2 (Fig. 2).

In the CONOP-derived curve, the marked increase (from biozone 1 to biozone 2) and climax (of biozone 6) in the number of species are both artefacts, which are mainly due to sampling bias. While the significant decline of SSF diversity in the Stage 2 might represent a taphonomic bias on the diversity pattern of SSFs globally (Porter, 2004). Overall, the results suggest that SSF diversity dynamics of the early Cambrian are mostly driven by phosphatization taphonomic windows, rather than the metazoan radiation patterns during this period.

Acknowledgments

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EARLY CAMBRIAN TOMMOTIIDS AND THEIR BIOSTRATIGRAPHICAL SIGNIFICANCE (CENTRAL TUVA)

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Key words: *Tommotiids, Cambrian, small shelly fossils, biostratigraphy.*

Tommotiids are a group of problematic phosphate scleritomorphic fossils, which include mostly dispersed symmetric and asymmetric, cap-shaped and saddle-shaped sclerites up to several tens of millimeters in size. Findings of sclerites accreted or jointed together are known (Demidenko, 2004; Skovsted et al., 2011; Larsson et al., 2014 etc.), but this is not enough to accurately determine the systematic position of this group. Recently, researchers have been trying to systematize the material and use the "multiscleritic" systematics, which allows sclerites of various morphotypes to be attributed to one species by morphological, microstructural features. Representatives of this group are most common in carbonate facies of the Tommotian – Atdabanian deposits in Russia (Yakutia, Tuva, Altai), Mongolia, China, India, Kazakhstan, England, Scandinavia, North Africa, Australia, USA, Canada, Mexico and Antarctica, and known up to the base of the middle Cambrian.

Despite the existing problems with tommothiid systematics, the high biostratigraphic potential for the lower Cambrian of the genus *Camenella* and genus *Lapworthella* for Tommotian Stage should be noted. In Atdabanian time, tommotiids appear to form internal partitions and species of the genera *Kelanella, Tannuolina* and *Lugoviella* become important for biostratigraphy.

From the Bayangol Formation of the Lower Cambrian Khairkan Section, located within the Central Tuva trough, tommothiids of the genera *Tannuolina, Kelanella* and *Lugoviella* were found. Earlier, only archaeocyaths and trilobits were described from this section (Zhuravleva et al., 1967).

Tommotiids of the genus *Tannuolina* are represented by species *Tannuolina fonini* Esakova in Esakova et Zhegallo, 1996 and *Tannuolina* sp. Genus *Kelanella* in the studied material are represented by several types of sclerites, which constituted a single scleritom of the species *Kelanella altaica* Missarzhevsky in Rozanov and Missarzhevsky, 1966.

The finds of the Early Cambrian tommothiids on the territory of Tuva were previously known from the Shanganskaya Formation located on the watershed of the East Tannu-Ola ridge in the upper reaches of the r. Shevelig-Khem River and in the lower reaches of the Ulug-Shangan River (Fonin, Smirnova, 1967; Zhuravleva et al., 1967), and represented by one species *Tannuolina multifora* Fonin et Smirnova, 1967.

The assemblages of small shelly fauna of the studied section is represented by tommotiids *Tannuolina, Kelanella* and *Lugoviella* and sclerites *Microdictyon effusum* Matthews, Bengtson et Missarzhevsky, 1981. This suggests a late Atdabanian age of the studied interval of the Khairkan Section.

Although tommothiids is mainly used for biostratigraphy with assemblages of other SSF (small shelly fossils), they have a high biostratigraphic potential, especially in cases where other skeletal residues are rare and absent.

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ORDOVICIAN CONODONT ZONATION FOR THE GORNY ALTAI: STATE-OF-ART, POTENTIAL FOR BIOSTRATIGRAPHY

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Key-words: *Ordovician, conodonts, biostratigraphy, Gorny Altai.*
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The first data on conodonts from the Ordovician of Gorny Altai were reported by Tamara A. Moskalenko (1977). However, still not enough monographic studies for this ortostratigraphic fossil group were done on this territory dew to several reasons. Findings of conodonts are rare, specimens number is low, as well as taxonomic diversity (Iwata et al., 1997; Izokh et al., 2003, 2005; Sennikov et al., 2015, 2018a, b; Obut et al., 2017). One of the main problems is state of preservation: in many cases it is rather poor because of high degree of deformation of Paleozoic sedimentary strata cropped out in Gorny Altai. Conodonts were found from both carbonate and siliceous rocks.

Defined the base of Ordovician conodonts *Iapetognathus* and *Iapetonudus* were discovered not long ago in the carbonate strata of the Upper Kamlak Subformation, Takoshkin Horizon, in the northwestern part of Gorny Altai (Sennikov et al. 2014). In the composite section, they are underlain by Upper Cambrian conodont bearing strata and overlain by carbonates yielded Tremadocian *Cordylodus angulatus* Zone conodonts.

Beds with *Paroistodus proteus* were defined in the violet chert of the upper Talitsa Formation (Zasur'ya Group), Takoshkin Horizon, and in the red chert and siliceous mudstone of the Marcheta Formation (Zasur'ya Group), Tuloi Horizon stratotype, in the western Gorny Altai. The assemblage includes: *Paroistodus* cf. *proteus*, *Paracordylodus gracilis*, *Cornuodus longibasis*, *Drepanodus reclinatus*, *Oneotodus* sp., and some other species in open nomenclature. The conodont assemblage allows dating this interval as late Tremadocian – early Floian.

Beds with *Oepikodus evae* were established in the red chert of the upper Marcheta Formation (Zasur'ya Group), Tuloi Horizon, in the western Gorny Altai. The conodont assemblage includes: *O. evae*, *Periodon* cf. *flabellum*, *Prioniodus* cf. *P. elegans*, *Baltoniodus* sp., and *Drepanoistodus* sp. The beds are aligned with the same-named zone in the upper Floian, establish for North Atlantic province.

Beds with *Periodon flabellum – Parapanderodus striatus* were defined in carbonates of the Voskresenka Formation, Kostinsky Horizon, in its type section in the north-western Gorny Altai. The assemblage includes diverse but rather poor preserved conodonts: *Semiacontiodus*? *mufushanensis*, *Acodus eletsus*, *Protoprioniodus* sp., *Cooperignathus* sp., *Periodon* cf. *P. flabellum, Tangshanodus tangshanensis*, *Parapanderodus striatus, Juanognathus jaanussoni*, *Drepanoistodus suberectus* s.l., *Triangulodus larapintinensis*, *Anodontus longus*, *Naimanodus degtiarevi*, *Panderodus*? *nogami*, and others. These taxa permit assigning the considered beds to lowermost Darriwilian.

Beds with *Eoplacognathus pseudoplanus* were defined in carbonates of the upper Voskresenka Formation, Kostinsky Horizon, in the north-western Gorny Altai. The conodont assemblage includes: *Eoplacognathus pseudoplanus, Periodon aculeatus*, *Scolopodus* sp., *Drepanodus arcuatus*, *Ansella* sp., and *Paroistodus* sp. The beds are aligned with the same-named zone in the lower Darriwilian of the northwestern East European Platform.

Beds with *Belodina compressa* and *Phragmodus undatus* were defined in limestones of the Gur'yanovka Formation, Khankhara Horizon, in the north-eastern Gorny Altai. Along with the *Belodina compressa* and *Phragmodus undatus* the assemblage includes *Panderodus* cf. *P. gracilis*, *Aphelognathus* sp., *Phragmodus sp.,* and *Drepanoistodus suberectus*. The coexistence of *B. compressa* and *Ph. undatus* is typical of the upper Sandbian – lower Katian on many continents, including North America and Eurasia (East European Platform).

Beds with *Protopanderodus liripipus* were established in a siliceous-terrigenous rocks of so-called Siliseous-terrigenous Body, Tekhten' Horizon, in the western Gorny Altai. Thin limestone layers yielded conodont assemblage: *Protopanderodus liripipus, Periodon grandis*, *Panderodus* sp., *Decoriconus* sp., *Paroistodus* ?*mutatus* and *B. compressa*. It allows correlation of the distinguished beds with the upper Katian.

Conodont zonation for Ordovician of Gorny Altai remains tentative. The assemblages defined in Lower-Middle Ordovician sections are characteristic mainly for the North Atlantic province, including few taxa described for Baltoscandia region. In Middle Ordovician sequences species described from Central Asian sequences are common. While Upper Ordovician assemblages bears some elements of North American and Midcontinent provinces.

Graptolites were established almost in all reference sections of Ordovician strata in Gorny Altai (Sennikov et al., 2011, 2018a, b), conodonts are still to be searched for. The potential for future are thick siliceous rocks of the Zasur'ya Group (Lower Ordovician) cropped out in the western Gorny Altai and carbonates of the Tekhten' and Khankhara Horizons exposed in north-eastern and east Gorny Altai.

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THE *HOLMOGRAPTUS LENTUS* ZONE (MIDDLE ORDOVICIAN) IN THE LA INVERNADA RANGE, PRECORDILLERA OF SAN JUAN, ARGENTINA

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Key words: *graptolites, Middle Darriwilian, Biostratigraphy, Precordillera, Argentina.*

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Darriwilian graptolite faunas are widely distributed in the Central and Eastern Precordillera, western Argentina, preserved in diverse lithofacies in the Gualcamayo, Los Azules, Las Aguaditas and Sierra de La Invernada formations.

The *Holmograptus lentus* Zone (middle Darriwilian) has been recognized in diverse localities of the Central Precordillera, placed above strata bearing graptolites of the *L. dentatus* Zone (Albanesi and Ortega, 2016 and references therein citated). Usually, a hiatus that encompasses the *Holmograptus spinosus* and *Nicholsonograptus fasciculatus* zones is present between the levels with the *H. lentus* assemblage and the overlying *Pterograptus elegans* Zone of the late Darriwilian.

In the Central Precordillera, San Juan Province, the *H. lentus* Zone was originally documented for the Middle Member of the Gualcamayo Formation at the La Corridita Creek section, Gualcamayo River area (Máspero-Castro et al., 2003) with the entrance of *H. lentus* and a low diversity graptolite assemblage. This biozone was also recognized at the lower member of the Los Azules Formation in the Cerro Viejo de Huaco section to the northeast of Jáchal City (Brussa et al., 2003; Ortega and Rickards, 2003; Ortega et al., 2007) by the first appearance of the genera *Hustedograptus*, *Archiclimacograptus* and *Haddingograptus*, in absence of the nominal taxon.

At the La Invernada Range, a probable graptolite assemblage of the *H. lentus* Zone was referred to the *H. spinosus* Zone in the Sierra de La Invernada Formation by Brussa (1999). Strata with graptolites of the *H. lentus* Zone were later recognized at the La Puerta Creek section by Ortega et al. (2017).

Recently, a rich graptolite fauna referred to the *H. lentus* Zone was identified at the eastern flank of the Villicum Range in the Eastern Precordillera, San Juan Province (Kaufmann, 2019). It ranges throughout the middle part of the Gualcamayo Formation and is recognized by the appearance of the

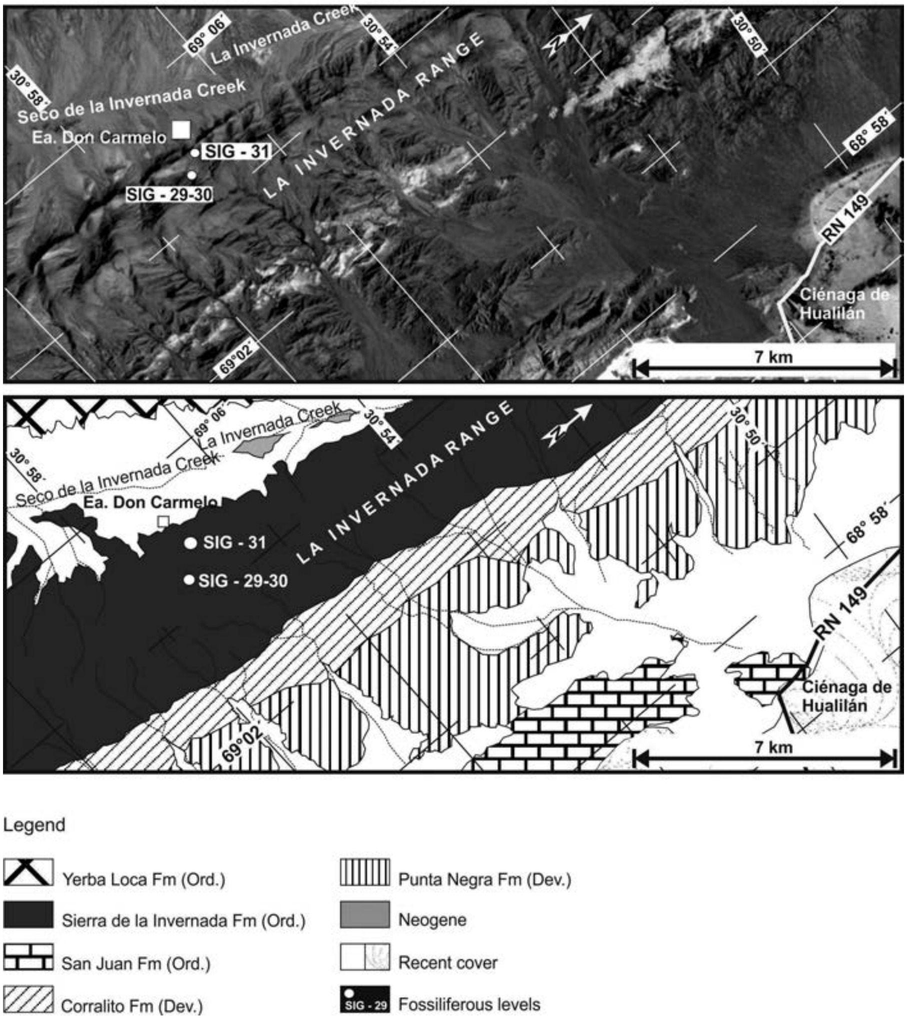

Fig. 1. Location map of the studied area at the Sierra de La Invernada Range, San Juan Precordillera, Argentina.

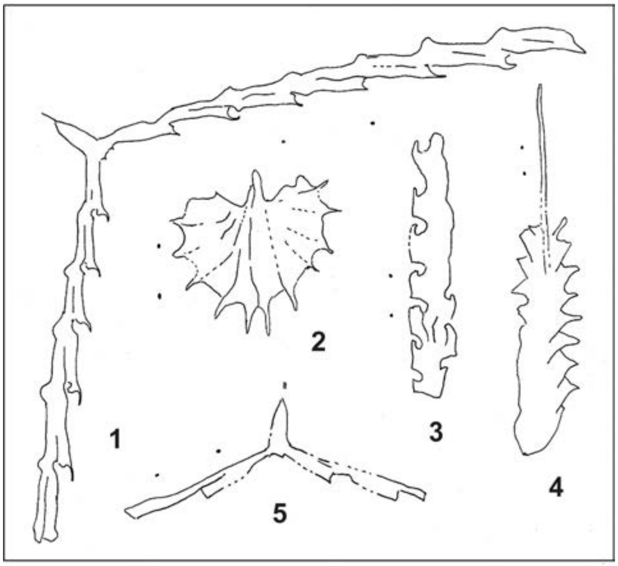

Fig. 2. Graptolites of the *Holmograptus lentus* Zone (middle Darriwilian), Sierra de La Invernada Formation, Don Carmelo Creek, La Invernada Range, San Juan Precordillera.

1. *Holmograptus lentus*, CORD-PZ 25927 B; **2.** *Arienigraptus angulatus*, CORD-PZ 25927 A; **3.** *Archiclimacograptus* sp., CORD-PZ 25940; **4.** *Cryptograptus schaeferi*, CORD-PZ 25936 A; **5.** *Acrograptus* sp., CORD-PZ 25927 A. The distance between dots aside the specimens represents 1 mm.

genus *Archiclimacograptus*. The record of *H. spinosus* marks the beginning of the succeeding homonymous biozone, only identified at the present in the Villicum Range (Kaufmann and Ortega, 2016) and in the Rinconada Range (Ortega et al., 2017) of the Eastern Precordillera.

The discovery of middle Darriwilian graptolites in calcarenites near the Estancia Don Carmelo hostel, on the western flank of the La Invernada Range is reported in the present work (Fig. 1). The study area is placed ca. 30 km to the south of the National Route Nº 149. The fossiliferous samples were taken few meters to the east of the hostel in a succession of sandstones, calcarenites, and shales corresponding to the middle part of the Sierra de La Invernada Formation.

The graptolite assemblage, referable to the *H. lentus* Zone of the middle Darriwilian, is composed of *Acrograptus* sp., *Holmograptus lentus* (Törnquist), *Arienigraptus angulatus* (Yu and Fang), *Cryptograptus schaeferi* Lapworth, *Archiclimacograptus* spp., *Hustedograptus*? sp., and *Eoglyptograptus*? sp., between others (Fig. 2).

The *H. lentus* Zone has been recognized in diverse regions throughout the world as Scandinavia, Germany, Belgium, North America, Australia and China (Maletz, 1995; 1997), which can be correlated with the studied assemblage from the Argentine Precordillera.

The records of *H. lentus* in the La Invernada Range on the western flank of the Central Precordillera contrast with the absence or scarce findings of this species in the Eastern Precordillera (Villicum Range) and in eastern sections from the Central Precordillera (*e.g.*, La Corridita Creek; cerro Viejo de Huaco). Probably, this could correspond to a facies preference considering that most of the records of this species from the Sierra de La Invernada Formation occurs in calcareous facies.

The illustrated specimens are housed in the collections at the Museo de Paleontología, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba (CORD-PZ).

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CLARIFYING HALJALA STAGE IN ESTONIA

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The Haljala Regional Stage was proposed by Jaanusson (1995) in order to improve regional correlation in the interval of previous Idavere and Jõhvi regional stages (today known as regional substages). Distinction between the Idavere and Jõhvi regional stages was formerly based on their palaeontological signatures that were recognisable in norther Estonian outcrop area but could not be used effectively in the offshore part of Baltoscandian Palaeobasin. Lithological features like kukersine content in carbonates or marker horizons like bentonite layers and hardgrounds have historically been used in mapping practice for defining the former Idavere and Jõhvi regional stages in the outcrop area, in parallel to the palaeontological criteria, but these criteria do not “work” well in the subsurface area. An integrated study can help to clarify the correlation of the boundary interval of the Kukruse and Haljala regional stages.

The Kukruse Stage is known for its kukersine–containing limestone but also for a remarkable hiatus corresponding to the upper part of a full succession in the outcrop area (Hints, 1997a). The hiatus is usually marked by a set of distinct hardgrounds of variable morphology. Even if the kukersine content is not strictly confined to the Viivikonna Formation that comprises the Kukruse Regional Stage in the outcrop belt, remarkable kukersine-rich layers are not known in the basal Haljala Regional Stage. A specific feature of the Haljala Regional Stage is the presence of K-bentonite layers that can be recognized across the Estonian part of the Baltoscandian Palaeobasin. One of the K-bentonites marks the substage boundary within the Haljala Regional Stage (Hints, 1997b). The listed features are only poorly expressed or sometimes missing in more offshore sections. Different criteria are needed for correlation of chronostratigraphic boundaries in the subsurface areas. So far, interpretations of the Haljala Regional Stage outside outcrop area (including the Baltic Oil Shale Basin) are notably different.

A multi-proxy biostratigraphic study at the Peetri section (NW Estonia) was carried out for correlating the boundary of the Haljala Regional Stage across different facies zones. Conodonts, chitinozoan, ostracodes, architarch and graptolites are used, in parallel with a stable isotopic marker, the so-called Upper Kukruse Low (or LSNICE). The results are partly contradictory but allow justifying the position of the stage boundary in the sections of Central and South Estonia. The *Amorphognathus tvaerensis* Conodont Zone with its three subzones based on the species of genus *Baltoniodus* corresponds to the transition from Kukruse into Haljala regional Stage in Baltoscandia. Specifically the base of *Baltoniodus gerdae* Conodont Subzone is regarded to position slightly below the base of the Haljala Stage (Männil, 1986). In majority of paleontologically studied sections position of the base of *B. gerdae* Subzone is related to different chitinozoan zones that are traditionally regarded as the upper Kukruse Regional Stage (zones of *Laufeldochitina stentor*, *Eisenackitina rhenana*)(Männik & Viira, 2005) or lowermost Haljala Stage (zones of *Armoricochitina granulifera*, *Angochitina curvata*, *Lagenochitina dalbyensis*)(Männik 2003, 2010; Viira & Männik, 1999). This discrepancy needs further attention in future studies. Ostracod distribution shows good correlation in northern Estonian successions and sharp change in composition can be linked to the level that marks also changes in macrofauna. Additionally, the first record of architarch *Leiosphaeridia baltica* is used to trace the base of the Haljala Stage in Baltoscandia but the conodont and chitinozoan evidence suggests that in some sections the appearance of *L. baltica* falls into the upper Kukruse Regional Stage.

The graptolite biozones give no hints for the base of the Haljala Regional Stage. The boundary between substages of the Haljala Regional Stage is tied to the first appearance of *Amplexograptus maxwelli* but considering the scarcity of graptolites in carbonate rocks, the value of this marker appears to be limited.

The so-called Upper Kukruse Low (or LSNICE) isotopic marker (Ainsaar et al., 2010) lies in a similar position in the central Estonian sections but is less prominent in the deeper part of the palaeobasin. The LSNICE level is drawn in the upper part of the Kukruse Regional Stage, considering the conodonts and chitinozoan biozones. However, being close to the base of the *B. gerdae* Subzone in Central Estonia (Männik & Viira, 2005), it is gradually shifted into the upper part of the *B. variabilis* Subzone in more offshore sections (Männik, 2003).

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LATE ORDOVICIAN CONODONTS FROM GORNY ALTAI

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Key words: *Ordovician, conodonts, Gorny Altai.*

Collection of conodonts has been investigated from Upper Ordovician Gur'yanovka Formation at Uimen'-Lebed' structural-facies zone of the Gorny Altai (south of West Siberia). Gorny Altai is the part of Central Asian Orogenic Belt, which is one of the biggest orogenic regions on our planet and stretches from the Ural Mountains to the Pacific Ocean. Paleozoic sedimentary rocks could be well dated by conodonts as an ortostratigraphic group in Gorny Altai and other parts of CAOB.

Our material is collected from the carbonate rocks of the Biya section, Gur'yanovka Formation, cropped out at the right bank of Biya river, between the villages Kebezen' and Verh-Biysk, on the north from Teletskoye Lake (Fig.1).

First investigation of this section was made by Kulkov and Severgina (1989), they showed availability of brachiopods and great potential for further studies. Later this section has been studied again by (Sennikov et.al, 2018a), they have made detailed lithological description of this section and found different fossils.

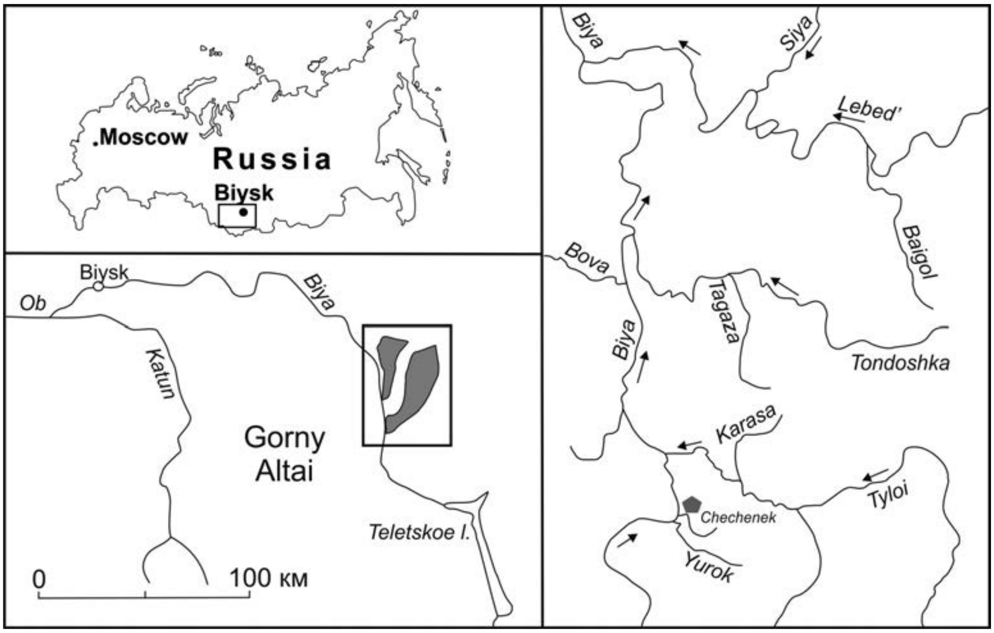

Fig. 1. Location of the studied area.

Lithological log of the formation is divided into two subformations the lower one consists of different types of grey massive limestones with sandy and clay components; the upper subformation consist of red siltstones and mudstones with limestone interlayers. Previous studies revealed different groups of fauna: brachiopods, crinoids, trilobites, ostracods and conodonts (Kulkov, Severgina, 1989; Sennikov et al., 2018a). Fossils confirmed the Late Sandbian- Early Katian age of formation. Conodont species were found only in the top and bottom (members 3 and 20) of section and represented by four species: *Bellodina compressa* (Br. et M.), *Panderodus gracilis* (Br. et M.), *Eraticodon sp.* and *Phragmodus undatus* (Br. et M.), which allowed to align it with *Bellodina compressa* and *Phragmodus undatus* conodont zones (Fig.2) (Sennikov et. al., 2018b).

Present collection of conodont elements has been obtained from rocks sampled from seven members of the section (members 3, 6, 7, 10, 13, 20, and 22) during previous studies, that were dissolved by 3-5 % acetic acid solution. Current conodont collection expands ranges of already found species through all the section and consists of *Bellodina compressa* (Br. et M.), *Panderodus gracilis* (Br. et M.), *Eraticodon sp.*, *Phragmodus undatus* (Br. et M.), *Aphelognatus rodesi* (Lindström), *Drepanodus sp.*, *Drepanoistodus* sp. (Fig. 3). Presence of *Phragmodus undatus* in the lower members of section allows to define accurate age interval for this part of section and to align it with *Phragmodus undatus* Zone.

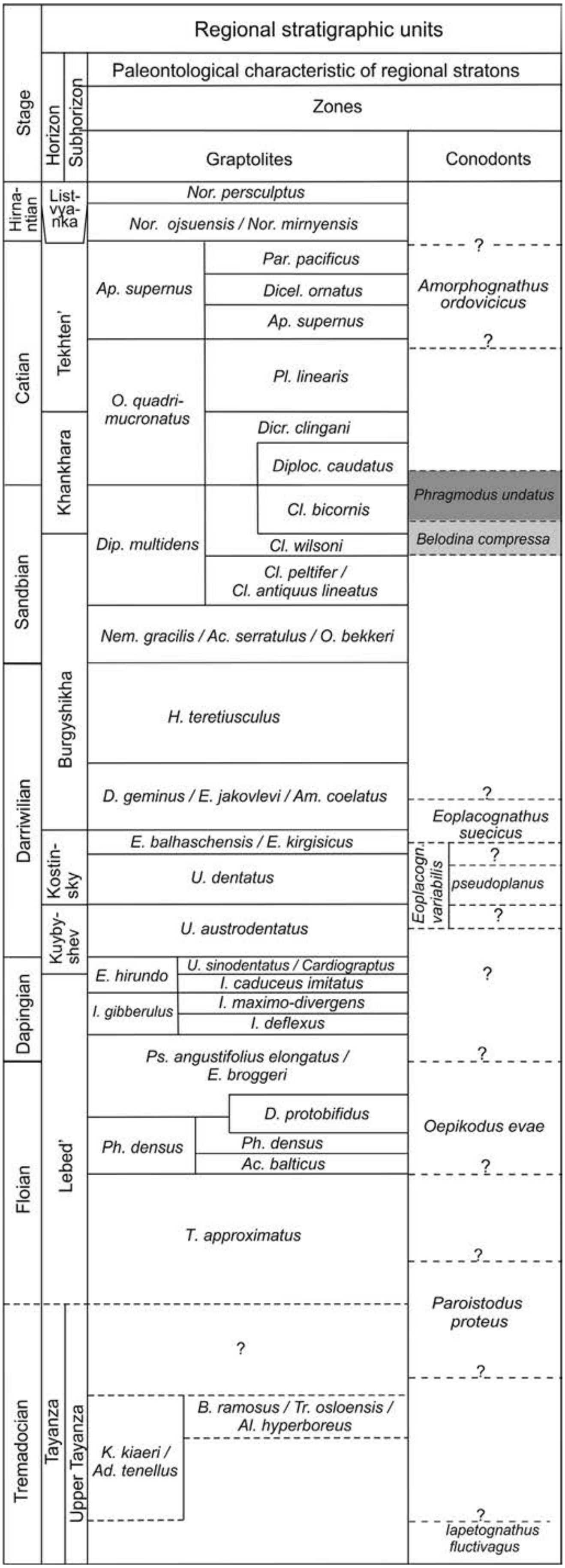

Fig. 2. Biostratigraphic chart of Gorny Altai (Sennikov et.al., 2018b).

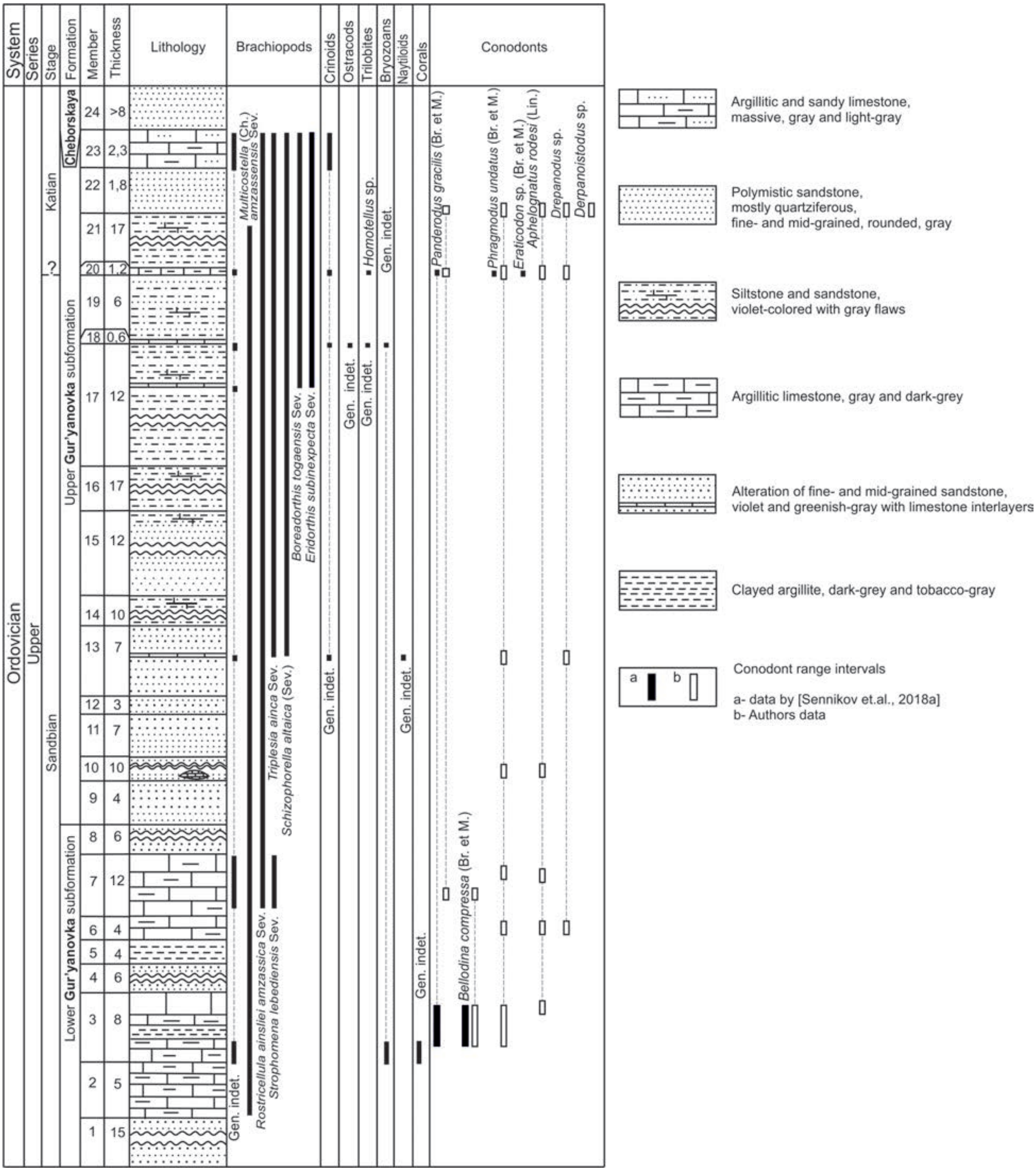

Fig. 3. Conodont ranges in the Biya Section, log after (Sennikov et. al., 2018a).

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COMPOSITION AND MICROFOSSILS OF THE BALTIC LITHOGRAPHIC LIMESTONE

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The Upper Ordovician Baltic limestone is exposed over a broad area of western Estonia, Sweden and the Baltic Sea, and was likely deposited on a wide, shallow marine shelf. This may represent a distinct, hitherto neglected, green-algal rich and extremely fine grained Ordovician depositional environment. We analysed the composition of the Baltic limestone to better understand the role of biogenic carbonate in its formation. Samples from outcrops, rock cores and glacial erratics of Estonia and the Åland archipelago were subjected to transmitted light and cathodoluminescence microscopy, and REE+Y compositions of clasts and matrix were measured using LA-ICPMS.

Micritic matrix and skeletal grains show seawater REE+Y signatures suggesting oxic conditions. Green algae, such as *Palaeoporella, Vermiporella* and dasycladaceans are abundant in many samples and are known to form mounds in a wide belt over the region. Alongside other bioclasts, our samples also contain an assemblage of calcitarchs, somewhat similar to Silurian examples interpreted as dinoflagellate or algal cysts. In the Baltic limestone, some morphotypes are particularly associated with algal mounds, suggesting a possible algal affinity. Widespread micritisation of the algae and the calcispheres suggest that they were contributors to the formation of the Baltic limestone facies and important calcareous ecosystem engineers. We suggest that the Baltic limestone is an example of ecosystem engineering within an Ordovician shallow-water carbonate environment, with green algae as major contributors.

TERRIGENOUS ROCKS OF THE ITMURUNDY ACCRETIONARY COMPLEX OF NORTHERN BALKHASH, CENTRAL KAZAKHSTAN: DETRITAL ZIRCON U-PB AGE, GEOCHEMISTRY AND ND ISOTOPES

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Key words: *Itmurundy accretionary complex, U-Pb ages, Pacific-type orogeny, greywacke.*

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The Itmurundy zone, including ophiolite belt and/or accretionary complex, is located in the western Central Asia Orogenic belt, at the northern shore of Lake Balkhash of central Kazakhstan. It is a part of the Junggar-Balkhash fold belt, which extends to the western Junggar region in NW China (e.g., Geological Map of the USSR, 1960; Patalakha, Belyi, 1981). The Itmurundy zone includes three main associations of rocks: mantle, orogenic and post-orogenic, which are separated from each other by regional to local faults.

The mantle association consists of pre-Ordovician dunite, wherlite, and gabbro, i.e. it represents a lower part of ophiolites. The orogenic assemblage includes mafic volcanic rocks (mostly basalt and dolerite), ribbon chert, hemipelagic siliceous thin-grained sediments (mudstone, siltstone, and shale), gray and greenish-gray sandstones and flyschoid greywacke. The Ordovician to early Silurian ages of the siliceous sediments were constrained by microfossil data (Zhylkaidarov, 1998; Nikitin, 2002; Safonova et al., 2019). The post-orogenic assemblage consist of early Silurian-late Carboniferous sandstones, carbonate rocks, conglomerates, and felsic volcanic rocks (Geological Map of the USSR, 1960).

The Itmurundy accretionary complex is a part of the orogenic association and includes volcanic and subvolcanic rocks of basaltic and andesibasaltic composition, pelagic sediments (ribbon chert), hemipelagic sediments (siliceous mudstone, siltstone and shale) and trench sediments (turbidite, sandstone, conglomerate). According to the Geological map the rocks of the accretionary complex belong to three formations: Itmurundy (O_{1-2}), Kazyk (O_{2-3}), and Tyuretai (O_3-S_1).

The Itmurundy Fm. consists of basalt (at the base of most sections), gray and brown ribbon cherts, chocolate, red, brown and greenish gray siliceous mudstones, siltstones and shales plus rare outcrops of sandstone. The Kazyk Fm. is dominated by red and brown ribbon chert, siliceous mudstone, siltstone and shale with subordinate basalt. The Tyuretai Fm. consists of coarser grained clastic sediments – gravelstone and sandstone, siliceous mudstone and siltstone and subordinate basalt and chert. The rocks of these three formations, both igneous and sedimentary, match the model of Ocean Plate Stratigraphy implying a regular succession of sedimentary and magmatic rocks that were deposited on the sea floor as the underlying oceanic basement made its inevitable journey from its formation at a mid-ocean ridge to its demise at a deep sea trench (e.g., Isozaki et al., 1990). We studied OPS sandstones, which typically occur at the top of all known OPS packages.

Greywacke sandstones of the Itmurundy and Tyuretai Fm. were sampled for detrital zircon U-Pb dating and geochemistry. The Itmurundy Fm. sandstones consist of subangular to subrounded, moderately to poorly sorted grains of quartz (5–7 %), feldspar (14–31 %) and rock fragments (55–75 %). The rock fragments are andesitic volcanic rocks and siliceous sedimentary rocks (chert, mudstone). The Tyuretai Fm. samples consist of subrounded, moderately to poorly grains of quartz (37–55 %), feldspar (18-27 %) and rock fragments (16–44 %). The rock fragments are andesite, dacite, and siliceous sedimentary rocks (chert, mudstone, and siltstone).

The Itmurundy Fm. greywackes show a relatively narrow variation in SiO_2 content from 55.2 wt. %-68.5 wt. %, with an average of 61.8 wt. %. The samples have wide ranges of Na_2O (2.2–5.6 wt. %) and K_2O (1.2–3.6 wt. %), with Na_2O/K_2O ratios averaged at 1.7 wt. %. In comparison with the Post-Archean Australian average shale (PAAS) (Taylor and McLennan, 1985) the Itmurundy Fm. samples yielded lower Al_2O_3 (av. 14.3 wt. %) and Fe_2O_3 (av. 6.8 wt. %) and higher MgO (av. 2.9 wt. %), implying a more mafic source. Although the Itmurundy and Kazyk Fm. greywackes have similar mineral/lithic assemblages, they exhibit clear geochemical differences. The Tyuretai Fm. greywackes have higher SiO_2 (64.1-74.6 wt. %) and lower Al_2O_3 (av. 12.8 wt. %), Fe_2O_3 (av. 5.1 wt. %), MgO (av. 2.4 wt. %), K_2O (av. 1.7 wt. %).

All rock samples are enriched in light Rare Earth Element (REE) and show moderately differentiated heavy REE (La_N/Yb_N=2.2–9.8). Although the Tyuretai Fm. samples have higher La_N/Yb_N ratios ($La_N/Yb_{N\ av.}$= 8.62) than those of the Itmurundy Fm. samples ($La_N/Yb_{N\ av.}$= 3.7), they all show similar moderate negative Eu anomalies (Itmurundy Fm.: Eu/Eu^*_{av}=0.77; Tyuretai Fm.: Eu/Eu^*_{av}=0.72), resembling PAAS (Eu/Eu^*_{av}=0.65). In the spider diagrams the Itmurundy Fm. samples display negative Ta-Nb anomalies similar to those typical of volcanic rocks of supra-subduction origin.

Itmurundy Fm. samples have positive εNd (0.99-5.29) suggesting the presence of intra-oceanic arc volcanic rocks in the source area. Unlike the Tyuretai Fm. samples showing negative εNd (-7.2) suggesting the presence of recycled material in the source area.

The Itmurundy Fm. sandstones yielded unimodal distributions of U-Pb ages peaked at 466-468 Ma suggesting their intra-oceanic arc origin. More evidence for this comes from the positive Hf_t values of zircons (9.2-17.6) and the occurrence of sparse outcrops of volcanic rocks possessing supra-subduction geochemical affinities. The samples of the Tyuretai Fm. have dacitic compositions and yielded multi-model U-Pb age probability curves peaked at 458-462, 988, 1020, and 2467 Ma suggesting a continental arc origin. Thus, on the one hand, the unimodal U-Pb age probability curves, the petrographic and geochemical features and the positive whole-rock εNd and εHf-in-zircon values from the Itmurundy Fm. sandstones suggest an Ordovician intra-oceanic arc. The scarcity of outcrops of supra-subduction rocks suggests that those arcs were tectonically eroded during oceanic subduction.

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C AND SR ISOTOPE STRATIGRAPHY OF THE ORDOVICIAN OF SIBERIAN PLATFORM

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Key words*: C & Sr isotope stratigraphy, Ordovician, Siberian Platform*

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The relatively shallow water Ordovician epicontinental deposits cover a vast area of the Siberian platform being the second in this respect after the Cambrian. Due to significant facies differentiation and endemism of fauna precise biostratigraphic correlation with other palaeocontinents is difficult. The first attempt of correlation of the Middle-Upper Ordovician rocks of the western part of the Siberian Platform (Kulyumbe and Podkamennaya Tunguska rivers) with the reference sections of Baltoscandia based on the carbon isotope composition demonstrated contradictory results (Ainsaar et al., 2015). Although the C-isotope curves show some similarities, the $\delta^{13}C$ values from the Siberian sections were 3–5 % and for some intervals even 6–8 % lower than from the Baltoscandian sections.

We studied isotope composition of carbon, oxygen, sulphur and strontium from two reference sections belonging to two different provinces of the Siberian platform: Moyero River and Vilyuy River. The $^{87}Sr/^{86}Sr$ ratio in the Ordovician gypsum and limestone of the Moyero River section diminishes upwards from 0,7091 in Irbukli Formation (Nya Regional Stage, Tremadocian Global Stage of the Lower Ordovician) to 0,7080 in the upper part of the Dzherom Formation (Dolborian Regional Stage, Katian Global Stage of the Upper Ordovician). This trend is in a good accordance modern knowledge about evolution of Sr-isotope composition in the World Ocean.

The most characteristic feature of the C-isotope curve for the Moyero River section is diminishing of the $\delta^{13}C$ values in limestone beds from slightly positive (0,5…1.1 ‰) in the Irbukli Formation (Nya Regional Stage) to strongly negative (–5,4…–5,8 ‰) in the middle part of the Kochakan Formation (top of the Kimai Regional Stage ~ base of the Darriwilian). Increasing of the $\delta^{18}O$ values from 20–22 ‰ till 26–28 ‰ in this stratigraphic interval and negative correlation between $\delta^{13}C$ and $\delta^{18}O$ points out that the negative excursion of $\delta^{13}C$ is of primary nature. Diminishing of $\delta^{34}S$ values in gypsum from 30–32 ‰ till 22–24 ‰ also shows that impoverishment of $\delta^{13}C$ in carbonates has no connections with sulphat-reduction and oxidization of organic matter during diagenesis.

On the Vilyuy River the Lower Ordovician is represented mainly by dolomites and marls which are not favorable for Sr-isotope stratigraphy. In gypsum of Kharjalakh Formation (O_2–O_3) the $\delta^{34}S$ values are quite monotonous (26,6±1,2 ‰) which indicates a week diagenetic changes. The $^{87}Sr/^{86}Sr$ values diminishes upwards the section from 0,7087 till 0,7080 which allows to specify more exactly the position of the Middle/Upper Ordovician boundary. This boundary should be drawn not at the top of the Kharjalakh Formation as it was done before but in the middle part of this formation. The $\delta^{13}C$ values in the carbonates of the Vilyuy section follow the trend of the Moyero section. They diminish upwards from 0,1…0,8 ‰ in the Lower Ordovician (Balyktakh Formation) till –4,1…–4,8 ‰ in the lower part of the Middle Ordovician (Kharjalakh Formation).

The upper part of the Ordovician succession at the Moyero River is characterized by relatively uniform values of $\delta^{18}O$ = 26±1 ‰ and by intercalations of intervals with decreasing (till –2…–3 ‰) and increasing (till 0,5…1,3 ‰) $\delta^{13}C$ values with magnitude and position of the excursions comparable to those of the reference sections of Baltoscandia. Contrary to this situation in the Upper Ordovician succession of the Vilyuy River the wide variations of the $\delta^{18}O$ and $\delta^{13}C$ values make it closer to the Podkamennaya Tunguska section. In our opinion it could be connected with periodical freshening of near shore waters in the basin of sedimentation.

There is a consensus of opinions that Hirnantian positive $\delta^{13}C$ excursion represents the main Ordovician C-isotope event which marks the end-Ordovician glaciations and the Great Extinction. It is possible however that negative $\delta^{13}C$ excursion at the upper part of the Kimaian Regional Stage (Dapingian and basal Darriwilian) is equally important (Fig.). Very similar negative excursions at this stratigraphic interval were also established in North America (Edwards, Saltzman, 2014; McLaughlin et al., 2016). This high magnitude (up tp –6 ‰) anomaly could be explained by appearance of land plants and development of soils at that time (Steemans et al., 2009). The data from Moyero River section also confirm the enrichment of $\delta^{18}O$ by 3–4 ‰ at the Lower/Middle Ordovician boundary which were previously established in the other continents and in different facies. This fact allow us to suggest global or sub-global character of this isotope event and its connection with changes of oxygen isotope composition in the World Ocean.

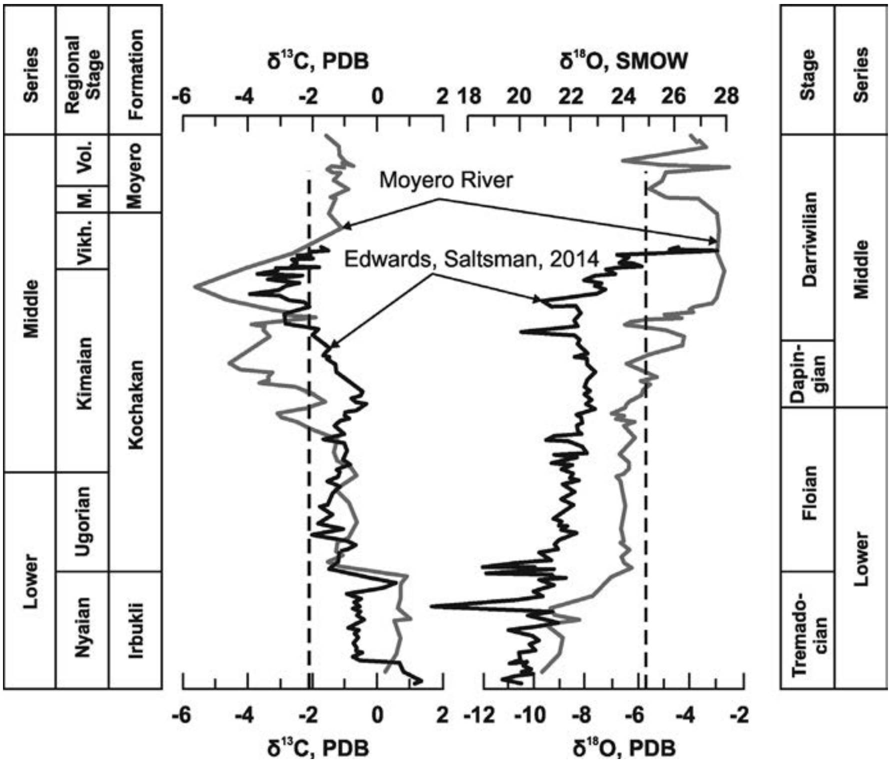

Fig. Comparison of $\delta^{13}C$ and $\delta^{18}O$ curves for the Lower and Middle Ordovician of the Moyero River section of the Siberian Platform (our data) and Shingle Pass section of the Great Basin of the North American Platform (McLaughlin et al., 2016).

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GLENDONITE OCCURRENCES IN THE TREMADOCIAN OF BALTICA: FIRST EARLY PALAEOZOIC EVIDENCE OF MASSIVE IKAITE PRECIPITATION IN TEMPERATE LATITUDES

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Key words: *Glendonite, Ikaite, Ordovician, Tremadocian, Baltica*

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The Tremadocian (Early Ordovician) is currently considered a time span of greenhouse conditions with tropical water surface temperature estimates, interpolated from oxygen isotopes, approaching 40°C (Bassett et al., 2007; Trotter et al., 2008). In the high-latitude Baltoscandian Basin, these data are in contrast with the discovery of glendonite, a pseudomorph of ikaite ($CaCO_3 \cdot 6H_2O$) and valuable indicator of near-freezing bottom-water conditions. Previous records of glendonites display an apparent gap from Neoproterozoic to Permian times (James et al., 2005; Selleck et al., 2007). However, similar calcareous nodular aggregates embedded in Tremadocian black shales of the East Baltica (so-called "antraconites") have been known for more than 150 years. These aggregates are documented from numerous localities in the Türisalu and Koporiye formations (*Cordylodus angulatus – Paltodus deltifer pristinus* zones) exposed along 600 km of the Baltic-Ladoga Glint and sporadically in the Orasoja Member (Kallavere Formation). All these units accumulated in the Baltoscandian Basin, an epeiric sea with a central flat-floored depocentre rimmed to the south (recent coordinates) by a chain of low islands and associated shoal complexes (Popov et al., 1989; Heinsalu and Bednarczyk, 1997). During Tremadocian times, the basinal depocentre recorded black shale deposition episodically punctuated by wave and storm-induced processes, pointing to a sediment-starved, distal offshore-dominant clayey substrate, in which organic matter and trace metals became highly concentrated due to extremely low deposition rates and an exceptionally low influx of siliciclastic material. In contrast, nearshore environments comprised uncemented, well-washed, cross-laminated quartzose sands, which included high concentrations of allochthonous obolid coquinas that were continuously reworked along the shorelines (Popov et al., 1989). Perhaps the most surprising aspect of this new record is that the precipitation of glendonite is contemporaneous with the record of conodonts displaying low $\delta^{18}O$ values, which would suggest high temperatures (>40°C) in the water column. Therefore, the early Tremadocian sediments of Baltoscandia contain both "greenhouse" pelagic signals and near-freezing substrate indicators. This apparent paradox suggests both the influence of isotopically depleted freshwater yielded by fluvial systems, and the onset of sharp thermal stratification patterns in a semi-closed basin, which should have played an important role in moderating subpolar climates and reducing latitudinal gradients.

This is a contribution to IGCP653 project.

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OSTRACODS AND THE BIOSTRATIGRAPHY OF THE UPPER ORDOVICIAN OF THE BOLSHAYA NIRUNDA RIVER BASIN (A TRIBUTARY OF THE PODKAMENNAYA TUNGUSKA RIVER)

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The Siberian platform is located between the Lena and Yenisei rivers. It is one of the largest area of Ordovician sediments in the world.

In the basin of the Bolshaya Nirunda River (right tributary of the Podkamennaya Tunguska River), four outcrops located in its lower reaches were studied in details (Fig. 1). Here the Baksanian, Dolborian, Nirundian and Burian horizons sediments are exposed. These outcrops have repeatedly draw the attention of many paleontologists and stratigraphers, whose research results are presented in a series of papers and monographs. In these publications, several fauna groups (brachiopods, trilobites, conodonts, corals, bryozoans, crinoidia) are analyzed, the data of which formed the basis for the biostratigraphic subdivision of these sections. Despite the detailed paleontological-stratigraphic studies of sediments on mentioned territory, the ostracods, which are of key importance for stratigraphic correlations, turned out to be one of the least studied groups of fauna. Previously, the ostracods from studied area were investigated by L. M. Melnikova (1976), but, unfortunately, they did not receive a clear stratigraphic reference (at best to the horizon, and in some cases to substage) and cannot be used to subdivision and correlation of sections. Also, references about ostracods (defined by L.M. Melnikova) are noted in (Rozman et al., 1979).

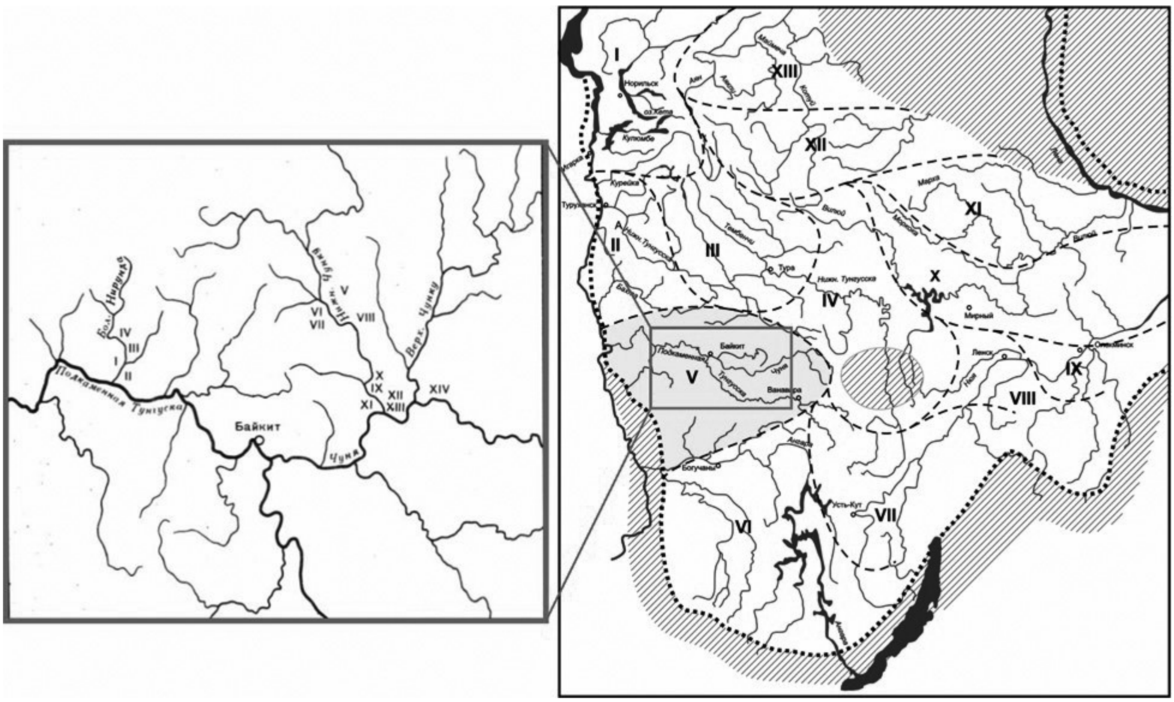

Fig. 1. Layout of structural- facies zones in the Ordovician of the Siberian platform (Kanygin et al., 2007). I- Igarka-Norilsk; II- Turukhansk; III- Central Tungus; IV- Ilimpa; V- South Tungus; VI- Angarsk; VII- Verkhnelenskaya; VIII-Nuyya-Dzherba; IX- Berezovka; X- Vilyui; XI-Markha-Markoka; XII- Moyero; XIII-Maymecha.

Based on a study of the ostracods obtained from the above-mentioned outcrops, the author presents the taxonomic composition of the ostracod complexes and their ranges (Fig. 2). Using data on ostracods correlation of the studied sections with that of adjacent regions in the lower reaches of the P. Tunguska River (stratotype of the Baksanian Horizon) and the Lower Chunku River (stratotype of the Burian Horizon) is done.

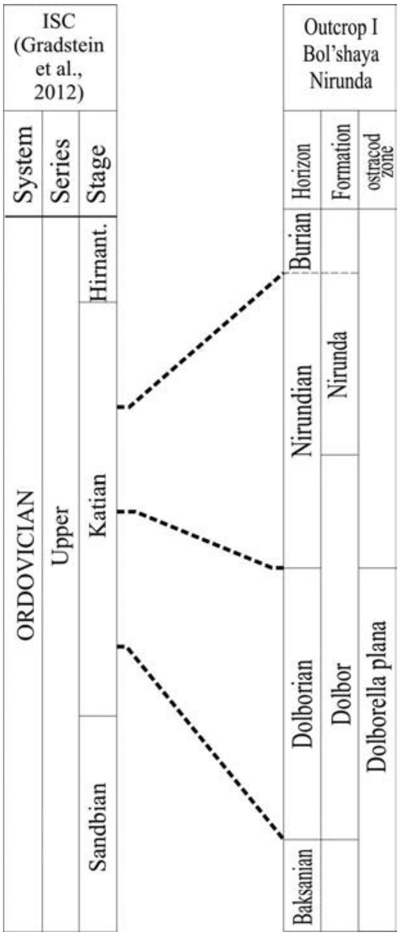

Fig. 2. Comparison of international and general stratigraphic charts with local units (Based on Kanygin et al., 2017).

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ACRITARCHS FROM THE MIDDLE AND UPPER ORDOVICIAN OF ESTONIA AND THEIR STRATIGRAPHIC IMPLICATIONS

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Being generally abundant and well-preserved, Ordovician acritarchs from the Baltic region are attractive objects for palynologists since the pioneering works of Eisenack, (e.g. 1931, 1938). However, despite the fact that hundreds of articles are dealing with acritarchs from the Ordovician of Baltica, no biostratigraphic zonation based on acritarchs has been established so far.

During the Early Palaeozoic, the Estonian territory was a part of an extensive epicontinental basin covering the south-western part of the paleocontinent Baltica (Jaanusson, 1995; Torsvik & Cocks, 2013). Relatively complete Ordovician successions are described from the northern part of the Baltic region in Estonia, where all global and regional stages of the system can be distinguished. In this area, predominantly carbonate sediments were accumulating in shallow open-sea environments favorable for microphytoplankon. In early 1990s Uutela and Tynni, (1991) studied Lower Ordovician to lowermost Silurian acritarchs from the Rapla reference drill core, central Estonia, in order to document the microfossil composition of Ordovician rocks of Estonia and evaluate the stratigraphic potential of acritarchs, These authors described and illustrated more than three hundreds species and analysed their distribution stratigraphically. However, besides providing general palynological characterisation of the studied strata, they concluded that "…it was impossible to establish floristic zones with any degree of certainty by reference to the Rapla core alone without carrying out any comparative studies…" and "…further research in Estonia and elsewhere in Baltic region was called for in order to determine the real range of the occurrence of each species before it will be possible to present a zonation of the Baltic in terms of acritarchs…" (Uutela & Tynni, 1991, p. 17). There have been some more recent palynological studies in Estonia (e.g. Delabroye et al., 2011), but these have focused on limited stratigraphic intervals. In consequence, it has remained difficult to identify key acritarch taxa for the purpose of regional biostratigraphy.

The aim of our study is to provide new data on the stratigraphic and geographic distribution of Ordovician acritarchs in Estonia, thereby start filling a gap in our knowledge and creating a provisional acritarch biozones usable across Baltoscandia. For this two reference boreholes (Valga-10 and Viki, Fig. 1) representing the most complete sequences of the Middle and Upper Ordovician, were sampled and investigated for acritarchs. Both sections are biostratigraphically and chemostratigraphically well constrained and lithologically characterized (Põldvere, 2001, 2010; Hints, 2014; additional data available at http://geocollections.info).

The Valga-10 borehole is located in southern Estonia (57°48′24″ N, 26°04′65″ E). The penetrated Ordovician sediments of ca 112 m in thickness are represented by the Lasnamägi and Uhaku regional stages of the upper part of the Middle Ordovician and by the all nine regional stages (Kukruse, Haljala, Keila, Oandu, Rakvere, Nabala, Vormsi, Pirgu and Porkuni) of the Upper Ordovician.

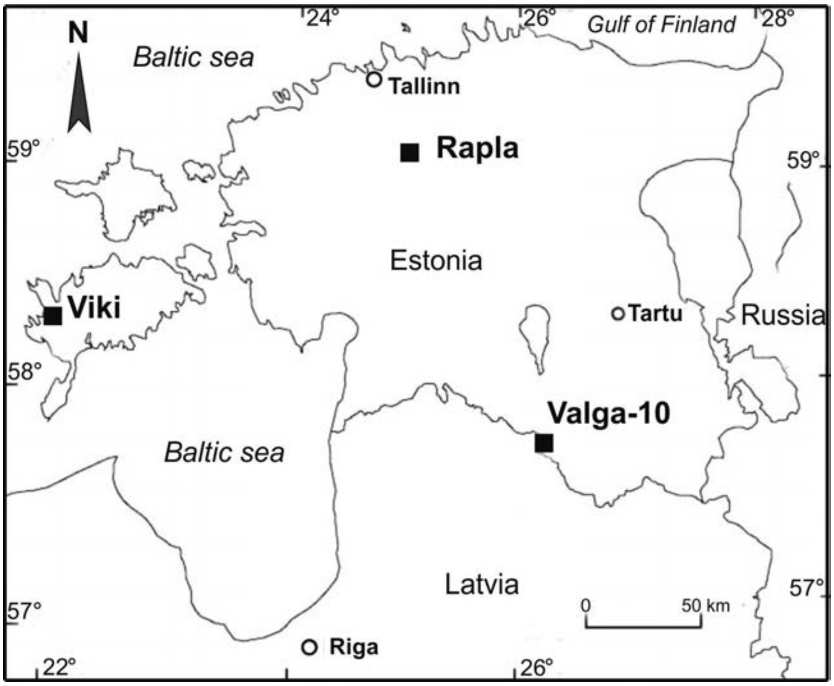

Fig. 1. Location of the studied and discussed boreholes in Estonia.

Plate

Middle and Late Ordovician acritarchs from the Valga-10 and Viki cores. All scale bars represent 20 μm.

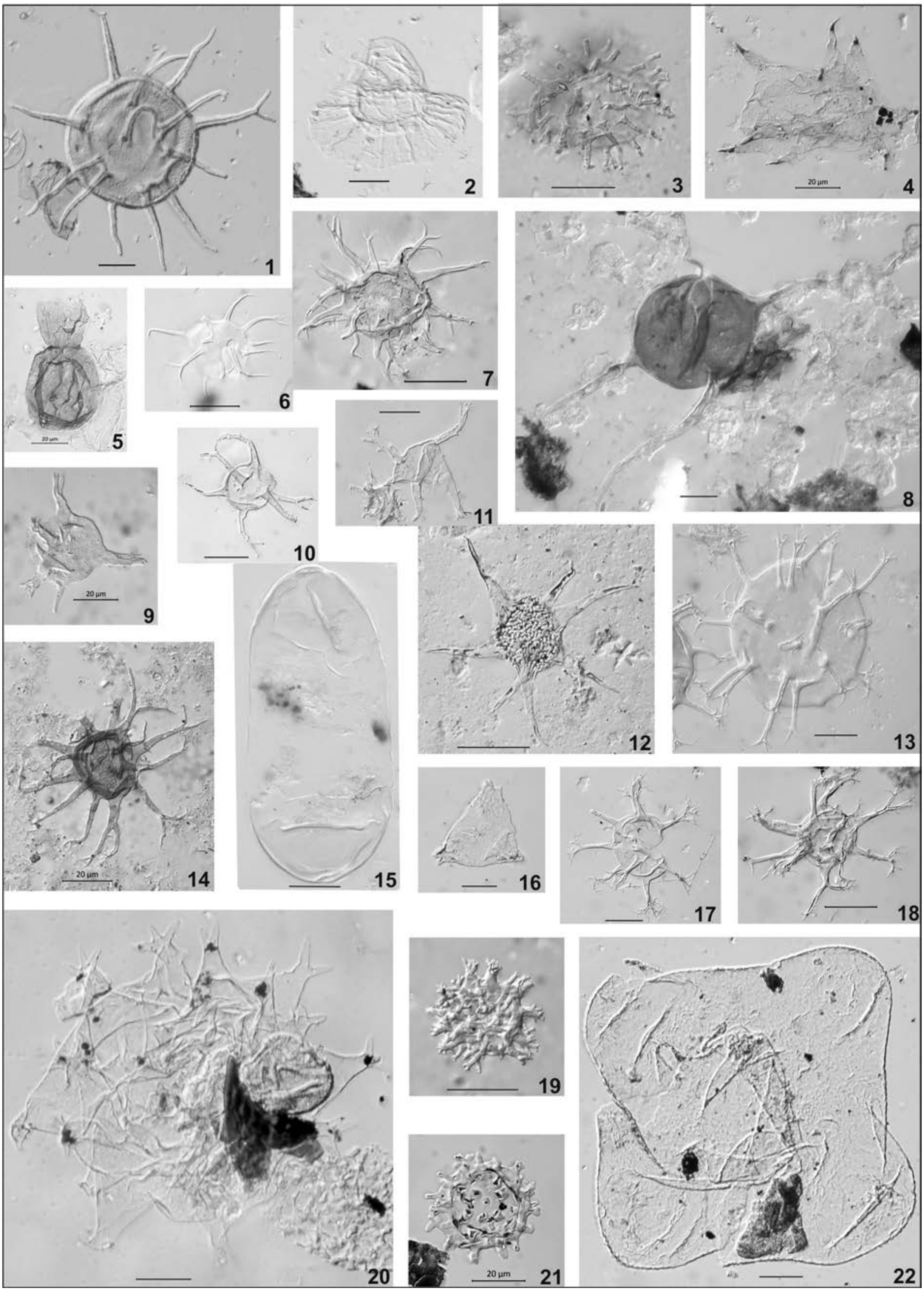

Fig. 1 – *Pachysphaeridium robustum* (Eisenack 1963) Fensome et al. 1990, Valga-10, slide VA-AC-14-51, EF: V24/2; **fig. 2** – *Pterospermopsis tranvikensis* (Tynni 1982) Uutela & Tynni 1991, Valga-10, slide VA-AC-14-50, EF: W25/1; **fig. 3** – Gen. *et* sp. *indet.* 1, Viki-1, slide VI-AC-14-21, EF: B24/4; **fig. 4** – *Gordonirundum tungustanum* Raevskaya & Servais, 2017, Viki-1, slide VI-AC-14-18, EF: P41/1; **fig. 5** – *Aremoricanium simplex* Loeblich & MacAdam 1971, Valga-10, slide VA-AC-14-51, EF: O24; **fig. 6** – *Cheleutochroa* sp., Viki, slide VI-AC-14-10, EF: D15/2; **fig. 7** – *Cheleutochroa gymnobrachiata* Loeblich & Tappan 1978, Viki, slide VI-AC-14-16, EF: LM31/4; **fig. 8** – *Orthosphaeridium rectangulare* Eisenack (1963) Eisenack 1968, Viki, slide VI-AC-14-21, EF: O25/2; **fig. 9** – *Evittia remota* (Deunff 1955) Delabroye & Vecoli 2011, Viki, slide VI-AC-14-22, EF: O33; **fig. 10** – *Evittia remota* (Deunff 1955) Delabroye & Vecoli 2011, Viki, slide VI-AC-14-18, EF: X18; **fig. 11** – *Evittia* sp., Viki, slide VI-AC-14-29, EF: D20/2; **fig. 12** – *Ferromia* sp. Viki, slide VI-AC-14-24, EF: XY27/3; **fig. 13** – *Excultibrachium concinnum* Loeblich & Tappan 1978, Viki, slide VI-AC-14-30, EF: TU46/4; **fig. 14** – *Cheleutochroa gymnobrachiata* Loeblich & Tappan 1978, Viki, slide VI-AC-14-22, EF: J15/1; **fig. 15** – *Navifusa ancepsipuncta* Loeblich 1970 ex. Eisenack et al. 1979, Viki, slide VI-AC-14-28, EF: R37; **fig. 16** – *Evittia pyramidalisiformis* Delabroye & Vecoli 2011, Viki, slide VI-AC-14-6, EF: V21; **fig. 17** – *Nexosarium* aff. *leherissei* Delabroye, Vecoli, Hints & Servais 2011, Viki, slide VI-AC-14-11, EF: D15/4; **fig. 18** – *Nexosarium* aff. *leherissei* Delabroye, Vecoli, Hints & Servais 2011, Viki, slide VI-AC-14-13, EF: X18/1; **fig. 19** – *Evittia porkuniensis* Delabroye, Vecoli, Hints & Servais 2011, Viki, slide VI-AC-14-16, EF: M36/2; **fig. 20** – *Hoegklintia visbyensis* (Eisenack 1959) Dorning 1981, Viki, slide VI-AC-14-2, EF: Z29/4; **fig. 21** – *Helosphaeridium tongiorgii* Delabroye, Vecoli, Hints & Servais 2011, Viki, slide VI-AC-14-7, EF: Q23/4; **fig. 22** – *Pulvinosphaeridium parvum*, Viki, slide VI-AC-14-2, EF: K23/3.

The Viki borehole is located , situated in Saaremaa Island, western Estonia (58°21′03″ N, 22°04′47″ E), where the Middle and Upper Ordovician succession is ca 120 m, including very condensed strata of the Volkhov, Kunda and Aseri regional stages of the lower part of the Middle Ordovician.

Stratigraphy of the sections is based on a detailed analysis of the distribution of conodonts (by Peep Männik) and chitinozoans (by Jaak Nõlvak) and is tied to both regional and international stratigraphic scales. Despite the presence of some stratigraphic gaps, their duration has apparently been relatively short as suggested by the presence of nearly all conodont and chitinozoan zones for the region (Nõlvak et al., 2006).

The condensed strata of the Middle Ordovician are composed mainly of gray bioclastic limestones with thin marl interlayers and films. The Upper Ordovician deposits make up a thicker succession of more variable lithologies including bioclastic limestones, carbonate mudstones, marly limestones, dolostones, etc.

For palynological analysis, samples were taken from the most clay-rich intervals of the sections. 50 samples were collected from the Valga-10 borehole and 35 – from the Viki core. Only eight samples out of 85 turned to be barren. The obtained paleontological material is characterized by a high abundance and diversity as well as excellent preservation (Plate). Altogether more than 120 acritarch taxa were identified from the sections, including 5 new taxa. Based on the stratigraphic distribution of the recovered taxa 11 time-constrained acritarch assemblages were distinguished. They occur in both sections in the same sequence, although in the Valga-10 section, the first appearance of some taxa was recorded somewhat earlier than in the Viki section, which may be due to denser sampling in the former section. In order to select the stratigraphically most useful species detailed analysis of the new material together with previously published data from the Pirgu-Porkuni interval of the Valga-10 core (Delabroye et al., 2011), and with well-documented information from the Rapla borehole (Uutela & Tynni, 1991) was undertaken. As a result of this analysis, ten levels characterized by change of taxonomical composition of acritarchs were identified. The ranges of the selected taxa and provisional acritarch zonation are shown on Fig. 2. Although the suggested scheme is preliminary and needs to tested based on data from outside Estonia, this study is a step forward in creating the acritarch-based biostratigraphic standard for the Ordovician of Baltica.

Acknowledgments

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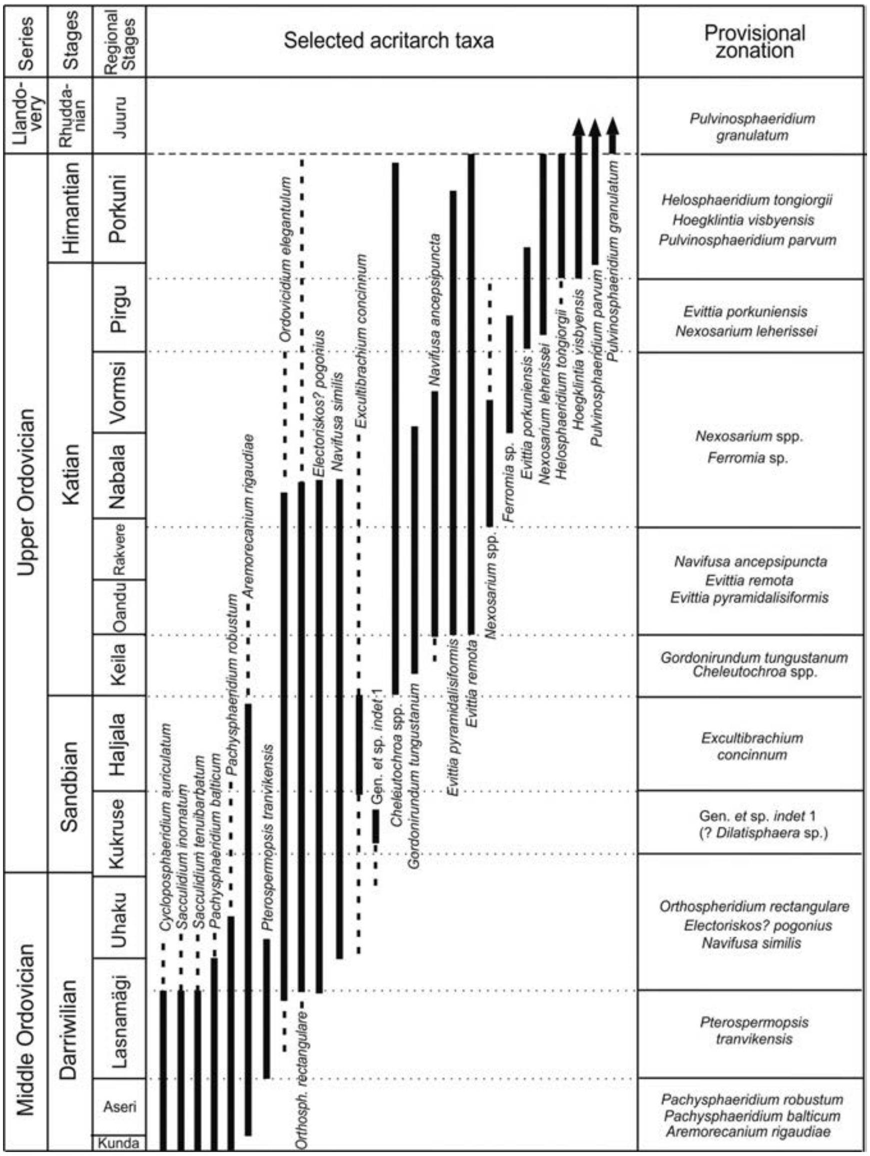

Fig. 2. Distribution of the selected acritarchs in the upper Middle and Upper Ordovician of Estonia, and suggested provisional stratigraphic zonation based on palynomorphs.

THE LATEST ORDOVICIAN *HIRNANTIA* BRACHIOPOD FAUNA OF MYANMAR: SIGNIFICANCE OF NEW DATA FROM THE MANDALAY REGION

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Key words: *Latest Ordovician; Hirnantia brachiopod fauna; Mandalay Region, Myanmar; faunal cluster analysis.*

A new, latest Ordovician brachiopod fauna is systematically described from the Hwe Mawng Purple Shale Member (Hirnantian) of the Naungkangyi Group of Pa-thin area, Mandalay Region, Myanmar, revealing one of the most diverse representatives of the typical *Hirnantia* Fauna. Rhynchonelliformean, craniiformean and linguliformean brachiopods studied belong to 23 genera and a few indeterminate taxa, in which *Kinnella* is the most abundant taxon, along with the four common genera (*Paromalomena*, *Pseudopholidops*, *Coolinia* and *Dalmanella*), and other genera (such as *Cliftonia*, *Draborthis*, *Hindella*, *Hirnantia*, *Leptaena*, *Mirorthis*, *Plectothyrella, Pseudopholidops*, *Skenidioides,* and *Xenocrania*) are recorded for the first time. This high diversity *Hirnantia* Fauna represents an ecological differentiation within the benthos of the Sibumasu Terrane during the end Ordovician global crisis. The palaeoeco-unit named herein as the *Kinnella-Paromalomena* community is assigned to lower BA 3. This paper includes a taxonomic revision with the following conclusions: 1) *Sinomena* Zeng *et al*., 2016 and *Yichangomena* Zeng *et al*., 2016 are treated as junior synonyms of *Eostropheodonta*, Bancroft, 1949; 2) *Hubeinomena* Zeng *et al*., 2016 is regarded as a juvenile form of *Coolinia* Bancroft, 1949; 3) *Paramirorthis* Zeng *et al*., 2016 is considered an immature growth stage of *Mirorthis* Zeng, 1983; 4) *Shanomena* Cocks and Fortey, 2002 is treated as a junior synonym of *Paromalomena* Rong, 1984; 5) *Scenidium*? *medlicotti* Reed, 1915 is re-designated as the type species of *Kinnella* Bergström, 1968 to replace with *Hirnantia*? *kielanae* Temple, 1965 since the two species are considered conspecific; 6) *Palaeocyclus haimei* Reed, 1915 has been designated as the type species of *Xenocrania* Chen and Rong, 2019. The distribution of the *Hirnantia* Fauna in Myanmar, Thailand and West Yunnan of the Sibumasu Terrane, emphasizes the distinctive nature of the Mandalay fauna, whereas analysis of the *Hirnantia* Fauna shows that Sibumasu was not located far from the South China and Lhasa palaeoplates during Late Ordovician.

ATTEMPT FOR EXPLAINING THE COOLING PALAEOCLIMATIC TREND THROUGH ORDOVICIAN. NEW RESULTS

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The climate during Ordovician evolved from a relative greenhouse state toward a glaciation, located on the Gondwana paleocontinent. This study aims to present an analysis to evaluate the suggested primary drivers' variations contributing to the climate evolution: the total solar irradiance, the surface albedo and the global sea level changes, the variations of atmospheric CO_2 and O_2.

During the 5th International Paleontological Congress in Paris last year, the results were given for an analyzed period of 40 Ma from Early Ordovician (480 Ma) to Late Ordovician-Early Silurian (440 Ma) (Rousselle, Meftah, 2018). But this present analysis is more pertinent for the justification of cooling climate evolution as the increase of O_2, factor of cooling, really began from Middle Ordovician (Edwards, C.T. et al., 2017).

So the studied period is for 25 Ma from of Dapingian (470 Ma) to beginning of Hirnantian (445 Ma). It is concluded that the cooling palaeoclimatic trend towards end of Ordovician can be demonstrated.

Method

The method I have developed is based on an analytical formula giving the quantity of solar energy received per second at Earth's surface. The parameters in this formula are the total solar irradiance, the albedo, the radius of the Earth and the Earth-Sun distance and they are dependent on time. The parameter albedo is also dependent of some suggested primary factors during Ordovician as sea level change of first order and variation of atmospheric CO_2 and $O_{2.}$ These suggested primary factors are also taken into account.

So it is calculated the variation of this quantity of energy through the period of time and if this variation is negative, a climate cooling trend is brought to the fore. The different components of this variation are also called radiative forcings linked with the physical parameter variation (total solar irradiance, sea level, atmospheric CO_2 and O_2).

The analyzed variation of time of 25 Ma remains sufficiently important so that the climatical impact of Milankovitch cycles can be eliminated.

Results

To calculate the radiative forcing induced by the variation of atmospheric $O_{2,}$ it is first necessary to estimate this last variation. For that, are used results of a study based on a proxy defined by paired bulk carbonate and organic isotope records (Edwards, C.T. et al., 2017).

It is therefore determined that between 470 Ma and 445 Ma, the atmospheric O_2 is rised from [10 % -12,5 %] to 22 % , so a rise of [+9,5 % to +12 %].

The calculation of the radiative forcing due to this atmospheric O_2 rise is based on the result of a modelization (Poulsen et al., 2015). The result in this publication gives a surface radiation long and short wave forcing of + 8,4 W/m^2 for a decrease of -11 % for atmospheric O_2 during Cenomanian.

So for the rise of [+9,5 % to +12 %] for atmospheric O_2 during the time interval of 25 Ma for Ordovician, the negative radiative forcing is evaluated in the range [-7,2 W/m^2 to – 9,2W/m^2].

The variation of atmospheric CO_2 is based on the best estimate curve of proxy data in figure 3 of (Lowry et al., 2014; modified after Royer, 2006).

For the time interval, the variation of atmospheric CO_2 is evaluated to – 188 ppmv between 470 and 445 Ma. The same publication of Lowry et al., 2014 gives a radiative forcing of [-3,1 W/m^2 to – 6 W/m^2] for a variation of -560 ppmv. So proportionally, it gives a negative radiative forcing of [-1,1 W/m^2 to – 2 W/m^2] for the evaluation of -188 ppmv for the variation of atmospheric $CO_{2.}$

The variation of the total solar irradiance is evaluated with the Gough's law. It takes into account a sun 30 % less powerful at beginning of the solar system than at present and a linear and continuous evolution of the solar irradiance. For the time interval of 25 Ma, the positive radiative forcing is evaluated to +2, 2 W/m^2.

The influence of sea level rise on the albedo during Ordovician has been evaluated during the study of 2018 (Rousselle, J., Meftah, M., 2018) with an estimated sea level rise of 100 meters between 480 and 440 Ma and use of palaeogeographical maps (Torsvik and Cocks, 2017). It is considered that sea surface has an albedo of 0,1 and continents a value of 0,3. The evaluated variation of total earth surface albedo is – $0,008^{+0,002}$ and the radiative forcing is in the range [+8 W/m^2 to +10,6 W/m^2]. So, proportionally to the time interval, the sea live rise is estimated to 60 meters and the positive radiative forcing to the range [+5 W/m^2 to +6,6 W/m^2].

Synthesis of the results for the analysis during 25 Ma from beginning of Dapingian (470 Ma) to beginning of Hirnantian (445 Ma):

Parameter	Negative radiative forcing (W/m²) (1)	Positive radiative forcing (W/m²) (2)	Addition (1)+(2) (W/m²)
Variation of atmospheric O_2	-7,2 to -9,2	0	
Variation of atmospheric CO_2	-1,1 to -2	0	
Variation of total solar irradiance	0	+2,2	
Variation of albedo due to sea level change	0	+5 to +6,6	
Total (W/m²)	-8,3 to -11,2	+7,2 to +8,8	**-1,1 to -2,4**

Conclusion

The resultant range of radiative forcing [-1,1 W/m² to -2,4W/m²] for the time interval of 25 Ma from Early Dapingian to Early Hirnantian is demonstrating the cooling tendency of the climate during the period. This can explain the occurrence of glaciations at the end of the Ordovician.

The main factor brought to the fore is this analysis for cooling the climate is the important rise of atmospheric O_2 : [+9,5 % to +12 %]. And it can at least counterbalance the important positive radiative forcing due to the sea level rise.

These two parameters are predominant during the time interval.

The role of ozone is not considered here but could be added. Rise of atmospheric O_2 should be correlated with rise of stratospheric O_3, involving a supplementary driver for climate cooling.

The role of methane and nitrogen variation should also be studied but probably with minor long term climate impacts (oxidation of methane into CO_2).

It can be proposed a global long term paleoclimate theory:

- Atmospheric O_2 rise associated with sea level fall: cooling tendency probable (this should be the case of the long Carboniferous-Permian glaciations).
- Atmospheric O_2 fall associated with sea level rise: warming tendency probable.
- Atmospheric O_2 rise associated with sea level rise /Atmospheric O_2 fall associated with sea level fall: no prediction possible – depends on the importance of each rise and radiative forcing effect. It needs a precise analysis if the rise parameters are known and also in taking into account the variation of total solar irradiance and variation of atmospheric CO_2. It is the case of this present analysis for Ordovician.

	Atmospheric O_2 rise	Atmospheric O_2 fall
Sea level rise	Precise analysis needed	Warming probable
Sea level fall	Cooling probable	Precise analysis needed

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THE ORDOVICIAN SUBSTRATE REVOLUTION IN THE BALTIC PALEOBASIN

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Key words: *Ordovician, Stemmed echinoderms, bryozoans, calcite detritus, firm ground, hardgrounds, bioherms.*

Introduction

The Ordovician Substrate Revolution is a rapid expansion of the area of grounds with a high content of carbonate detritus in the shallow epicontinental seas of the Baltic and Laurentia at the end of the Early – the beginning of the Middle Ordovician and the associated benthic change. Substrate changes in the cold-water seas of Gondwana took place gradually because terrigenous sedimentation was dominated there during the Ordovician, and many elements of the Cambrian evolutionary fauna coexisted with the emerging elements of the Paleozoic evolutionary fauna for a long time. Substrate revolution and the associated change of the dominant benthic fauna was the main content of the Great Ordovician Biodiversification Event. In the Baltic, these events were manifested most clearly, and the mechanism for the development of the substrate revolution is reconstructed most convincingly and clearly (Rozhnov, 2019).

Conditions for the development of the Ordovician substrate revolution in the Baltic

Numerous organisms with high carbonate productivity and a skeleton that can easily collapse after death are necessary for the predominance of carbonate detritus in the ground. At the same time, the rate of receipt and the volume of detritus should exceed the inflow of terrigenous material here. All these necessary conditions existed in many places of the Baltic paleobasin, starting at the end of the Early Ordovician. Large areas of shallow water, in the absence of large terrigenous source from the surrounding land, made it possible for carbonaceous sedimentation to predominate after being settled by highly productive calcium carbonate producers.

Calcite detritus producers in the Baltic Ordovician Basin

Since the beginning of the Middle Ordovician, echinoderms have become the dominant source of detritus in the Baltica. At the end of the early Ordovician, they, together with bryozoans, joined the already existing detritus producers – trilobites, brachiopods, and ostracods. Soon, echinoderms transformed grounds on the broad areas due to the large volume of stereomic calcite skeleton produced by them, which is able to easily break up into fragments and easily split along cleavage. Judging by the attachment structures, the largest producers of detritus among them were crinoids. Many of the Ordovician crinoids had a massive long stem of pentameric columnals, which, like the crown, after the death of the animal, quickly disintegrated into small fragments that were carried far beyond their settlement. Other important sources of calcite detritus among echinoderms was eocrinoid *Rhipidocystis baltica*, thecae of which disintegrated into the characteristic large marginal plates. In some places, these plates constitute up to 30-40 % of detritus. In the third place among echinoderms in the fabric of detritus was rhombiferan cystoid *Echinoencrinites*, confined to quieter conditions, where storm waves only occasionally reached. It is impossible to identify exactly the majority of echinoderm remains although the diversity and abundance of attachment structures clearly indicates important role of crinoids in the Middle Ordovician biotopes. Comparison of the morphological diversity, size and number of attachment structures of echinoderms well reflects the difference between the predominant grounds of the shallow epicontinental seas of the Cambrian and Ordovician (Rozhnov, 2019). Bryozoans at the end of the Early Ordovician were represented only by the 7 genera of two orders Cystoporida (1 genus) and Trepostomida (6 genera). During the Volkhov time, bryozoans sharply increased in diversity (16 genera), among which Trepostomida still dominated (12 genera), and first appeared here representatives of the orders Tubuliporida and Cryptostomida did not play a significant role in enriching the ground with detritus (Koromyslova, 2011). Trilobite remains constitute a common background in the composition of detritus. Articulate brachiopods have the calcite shell and played a significant role in changing the composition of the Ordovician substrate due to its abundance. Among them Orthids and a little later Billingsellids strongly dominated, pentamerids and strophomenids are of minor importance. The Orthids had a strong, though usually small, shell, the valves of which constituted a significant part of the substrate in places. Large brachiopod shells, like large trilobite remains, were a good substrate for the attachment of bryozoans and small stemmed echinoderms.

The role of microbial communities in the development of substrate revolution

The settlements of echinoderms and bryozoans were first located on hardgrounds and firm grounds on and around complicated microbial bioherms, widespread in the Volkhov time in the east of the Baltic basin. These settlements were a high performance detritus fabric. The bioherms had a complex structure. Their origin is associated with filter feeders, most likely with sponges, which initially formed a small silty mound. Because of the siltation after filtration, the settlements of the filter feeders perished or shifted to the periphery of the mound and most part of

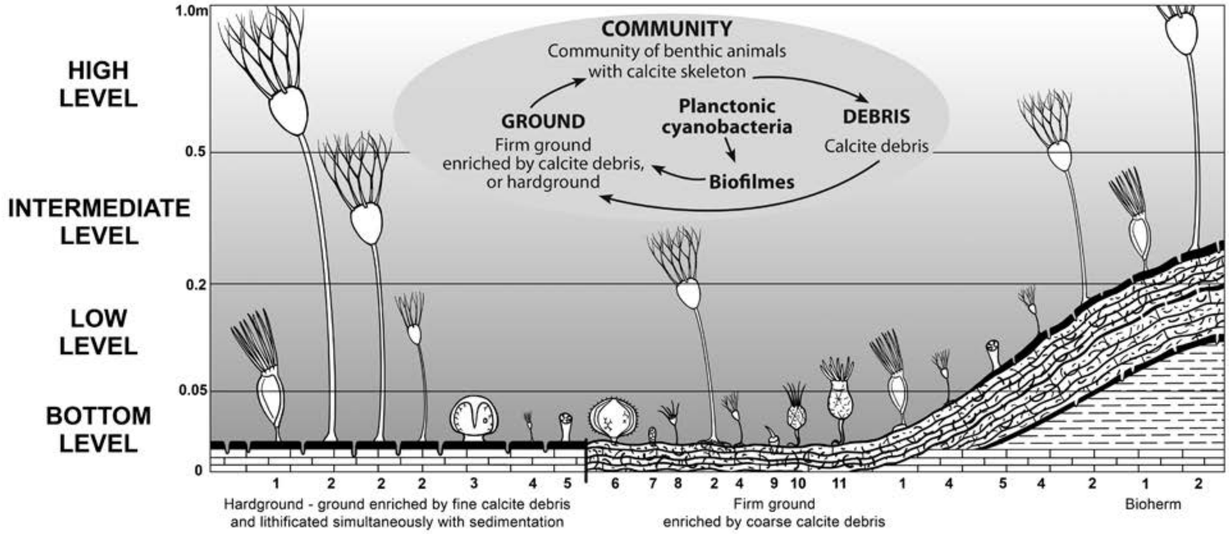

Fig. Echinoderm communities on the bioherms, firm coarse grained grounds and hardgrounds during Volkhov time in the East part of the Baltic region and feedback circuit between community and the grounds with influence cyanobacterial films in the beginning of the Ordovician substrate revolution.

Numbers denote: 1 – eocrinoid Rhipidocystis; 2 – crinoids; 3 – edrioblastoids; 4 – various young and small crinoids; 5 – edrioasteroid Cyathocystis; 6 – diploporitan Mesocystis; 7 – edrioasteroid Pyrgocystis; 8 – diploporan Asteroblastus; 9 – eocrinoid Bolboporites; 10 – rhombiferan Echinoencrinites; 11 – rhombiferan Cheirocrinus.

mound occupied by cyanobacterial communities forming the biofilms. Extracellular polymeric substance (EPS) forms a matrix integrating a biofilm around cyanobacterial cells. The EPS was catching, enveloping and cementing small calcite grains of the sediment and mineralized. In result the hardground was formed (Rozhnov, 2017, 2018, 2019). The hardground on bioherms after the death of cyanobacterial communities was colonized by attaching echinoderms, primarily eocrinoids and crinoids, as well as bryozoans. Numerous borers *Trypanites* were settled in hardground too. Detritus from these settlements accumulated around bioherms. Microbial communities that have settled on detritus ground also consolidated the ground with EPS but did not turn it into a hardground because the bulk of mineralized EPS was not enough to firmly bind large-size detritus. Under low-water conditions and weak fine-grained sedimentation, thick cyanobacterial biofilms were formed on very large areas, and the mineralized EPS bound the fine-grained sediment on the seabed surface to a hardground. Such a surface was particularly suitable for the settlement of echinoderms, bryozoans and numerous borers. Large areas of hardground, inhabited by attached echinoderms and bryozoans, are characteristic of several levels of the Volkhov regional stage.

Mechanism of the Ordovician Substrate Revolution

The detritus substrates and hardgrounds were very favorable for the settlement of the suppliers of detritus, firstly for the echinoderms and bryozoans. This is well illustrated by the coevolution of grounds and attachment structures of echinoderms in the epicontinental seas of the Cambrian and Ordovician. Detritus produced by these settlers increases the area of such a substrate and the community living on it. The development of cyanobacterial biofilms on this substrate consolidates the ground and in some cases turns fine-grained sediment into a hardground. As a result, emerging positive feedback between the substrate and inhabiting it community of detritus producers led to an explosive expansion of the area of the detritus ground and the community (Fig.). This process is intensified due to the influence of the microbial communities on the substrate. The emergence of detritus grounds favorably affected the development of infauna due to the increased porosity and oxygen saturation of such ground. The process of explosive spreading of detritus grounds and hardgrounds with inhabiting communities in the beginning of the Middle Ordovician in Baltica and Laurentia can rightfully be called a substrate revolution.

Conclusion: Cambrian and Ordovician Substrate Revolutions differ sharply

The Ordovician Substrate Revolution is fundamentally different from the change of grounds during the Cambrian evolutionary explosion, which is also called the substrate revolution. The Cambrian ground change was associated with the abundant supply of organic matter from the uppermost layer of the water column due to the appearance of planctonic filter feeders, the fecal pellets of which began to overcome the thermocline and sink to the bottom. Due to the saturation of the organic matter of the marine ground in the Cambrian, the abundance of benthos increased dramatically and appeared detritivores penetrate into the upper part of the ground. Therefore, the Cambrian revolution is better called agronomic (Seilacher, Pflüger, 1994) rather than substrate (Bottjer et al. 2000, Zamora et. al., 2017)). In contrast to the Cambrian, the substrate revolution in the Ordovician was due to positive feedback between the ground and the community of animals that lived on this substrate, and not to the waste products of pelagic organisms.

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THE ORDOVICIAN PERIOD OF THE EVOLUTION OF THE PALEO-ASIAN OCEAN: OCEAN PLATE STRATIGRAPHY, INTRA-OCEANIC ARCS AND TECTONIC EROSION

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Key words: *ocean-plate stratigraphy, tectonic erosion, Late Ordovician, Central Kazakhstan.*

The Paleo-Asian Ocean (PAO) opened at 950-900 Ma by a series of episodes of rifting in the Baikal region (Dobretsov et al., 1995). At different stages the PAO separated the Siberian, Kazakhstan, Tarim and North China continents. The evolution and suturing of the PAO and subsequent collisions of those four continents formed the Central Asian Orogenic Belt (CAOB). The CAOB extends over a huge area from Kazakhstan in the west, through Kazakhstan, Kyrgyzstan, Uzbekistan, north-western China to Altai-Sayan and Transbaikalia in Russia, Mongolia, and north-eastern China to the Russian Far East (e.g., Zonenshain et al., 1990; Windley et al., 2007; Xiao et al., 2010; Safonova, 2017). The main oceanic terranes recording their evolution from the birth at mid-oceanic ridge to the death at subduction zones are fragments of oceanic crust/floor and active margins, i.e. intra-oceanic island arcs and continental arcs. Numerous reconstructions of the PAO are based on investigations of fragments of oceanic crust or Ocean Plate Stratigraphy (OPS) preserved in accretionary complexes and intra-oceanic arcs.

OPS implies a regular succession of igneous and sedimentary rocks of the oceanic lithosphere, which were, respectively, erupted and deposited on the sea floor as the underlying oceanic basement traveled from mid-oceanic ridge to subduction zone. During oceanic subduction, OPS units are incorporated into accretionary complexes (ACs) of Pacific-type (P-type) orogens. A typical OPS succession includes (i) pelagic chert often associated with MORBs; (ii) hemipelagic siliceous shale, greywacke and mudstone; and (ii) trench turbidites (Isozaki et al., 1990). The oceanic subduction formed numerous P-type orogens and ACs of Central and East Asia. There are more than 30 ACs in the CAOB hosting OPS units, however, only four of them are of Ordovician age: Fan-Karategin AC in Tajikistan, Tangbale-Maili and Darbut in western Junggar and Kalamaili in eastern Junggar (NW China). So, the records of Ordovician OPS in the CAOB are scarce (Safonova and Santosh, 2014).

Intra-oceanic arcs (IOAs) form at Pacific-type convergent margins, in the upper “stable” plate, when the subducting plate submerges to the depths of melting, i.e., to ca. 50-100 km. A typical IOA system, such as Mariana-Bonin and the Philippines Sea, consists of subduction zone, fore-arc region with accretionary prism, frontal or active arc, marginal basin with spreading center, and, in some cases, one or more remnant arcs and inactive marginal basin. The IOAs of the Paleo-Asian Ocean fromed during a period from the late Neoproterozoic to the late Paleozoic. Their fragments have been preserved in the central, western and southwestern segments of the CAOB, in almost all major orogens or foldbelts of the CAOB. Twenty one intra-oceanic arcs have been identified in the Central Asian Orogenic Belt. They formed during three time intervals in the evolution of the Paleo-Asian Ocean: Neoproterozoic, early Paleozoic and middle Paleozoic (Safonova et al., 2017). However, only four Ordovician IOAs have been identified so far: Bozshakol-Chingiz (Late Cambrian – Early Ordovician, Baydaulet-Aqbastau (Floian to late Ordovician) and Chatkal-Atbashi (Kyrgyz Tienshan) and Fan-Karategin (Tajik Tienshan).

Recently, we have obtained new geological, geochronological, microplaeontological, geochemical and isotope data from one more locality of Ordovician OPS and IOA in the western CAOB – in the Itmurundy zone of central Kazakhstan. The Itmurundy ophiolite belt and/or accretionary complex is located at the northern shore of Lake Balkhash. In the early 1980-ties the Itmurundy belt was called a spillite-jasper complex hosting ophiolites of unclear ages, Riphean to Sinian, Cambrian or Ordovician (Patalakha and Belyi, 1981). Since the late 1990-ies and 2000-s this belt has been classified as an accretionary prism or complex (Zhylkaidarov, 1998; Stepanest, 2016), which formation was linked to the evolution of the PAO. The Itmurundy belt includes three main assemblages of rocks: mantle, orogenic and post-orogenic, which are separated from each other by regional to local faults.

The mantle assemblage consists of probably pre-Ordovician peridotites, dominantly dunite, harzburgite, wherlite, gabbro and plagiogranite, i.e. it represents lower parts of an ophiolitic package. The rocks occur as polymictic and serpentinitic mélanges. The mélange is overlain by the orogenic assemblage, which was previously considered as an Upper Ordovician olistostrome carrying ophiolitic clastic material. In Soviet literature of the 1970-80-ies, the rocks of the olistostrome or orogenic assemblage were called chaotic units. In modern terminology those rocks represent an accretionary complex (AC). Term ”orogenic” is quite appropriate because these rocks obviously formed in oceanic and convergent margin environments and were piled up together during Pacific-type orogeny and related accretion (Safonova, 2017). There are three main groups of rocks: OPS, accretionary and supra-subduction. The orogenic or accretionary assemblage includes mafic volcanic rocks, ribbon chert, hemipelagic siliceous thin-grained sediments (mudstone, siltstone, shale), gray and greenish-gray sandstones and flyschoid greywacke sandstones. The post-orogenic assemblage consists of mid-Silurian to Carboniferous continental margin to continental sediments (sandstones, carbonates, conglomerates) and felsic volcanic rocks deposited after the suturing of the PAO.

OPS units are abundant in the central part of the Itmurundy AC. The rocks of the accretionary complex belong to three formations (bottom to top): Itmurundy, Kazyk and Tyuretai (Patalakha and Belyi, 1981). The Itmurundy Fm. consists of basalt, gray, red and brown ribbon chert, chocolate, violet, brown and greenish gray siliceous mudstones, siltstones and shales and sandstone. The Kazyk Fm. is dominated by red and brown ribbon cherts with Ordovician conodonts, siliceous mudstone, siltstone and shale with subordinate basalt and sandstone. The rocks of the Tyuretai Fm. are dominated by coarser grained clastic sediments – siliceous mudstone, siliceous siltstone and sandstone with subordinate basalt and chert containing upper Ordovician conodonts and early Silurian graptolites. The whole structure of the AC represents a mélange and/or tectonically piled up sheets, i.e. typical of accreted oceanic rocks and sediments delivered from the erosion of adjacent arcs, all formed at a Pacific-type convergent margin.

We sampled igneous and sedimentary rocks (chert, siliceous mudstone, sandstone) of the Itmurundy AC. The igneous assemblage is dominated by basalts which possess geochemical affinities of boninite, island-arc tholeiite, N-MORB, E-MORB and OIB. The basalts often occur as pillow lavas or form flows of changing thickness. For age constrains we sampled turbiditic and greywacke sandstone. The grey and dark-grey-greenish sandstones of the Itmurundy Fm. are gray in color and have andesitic major element composition. They yielded unimodal distributions of U-Pb ages peaked at 470-450 Ma suggesting their intra-oceanic arc origin. More evidence for this comes from the positive Hf_t values of zircons (9.2-17.6) and the occurrence of sparse outcrops of volcanic rocks possessing supra-subduction geochemical affinities. The sample of the Tyuretai Fm. OD-1 has dacitic compositions and yielded multi-model U-Pb age probability curves peaked at 455-465, 750, 1100, and 2400 Ma suggesting a continental arc origin. Thus, on the one hand, the unimodal U-Pb age probability curves and the positive epsilon Nd and Hf values suggest an Ordovician intra-oceanic arc. On the other hand, the scarcity of outcrops of supra-subduction rocks suggests that those arcs were tectonically eroded during oceanic subduction.

Thus, there are three lines of evidence about the sting tectonic erosion at the active margins of the PAO in Ordovician time. One comes from the Ordovician “gap” in the record of accreted OPS in the accretionary complexes of the CAOB (Safonova and Santosh, 2014). The second line of evidence is in the scarcity of Ordovician intra-oceanic arcs in the CAOB (Safonova et al., 2017). The third evidence comes from the Itmurundy accretionary complex of central Kazakhstan, where the records of intra-oceanic arcs have been preserved only on their related greywacke sandstones (new data).

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THE O/S BOUNDARY IN SALAIR VOLCANIC-SEDIMENTARY DEPOSITS: FAUNA, ISOTOPIC AGE (SOUTH SIBERIA, RUSSIA)

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Key words: *O/S boundary, Salair, isotopic age.*

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Early Paleozoic Salair volcanic complex, cropped out on the south of Siberia, is comprised of rhyolite-trachybasalts. It belongs to Middle-Late Cambrian Orlinaya Gora – Arinichevo and Late Cambrian-Early Ordovician Chebura-Krasnyanka complexes. Later volcanism occurred at Late-Ordovician – beginning of Silurian.

Ordovician-Silurian boundary defined by biostratigraphic data and its alignment with the local stratigraphic units mapped by geological survey remains a matter of discussion. Previously this boundary was proposed between the Veber and Oselki (Lower part of the Yurman Group) formation (Decisions…, 1983).

In the upper part of the stratotype section of the Veber Formation near Gurievsk town graptolites were obtained. They belong to *myrniensis* Zone that is analogue of lower Hirnantian substage *extraordinarius* graptolite Zone. Graptolite assemblage includes: *Hedrograptus mirnyensis* Obut et Sob., *Ptilograptus glomeratus* Pocta, *Koremagraptus kozlowskii* Bulman, *Acanthograptus* sp. and *Rhadinograptus* aff. *jurgensonae* Obut. From the underlain limestone trilobites were found: *Holotrachellus pinctillosus* Tornq., *Illaenus oviformis* Warb., *Il. salairicus* Web., *Brontochephalina nuda* (Ing.), *Amphilichas sniatkovi* Web., *Cheirurus gelasinosus* Portl., *Isocolus sjogreni* Ang. and *Sphaerexochus calvus* McCoy.

The upper Hirnantian graptolites were collected from the Oselki Formation: *Normalograptus* ? ex gr. *persculptus* (Salter), *Glyptograptus* sp., *Metaclimacograptus* ex gr. *hughesi* (Nicholson) and *Hedrograptus* sp. They were recovered from the yellow-gray mudstones in the stratotype of the Yurman Group, along the Yurman River.

Geological mapping of the south Salair, carried out in the recent years revealed presence of volcanics – tuffites and tuff sandstone and different lava and tuff covers as well as subvolcanic sediments (Gusev et al., 2018; Tokarev et al., 2018).

Cover facies sediments. In the North Salair in the stratotype of the Oselki Formation rhyolite-dacite tuff bed was found. Rocks are massive, crystalline-lithoclastic with silty-psammitic and psammite-fine psephitic textures. Size of the angular clasts of the plagioclase-porphyritic rhyolite-dacite is from 0.1 to 2 mm, rare up to 5 mm. Studied rhyolite-dacite is fully crystalline, fine-grained, micro-aplite, sericite-quartz-feldspar. Feldspar phenocrysts 0.2-1 mm comprise to 40 % of the rock, quarzitic phenocrysts are sporadic.

In the South Salair cover facies found in the Oselki Formation is composed of lavas, basaltic tuff, dacitic and rhyolite-dacitic tuff. Basalts are pyroxene-porphyritic with rare small amygdules filled by chlorite.

Basalts are low-titanium (TiO_2 = 0.73–0.9 %), low ferrum (F = 32.5–36.7 %), very low K_2O contents (0.1–0.2 %).

Basaltic tuff found in the southern slope of Salair are lithoclastic, psammitic-psephitic, with irregular shape clasts of cheery-color and dark-green basalts, from 1 to 4-7- mm in size.

Clasts of feldspar – porphyroclastic dacite are angular and poor-rounded (up to 80 %). Pyroclasts size is 0.2–2.5 mm.

Subvolcanic strata in the Oselki Formation are represented by the Sluchainaya Mountain massif situated on the watershed of the Bedrep and Uksunai rivers, southern slope of Salair. It is a plutonic stock breakout Upper Ordovician Veber Formation carbonate-terrigenous sediments. The Veber Formation limestone yielded trilobites *Parillaenus depressa* (Holm) and *Isotelus robustus* (Roemer), characteristic for Hirnantian Stage of Upper Ordovician of Estonia and Taimyr; brachiopods *Hesperortis* cf. *lebediensis* Sev. *Trucizetina* sp., *Protochonetes* sp., *Bracteoleptaena* sp., Strophodontidae, known in the Upper Ordovician of Gorny Altai; ostracods *Hermannina* sp.; tabulate corals *Lyopora minima* Dziubo, characteristic for Upper Ordovician of Gorny Altai.

The Sluchainaya Mnt. massif is composed of dolerite. Feldspar content is 60–70 %, and clinopyroxene content is 30–40 %. Silicate analysis show that this rock is gabbroid (X-ray fluorescence analysis, VSEGEI laboratory), with low titanium (TiO2 = 0.77–1.21 %), low phosphorus (P2O5

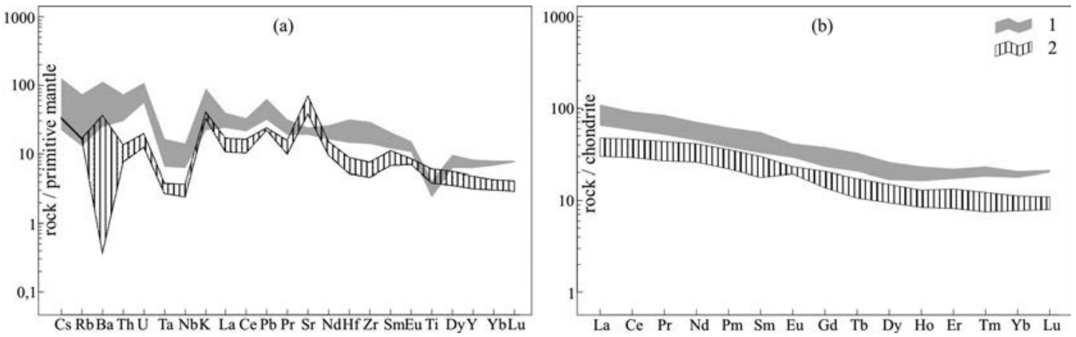

Fig. 1. Multielement diagrams for the Oselki Formation sediments.

1 – rhyolite-dacitic and dacitic tuff (4 samples); 2 – the Sluchainaya Mountain massif dolerite (2 samples) (VSEGEI data).

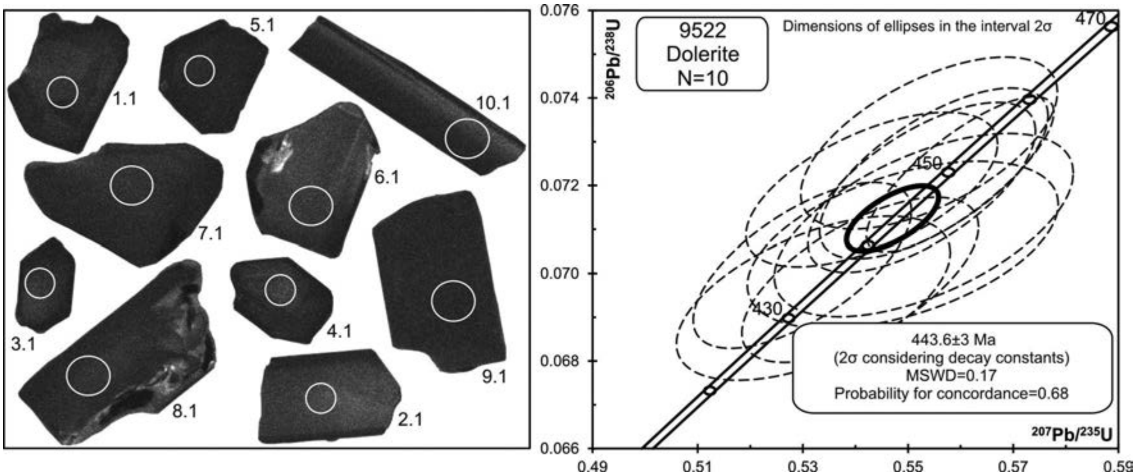

Fig. 2. Cathodoluminescent (CL) images of zircons with measurement points (white circles) and U-Pb age of the Sluchainaya Mountain massif dolerites (VSEGEI data).

= 0.13–0.24 %), low ferrum (F = 37.1–40,8 %) contents, natrium alkalinity (Na2O/K2O = 1.93–6.31). By these parameters subvolcanic rocks of the Gora Sluchainaya massif could be aligned with Oselki Formation basalts, and suggest comagmatic origin. Relative dating was based on the fact that it breakout paleontologically dated Upper Ordovician Veber Formation. In addition U-Pb zircon dating of dolerite from the Sluchainaya Mnt. massif revealed 443.2 ± 2,39 Ma (SIMS SHRIMP, VSEGEI) (Fig. 1, 2, Plate), that is Lower Silurian. Ordovician/Silurian boundary is defines as 443.8 Ma (Gradstein et al., 2012).

Plate

Sm and Nd isotopic composition in the dolerites of the of the Sluchainaya Mountain massif

Sample No	Sm, g/t	Nd, g/t	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	ε_{Nd}(T)	T_{Nd}(DM) billion years	T_{Nd}(DM-2St) billion years
8114	4,52	18,97	0,1440	0,512759	+5,4	0,86	0,75
9522	2,79	11,64	0,1451	0,512731	+5,1	0,90	0,77

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UPPER ORDOVICIAN DEPOSITS OF THE BASEMENT OF THE WEST SIBERIAN GEOSYNECLISE (RUSSIA): EVIDENCE FROM BOREHOLE MATERIALS

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Key words: *Upper Ordovician, West Siberian Geosyneclise, Pavlov Regional Stage.*

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West Siberia is a vast territory situated between Urals and Yenisey River. On the south it borders with Kazakhstan, China and Mongolia. Paleozoic rocks cropped out on the south of West Siberia – in the Altai-Sayan Folded Area, while on West-Siberian lowlands Paleozoic rocks are overlaid by Mesozoic-Cenozoic sedimentary cover.

On the West-Siberian Lowlands Paleozoic rocks comprise the basement complex of the West-Siberian Plate. Its cover occurs at 2500-35000 m depths, and on the north goes down up to 7000 m. On the south of the region, Paleozoic rocks occur relatively close to the surface, under the Quaternary deposits. Folded Paleozoic basement along with Mesozoic-Cenozoic plate complex comprise structure called in Russian literature as West Siberian Geosyneclise.

Ordovician strata in the basement of the West Siberia Geosyneclise were developed by drilling wells in the different facies regions (Yolkin et al., 2001). Upper Ordovician sequences were best studied since they were developed by tens of drilling wells with core sampling, and consist of volcanic-sedimentary and sedimentary rocks. Latter are represented by chert (including radiolarite), jasper, sandstone, siltstone and limestone. Fauna includes: radiolarians, trilobites, brachiopods, ostracods, bryozoans, tabulate corals, stromatoporoids, conodonts. Relatively diverse Upper Ordovician fauna was reported from Beryozovo-Syrtan'ya, Sherkala, Var'yogan, Nyurol'ka and Ermakovo structural-facies zones (Fig. 1).

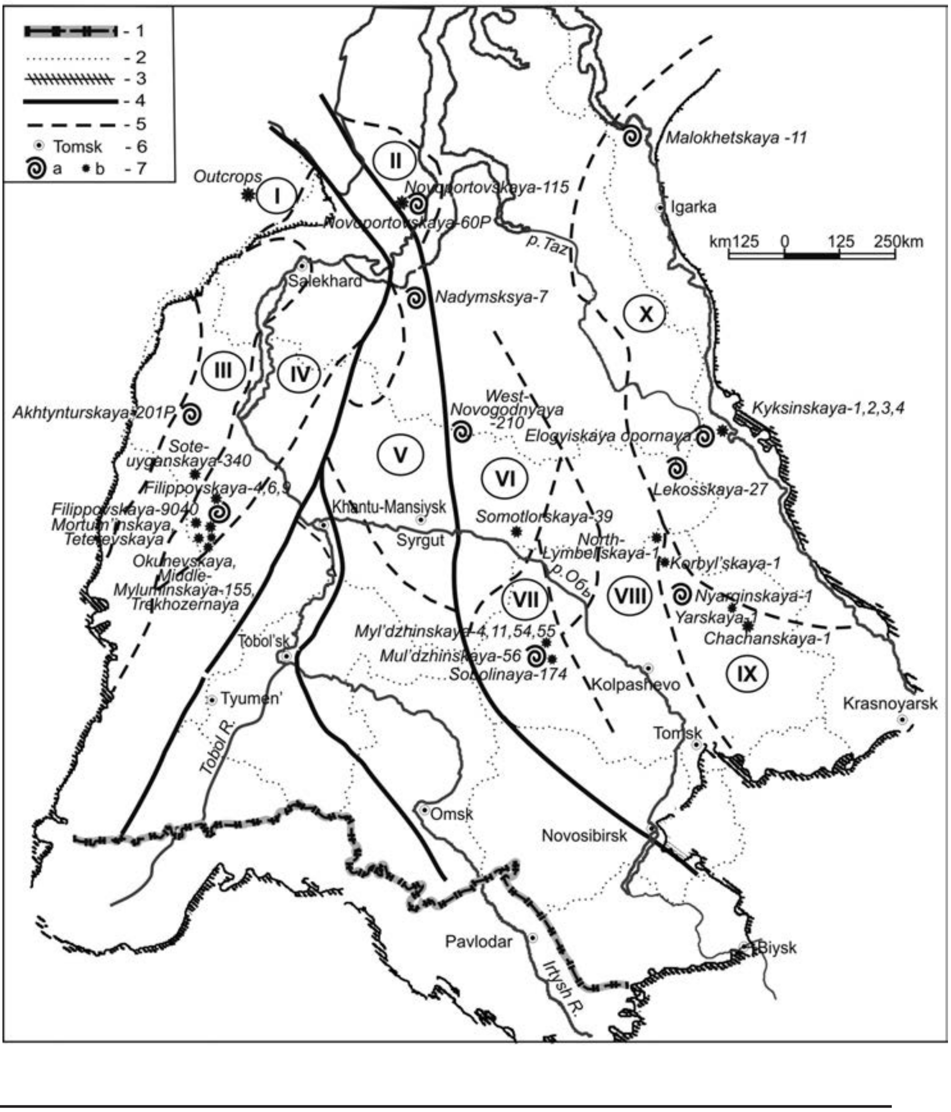
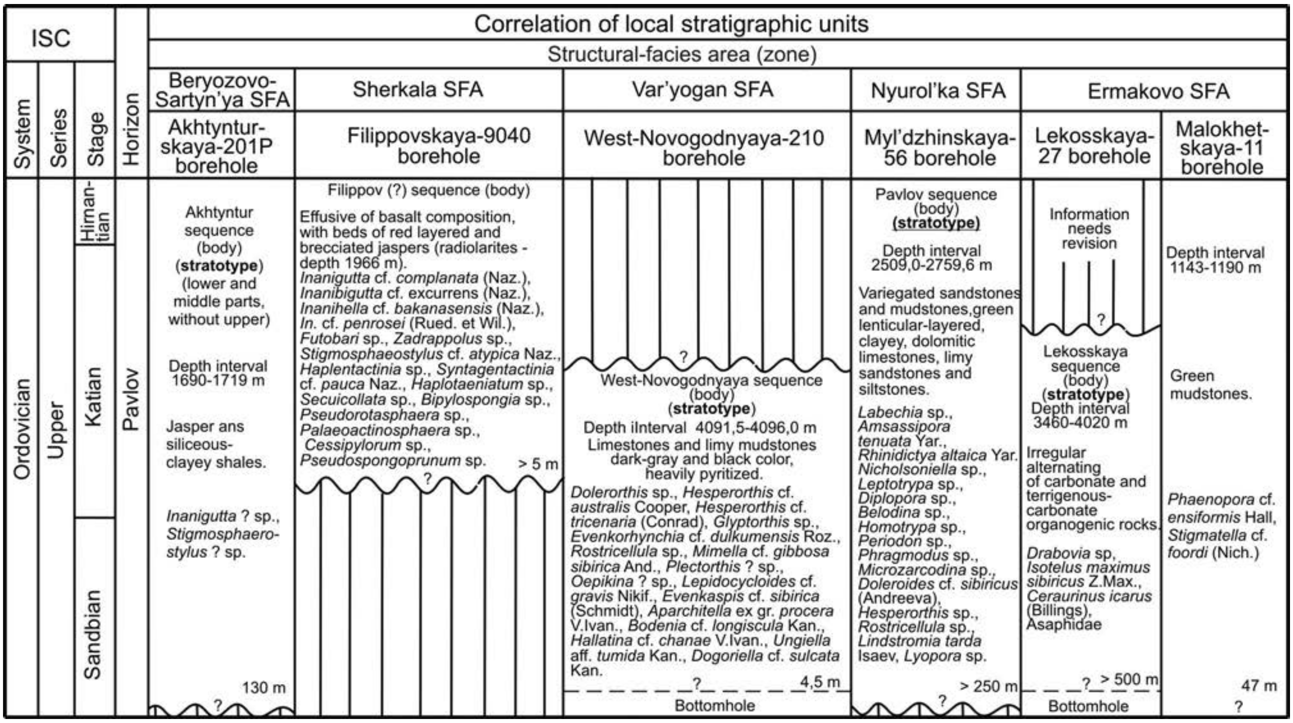


Fig. 1. Structural-facies zonation for the sedimentary basement of the West Siberian Geosyneclise (after Yolkin et al., 2001), with specification of boundaries).
1 – Russian state border; 2 – boundaries of administrative divisions; 3 – boundary of the folded framing; 4 – large faults, limiting main reginal blocks; 5 – boundaries of the structural-facies zones; 6 – settlements; 7 – drilling wells: a) with fauna and flora, b) without fossils (including radiometric dated).
Structural-facies area (zone): I – Shuchyay, II – Novy-Port, III – Beryozovo-Sartyn'ya, IV – Sherkala, V – Ust'-Balyk, VI – Var'yogan, VII – Nyurol'ka, VIII – Kolpashevo, IX – Vezdekhodny, X – Ermakovo.



ISC				Correlation of local stratigraphic units					
				Structural-facies area (zone)					
				Beryozovo-Sartyn'ya SFA	Sherkala SFA	Var'yogan SFA	Nyurol'ka SFA	Ermakovo SFA	
System	Series	Stage	Horizon	Akhtyntur-skaya-201P borehole	Filippovskaya-9040 borehole	West-Novogodnyaya-210 borehole	Myl'dzhinskaya-56 borehole	Lekosskaya-27 borehole	Malokhet-skaya-11 borehole
Ordovician	Upper	Himantian Katian Sandbian	Pavlov	Akhtyntur sequence (body) (**stratotype**) (lower and middle parts, without upper) Depth interval 1690-1719 m Jasper ans siliceous-clayey shales. *Inanigutta* ? sp., *Stigmosphaerostylus* ? sp. 130 m ?	Filippov (?) sequence (body) Effusive of basalt composition, with beds of red layered and brecciated jaspers (radiolarites - depth 1966 m). *Inanigutta* cf. *complanata* (Naz.), *Inanibigutta* cf. excurrens (Naz.), *Inanihella* cf. *bakanasensis* (Naz.), *In.* cf. *penrosei* (Rued. et Wil.), *Futobari* sp., *Zadrappolus* sp., *Stigmosphaeostylus* cf. *atypica* Naz., *Haplentactinia* sp., *Syntagentactinia* cf. *pauca* Naz., *Haplotaeniatum* sp., *Secuicollata* sp., *Bipylospongia* sp., *Pseudorotasphaera* sp., *Palaeoactinosphaera* sp., *Cessipylorum* sp., *Pseudospongoprunum* sp. > 5 m ?	? West-Novogodnyaya sequence (body) (**stratotype**) Depth iInterval 4091,5-4096,0 m Limestones and limy mudstones dark-gray and black color, heavily pyritized. *Dolerorthis* sp., *Hesperorthis* cf. *australis* Cooper, *Hesperorthis* cf. *tricenaria* (Conrad), *Glyptorthis* sp., *Evenkorhynchia* cf. *dulkumensis* Roz., *Rostricellula* sp., *Mimella* cf. *gibbosa sibirica* And., *Plectorthis* ? sp., *Oepikina* ? sp., *Lepidocycloides* cf. *gravis* Nikif., *Evenkaspis* cf. *sibirica* (Schmidt), *Aparchitella* ex gr. *procera* V.Ivan., *Bodenia* cf. *longiscula* Kan., *Hallatina* cf. *chanae* V.Ivan., *Ungiella* aff. *tumida* Kan., *Dogoriella* cf. *sulcata* Kan. ? 4,5 m Bottomhole	Pavlov sequence (body) **(stratotype)** Depth interval 2509,0-2759,6 m Variegated sandstones and mudstones,green lenticular-layered, clayey, dolomitic limestones, limy sandstones and siltstones. *Labechia* sp., *Amsassipora tenuata* Yar., *Rhinidictya altaica* Yar. *Nicholsoniella* sp., *Leptotrypa* sp., *Diplopora* sp., *Belodina* sp., *Homotrypa* sp., *Periodon* sp., *Phragmodus* sp., *Microzarcodina* sp., *Doleroides* cf. *sibiricus* (Andreeva), *Hesperorthis* sp., *Rostricellula* sp., *Lindstromia tarda* Isaev, *Lyopora* sp. > 250 m ?	Information needs revision ? Lekosskaya sequence (body) (**stratotype**) Depth interval 3460-4020 m Irregular alternating of carbonate and terrigenous-carbonate organogenic rocks. *Drabovia* sp, *Isotelus maximus sibiricus* Z.Max., *Ceraurinus icarus* (Billings), Asaphidae ? > 500 m Bottomhole	Depth interval 1143-1190 m Green mudstones. *Phaenopora* cf. *ensiformis* Hall, *Stigmatella* cf. *foordi* (Nich.) 47 m ?

Fig. 2. Correlation of the Upper Ordovician local stratigraphic units of the West Siberian Geosyneclise.

Summarizing all obtained data for the Upper Ordovician of the basement of West Siberia Geosyneclise we propose the new Regional Stage – Pavlov Horizon. To define this new regional stratigraphic unit we used paleontological and stratigraphic data about the local stratigraphic units (or bodies) obtained from different facies zone within the West Siberia Geosyneclise.

Age of the Pavlov Horizon is dated as Late Ordovician – Sandbian, Katian and Hirnantian by fauna recovered from the tratotype of the same-named body (Nyurol'ka structural facies zone, Myl'dzhinskaya-56 drilling well, interval 2509,0-26759,6 m): conodonts *Belodina* sp., *Periodon* sp., *Phragmodus* sp. and *Microzarcodina* sp.; bryozoans *Labechia* sp., *Amsassipora tenuata* Jarosch., *Rhinidictya altaica* Jarosch., *Nicholsoniella* sp., *Leptotrypa* sp., *Diplopora* sp. and *Homotrypa* sp.; brachiopods *Doleroides* cf. *sibiricus* (And.), *Hesperorthis* sp., *Rostricellula* aff. *subrostrata* (Nikif.) and *Rostricellula* sp.; tabulate corals *Lindstromia tarda* Isaev and *Lyopora* sp.; stromatoporoids *Labechia* sp. and *Pachystylostroma* sp. (Fig. 2).

This is a contribution to IGCP653 project.

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ECOSYSTEM RECONSTRUCTION FOR THE ORDOVICIAN BASIN OF THE CENTRAL TUVA (SOUTH SIBERIA)

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Key words: *Central Tuva, Ordovician, lithology, ecosystems.*
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Tuva region is one of the least studied geological structures of the Altai-Sayan Folded Area, part of the Central Asian fold belt. The Ordovician sequences cropped out in the Central Tuva region belong to the Khemchik structural-facial zone (Fig. 1).

Ordovician sequences of the Central Tuva belong to the Shemushdag Group in stratigraphical succession consist of Dagyr-Shemi, Ayangaty and Adyrtash formations, and to the lower part of the Chergaky Group – lower subformation of the Alavelyk Formation (V.Sennikov, 1977) (Fig. 2).

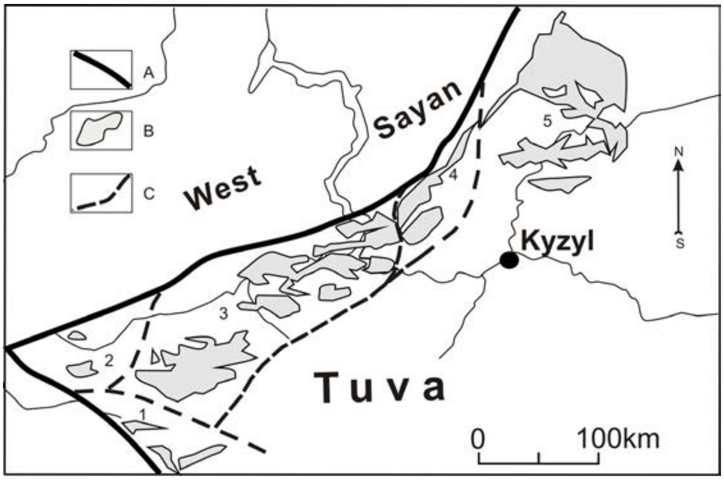


Fig. 1. Structural–facies zonation of the Tuva Ordovician sequences.
A – deep faults bordering the largest regional blocks; B – area of distribution of Ordovician, C – margins of the structural-facies zones.
1 – Karga zone, 2 – Alash zone, 3 – Khemchik zone, 4 – Uyuk zone, 5 – Systyg-Khem zone.

The Lower Dagyr-Shemi Subformation is composed of gray sandstone, siltstone, and in the upper part – of gray and red sandstone and mudstone with ripple marks, rain-drop imprints, desiccation cracks, ichnofosills etc. (Sennikov, 2005, 2006, 2018, 2019; Sennikov, Obut, 2018). The Upper Dagyr-Shemi Subformation consists of red sandstone, siltstone with basal conglomerate. Conditionally Dagyr-Shemi Formation is aligned with Floian (lower subformation) and Dapingian (upper subformation), Lower and lowermost Middle Ordovician.

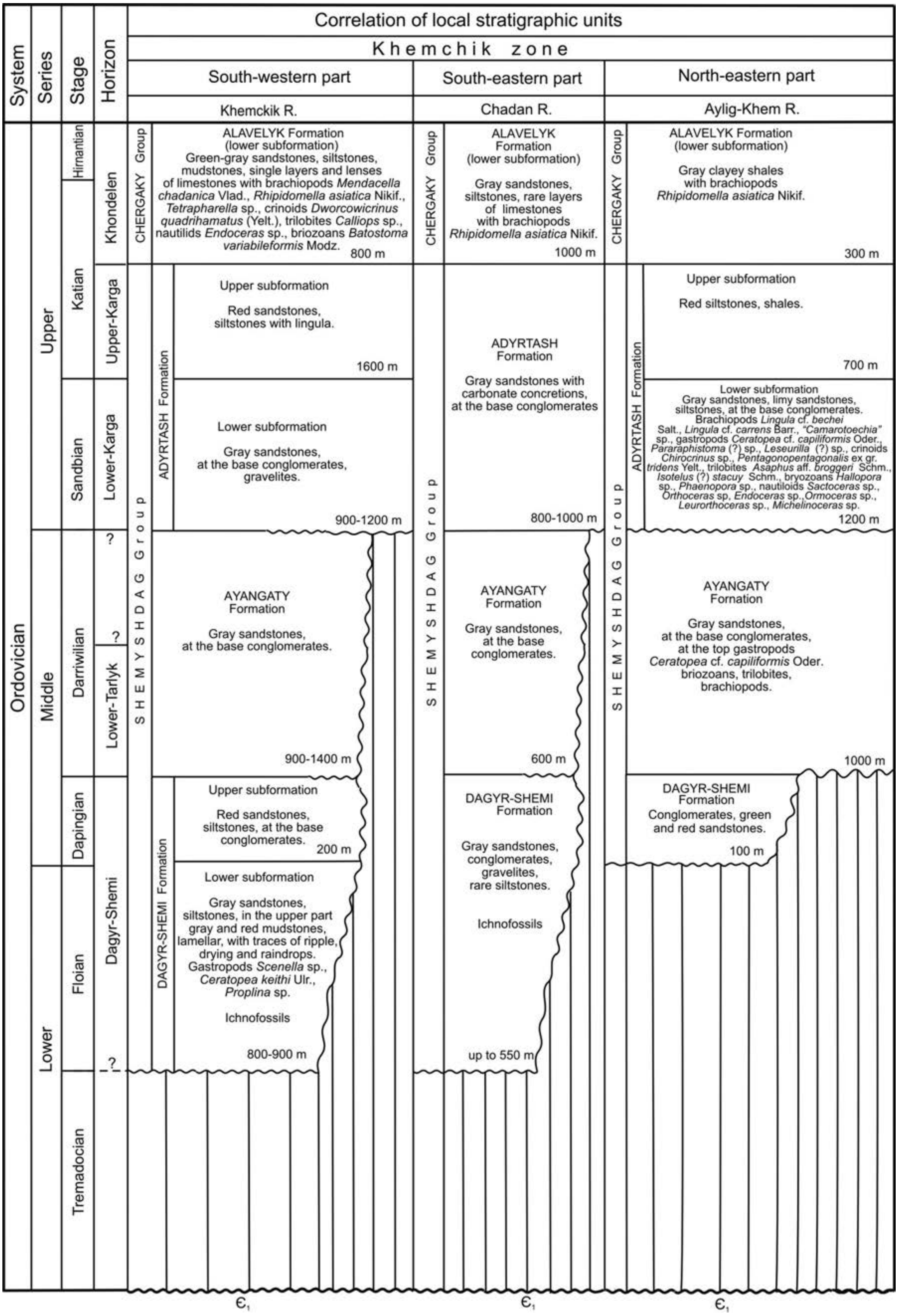
The Ayangaty Formation is represented by gray sandstone with basal conglomerate. In the upper part of the formation trilobites, brachiopods, bryozoans, gastropods and ichnofossils were found. The Ayangaty Formation conditionally is aligned with Darriwilian Stage, Middle Ordovician.

The Lower Adyrtash Subformation is composed of gray sandstone with basal conglomerate. Trilobites, nautiloids, crinoids, gastropods and lingulids were found there. The Upper Adyrtash Subformation consists of red sandstone, siltstone yielded lingulids. Based on fossils the lower subformation is conditionally aligned with Sandbian Stage, and the upper subformation provisionally aligned with the lower half of the Katian Stage, Upper Ordovician.

The Lower Alavelyk Subformation is represented by gray and green sandstone, siltstone, mudstone, with rare limestone lenses. Among found fossils are brachiopods, nautiloids, crinoids and bryozoans. Beyond the Khemchik facies zone, in the Alash facies zone conodonts were obtained. The Lower Alavelyk Subformation is aligned with second half of Katian and with Hirnantian Stage, Upper Ordovician.

Proposed paleogeographic reconstructions suggested presence of the apparently isolated Tuvinian marine basin during Early Ordovician with expansion of the basin area later during Middle and Late Ordovician (Vladimirskaya, 1967). On the whole, mentioned paleobasin (or group of paleobasins) was supposed to be semi-closed with sometimes discontinued communication with an opened sea. Such suggestion was made due to sporadic fossil occurrences, low taxonomic diversity of genus and species of the restricted fauna found there.

Recent field studies turned out the following direct sings-indications of the littoral environments in Ordovician of Tuva: a) sandy channels (water galls), lenticular (upwardly convex) shapes of bar sand bodies, c) double clay layers, d) sigmoidal clay layers, e) symmetric ripple marks, f) desiccation cracks. Also we have found signs of delta (semi-aquatic) sedimentary environments: a) presence of dislocations; b) sharp changes in the members and formations thickness (Dagyr-Shemi Fm. from 100 to 900 m, Ayangaty Fm. from 600 to 1400 m, Adyrash Fm. from 800 to



ALAVELYK Formation
(lower subformation)
Green-gray sandstones, siltstones, mudstones, single layers and lenses of limestones with brachiopods *Mendacella chadanica* Vlad., *Rhipidomella asiatica* Nikif., *Tetrapharella* sp., crinoids *Dworcowicrinus quadrihamatus* (Yelt.), trilobites *Calliops* sp., nautilids *Endoceras* sp., briozoans *Batostoma variabileformis* Modz.
800 m

Upper subformation
Red sandstones, siltstones with lingula.
1600 m

Lower subformation
Gray sandstones, at the base conglomerates, gravelites.
900-1200 m

AYANGATY
Formation
Gray sandstones, at the base conglomerates.
900-1400 m

Upper subformation
Red sandstones, siltstones, at the base conglomerates.
200 m

Lower subformation
Gray sandstones, siltstones, in the upper part gray and red mudstones, lamellar, with traces of ripple, drying and raindrops. Gastropods *Scenella* sp., *Ceratopea keithi* Ulr., *Proplina* sp.
Ichnofossils
800-900 m

ALAVELYK
Formation
(lower subformation)
Gray sandstones, siltstones, rare layers of limestones with brachiopods *Rhipidomella asiatica* Nikif.
1000 m

ADYRTASH
Formation
Gray sandstones with carbonate concretions, at the base conglomerates
800-1000 m

AYANGATY
Formation
Gray sandstones, at the base conglomerates.
600 m

DAGYR-SHEMI
Formation
Gray sandstones, conglomerates, gravelites, rare siltstones.
Ichnofossils
up to 550 m

ALAVELYK Formation
(lower subformation)
Gray clayey shales with brachiopods *Rhipidomella asiatica* Nikif.
300 m

Upper subformation
Red siltstones, shales.
700 m

Lower subformation
Gray sandstones, limy sandstones, siltstones, at the base conglomerates. Brachiopods *Lingula* cf. *bechei* Salt., *Lingula* cf. *carrens* Barr., "*Camarotoechia*" sp., gastropods *Ceratopea* cf. *capiliformis* Oder., *Pararaphistoma* (?) sp., *Leseurilla* (?) sp., crinoids *Chirocrinus* sp., *Pentagonopentagonalis* ex gr. *tridens* Yelt., trilobites *Asaphus* aff. *broggeri* Schm., *Isotelus* (?) *stacuy* Schm., bryozoans *Hallopora* sp., *Phaenopora* sp., nautiloids *Sactoceras* sp., *Orthoceras* sp, *Endoceras* sp.,*Ormoceras* sp., *Leurorthoceras* sp., *Michelinoceras* sp.
1200 m

AYANGATY
Fornation
Gray sandstones, at the base conglomerates, at the top gastropods *Ceratopea* cf. *capiliformis* Oder. briozoans, trilobites, brachiopods.
1000 m

DAGYR-SHEMI
Formation
Conglomerates, green and red sandstones.
100 m

Fig. 2. Correlation of Ordovician local stratigraphic units in the Central Tuva region.

2800 m); c) red color of the sedimentary strata; d) seasonal rhythms of sandy and clayey layers; e) intraclasts – traces of erosion and destruction of layers with the formation of flat aleuritic pebbles, as an indicator of the environments for accumulation of the basal layers of alluvia, formed when river flows change their position (including marker for the base of modern rivers delta deposits); f) traces of ice crystals on sandy surfaces; g) traces of raindrop imprints on sandy surfaces; h) presence of different-size terrigenous clasts up to coarse, often poorly rounded; i) deep desiccation cracks, with the formation of overturned crusts formed while drying; j) traces of water galls, filled with coarse clastic terrigenous material.

Concluding all obtained data we propose that during Ordovician in the Central Tuva occurred coastal plain facies characterized by: 1) significant distribution of the plane denudation of continental sediments; 2) widespread delta sediments; 3) large-scale (in area) tides; 4) waves and wave currents; 5) eolian transportation. Thus, two ecosystems – marine and continental existed during Ordovician throughout the Tuva territory. They changed each other both chronologically (always with increasing role of the marine ecosystem), and in the lateral series.

This is a contribution to IGCP653 project.

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THE GREAT ORDOVICIAN BIODIVERSICATION EVENT (GOBE) OF LAND PLANTS

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Key words: *palynology, cryptospores, miospores, biomarkers*
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Molecular clock data suggest a Cambrian or even Precambrian origin for various clades of land plants, indicating that the terrestrialization of plants probably began more than one billion years ago. The fossil record of the 'Cambrian explosion' was limited to marine organisms and not visible in the plant fossil record. The most significant changes in early land plant evolution occurred during the Ordovician: the microfossil record identifies the earliest bryophyte-like cryptospores in the Middle Ordovician and the first macrofossil record the oldest fragments of the earliest land plants in the Late Ordovician. Organic geochemistry studies on biomarker compositions confirm a transition from green algae to land plants during the early Palaeozoic, in particular the Ordovician, when modern marine ecosystems developed during the 'Great Ordovician Biodiversification Event' (GOBE). The colonization of the terrestrial realms by land plants clearly had an impact on marine ecosystems. Interactions between the terrestrial and marine biospheres have been proposed and the radiation of land plants potentially impacted on CO_2 and O_2 concentrations and on global climate. In addition, the shift of strontium isotopes during the Ordovician is probably linked to changing terrestrial landscapes, affected by the first massive invasion of eukaryotic terrestrial life on the continents. The land plants seem unaffected by the first global mass extinction at the end of the Ordovician that eliminated many marine invertebrate taxa.

BRACHIOPODS FROM UPPER ORDOVICIAN SECTION NORTHEAST OF THE GORNY ALTAI (TELETSKOE LAKESIDE AREA)

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Key words: *brachiopods, Upper Ordovician, Gorny Altai.*

The Teletskoe Lakeside structural-facies zone is located in the west of the northern part of Teletskoye Lake, in the northeast of the Gorny Altai. It was distinguished by Sennikov et al. (2018a). Sedimentary rocks found there belong to Tozodov, Samysh and Iogach bodies, aligned with Darriwilian-Hirnantian Stages of Middle-Upper Ordovician.

The Tozodov Section crops out on the right side of the Tozodov Creek, right tributary of the Iogach River, 1 km from the mouth of the creek in two road quarries (Fig.). It consists of two parts: gray color Tozodov and variegated Iogach formations. The detailed lithological characteristic of this section was reported by Sennikov et al. (2018b). Fauna was revealed only from the Tozodov Body and include brachiopods, nautiloids, trilobites, ostracods, gastropods, bryozoans and ichnofossils.

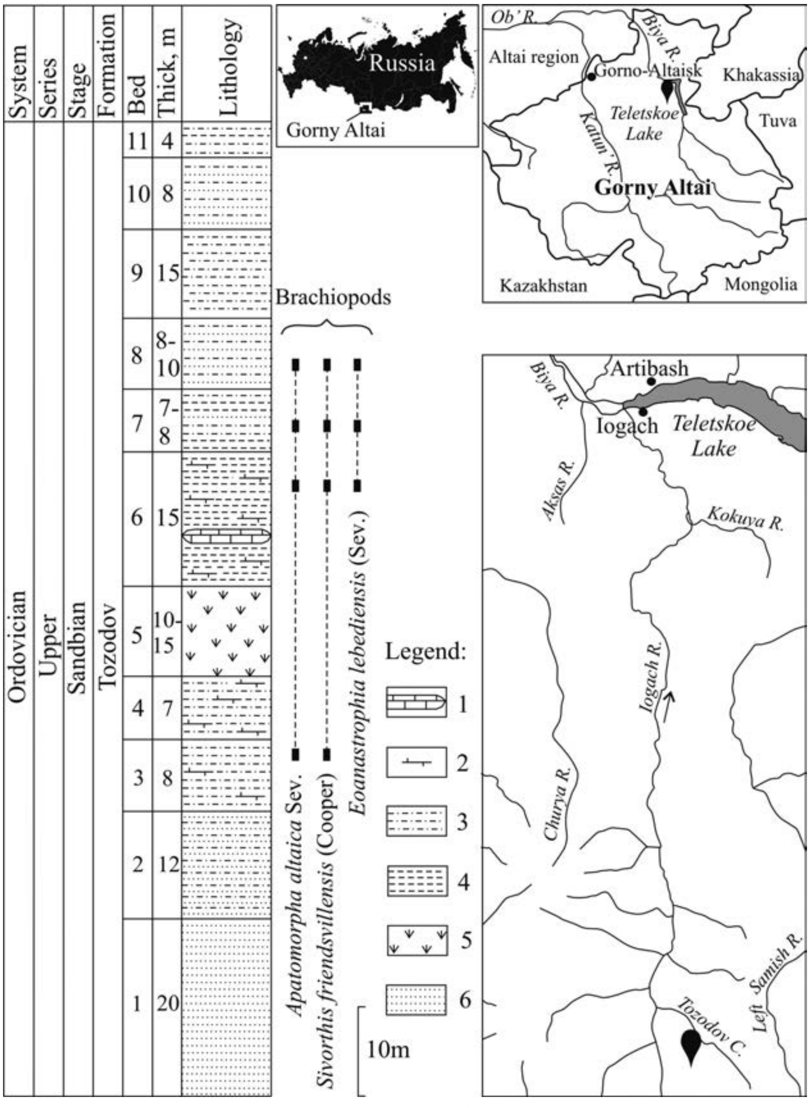
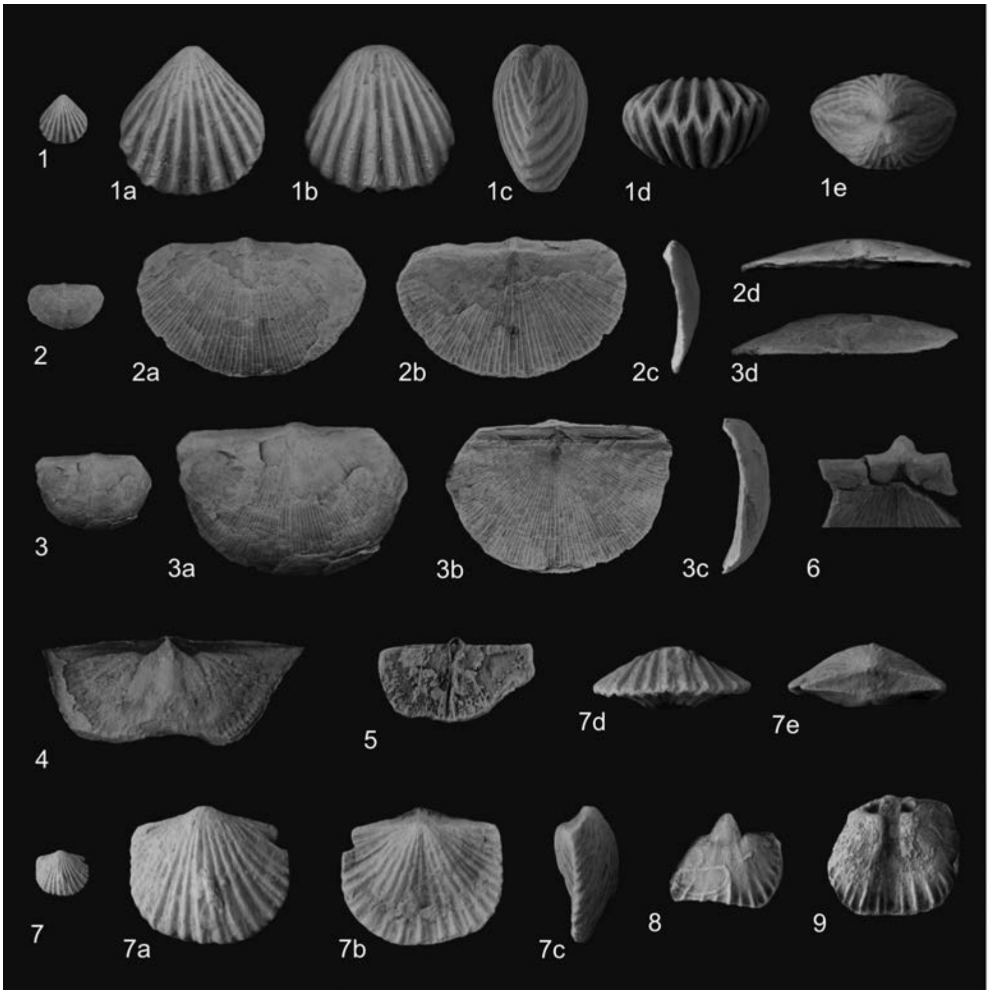


Fig. Location of the Tozodov Section. Ranges of brachiopods in the Tozodov Body (modified from Sennikov et al., 2018b).
1 – limestone lenses; 2 – calcareous rocks; 3 – siltstone; 4 – mudstone; 5 – covered interval; 6 – sandstone.

Plate

Upper Ordovician brachiopods from the Tozodov section, Gorny Altai



1. *Eoanastrophia lebediensis* (Severgina). 1 – specimen Tozodov-6/1, bed 6, ventral exterior, natural-sized. 1a – ventral exterior; 1b – dorsal exterior; 1c – lateral view; 1d – anterior view; 1e – posterior view; all ×3. 2-6. *Apatomorpha altaica* Severgina. 2 – specimen C-1440/2, bed 3, ventral exterior, natural-sized. 2a – ventral exterior; 2b – dorsal exterior; 2c – lateral view; 2d – posterior view; all ×3. 3 – specimen C-1440/3, bed 3, ventral exterior, natural-sized. 3a – ventral exterior; 3b – dorsal exterior; 3c – lateral view; 3d – posterior view; all ×2. 4 – specimen C-1441/4, bed 7, internal mold of ventral valve, ×3. 5 – specimen C-1442/5, bed 8, internal mold of dorsal valve, ×3. 6 – specimen C-1442/6, bed 8, cardinal process, ×3. 7-9. *Sivorthis friendsvillensis* (Cooper). 7 – specimen C-1440/7, bed 3, ventral exterior, natural-sized. 7a – ventral exterior; 7b – dorsal exterior; 7c – lateral view; 7d – anterior view; 7e – posterior view; all ×3. 8 – specimen C-1442/8, bed 8, internal mold of ventral valve ×3. 9 – specimen C-1442/9, bed 8, internal mold of dorsal valve, ×3.

Brachiopods were identified for the first time from beds 3, 6, 7, 8 of the Tozodov Section (Plate). The brachiopod complex is poor in taxonomic diversity and consists of three species: *Apatomorpha altaica* Severgina, *Sivorthis friendsvillensis* (Cooper) and *Eoanastrophia lebediensis* (Severgina). The first two species dominate, represented by a large number of specimens.

Species *Apatomorpha altaica* and *Sivorthis friendsvillensis* were reported from Altai-Sayan folded area from the upper part of Bugryshikha Horizon (Sandbian), yielded graptolites *Retiograptus geinitzianus* Hall (Kulkov, Severgina, 1989). Species *Retiograptus geinitzianus* Hall was found from Nemagraptus gracilis and Climacograptus bicornis graptolite zones, Sandbian Stage of Upper Ordovician (Williams et al., 2004). Species *Eoanastrophia lebediensis* is a characteristic species of lower third of Khankhara Horizon that is aligned with upper part of Sandbian (Sennikov et al., 2018a).

First discovered co-occurrence of *Apatomorpha altaica* and *Sivorthis friendsvillensis* known from upper part of Bugryshikha Horizon along with *Eoanastrophia lebediensis* known from Khankhara Horizon points the necessity to reconsider (or expand) ranges for brachiopod species *Apatomorpha altaica* and *Eoanastrophia lebediensis*. This question requires additional studies.

Thus, Sandbian age, Upper Ordovician, is suggested for Tozodov Body based on brachiopods.

This is a contribution to IGCP653 project.

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ORDOVICIAN DEPOSITS OF KOTELNY ISLAND (NEW SIBERIAN ISLANDS)

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Key words: *Kotelny Island, Ordovician, stratigraphy.*

The Ordovician deposits are widespread on Kotelny Island, especially in the north-east.The Ordovician based on faunal determination was recognized there as early as in 1955 by geologists D.A. Vol’nov, D.S. Sorokov and O.V. Cherkesov from the Institute of Arctic Geology in the course of the geological survey at a scale of 1:1 000 000. As a result, the oldest deposits of Kotelny Island were grouped into the Diringayan Formation, whose lower part was assigned to the Middle and Upper Ordovician (Zhizhina, 1959, Nekhorosheva, 1957, Stratigrafia i fauna…, 2018).

The most complete data on the Phanerozoic stratigraphy including the Ordovician of Kotelny Island were obtained in 1972–1975 in the course of geological survey at a scale of 1:200 000 caried by geologists from “Sevmorgeo” guided by M.K. Kos’ko. The collected material made it possible to confirm the recognition in the Ordovician of Kotelny Island of two structural-facies zones (SFZ): the north-eastern dominated by shallow-marine carbonate deposits and south-western containing mainly by more deep-water carbonate-terrigenous deposits (Kos’ko et al., 1975). Later these zones have got geographical names, i.e. north-eastern SFZ – Reshetnikova-Kozhevina and south-western SFZ– Hos-Teryuteekh-Nikola (Stratigrafia i fauna…, 2018). The Ordovician of these zones is represented by four formations (in ascending order): Ayan (Tremadocian – Lower Darrivilian), Malodiring-Ayan (Darrivilian – Lower Katian), Anisiy and Teryutekh (Upper Katian – Hirnantian). The Ayan Formation was reported only from the north-eastern SFZ, Malodiring-Ayan Formation was found in both SFZ, Anisy and Teryutekh Formations in the north-eastern and south-western SFZ respectively (Fig. 2).

I. Reshetnikova-Kozhevina SFZ

Within this zone the Ordovician deposits have most complete outcrops in the Reshetnikova River basin, on the southern bank of Eseleekh lagoon at a creek between this lagoon and Anisiy lagoon, along the banks of Dyakhsaiar lagoon and in the Diring-Ayan, Kozhevina, Kazarka, and Taba-Yurekh basins.

The Ayan Formation is the oldest Paleozoic unit on Kotelny Island stretching along Eseleekh southern bank as well as on Malyi Diring-Ayan and Grebyenochnaya River (Fig. 1). The formation consist of clay and silty dolomites interlayed with limestones locally with abundant brachiopods *Angarella* aff.*lopatini* Asatkin (At present the assignement of *Angarella* to brachiopods has not been confirmed). There also occur trilobites *Pliomerops* aff. *canadensis* (Bill.), *Omulovia* sp., Batiyuridae and conodonts *Semicontiodus* sp., *Drepanodus* sp. Based on faunal definition, its age is determined as the Early-Middle Ordovician (Tremadocian-Lower Darriwilian). The total thickness of the formation is 430-600 m. The formation is correlated with the Grustnaya and Toll horizons of Taimyr and Nyaia, Ugor and Kimaj horizons of the Siberian platform, and with Inanya, Hitin and Engelchak horizons in the North East Russia.

The Malodiring-Ayan Formation is located in the same parts as Ayan Fm., it was found in the Reshetnikova River basin and on that of Tuor-Yurekh (Balyktaakh River basin). Its stratotype section crops out at the Malyi Diring-Ayan River 10-15 km of its mouth (Fig. 1). It overlais conformly on the Ayan Formation and its lower boundary is carried at a limestone unit having first occurences of fairly abundant ostracods. The formation is composed of limestones varying from pelitomorphic silty to biogenic-detrital and coquina. Flints occur sporadcaly. The formation stratotype section totaling 500-550 m contains diverse fauna, namly bryozoans, brachiopods, ostracods,. tabulate corals and oth. The folowing bryozoans were determind: *Nicholsonella polaris* Modz., *Rhinidictya mutabilis* Ulrich, *Rh.minima* Ulrich, *Batostoma varians* (James). Brachiopods are represented mainly by *Atelelasma carinata* (Andr.). Ostracods *Aparchitella magna* Meln., *Bolbinella cumulate* V.Ivan., *Bodenia aspera* V.Ivan., *Martinssonopsis multifaria* V.Ivan., *Egorovella (Egorovella) defecta* V.Ivan., *E.(E.) dorsilobata* Kan., *Eochilina (Eochilina) convexa* (Kan.) and *Sobolitella rimmae* Gonta et Kan. are the most abundant. Tabulate corals *Billingsaria* sp., *Tetraporella monticuliporoides* (Troeds.) and algae *Goldsonia* sp. are scarce. Abundant and diverse fauna was found apart from the fauna assemblage mentioned at the upper Kazarka River and in the Reshetnikova River (Stratigrafia i fauna…, 2018). Based mainly on monographic study of bryozoans, ostracods and conodonts allowed us to determine the age of the Malodiring-Ayan Formation as Middle-Late Ordovician from the Upper Llanvirn (zone H. teretiusculus) to the Upper Caradocian (zone D. clingani) correlating so with the Upper Darrivilian, Sandbian and Lower Katian stage. The total thickness of the abave formation 450-600 m. It is correlated with the Engelgardt and Tolmachev horizons of Taimyr, as well as with the Volgin-Baksan horizons of the Siberian platform, Lachuga and Harkindzha horizons of North East Russia.

Anisiy Formation. The formation stratotype lies 6-6,5 km south-west from the north-eastern end of Eseleekh

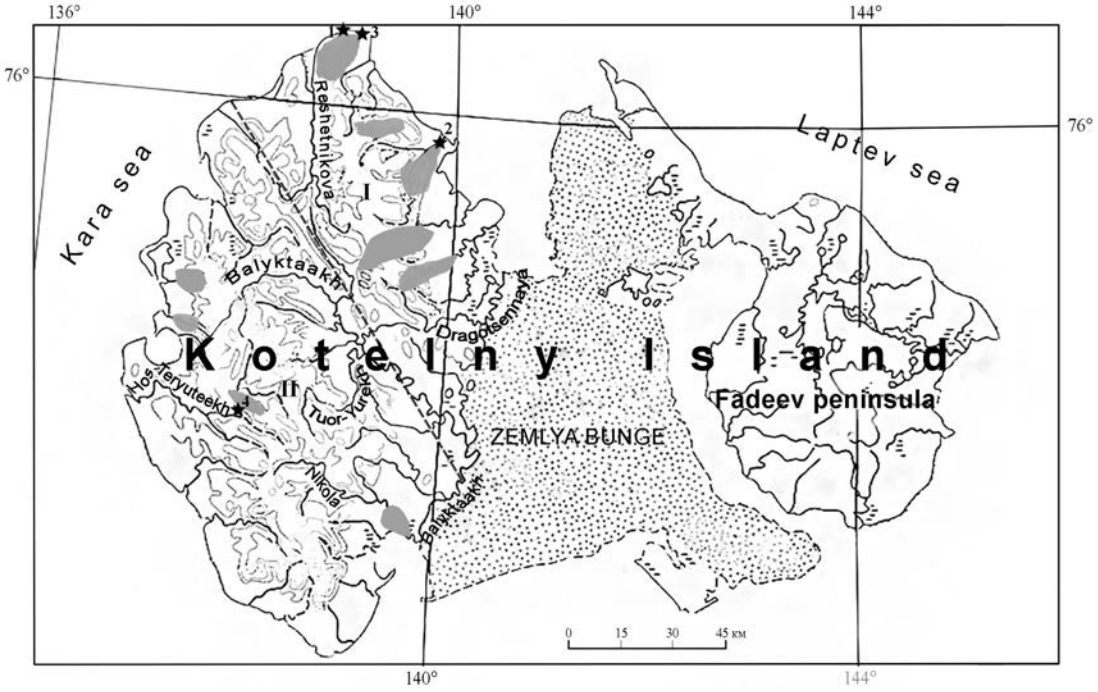

Fig. 1. Main location of the ordovician deposits on Kotelny Island (▬).
Structural-facies zones (SFZ): I — Reshetnikova — Kozhevina (north-eastern); II — Hos-Teryuteekh —Nikola.
– – – – Boundary of SFZ.
✯ – Stratotype formation: 1 — Ayan; 2 — Malodiring-Ayan; 3 — Anisiy; 4 — Teryutekh.

GSS, 2011, 2012*) (Resolution ISC, issus 41, 42)**)			Kotelny Island		Taimyr	Siberian platform	North East Russia
System	Series	Stage	Hos-Teryuteen-Nikola	Reshetnikova-Kozhevina	Horizons		
			Formations				
Ordovician	upper	Hirnantian	Teryuteekh	Anisiy	Barkov	?	Tirekhtyakh
		Katian				Bursky	
						Nirunda	
						Dolbor	Padun
			Malodiring-Ayan		Tolmachov	Baksan	Harkindzha
		Sandbian				Tchertov	
	middle	Darrivilian			Engelgardt	Kiren-Kudrin	Lachuga
						Volgin	
			?	Ayan	Toll	Muktej	Elgenchak
						Vikhorev	
		Dapingnian				Kimaj	Hitin
	lower	Floian				Ugor	
		Tremadocian			Grustnaya (upper part)	Nyaia	Inanya

Fig. 2. Correlation of the Ordovician of Kotelny Island with Ordovician deposits of Taimyr, Siberian platform and North East Russia.
*) General Stratigraphic Scale (GSS)
**) Resolution of Interdepartmental Stratigraphic Committee (ISC) of Russia

lagoon (Fig. 1). Besides, it is located at the same sites as the Malodiring-Ayan Formation. The abave formation rests conformably on the Malodiring-Ayan Formation and its lower boundary is carried out at the base of limestone unit containing abundant tabulate corals.The formation is composed of dark limestones, usually pelitomorphic and fine-grained yilding abundant tabulate corals whose cores are often rock-forming, there occur biogenic-detrital limestones along with lenses and bands of black flints. Tabulate corals often occur together with rugose, bryozoans, brachiopods, ostracods; pelecypods are less common. The paleontological evidence became more renovated within the Anisiy Formation. For example tabulate corals *Plasmoporella* aff.*convexitabulata* Kiaer, *Mesofavosites scherbakovi* Smirn., *Calamopora inaensis* (Prbz.), *Cyrtophillum ensis* Dzubo and other were reported for the first time. The ostracod community which survived from the Malodiring-Ayan Formation was supplemented by the addition of such species as *Soanella ampla* Kan., *Pseudokiesowia massivolobus* Gonta et Kan., *Eoprimitia helenae* V. Ivan., *Parenthatia conituberculata* Gonta et Kan. Bryozoans community was reneved due to the appearance of species *Cyphotrypa kotelnika* (L.Nekh.). Trilobites consist of genera occurring both in Middle and Late Ordovician: *Isotelus, Ceraurinus, Ceratevenkaspis, Evenkaspis (E.* cf. *nikiforovae* Z.Max.). Conodonts are represented by three genera occurring both in Middle and Late Ordovician: *Dapsilodus, Drepanoistodus, Panderodus.*

The formation thickness in stratotype is 370-480 m, totaling – 520 m. Based on the above mentioned fauna, the age of the Anisiy Formation may be with confidence dated as Late Ordovician and correlated with lager (upper) part of the Katian and Hirnantian as well as with the Barkov horizon of Taimyr, Dolbor, Nirunda and Bursky horizons of the Siberian platform and with the Padun and Tirekhtyakh horizons in North East Russia.

II. Hos-Teryutekh-Nikola SFZ

The Ordovician deposits of this zone occur in the Kieng-Urasa, Chokurka, Hos-Teryuteekh, Dragotsennaya, Nikola, Yueteekh-Yurekh (Balyktaakh), river basins. There occur also the Malodiring-Ayan and Teryutekh Formations, the former being incomplete.

The Malodiring-Ayan Formation crops out most completely at the Yueteekh-Yurekh River to its inflow into the Yueteekh-Salaa. The formation at these rivers is composed of grey pelitomorphical and clay limestones interlayed with green mudstones, biogenic-detrital limestones interlayered with gravel and pebble of pelitomerphic limestones. Biogenic-detrital limestone contain bryozoans *Phaenoporella transenna-mesofenestralia* (Schoenmann), *Ph. multipora* Nekh., *Stigmatella* sp., along with brachiopods *Mimella panna* Andr., *Triplesia* cf. *baxanica* Nikif., *Oepekina* cf. *tojoni* Andr., trilobites *Monoracos nordicus* Balash.

M.K. Danukalova and A.V. Kuzmichov have collected from the formation on the Tuor-Yurekh River conodonts *Pseudobelodona* sp., *Panderodus* sp., *Erraticodon gratus* Mosk., *Belodina* cf. *B. compressa* (Branson et Mehl) at al. (Danukalova at al., 2015).

The total thickness of the exposed section is 210-270 m. The fauna determined from the Malogiring-Ayan Formation of the Hos-Teryutekh-Nikola SFZ like in the Reshetnikova-Kozhevina SFZ allowed us to date their age as Middle-Late Ordovician (Fig. 2).

Teryutekh Formation. Its sratotype is located on meridional site of the Hos-Teryuteekh River 10 km from the turn when it changes the direction to latitudinal. The lower part of the formation is not exposed therefore. It was determened on the parastratotype at the Chokurka River 14-17 km from the mouth (The Ordovician…, 2018).

The formation also crops out along the Kieng-Urasa River down streem of the Chkurka and on Nikola River. It rests conformably on the Malodiring-Ayan Formation and its lower boundary is drawn at the base of a limestone unit containing in abundant interlayers of black flints and the Ashgillian fossils. The formation is composed of dark pelitomorphic fine-grained limestones interlayered with biogenic-detrital and clay diversities. A peculiar feature is the occurrence of interlayered lenses and black flints.

Biogenic and biogenic-detrital limestones of the parastratotype contain abundant fauna. Tabulate corals *Catenipora minima* Tchern., *C.* aff. tapsaensis (Sok), *Tollina evenkiana* Sok., *T. warsanofieva* Barsk., *T.* aff. *tollinoides* Zhizhina, *Nictopora nicholsoni* (Radugin) *Clamopora schmidti* (Sok), *Karagenia* sp., *Cyrtophillum* sp. are the most abundant. Bryozoans are less diverse than those from the Malodiring-Ayan Formation. They contain *Phaenopora multifora* Nekh., *Ph. erecta* Nekh., *Phaenoporella multipora* Nekh., *Rhinidictya* sp., *Homotrypa* aff. *astricta* (Astr.) and *Diplotrypa* sp. Brachiopods are less common but diverse: *Plectambonites* sp., *Tcherskidium unicum* (A.Nik.), *Hesperorthis tricenaria* (Conrad), *Oxoplecia* sp., *Sowerbyella* aff. *septocostellata* Rozm., *Oepekina gibbosa* Andr., *Hesperorthis piramidalis* (Twenhofel). Noteworty, that was *Tcherskkidium unicum* first recorded in the Ashgillian of North East Russia, where it was found together with tabulate corals. A similar community of brachiopods and tabulate corals was reported from Kotelny Island as well. It occurs at the same stratigraphic level. Conodonts found in the formation stratotype include: *Belodina compressa* (Branson et Mehl), *Panderodus* cf. *repens* (Mosk.), *P. dispansa* (Glonister), *Pseudooneoyodus mitratus* (Mosk.), *Walliserodus amplissimus* (Serpagli), *Yaoxianognathus (?) tunguskaensis* (Mosk.), *Oulodus* sp. Noteworthy, that ostracods have not been reported both from the Anisiy and Teryutekh Formations, they “gave way” to tabulate corals and brachiopods.

The formation thickness in the stratotype is 230-380 m, the greatest being 385 m.

The Teryutekh Formation is dated with confidence as Ordovician and correlated with larger upper part of the Katian and Hirnantian stages. It, as in case with the Anisiy Formation is correlated with the Barkov horizon of Taimyr, Dolbor, Nirunda and Bursky horizons of the Siberian platform and with the Padun and Tirekhtyakh horizons of North East Russia.

In conclusion it should be noted that Kotelny Island since Early Ordovician was assigned to submergence area. Transgression has first covered its north-east, extending later to the entire island. Carbonate deposits dominated, carbonate-terrigenous were less common. At the Ordovician-Silurian boundary sedimentation was suspended due to the Gondwana Glaciation followed by cooling and shallowin of shelf seas on the Earth. This fact gave rise to the impoverishment of faunal assamlages. As to Kotelny Island, this reflected in the absence of ostracods and in the impoverishment of their brachiopods and bryozoan comunities as clearly evidenced in the Anisiy and Teryutekh Formations. A subsequent global Llandoverian transgression favoured the faunal exchange between marine basins. However, Siberian faunal habitat has preserved in the Silurian of Kotelny Island.

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LATE ORDOVICIAN ENDEMISM IN A PALEOGEOGRAPHICALLY SIGNIFICANT BRACHIOPOD FAUNA FROM TARIM (NORTHWEST CHINA)

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Key words: *Brachiopoda, Hadabulaktag, Katian, paleobiogeography*

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Introduction

During the Late Ordovician the Tarim paleoplate was located approximately near the equatorial latitudes but the precise position of Tarim in the Ordovician has been difficult to determine due to poor paleomagnetic data coverage. The position of Tarim and other Central Asian terranes relative to North and South China has been estimated using existing paleontological data (Popov and Cocks, 2017), but in the case of Tarim, only limited trilobite occurrence data were available.

To supplement this paleobiogeographical dataset, brachiopods were collected the upper Katian (Upper Ordovician) Hadabulaktag Formation in the northeastern part of the Taklamakan Desert near Turpan in the semi-autonomous region of Xinjiang in Northwest China (Fig. 1). The shells are abundant but poorly preserved and are dominated by only a few forms. The two most abundant species have already been described (*Schachriomonia pentagonia* — see Sproat and Zhan, in press; *Altaethyrella tarimensis* — see Sproat and Zhan, 2018), and work is ongoing to finish descriptions of the remaining species.

Many of the brachiopod lineages that comprise the Tarim have homeomorphic counterparts on other paleo-equatorial plates, but detailed analysis that included an examination of internal shell characters has revealed that these homeomorphs belong to different families within the same order. This underscores the importance of specimen-based approaches in contemporary paleontology.

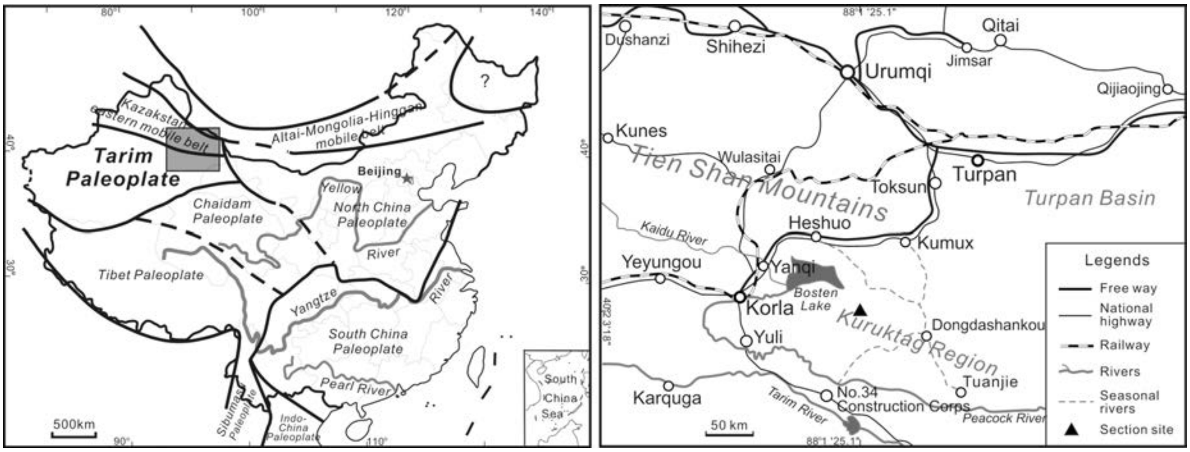

Fig. 1. Brachiopods were collected from a remote locality in Northwest China near Turpan in the Xinjiang region that was located near the margin of the Tarim paleoplate during the Late Ordovician.

Geological setting

The late Katian Hadabulaktag Formation is the uppermost unit of the Kuruktag Platform that forms the northeastern margin of the Tarim paleoplate. Brachiopods were collected from thin- to medium-bedded intercalated argillaceous, bioclastic, and micritic limestones and interbedded calcareous mudstones in the upper part of the formation. Fossils readily weather out of these less consolidated layers and can easily be collected from the surface of the outcrop. However, due to the persistent, abrasive desert winds preservation is poor and shells are often incomplete. Brachiopods are the most common element of the fossil assemblage but other corals, bryozoans, bivalves, and gastropods are also abundant.

Paleobiogeographic significance

In the lineages that have been studied in detail thus far, the Late Ordovician brachiopods from Tarim (Fig. 2) demonstrate a close affinity to coeval faunas from the Kazakh terranes and less so to those of North and South China. The rhynchonellide *Altaethyrella* is known from collections across these plates and terranes, but *Altaethyrella tarimensis* is very similar to *Altaethyrella otarica* from the Altai Mountains of Kazakhstan (e.g. Popov et al., 2000), differing only in being generally more convex and wider with slightly fewer ribs. The most common element of this fauna, the atrypide *Schachriomonia pentagonia,* most closely resembles *Schachriomonia parva* from the Chingiz range of Kazakhstan, being only slightly more convex and having somewhat fewer ribs (Popov et al., 1999). This genus has also been reported from China as the synonymous *Ovalospira* (e.g. Zhan and Cocks, 1998). The orthide *Weberorthis,* also found in Tarim, is similar in external appearance to *Hebertella* and *Mimella* but has thus far only been reported from Kazakhstan. Other elements of the fauna, such as the plectambonitoid *Sowerbyella* were relatively cosmopolitan in the Late Ordovician and are of limited paleobiogeographic significance.

The proposed position of Tarim in the paleoequatorial region near the Chu-Ili terrane (Popov and Cocks, 2017) where the most similar *Altaethyrella* species to that of Tarim has been described is reasonable. Detailed paleogeographic comparisons with the brachiopod faunas of other terranes as well as North and South China will be undertaken once the remainder of the fauna has been completely systematically described, and may reveal more detailed relationships between the brachiopod fauna of Tarim and those of surrounding landmasses during the Late Ordovician.

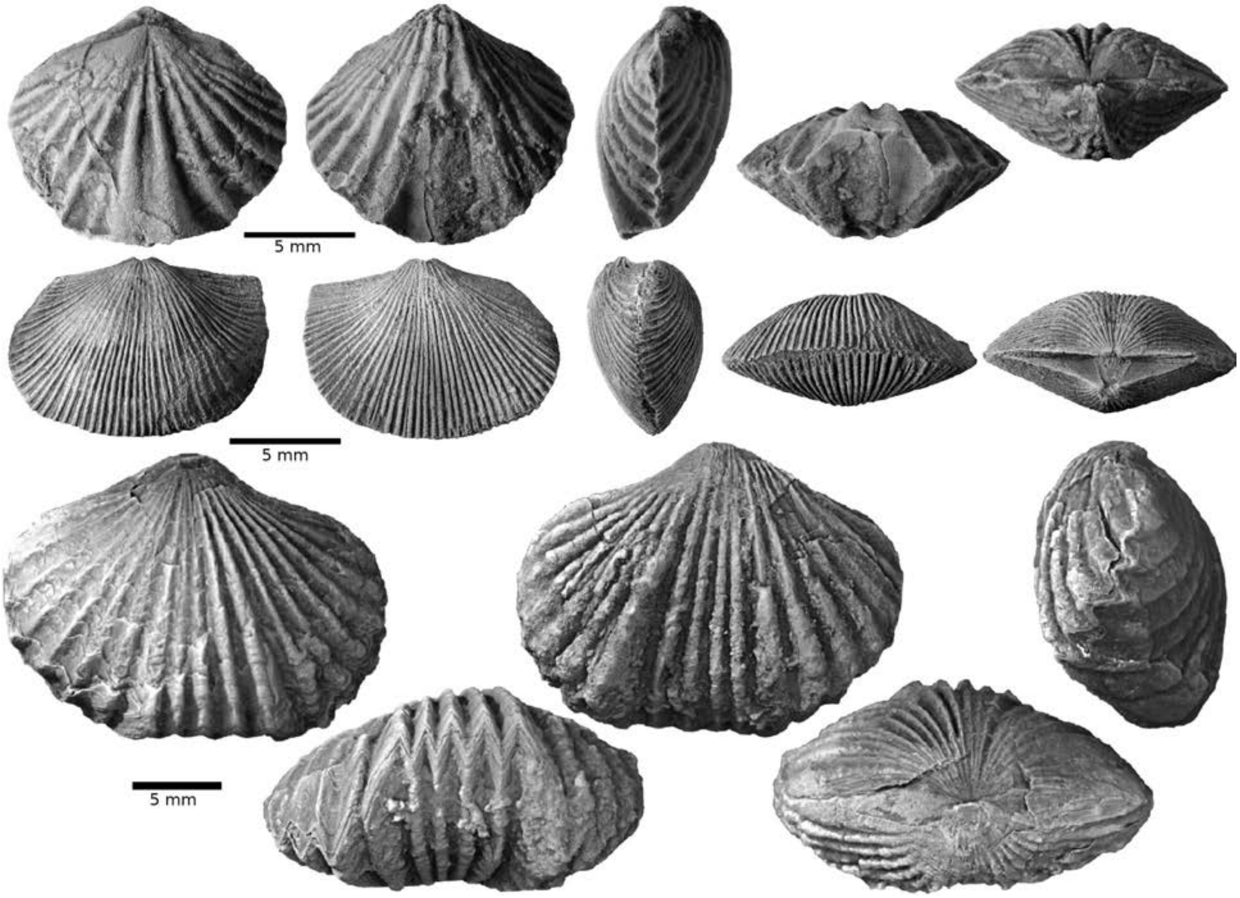

Fig. 2. Three of the most common species of brachiopods collected from the upper Katian (Upper Ordovician) Hadabulaktag Formation: the atrypide *Schachriomonia pentagonia* (top), orthide *Weberorthis* sp. (middle), and rhynchonellide *Altaethyrella tarimensis* (bottom).

Hidden endemism in the brachiopod faunas of Central and Eastern Asia

Harper et al. (2013) did not include Tarim in their paleobiogeographic analysis of worldwide Ordovician brachiopods. Tarim was tentatively positioned near the Kazakh terranes and South China alongside Laurentia, Siberia, and northern Gondwana (Australia) in an equatorial low latitude biogeographic province. Although Tarim, the Kazakh terranes, and North and South China hosted a shallow marine fauna that was morphologically and ecologically similar to that of Laurentia and Gondwana, the brachiopods belonged to different evolutionary lineages.

Some of these lineages were externally very similar, and were commonly identified as homeomorphs in earlier literature. Large, coarsely ribbed and biconvex rhynchonellides in central and eastern Asia were described as the predominantly North American genus *Rhynchotrema.* Detailed re-study of the genus has revealed unfused hinge plates in the shell interior characteristic of the ancistrorhynchoide genus *Altaethyrella*.

Large, convex orthides evolved in both regions but the orthoides of North America are poorly known from the Kazakh terranes or China. Only plectorthoides became a significant component of the faunas there.

The atrypides were very different between these regions, however. In Laurentia, only small Protozygidae (*Protozyga*) and Anazygidae (*Anazyga, Zygospira*, and *Catazyga*) evolved (Copper, 1977). *Protozyga* and *Anazyga* have also been described from the Upper Ordovician of Australia (Laurie, 1991; Percival, 1991). In Tarim and the rest of central and eastern Asia, a diverse suite of Spirigirinae (early members of the Atrypinidae) evolved in similar environments. Although superficially similar in form, this group is generally much smaller than the Zygospiridae with a reversed dorsal fold and ventral sulcus at the anterior, and feature a disconnected jugal process at the base of the spiralia rather than the fused jugum typical of the Zygospiridae.

These sometimes cryptic differences in the fauna signal divergent paths of dispersal and evolution in each of these regions. The fact that similar external shell forms evolved in some groups despite these differences, however, perhaps reflects a similar set of paleoecological constraints influencing the brachiopods on plates near the equator during the Late Ordovician.

Acknowledgments

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STABLE CARBON ISOTOPE COMPOSITION OF EARLY PALAEOZOIC MACROALGAL, INVERTEBRATE AND VERTEBRATE FOSSILS: IMPLICATIONS FROM THE KALANA *LAGERSTÄTTE* (SILURIAN, ESTONIA)

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Stable carbon isotope composition of sediments has long been used as a tool in stratigraphic correlations as well as a proxy for palaeoenvironmental changes in carbon cycle. Several studies have demonstrated that various rock components, such as carbonate fossils or organic matter of different taxonomic groups show carbon isotope composition which differ from that of the surrounding sedimentary rock. Here we present results of carbon isotope analyses from organic material preserved in the fossils from the Kalana *Lagerstätte*, Estonia. The Kalana *Lagerstätte* contains fossils of Aeronian (Llandovery, Silurian) age and is mainly known for its diverse, exceptionally preserved macroalgal fossils (Tinn et al. 2009). However, the Kalana biota also includes completely or partially organically preserved invertebrate fossils such as crinoids (Ausich et al., 2019), sponges and worms, but also hemichordate and vertebrate fossils (Tinn & Märss, 2018), etc.

In the present study we sampled thalli of red and green (dasycladalean) algae, crinoids, periderms of graptoloid and dendroid graptolites, and an agnathan fish from the Kalana Lagerstätte. The $\delta^{13}C_{org}$ analyses of individual fossils were supplemented with the whole-rock $\delta^{13}C_{carb}$ and dispersed organic material $\delta^{13}C_{org}$ analyses from the same rock slabs. In ecological terms, the sampled taxa represent marine autotrophs (benthic producers: algae) and heterotrophs (benthic (crinoids and dendroid graptolites), planktonic (graptoloid graptolites) and nektonic (agnathan) consumers.

The overall $\delta^{13}C_{org}$ values for taxon specific samples range from –28.04 ‰ for graptoloid graptolite *Coronograptus* to -30.50 ‰ for rhodophyte *Leveilleites*. The $\delta^{13}C_{org}$ values of dispersed organic material from surrounding rock samples varies from –23.64 ‰ from the sample with crinoid specimens to –26.55 ‰ for a slab which contained dendroid graptolites. The $\delta^{13}C_{org}$ values of rock analyses were consistently more positive than the values of fossil specimens themselves, but mostly fall in the range of $\delta^{13}C_{org}$ values published for the Aeronian marine sediments (Tomescu et al., 2009). Generally the $\delta^{13}C_{org}$ values from the slabs with algal fossils (from –26.12 ‰ to –25.25 ‰ was lower compared to slabs with crinoids (–23.64 ‰) and graptolites (–24.14 ‰ to –26.55 ‰).

The acquired data was compared with the published values from previous studies. LoDuca and Pratt (2002) analysed comparable algal and graptolite fossils from different *Lagerstättes*. Although the carbon isotope values obtained in our study mostly fall within the same range, the values for algae from the Kalana *Lagerstätte* show less variation and are more positive than the published values from the Eramosa, Goat Island and Cape Phillips samples. The graptolite isotope values in Kalana, however, are more negative than that of the similar samples from Rochester and Goat Island.

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BIOSTRATIGRAPHY AND BIODIVERSITY OF THE ORDOVICIAN CONODONTS FROM THE DEEP-WATER SILICEOUS DEPOSITS OF WESTERN PART OF CENTRAL-ASIAN FOLD BELT

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Key words: *biostratigraphy, biodiversity, Ordovician, conodonts, deep-water deposits, cherts, Central-Asian Orogenic Belt, Kazakhstan, Southern Urals.*

Abstract: Study of conodonts from siliceous, siliceous-siliciclastic and siliceous-volcanogenic rocks in the western part of the Central Asian Fold Belt (Kazakhstan, Middle Tien Shan, and Southern Urals) allowed to define a taxonomic composition of conodonts of an open-sea biogeographical province and provide a conodont biostratigraphy for the deep-water siliceous deposits. An overall taxonomic diversity of the deep-water conodonts in the Ordovician is no less than 50 species. It is generally less than diversity of conodonts in shallow-water carbonate facies, with exception for the Floian and lower part of the Darriwilian stages where it is approximately the same. The conodont zonation comprises 12 zones (in ascending order): *Cordylodus lindstroemi, Cordylodus angulatus, Paltodus/Rossodus, Acodus longibasis Prioniodus cf. P. honghuayuanensis, Oepikodus evae, Periodon flabellum/macrodentata, Paroistodus horridus, Periodon aculeatus, Pygodus serra, Pygodus anserinus, Periodon grandis*. Each biozone is limited at the base by the first appearance of the eponymous species, and bounded at the top by a base of an overlying zone.

The Ordovician siliceous rocks are widespread in the western part of the Central Asian Orogenic Belt (Kazakhstan, Middle Tien Shan, and Southern Urals), where they compose a part of tectonized oceanic, island arc and rift complexes. In siliceous rocks – cherts and siliceous siltstones conodonts are common and is the only fauna allowing age determination of a rock.

Studies of conodonts from the Ordovician siliceous rocks of Southern Scotland, Canada and eastern Australia (Armstrong et al., 2001; Glen et al., 2004; Percival, 2012) showed that pelagic conodont faunas are taxonomically poor and composed of taxa of cosmopolitan and wide geographic distribution. Based on this observation, the deep-water conodonts were assigned to a major biogeographic entity – the Open-Sea Realm (Zhen, Percival, 2003), encompassing all the relatively deep-water Ordovician areas with a predominantly pelagic sedimentation.

At present, we have a lot of data on taxonomic composition of conodont assemblages and stratigraphic distribution of taxa from different sections and localities of the Ordovician siliceous rocks in Kazakhstan. The conodonts were studied in Southwestern and Northern Balkhash Lake area, Erementau, Iradyr, Tekturmas, Cis-Chingiz, and Boschekul zones of Northern and Central Kazakhstan, in Sarydzhaz zone of the Middle Tien Shan and in Magnitogorsk zone of the Southern Urals (Tolmacheva et al., 2001, 2004, 2009; Dubinina, Ryazantsev, 2008; Tolmacheva, Degtyarev, 2012; Tolmacheva, 2014, Danelian et al., 2011).

This permits estimation of the conodonts taxonomic composition of the Open-Sea biogeographic Realm and to propose a biozonal subdivision for the deep-water Ordovician sediments.

Conodont Biodiversity

The conodont taxonomic diversity in the siliceous rocks of the western Central-Asian Fold Belt varies considerably within the Ordovician time span. The most diverse are the Floian and Early Darriwilian conodont assemblages of the Burubaital Formation (South-Western Balkhash) and Iradyr Formation of the eponymous zone of northern Kazakhstan. In the Burubaital Formation the taxonomic diversity of the conodont assemblages reaches 15 and 12 taxa (Fig.) that is comparable to the conodont diversity in shallow-water carbonate facies of continental shelves. The Dapingian, as well as the second half of the Darriwilian and Sandbian (Burubaital and Kushekin formations, South-Western Balkhash, Iradyr and Kazyk formations of the Northern Balkhash, Yerzhan Formation of the Boshchekul zone) are characterized by no more than 6-8 species. This is substantially lesser than the diversity of contemporaneous shallow-water sediments. Totally, 53 taxa were found in the siliceous deposits of Kazakhstan, Middle Tien Shan and the Southern Urals, comprising forms represented by single elements, identifiable only in an open nomenclature.

All conodont species from the siliceous deposits are cosmopolitan or have wide geographic distribution. They are known from relatively deep-water carbonates of almost all continental shelfs, including Newfoundland, Taimyr, the Arctic Canada Islands and Novosibirsk Islands (Stouge, 1984; Pyle, Barnes, 2002, etc.). However, some Lower Ordovician species, such as *Kallidontus serratus, Kallidontus corbatoi, Tropodus*? *sweeti, Protoprioniodus gradatus, Bergstroemognathus. extensus, Prioniodus oepiki, Oepikodus intermedius, Acodus longibasis* and representative of

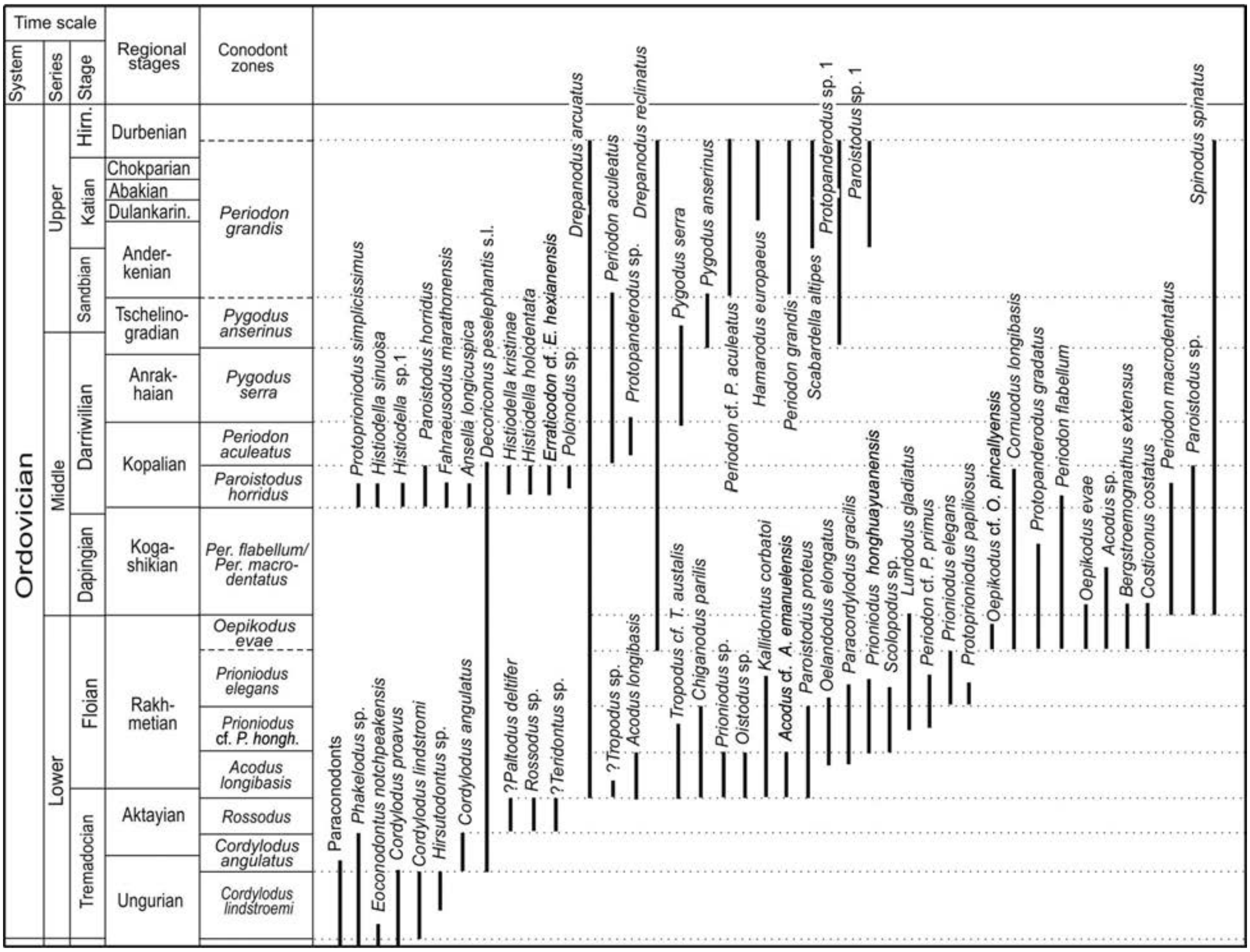

Fig. Distribution of conodonts in siliceous sediments of the Ordovician of Kazakhstan and the proposed conodont biozonation of deep-water facies.

the genus *Hirsutodontus*, have been found, except for Kazakhstan, only in warm-sea basins. They are absent in a relatively cold-water Baltoscandia. This may indicate an existence of at least two climatic zones in the Early Ordovician biogeographic Open-Sea Realm.

Biostratigraphy of Ordovician siliceous rocks

Conodont assemblages from the Ordovician siliceous deposits have a common or very similar taxonomic composition. Therefore, it is possible to compile a conodont biostratigraphic scale for the pelagic deposits of the biogeographic Open-Sea Realm. The proposed scale allows age determination of the siliceous and other deep-water deposits and provides correlation of their sections. The choice of index types of zonal subdivisions was determined by the ease of their identification in siliceous sediments.

The zonal scale is based on the first appearance of taxa, with the exception of acme zone *Periodon flabellum / macrodentata* and *Periodon aculeatus*, where no other characteristic species are found or are found in insignificant amount insufficient for the species identification. The conodont zonation comprises 12 zones: *Cordylodus lindstroemi, Cordylodus angulatus, Paltodus Rossodus, Acodus longibasis, Prioniodus cf. P.honghuayuanensis, Oepikodus evae, Periodon flabellum macrodentata, Paroistodus horridus, Periodon aculeatus, Pygodus serra, Pyrodus serra, Pyrodus macrodentata, Periodon flabellum macrodentata, Periodon flabellum macrodentata.* The zones from the Lower to the middle of the Middle Ordovician were developed in continuous sections of the Burubaital Formation (SW Balkhash region, Tolmacheva, 2014). The *Pygodus serra, Pygodus anserinus* and *Periodon grandis* zones are the best characterized in the Yerzhan Formation of the Boshchekul District (Tolmacheva et al., 2009) and the Northern Balkhash (Tolmacheva et al., in preparation).

The widely distributed conodont species, providing the scale basis, with rare exceptions, have long intervals of distribution. Therefore, it has a good correlation potential, but a rather poor resolution.

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BIOGEOGRAPHY OF ORDOVICIAN CONODONTS IN THE RUSSIAN ARCTIC AND ITS IMPLICATION FOR PALEOGEOGRAPY

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Key words: *paleogeography, biogeography, Ordovician, conodonts, Russian Arctic.*
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Abstract: Study of Ordovician conodonts from the northern part of East European and Siberian platforms, the Subpolar and Polar Urals, Taimyr, Severnaya Zemlya and the New Siberian Islands provided keys for definition of the biogeographic affinity of conodont fauna from Ordovician paleobasins of the Russian part of the Arctic. The conodont biogeography allows assessment of the Arctic paleogeographic models.

Ordovician paleogeographic reconstructions are traditionally based on paleomagnetic studies, as well as on biogeography of benthic fauna groups, mainly trilobites and brachiopods. Pelagic faunas, including conodonts, are rarely used for paleogeographic reconstructions (e.g. Rasmussen, 1998; Armstrong, Owen, 2002). This is largely because their biogeography is controlled not only by the location of paleocontinents, but also related to climate and ocean circulation, water temperature, salinity, light and nutrient influx.

The creation of generally accepted biogeographic reconstructions of the Ordovician conodonts is still a matter of the future. For the Lower and Middle Ordovician, the most reasonable at present are the conodont biogeographic divisions of Zhen and Percival (2003). According to them, conodonts from deep-water deposits belong to the paleobiogeographic Open-Sea Realm, whereas conodonts from neritic deposits – to the Shallow-Sea Realm. The latter is divided into provinces confined to different paleocontinents: Laurentian, Australian, North China, South China, Argentine Precordillera and Balto-Scandian. Further, they are partitioned to Tropical, Temperate and Cold Domains (climatic zones) depending on their geographic location and ocean currents. Notably, the general biogeographical division of conodont faunas is in good agreement with modern paleogeographic reconstructions of the Ordovician (e.g., Golonka, 2011; Torsvik, Cocks, 2016; Metelkin et al., 2015).

The biogeographic affinity of conodonts in Russian part of the Arctic are poorly known. At the same time, a plenty of data on conodonts in these regions have already been accumulated. The Ordovician conodonts were studied in the north of the East European Platform (Arkhangelsk Region, Kolguev Island, Timano-Pechora Region) and Siberian Platform, the Polar Urals and Taimyr, on Severnaya Zemlya, and the Novosibirsk Islands. In Novaya Zemlya, the Ordovician conodonts are unknown. These data allow to define the biogeography of the Ordovician conodonts in the Arctic as well as to test the recently proposed Arctic paleogeographic reconstruction.

In the north of the East European Platform the Ordovician constitute a part of the sedimentary cover of the Timano-Pechora region. It occurs in Kolguev Island in the west of the region at a depth of 4000 m, and exposed at riverbanks in the east – in the Subpolar and Polar Urals. In the west of the northern part of the East European Platform, the lower Paleozoic is absent in the sedimentary cover, being eroded, but it has been found in xenoliths from kimberlite pipes of the Archangelsk region. The Early Ordovician conodont faunas of the latter region comprise species of *Baltoniodus, Scalpellodus*, and *Scolopodus* characteristic of Baltoscandia (Tolmacheva et al., 2013). In the Middle and lower part of the Upper Ordovician, no taxa common with Baltoscandia are present in the Archangelsk region, while endemic species of *Acodus, Triangulodus,* as well as representatives of *Pectinognathus*, characteristic of the Timano-Pechora appear (Melnikov, 1999). On Kolguev Island, only Upper Tremadocian conodonts *Rossodus* sp., *Scolopodus* cf. *S. subrex*, and *Ulrichodina* sp. are known. This fauna is different from the Baltoscandian and have a pronounced warm-water affinity.

The Polar and Subpolar Urals the Lower – Middle Ordovician conodont faunas consists of deep-water taxa of a wide geographic distribution as well as contain sparse endemic taxa (Tolmacheva et al., 2011). Both Siberian and Baltoscandian species are unknown here. A finds of phosphatic problematic *Ptiloncodus simplex* Harris, 1962 in the Bolshaya Kos'yu River of the Northern Ural (Schmeleva, Tolmacheva, 2016) is important for the Ordovician biopaleogeography. *P. simplex* is considered an endemic for the Laurentia and its folded fringes (Ethington, 2010). Within the Laurentia, this taxon is found almost everywhere in sediments from the Floian to the Hirnantian stages, but until recently was unknown outside of this paleocontinent. Its discovery in the Northern Urals as well as in Taimyr and in the north of the Siberian Platform indicates a wider geographical distribution of *Ptiloncodus* than expected.

Plate

Conodont species that indicate the bio-geographic provinces of the Arctic Ordovician

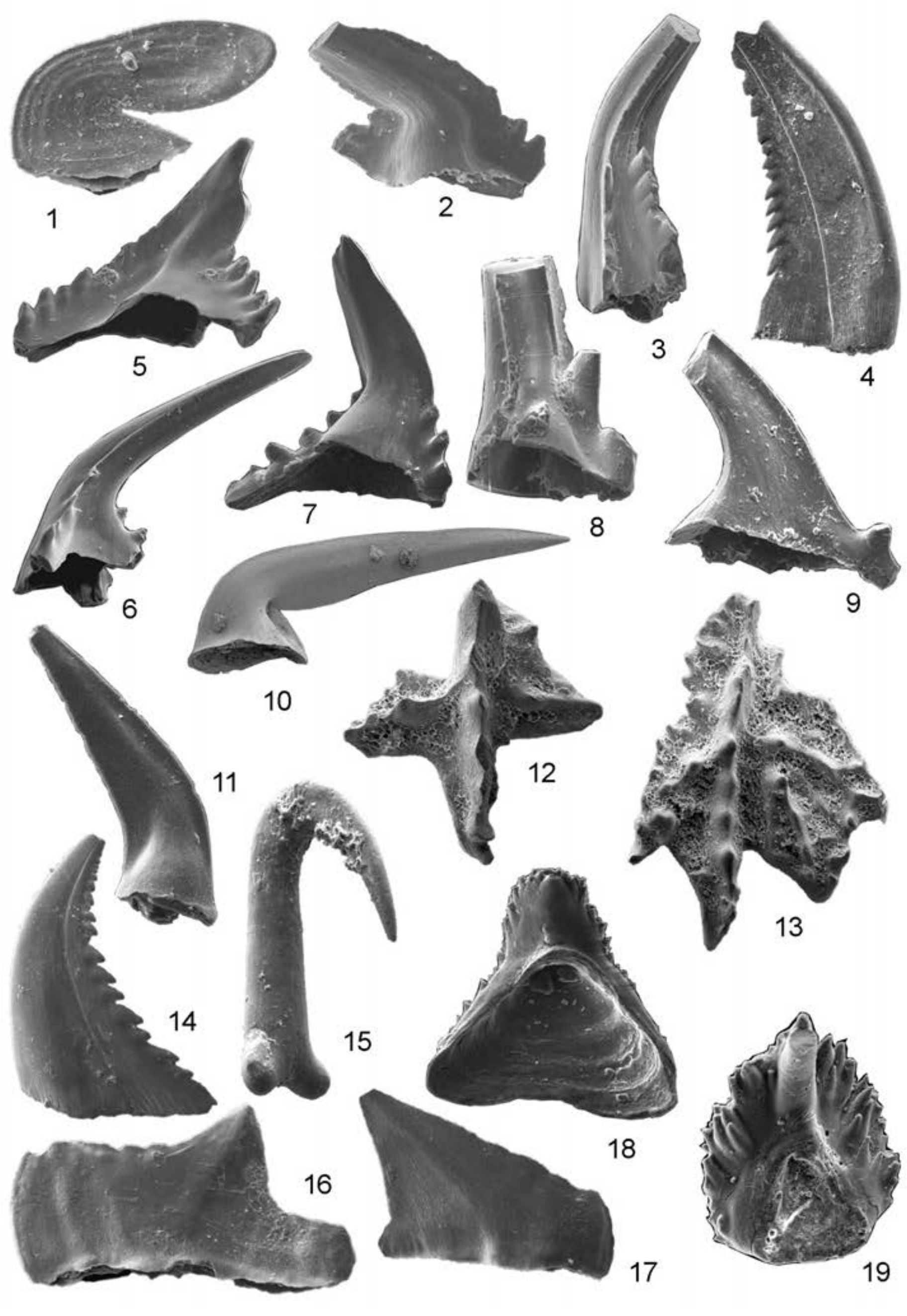

Fig. 1. *Oistodus petaloideus* Moskalenko, 1977, Taimyr, Vesenino Formation, the Upper Darriwilian, sample 138/4, ×45.

Figs 2, 3. *Pectinognathus* sp., Severnaya Zemlya, Ozernaya Formation, the Upper Darriwilian sample 56: 2 – Pa? element, ×38; 3 – Sd element, ×63.

Fig. 4. *Pseudobelodina? repens* (Moskalenko, 1973), Kotelnyi Island (New Siberian Islands), Malodiring-Ayan Formation, the Sandbian – Lower Kataian, sample 866/2, no. 03/25112, ×57.

Figs 5, 6, 7. *Pectinognathus khoreyvericus* Melnikov, 1999, East- European Platform, southeastern part of the White Sea region, the Upper Darriwilian – Lower Sandbian xenolith block: 5 – Pb? element, x45; 6 – Sd element, ×64; 7 – Pb element, 17/11107, ×52.

Figs 8, 9. *Ptiloconus* sp., Severnaya Zemlya, Ozernaya Formation, the Upper Darriwilian sample 56: 8 – ×69 ; 9 – ×63.

Figs 10, 11. *Rossodus* sp., Kolguev Island, borehole Bugrino 1, 4025 m: the Upper Tremadocian, 10 – M element, ×45, 11 – S element, ×52.

Figs 12, 13. *Polyplacognathus*? *angarense* Moskalenko. Siberian Platform, the Moyero River, Kochkan Formation, sample III-3: 12 – Pb element, ×42; 13 – Pa element, ×45.
Figs 14. *Pseudobelodina*? cf. *repens* (Moskalenko, 1973), Siberian Platform, the Moyero River, Dzherom Formation, the Sandbian, sample II-4, ×35.
Figs 15. *Ptiloncodus* sp., Siberian Platform, the Moyero River, Moyero Formation, the Upper Darriwilian, sample III-5, ×93.
Figs 16, 17. *Histiodella angulata* Moskalenko, 1982, Siberian Platform, the Moyero River, Moyero Formation, the Lower Darriwilian, sample III-1: 16 – ×87; 17 – ×75.
Figs 18, 19 *Hispidodontus triangularis* (Abaimova, 1975), Siberian Platform, the Kulumbe River, Il'tyk Formation, the Upper Cambrian, 18 – Sd element, CM 61/23105, sample 811-51; ×91; 19 – P element, CM 64/23105, sample 811-51, ×128;

On **Severnaya Zemlya** the Ordovician conodonts are known from the central and southern parts of the archipelago largest October Revolution Island (Mannik et al., 2009). The Lower and Middle Ordovician conodont assemblages encompass representatives of genera *Phragmodus* sp., *Erraticodon* sp. that widely occur in Siberia and Laurentia. However, no specific Siberian taxa are present there. In contrast, the Middle Ordovician fauna is dominated by *Pectinognathus* sp., the genus reported only from the north of the East-European Platform (Timano-Pechora, Arkhangelsk region, Moscow Syneclise) (Melnikov, 1999; Tolmacheva et al., 2013). This clearly demonstrates that the October Revolution fauna has a stronger biogeographic resemblance to the conodont faunas of the Timano-Pechora region than to those of the Siberian Platform.

The Ordovician conodont faunas of the **Siberian Platform** apart of the widespread taxa include a significant number of species characteristic only for this region (e.g. Moskalenko, 1983; Tolmacheva, Abaimova, 2009). Biogeographically, the Ordovician Siberia is a separate province, characterized by such species as *Hispidodontus kulumbense* Tolmacheva et Abaimova, *Histiodella*? *angulata* Moskalenko, *Polyplacognathus*? angarense Moskalenko, *Culumbodina mangazeica* Moskalenko and many others regional endemics.

The Ordovician of **Taimyr** is represented by different facies varying from shallow-water carbonates, like on the Siberian Platform, to deep-water siltstones with rare carbonate lenses (Sobolevskaya et al., 2016). Ordovician conodonts are much less studied there then in Siberia, however all the currently available data show the biogeographic resemblance of Taimyr and Siberian conodont fauna (Abushik et al., 2003, personal data). Taimyr conodont faunas in addition to the widespread deep-water conodonts contain typical Siberian conodonts e.g. *Oistodus petaloideus* Moskalenko (Plate).

On the **New Siberian Islands**, the Ordovician is exposed on Kotelny and Bennett islands. Studies of conodonts from shallow warm-water carbonates of Kotelny Island (Tolmacheva in Nekhorosheva et al., 2018; Danukalova et al., 2015) have revealed an occurrence of *Pseudobelodina*? *repens* (Moskalenko), *Erraticodon gratus* and *Ozarkodina* cf. *O. dolborica* thaa are known from the Siberian Platform, northeastern Russia, and Alaska (Moskalenko, 1983; Dumoulin et al., 2014; Tarabukin, 2006). In more deep-water facies of Bennett Island, only deep-sea conodonts of wide geographic distribution have been found.

Considering the biogeographic affinity of the Ordovician conodonts from the Russian Arctic, the following conclusions can be drawn. In the Middle Ordovician the northern margin of the East European Platform was inhabited by warm-water conodont faunas different from Baltoscandian. That was probably caused by existence of paleogeographic barriers separating the southern and northern parts of the platform. In the Lower and Middle Ordovician the Laurentia, Siberia and the northern margin of the Baltic were presumably located at closer distances than in all the proposed paleogeographic reconstructions. This is confirmed by a wide distribution of *Phragmodus* species and *Ptiloncodus simplex* Harris, 1962. The proximity of the Kara microcontinent to the northern edge of the East European Platform is followed from the unity of the biogeographical provinces of the Timano-Pechora region and Severnaya Zemlya (October Revolution). The conodonts of the Lower and Middle Ordovician of the Siberian Platform, Taimyr, Northeast Russia and, possibly, the Novosibirsk Islands (Kotelny Island) belong to the Siberian biogeographical province, that suggests the paleogeographic unity of these paleobasins. Based on the biogeography of conodonts, the Novosibirsk Islands are located much closer to the Siberian platform than to Alaska.

This is contribution to IGCP 653 project "The Onset of the Great Ordovician Biodiversity Event".

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MICRO-COPROLITES INSIDE ORDOVOCIAN BODY FOSSILS FROM ESTONIA

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Key words: *shallow-marine carbonates, micro-coprolites, Coprulus, Tubularina, Lumbricaria, Ordovician, Estonia.*

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Trace fossils are important environmental indicators, providing valuable knowledge on animal behavior in geological past. Coprolites and faecal pellets are distinct category of trace fossils. Faeces, like all soft-sediment fossils, have generally low fossilization potential and their finds from non-carbonate sediments are related to deeper water environments, higher sedimentation rates and different exceptional preservation conditions characteristic of Lagerstätten. The preservation of micro-coprolites in carbonate sediments is usually related to tropical shallow-marine environments and is common in the Mesozoic and Cenozoic. The majority of pellets in these environments are produced by crustaceans; they have characteristic internal structure and belong to the ichnofamily Favreinidae. Very elongated coprolites are representing the ichnofamily Lumbricariidae. Small cylindrical bodies with outer ornamentation are described from several different ichnogenera. Isolated rounded pellets without characteristic internal structure and smooth surface are representing the ichnofamily Coprulidae. They are described as infill in different trace fossils and shells. The size, shape and number of produced faecal pellets is, in general, a combination of structure and function of digestive organs and the nature of the diet of the producers.

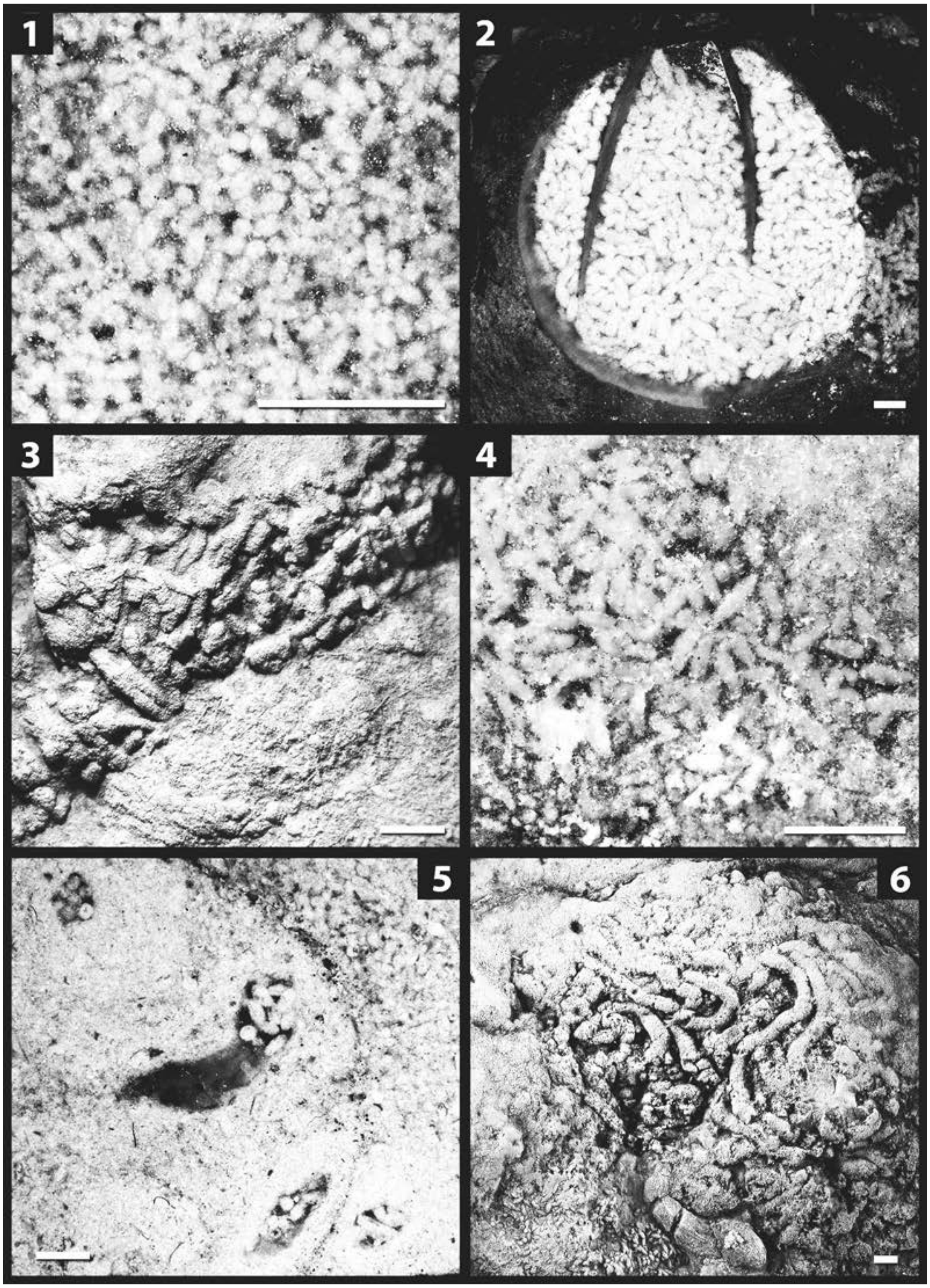
Small faecal pellets are particularly typical for the Ordovician of Europe. Usually they are identified as *Tomaculum* Groom, 1902 and in rare cases as *Cilindrotomaculum* Gutiérrez Marco, 1984. Bruthansová & Kraft (2003) reported small pellets inside different Darriwillian to Katian shelly fossils from offshore environments of Bohemia, preserved via silicification. From the Ordovician shallow-marine carbonate succession of Estonia, the occurrence of pellets was noted by Põlma (1982). The latter author suggested that the pellets have been trapped inside shells and may have faecal origin.

Our studies on large Estonian paleontological collections housed at the Department of Geology, Tallinn University of Technology (GIT) and the Natural History Museum, University of Tartu (TUG), brought up new data on the occurrence of small pellets in Ordovician shallow-marine carbonates. Stratigraphically such finds range from the Kunda (Lower Darriwillian) to Pirgu (Upper Katian) regional stages with higher number of better preserved pellets at two levels: Haljala (Sandbian) and Rakvere (Katian) regional stages. All pellets recovered are devoid of internal structure, without wall and lining, and with smooth outer surface. They are elongated, varying from oval to rod-shaped, with circular cross section, almost constant in their dimensions within an individual accumulation. The size of pellets between accumulations is, however, very variable, ranging from 0.1 to 1.8 mm in length, and from 0.08 to 0.5 mm in diameter. An important diagnostic feature, the length/width ratio ranges from 2 to 6. The number of pellets in individual accumulations depends on the size of pellets; for the larger ones a few dozen may be observed and for the smallest pellets a single accumulation may contain up to a thousand pieces. The host shells derive from gastropods, bivalves, cephalopods, brachiopods, echinoderms and trilobites. Pellets inside the shells are preserved in two different modes: the majority of cases are massive accumulations and fewer finds are related to small burrows within shells.

The shelly fossils with pellets inside derive from temperate to tropical carbonates in Baltoscandia. Rapid lithification and small size of pellets have played an important role for the preservation of pellets in carbonates. EDS chemical analyses have shown that the composition of pellets is similar to the rock matrix; however, specimens from the Haljala Regional Stage suggest that silicification may have supported the preservation of pellets. We have identified the following ichnospecies: *Coprulus oblongus* Mayer, 1952 (Pl., Fig. 1) and *C.* cf. *oblongus* (Pl., Fig. 2) *sensu* Knaust 2008, *C. bacilliformis* Mayer, 1955 (Pl., Fig. 3) and *C.* cf. *bacilliformis* (Pl., Fig. 4). In addition, *C. oblongus* was found to be as a constituent of a compound trace fossil *Tubularina* Gaillard et al., 1994 (Pl., Fig. 5). According to Bruthansová & Kraft (2003), only a limited number of taxa could have been the producers of pellets inside empty shells, mostly scavengers and filter feeders looking for a shelter. Our study supports this idea, but the large variation

Plate

Micro-coprolites inside Ordovician shelly fossils



Scale bar is 1 mm. Fig. 1. *Coprulus oblongus,* Värska 6 borehole, 381.8 m, Haljala Regional Stage, GIT 156-1066-1. Fig. 2. *Coprulus* cf. *oblongus*, Oandu River outcrops, Rakvere Regional Stage, GIT 619-85-5. Fig. 3. *Coprulus bacilliformis*, Rakvere, Rakvere Regional Stage, TUG 1779-477-1. Fig. 4. *Coprulus* cf. *bacilliformis*, Kullaaru ditch, Oandu Regional Stage, GIT 694-93-3. Fig. 5. *C. oblongus* as constituent of compound trace fossil *Tubularina*, Aluvere Quarry, Haljala *oprulus*. Fig. 6. *Lumbricaria intestinum*, Rägavere quarry, Rakvere Regional Stage, TUG 73-148-2.

in size, shape and in the number of pellets in accumulations suggest even a wider spectrum of potential tracemakers.

Besides the pellets, a single examined steinkern of large gastropod contained a very elongated (the length far exceeds the width), convolute, cylindrical coprolite, without internal structure, showing an overlapping pattern and exhibiting constrictions. This specimen comes from the Rakvere Regional Stage (Katian) and is assigned to the rare ichnogenus *Lumbricaria* Münster in Goldfuss, 1831 (emended by Kietzmann & Bressan, 2019) (Pl., Fig. 6). This ichnogenus was previously described from Jurassic shallow subtropical carbonates. Different origins have been proposed for *Lumbricaria*, more recently holoturians (Kietzmann & Bressan, 2019). Holothurians use the shelters for hiding and are known from the Upper Ordovician of Estonia. The specimen from the Rakvere Regional Stage is small (the diameter is about 0.7-0.8 mm, and the length of loops is more than 10 mm) and is probably representing a juvenile tracemaker.

In summary, our study showed that the fauna inhabiting different empty shells was diverse through the Middle and Late Ordovician in Estonia~~,~~ and consisted of different mobile tracemakers. Data on individual specimens and related micro-coprolites (including images and localities) is deposited in the Estonian geocollections database SARV, which is accessible online at https://geocollections.info.

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BIOSTRATIGRAPHY OF CAMBRIAN-ORDOVICIAN CONODONTS FROM THE LOS SOMBREROS FORMATION, WESTERN PRECORDILLERA, ARGENTINA

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Key words: *Conodonts, Cambrian-Ordovician, Biostratigraphy, Precordillera, Argentina.*
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1. Introduction

The Los Sombreros Formation corresponds to the western tectofacies (Astini, 1991) of the Argentine Precordillera. This formation crops out in the Tontal Range (Cuerda et al., 1984) to the south of the San Juan River up to the latitude of Jáchal City (Benedetto and Vaccari, 1992) and the Ancaucha River (Albanesi et al., 1995). This exposure constitutes a significant piece for the interpretation of the Precordilleran continental slope. Without considering the structural complexity and the scarcity of the fossil record to determine a detailed depositional scheme, a spectrum of ages ranging from the Ordovician to the Devonian was proposed for the Los Sombreros Formation (Benedetto and Vaccari, 1992; Albanesi et al., 1995; Peralta, 2005). Recently, Voldman et al. (2018) documented the appearance of conodont species from the upper Furongian and upper Tremadocian found in gravity flow deposits with sinsedimentary deformational features, which suggest the existence of an active continental slope from the late Cambrian until the Middle Ordovician.

New conodont records are reported in the present contribution for the Los Sombreros Formation in the Tontal and Yerba Loca ranges (Fig.1). The consequent biostratigraphic data are significant to determine the correspondence of this formation with the sedimentary source in the carbonate platform of the Precordillera, as well as for precise geological correlation to intercontinental scale.

2. Methods

Limestone samples were taken in the surveyed stratigraphic section of the El Salto creek in the Tontal Range, and in the Tunnels section, located on the right margin of the Jáchal River, across the Yerba Loca Range. The calcareous samples for conodonts, 3 kg each, were treated according to conventional laboratory techniques for the search of phosphatic microfossils (Stone, 1987); using 10 % formic acid for rock digestion, the separation of the heavy fraction by means of sodium polytungstate, and the picking technique for the recovery of specimens.

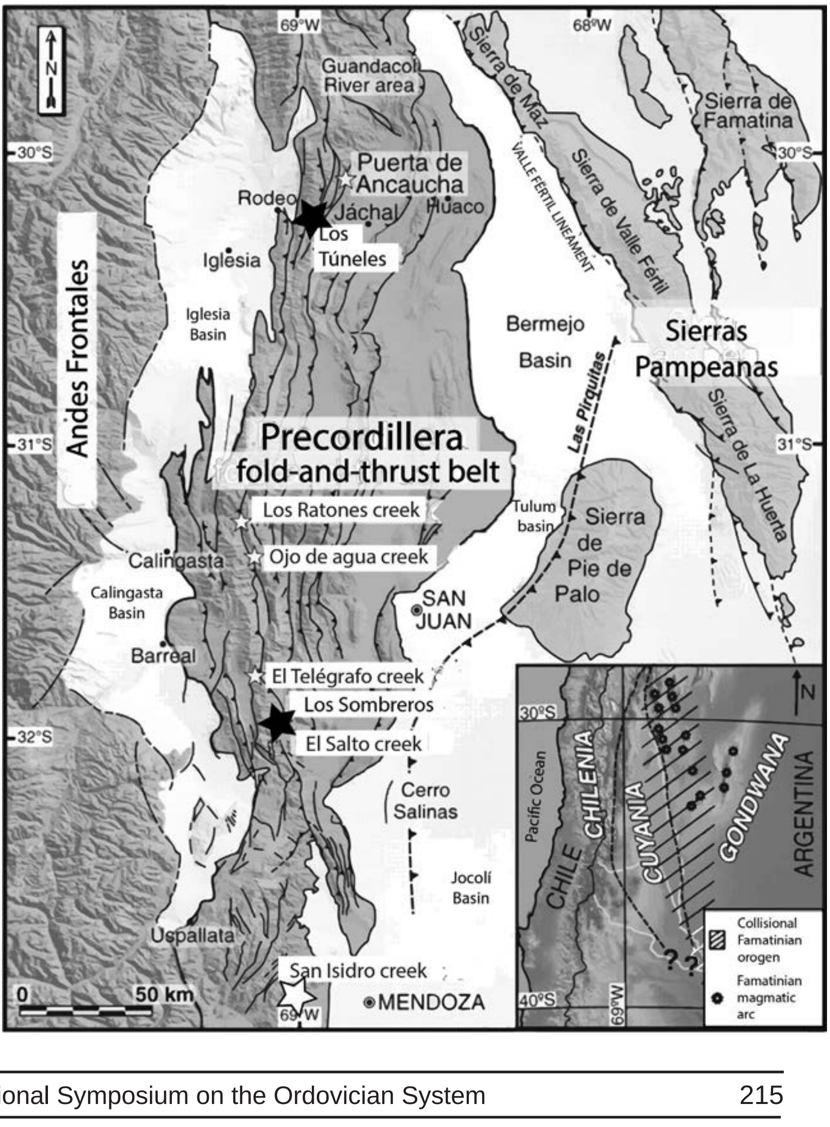

Fig. 1. Location map of the Argentine Precordillera fold-and-thrust belt, overlying the shaded topographic map derived from the Shuttle Radar Topography Mission (SRTM). Black stars indicate the studied sections (adapted from Voldman et al., 2009).

3. Results

At the El Salto section in the Tontal Range, only one sample from the middle-upper part of the Los Sombreros Formation was fossiliferous, which allowed for determining the age of an allochthonous block by conodont biostratigraphy. The taxonomy of the identified species is known following the description of previous authors; thus, the different species were distinguished considering the morphology of diagnostic elements, the denticulation patterns and the configuration of the basal cavity (number of apices, depth, position and design of its anterior margin). *Cordylodus proavus* (Müller) and *Eoconodontus notchpeakensis* (Miller) were identified in the sample from the El Salto section (Fig. 2). These species are representative of the *Cordylodus proavus* Zone, which covers part of the Stage

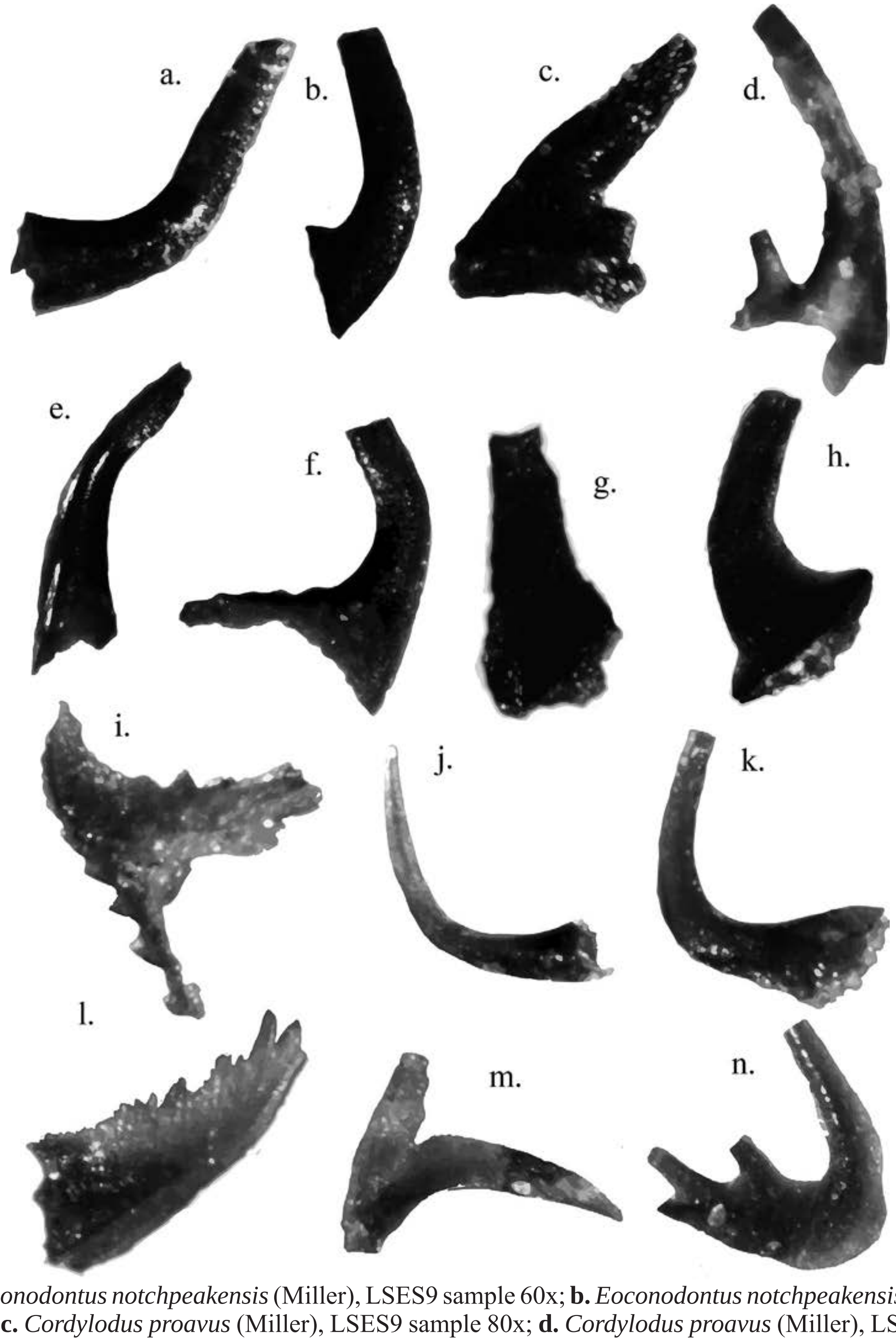

Fig.2. a. *Eoconodontus notchpeakensis* (Miller), LSES9 sample 60x; **b.** *Eoconodontus notchpeakensis* (Miller), LSES9 sample 60x; **c.** *Cordylodus proavus* (Miller), LSES9 sample 80x; **d.** *Cordylodus proavus* (Miller), LSES9 sample 60x; **e.** *Eoconodontus notchpeakensis* (Miller), LSES9 sample 80x; **f.** *Cordylodus proavus* (Miller), LSES9 sample 80x; **g.** *Paltodus deltifer* (Lindström), Los Túneles sample 60x; **h.** *Juanognathus jaanussoni* (Serpagli), Los Túneles sample 60x; **i.** *Baltoniodus medius* (Dzik), Los Túneles sample 80x; **j.** *Costiconus costatus* (Dzik), Los Túneles sample 60x; **k.** *Cornuodus longibasis* (Lindström), Los Túneles sample 100x; **l.** *Ansella jemtlandica* (Löfgren), Los Túneles sample 100x; **m.** *Fahraeusodus jachalensis* Feltes and Albanesi, Los Túneles sample 80x; **n.** *Paroistodus horridus secundus* (Albanesi), Los Túneles sample 80x, CORD-MP 28514.

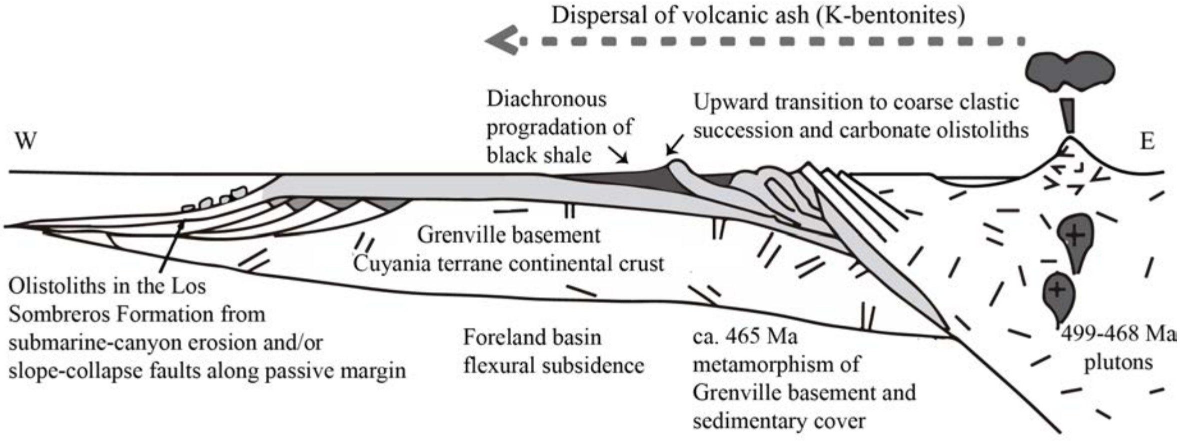

Fig. 3. Schematic cross section showing the collision of Cuyania with the Famatinian magmatic arc along the western margin of Gondwana during the Middle Ordovician (modified from Thomas and Astini, 2003).

10 of the Furongian Series, Cambrian System. The calcareous sample taken from the middle part of the Los Sombreros Formation at the Los Túneles section produced 367 conodont elements, whose specific ranges represent the zones of *Lenodus variabilis* (Darriwilian) and *Paltodus deltifer* (Tremadocian), following the scheme of Albanesi and Ortega (2016) (Fig.2).

The identification of the *Cordylodus proavus* Zone (upper Furongian), the *Paroistodus horridus* Subzone of the *Lenodus variabilis* Zone (lower Darriwilian), and the determination of the *Paltodus deltifer* Zone (upper Tremadocian) in the Los Sombreros Formation, allow us to adjust the stratigraphic correlation between the coetaneous slope facies in the Western Precordillera and those of the carbonate platform of the eastern domain, as sedimentary source (San Juan and La Silla formations).

The conodonts recovered from the Los Túneles section that are assigned to the *Lenodus variabilis* Zone exhibit a brown color, which corresponds to the Color Alteration Index 3 (CAI 3), reflecting burial palaeotemperatures between 110 and 200° C. Conodonts corresponding to the *C. proavus* and *P. deltifer* zones recovered from both, the El Salto and the Los Túneles sections have a black color corresponding to a CAI 5 that represents palaeotemperatures of 300-480ºC, which determine a very low metamorphism, i.e., green schist facies (Epstein et al., 1977) (Fig. 2). According to Voldman et al. (2009), the redeposited carbonate blocks affected by metamorphism would come from sheets brought to the platform during the collisional process of the Cuyania Terrane with the South American continental margin of Gondwana (Fig. 3).

4. Discussions and Conclusions

Due to the complex structure and limited biostratigraphic control that characterizes the Los Sombreros Formation, the age of the olistostromic deposition is usually a source of discussions, having been attributed to the Ordovician (e.g., Benedetto and Vaccari, 1992, Banchig and Bonardo, 1994; Voldman et al., 2009) and Devonian systems (e.g., Peralta, 2005). However, the appearance of graptolites in shales of the early Floian in the Ojo de Agua creek (Banchig and Moya, 2002) and the Darriwilian in the El Salto creek (Ortega et al., 2014) indicate that the age of the formation is mostly assignable to the Ordovician. Voldman et al. (2018) recognized conodont associations that belong to the *Cordylodus proavus* Zone (upper Furongian) in calcareous breccias exposed on the eastern flank of the Tontal Range. Also at this range, the record of *Araneograptus murrayi* (Hall) in the lower levels of the Los Sombreros Formation, at the Seca section, indicates a late Tremadocian age for the bearer strata. Moreover, associations of conodonts referable to the *Paltodus deltifer* Zone (upper Tremadocian) of calcareous breccias and clastic-carbonate turbidites were obtained from other sections of the referred range and the Jáchal River section (Voldman et al., 2009). A number of autochthonous conodont species from the Los Sombreros Formation matrix at the Los Túneles section were recovered by Voldman et al. (2009), which apparently represent the *Yangtzeplacognathus crassus* Zone. In autochthonous blocks of the Los Sombreros Formation, exposed in La Invernada Range, Voldman et al. (2016) recorded the occurrence of conodonts referable to the *Hirsutodontus simplex* Subzone of the *Cordylodus intermedius* Zone (upper Furongian) and the *Macerodus dianae* Zone (upper Tremadocian). The latter biozone was recently documented in the upper strata of the La Silla Formation (Albanesi et al., 2016), at the section of the Portezuelo de Jáchal, revealing that towards the late Cambrian-Early Ordovician an active continental slope zone was already established.

The new data of conodonts from the Los Sombreros Formation in the Tontal Range verify that the sedimentation in the Precordilleran slope took place from the late Cambrian. The recognition of the *C. proavus* Zone (upper Furongian, Cambrian) and *P. deltifer* Zone (middle Tremadocian, Ordovician) allows the correlation of the Los Sombreros Formation with the La Flecha and La Silla formations, respectively, of the carbonate platform of the Eastern and Central Precordillera. The *Paroistodus horridus* Subzone of the *Lenodus variabilis* Zone is identified for the first time in the Los Sombreros Formation at the Los Túneles section of the Jáchal River. These conodont elements that reflect burial palaeotemperatures between 110–200 °C reveal the thermal history related to the sedimentary burial of the Western Precordillera. The conodonts of the *P. deltifer* Zone recovered from allochthonous clasts, which in turn were retrieved from the referred calcareous matrix have thermal alterations due to the effects of very low-grade metamorphism *i.e.* green schist facies. These elements would have been re-transported in exotic blocks that compose the sedimentary succession of the Los Sombreros Formation, whereas they were deposited in facies of the slope combined with the autochthonous elements of the matrix. The conodonts from to the *C. proavus* Zone recovered from allodapic limestones interlayered with dark shales, in the lower upper part of the formation at the El Salto section, derive from a carbonate series of the upper Cambrian platform and later redeposited in the slope, as exotic blocks, during the Middle Ordovician.

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ABOUT POSSIBLE CAUSES OF APPEARANCE AND PECULIARITIES OF LENSES WITH THE SELECTIVE SILICIFICATION OF THE FOSSILS IN THE ORDOVICIAN DEPOSITS OF THE EAST OF BALTOSCANDIA

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Key words: *Baltoscandia, Ordovician sediments, Beekite rings, silicification of fossils.*

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Silicification is an ordinary case of fossilization of fossils along with other fossilization methods (calcification, dolomitization, pyritization etc.). The character of silicification of fossils is usually considered only from the point of view of informativeness of the transfer of the morphological features of fossils. However, there is a special form of selective silicification, which gives fossils a peculiar ornamentation. These are concentric-spherical aggregates on shells of invertebrates: brachiopods, coleoidea, bivalvias, corals. E.A. Ivanova and T.G. Sarycheva (1963) have warned of the danger of erroneous interpretations of such formations as features of the shell structure or sculpture. B.P. Markovskii (1966) interpreted a similar pattern as traces of the vital activity of algae. Thus paleontologists considered these patterns either as a factor complicating the species diagnostics or as a new biogenic form. The later described concentric-zonal aggregates of silica were identified as Beekite rings, in honor of the English botanist Henry Beek, which was the first who described them. Currently Beekite rings are fixed on systematically different groups of invertebrates of different stratigraphic ages, but among the samples with these aggregates, there is a clear dominance of the Paleozoic fossils (Butts, Brigg, 2011). Despite the fact that lately in foreign literature one pays attention to Beekite rings, the mineralogical side of the formation of such aggregates is usually considered, and the issues of paleogeography and features of the paleontological substrate are little affected. Nevertheless, the widespread distribution of fossils with Beekite rings provokes an increase in interest in them and, as a result, attempts to use Beekite rings to solve a wide range of geological problems. So in the work of N. Kazanci and B. Varol on the example of the alluvial Paleocene sediments of Central Anatolia (Kazanci, Varol, 1993) the stratigraphic pattern of the distribution of layers with a similar silicification of fossils was noted. Horizons with these fossils fixed levels of stratigraphic unconformities. From a paleontological point of view (Butts, Brigg, 2011) microstructure and composition of the shells of some fossils groups was favored to the formation of Beekite rings. An increase of amount of organic material in the shell, the ratio of carbonate minerals in favor of calcite, more resistant to dissolution compared with another modification of calcium carbonate, aragonite, the presence of porosity, a certain nature of the geometric structure of the surface of the shell (the preference of a parallel fiber structure layered) are the factors favoured to the formation of these aggregates. As possible sources of silica for the formation of Beekite rings on shells are considered both volcanogenic mineralized solutions and solutions mineralized because of leaching of volcanic rocks, interlayers of bentonite clays, rocks composed of substantial fraction of the remains of organisms with a siliceous skeleton. As for the environments conducive to the emergence of Beekite rings on fossils, it is assumed that it is possible to form such structures both in the subaerial and in the subaqual conditions. Within the sea basins, the possibility of forming of such spherulites is considered in the wide range of depths from the suprolithoral to the deep parts of the shelf and possibly the continental slope.

The authors found specimens with Beekite rings in the collections of the Mining Museum (collections of various authors of the XIX century dedicated to the Ordovician invertebrates of the St. Petersburg and Estland provinces, modern Leningrad region and Estonia). These are the samples of the brachiopod of the suborder Syntrophiidina (genus *Porambonites* Pander): *Porambonites (Porambonites) altus* (Pander) and *Porambonites teretior* Eichwald. In addition a sample of *Porambonites (Equirostra) aequirostris* Schlotheim, also having Beekite rings, was also identified in the collection of the Department of Historical and Dynamic Geology of the Mining University. Unfortunately, the non-monographic collections of the Mining Museum, as well as the collections of the department, are currently in the very poor condition: many samples are missing or confused, the labels on the samples from the collections of the XIX century are extremely superficial. It was possible to establish (during the attribution of the collection of the Mining Museum) that the discovered specimens of *Porambonites (Porambonites) altus* (Pander) (Fig. 1) were collected by Major Ozeretskovsky in the place Spitham (Estonia).

This location is currently lost. According to E. Eichwald (1840) this was the famous location in the XIX century. This location was not an outcrop, but a strip of coastal sand containing rounded pebbles of the Ordovician limestone and fossils. This species is characteristic for the Volkhov regional stage (Dapingian) of Baltoskandia. Unfortunately, the revision of the genus *Porambonites* Pander was not done and the exact stratigraphic and geographical

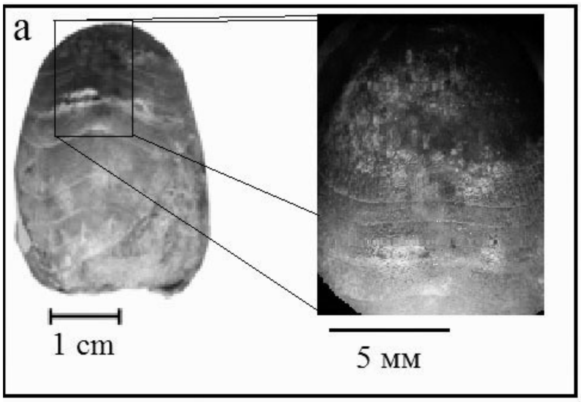

Fig. 1. *Porambonites (Porambonites) altus* (Pander): a – general view; b – rings under a binocular microscope.

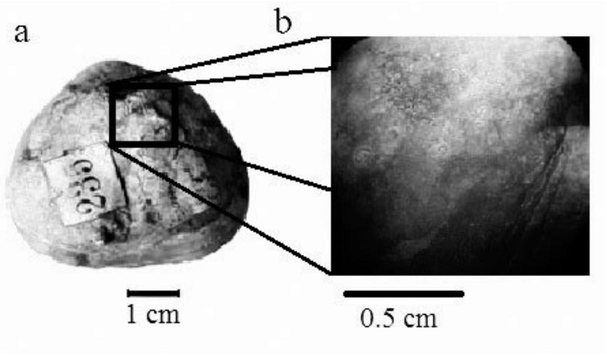

Fig. 2. *Porambonites teretior* Eichwald a – top view; b – top view under the binocular microscop.

Fig.3. *Porambonites* (*Equirostra*) *baueri* Noetling.

distribution of the described species is not known. Samples of *Porambonites teretior* Eichwald (Fig. 2) were identified as belonging to the collection by X. Pander from the location Uchten' (modern Uchtna) also located in north-eastern Estonia.

Currently this location also belongs to the lost outcrops. Representatives of the species *P. teretior* Eichwald are found in the sediments of the Kukruse regional stage of Baltoscandia (Lower Sandbian). The instance *Porambonites (Equirostra) aequirostris* (collection of the department) was found in some locations of the central part of the Izhora plateau. This species is characteristic of the interval of the Lasnamagi (Darriwilian) – Idavere (Sandbian) regional stages. In addition on the site https://fossiilid.info/ images of *Porambonites (Equirostra) baueri* Noetling with clearly visible structures similar to Beekite rings on specimens of this genus was found in the Mining Museum (Fig. 3, https://fossiilid.info/8618?mode=in_baltoscandia&lang=en#gallery-7).

These samples were also obtained from northeastern Estonia (Aluvere quarry), where, according to T. Meidla and L. Ainsaar (2014), bentonite interlayers were recorded in the Sandbian sediments.

Thus, there is a clear association of the formation of Beekite rings on shells of the genus *Porambonites* Pander (in the absence of stratigraphic and geographical patterns of distribution of fossils with these aggregates). A fibrous secondary layer characterizes the suborder Syntrophiidina, which, as mentioned above, is more favorable for the development of silicification of the type of Beekite rings. Probably organic shells, which contour each calcite crystal of this fibrous secondary layer, played the key role. Representatives of the whole family of Porambonitidae are characterized by a peculiar sculpture consisting of very thin radial ribs, small pits and thin but sharp concentric growth lines; the combination of these elements often gives the surface of the sinks a kind of "reticulation". When studying shells of the genus *Porambonites* Pander under the binocular microscope (Zeiss AX10 Imager A2m, x4), there are two zones of localization of Beekite rings noted. The first zone, characterized by the rings that are less distinct in the microrelief of the shell, is localized near the lateral edges and the anterior edge of the ventral and dorsal valves. In this case, there is a banded arrangement of rings, the direction of the bands coincides with the direction of growth lines (Figs 1, 2 – b). The second zone is localized in the posterior part of the valve and is characterized by the rings that are more pronounced in the microrelief of the shell. The most thickened secondary layer distinguishes this part of brachiopod shells. Thus, both the microstructure and the sculpture of brachiopod shells influenced the character of the growth and distribution over the surface of the shell of Beekite rings, and one can say that the appearance of Beekite rings is inherent in specific small taxa. For the preserving of the integrity of the museum samples, these shells were studied under the binocular and by X-ray microtomography method. Tomography of the brachiopod shells showed the presence of poor (about 1-3 % of the total) impregnation of minerals with a density much higher than the density of carbonate matrix, presumably iron oxides and hydroxides, possibly manganese, and individual sulphide grains, most likely pyrite or marcasite. The authors suggest the exogenous nature of these minerals. The Beekite rings are composed of chalcedony spherulites, similar to those in agates. The main difference is the much smaller radius of chalcedony spherulites, which is a fraction of a millimeter against the first millimeters to tens of millimeters in agate secretions, which is due to constrained growth conditions. Geometric selection of chalcedony crystallites in Beekite rings is weaker than in large agate secretions due to a larger number of growth points, and a shorter crystallite length.

The question of the relationship between the growth conditions of chalcedony of Beekite rings and agates remains controversial. The preservation of the original sculpture of shells, distinguishable from under the Beekite rings, as well as the peculiarities of the chemical composition of fossils indicate the formation of aggregates at the post-diagenetic stage. The stratigraphic disconnection of horizons with brachiopods with Beekite rings may testify in favor of formation at the stage of hypergenesis, in subaerial conditions due to infiltration of meteoric and groundwater. This assumption can also be served by the peculiarities of the distribution of silicified fossils in Aluvere quarry, the concentration of such fossils only in the southern wall of the quarry recorded by T. Meidla and L. Ainsaar (2014). Possibly this wall was distinguished by increased fracturing of limestones, which promotes more active process of hypergenesis.

This is contribution to IGCP 653 project.

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ORDOVICIAN CONODONT-GRAPTOLITE BIOSTRATIGRAPHY AT THE VALLECITO CREEK, SOUTHERN LA INVERNADA RANGE, ARGENTINE PRECORDILLERA

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Key words: *conodont, graptolite, biostratigraphy, Ordovician, Precordillera, Argentina.*

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The Sierra de la Invernada Formation is a lower Darriwilian – middle Katian (Middle-Upper Ordovician) siliciclastic succession located at the western margin of the Central Precordillera, San Juan Province, Argentina. It crops out for ca. 60 km along the N-S Sierra de la Invernada, varying between 1000 and 4000 m in stratigraphic thickness, probably involving tectonic repetitions. It is characterized by shale and sandstone alternations, interspersed with sporadic conglomerates, calcarenites and limestone breccias deposited in a shallow marine system above or at the storm wave base (lower shoreface or inner shelf) (Moretti et al., 2006), interbedding with deepest greyish shaly facies bearing graptolites. In the course of recent years, several studies have dealt with its conodont and graptolite content, mainly proceeding from the more accessible northern stratigraphic sections (e.g., Brussa, 1997; Ortega et al., 2008), allowing to improve the conodont and graptolite biostratigraphic schemes for the Precordillera and its global correlation (Albanesi and Ortega, 2016). The distant southern outcrops of the Sierra de la Invernada were firstly studied by Furque et al. (1990) and Caballé et al. (1992), with pioneer contributions from the Vallecito Creek, where the authors proposed an Ordovician stratigraphic scheme for the Central – Western Precordillera, that was temporally constrained by graptolite biozonations.

In the present contribution, new conodont and graptolite data from the Sierra de La Invernada Formation at the Vallecito Creek (Fig. 1) are introduced. From the 1010 m thick measured stratigraphic profile, 18 rock samples (25 kg of calcareous rocks) were obtained, yielding ca. 2300 conodont elements. The conodont collection includes, in the lower productive sample (VA7), an association representative of the *Eoplacognathus pseudoplanus* Zone, with the eponymous species, *Ansella jemtlandica* Löfgren, *Dzikodus newfoundlandensis* (Stouge), *Juanognathus serpaglii* Stouge, *Parapaltodus simplicissimus* Stouge, *Paroistodus horridus* (Barnes & Poplawski), *P. origi-*

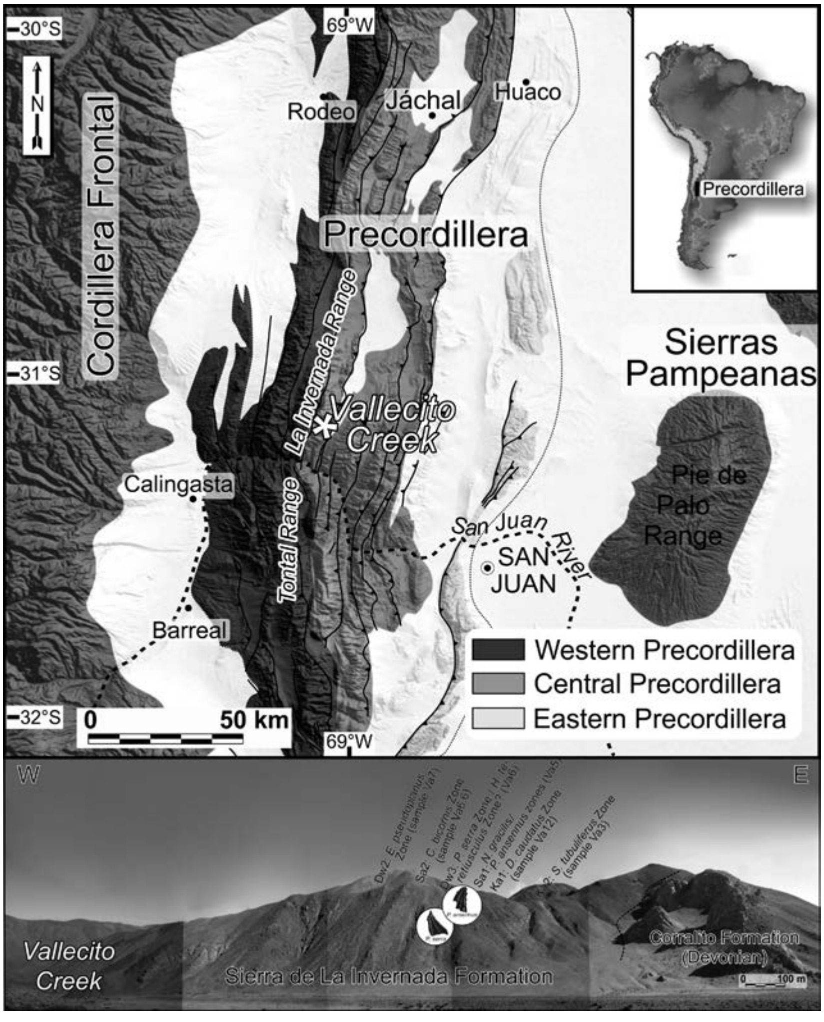

Fig. 1. Location map and panoramic view of the Vallecito Creek with productive conodont and graptolite samples.

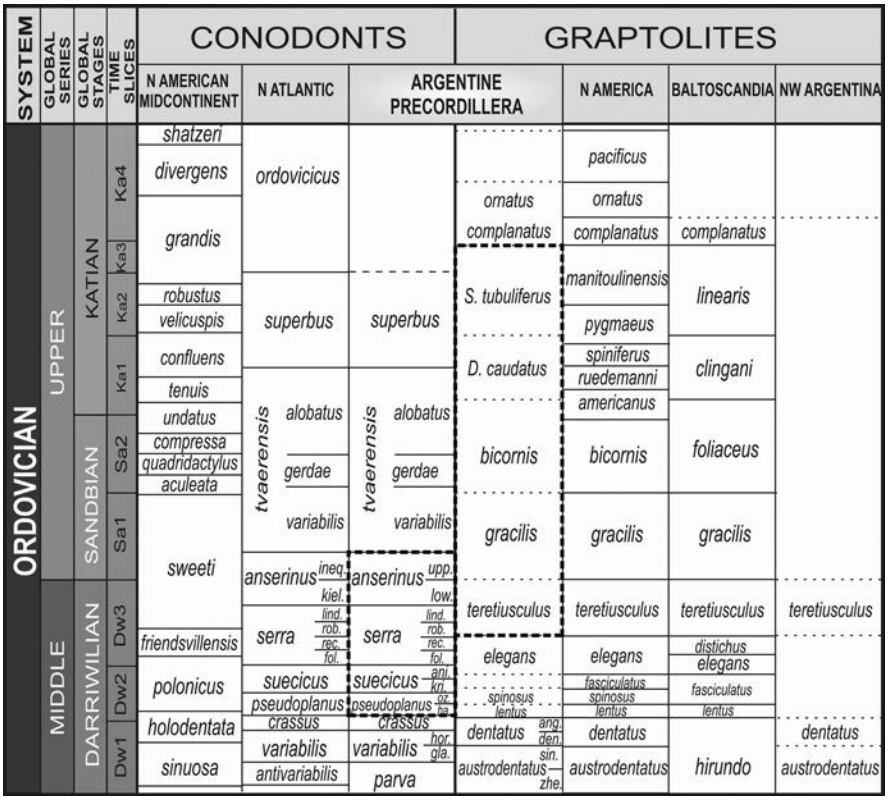

Fig. 2. Biostratigraphic chart (modified from Albanesi and Ortega, 2016) with recognized conodont and graptolite biozones in the Sierra de La Invernada Formation at Vallecito

nalis (Segeeva), *Periodon aculeatus* Hadding, *P. macrodentatus* (Graves & Ellison), *Protopanderodus gradatus* Serpagli, *Pteracontiodus cryptodens* (Mound), *Spinodus spinatus* (Hadding), and *Strachanognathus parvus* Rhodes, among others species. The occurrence of the index species *Pygodus serra* (Hadding), in sample VA6, and *P. anserinus* Lamont & Lindström associated to *Eoplacognathus reclinatus-lindstroemi* transitional forms, and *Scabbardella altipes* Henningsmoen, in samples VA5,2-3, verify the homonymous biozones from the late Darriwilian to early Sandbian in the referred formation. Additionally, conglomerate limestone clasts yielded late Floian *Oepikodus evae* Lindström conodont elements, probably derived from the Central Precordillera carbonate platform, located to the east (present coordinates).

The graptolite records are diverse and represent the following biozones: *Hustedograptus teretiusculus* (? –sample Va6), *Nemagraptus gracilis*, *Climacograptus bicornis*, *Diplacanthograptus caudatus*, and *Styracograptus tubuliferus*. The graptolite associations are largely dominated by axonophorans, with scarce pterograptids, sigmagraptids, glossograptids, and transported dendroid fragments. Conodont and graptolite records from the Vallecito Creek verifies younging to the east, with conodont associations that represent the *Eoplacognathus pseudoplanus*, *Pygodus serra*, and *Pygodus anserinus* zones, respectively, conversely to what is documented for the northern sections. According to both graptolite and conodont records, as anticipated by Ortega et al. (2010), the outcrops of the Sierra de La Invernada Formation at Vallecito Creek constitute one of the most representative siliciclastic successions from the late Darriwilian – mid Katian of the Argentine Precordillera (Fig. 2).

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ORDOVICIAN SEQUENCE STRATIGRAPHY AND CORRELATION IN THE MIDDLE-UPPER YANGTZE REGION, SOUTH CHINA

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Key words: *sequence stratigraphy, correlation, different facies, Ordovician.*

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The Ordovician successions of platform facies, slope facies and basinal facies are well developed in the Middle-Upper Yangtze Region, South China. The precise correlation of the Ordovician successions in different facies is difficult due to the changes of the tecto-paleogeography in South China. Based on previous studies, the authors recognized 10 3rd grade sequences, i. e., OSq1 to OSq10 in ascending order, by the integrated study of chronostratigraphy, biostratigraphy as well as the analysis on the sedimentary facies.

An unconformity surface can be observed at the base of the Ordovician in the platform facies zone, and can be traced in the slope facies zone. There are 4 third grade sequences can be recognized and correlated in different facies zone during the Early Ordovician, although the response for the sea-level fluctuations is much more obvious in the platform faices zone than in the slope and basin facies zone.

It is witnessed a sustainable large scale sea-level rising during the Middle and Upper Ordovician. The transgression is started at late of Early Ordovician, which onlap surface is diachronously changed from the level of *Acrograptus filiformis* zone in northern Guizhou to the level of *Dydimograptellus bifidus* in western Hubei. The OSq5 to OSq10 can be recognized and correlated in different facies. The study on the sequence stratigraphy and correlation of this time interval will provide powerful evidence for the analysis of the onset of the evolution of the foreland basin triggered by the Guangxi orogeny movement. New data on the graptolite fauna from YD-1 drill core in eastern of Yangtze Gorges area shows that the range of the bulge of the foreland basin was migrated forward to northwest from Hirnantian to early Aeronian. The panorama of the tecto-paleogeography is more complicated than the previous study.

MICRO-CT OBSERVATION OF INTERNAL STRUCTURES IN SOME LATE ORDOVICIAN GRAPTOLITES FROM SOUTH CHINA

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Key words: *climacograptids, Late Ordovician, South China, pyritization, Micro-CT.*
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Introduction:

Graptolites (an iconic marine fossil group of Ordovician and Silurian strata) are commonly preserved as flattened carbonaceous or phyllosilicate films on bedding surfaces. In some specimens the original tubarium is preserved in three dimensions; important information on graptolite structure can be obtained from this type of material. Pyrite infilling/replacement of graptolites can produce three-dimensionally preserved specimens, and is known in strata from a variety of ages and palaeocontinents (e.g. Spjeldnaes, 1973; Bjerreskov, 1991; Mitchell et al., 2007; Blackett et al., 2009; Snelling et al., 2010). Pyrite-filled graptolite specimens can replicate the original structures of the tubarium, and thus are valuable in the study of graptolite taxonomy.

Many excellently-preserved pyritized steinkerns (internal moulds) of graptolites were collected during recent field work in South China, including specimens with "pits/dimples aligned in a row or two rows appearing at the proximal end of the interthecal line" (in Mu, 1949, page 140) as reported by Mu et al. (1993) from Middle and Upper Ordovician successions in South China. This structure is so distinctive that several species— *Amplexograptus hubeiensis* Mu and Lin, in Mu et al., 1993, *Pseudoclimacograptus chiai* (Mu, 1949), *Pseudoclimacograptus arcanus* Lin, in Mu et al., 1993 and *Pseudoclimacograptus yilingensis* Mu and Lin, in Mu et al. 1993—were erected mainly on the basis of this character on pyritized specimens. These species may be junior synonyms of *Styractograptus putillus*, but until now there has not been sufficient evidence to confirm or refute this hypothesis; thus, a detailed study of these structures is much needed. As there is a large density difference between the pyritized specimens and the surrounding rock, the material is suitable for non-destructive micro-computed tomography (micro-CT) scanning. We performed micro-CT reconstruction of pit-bearing graptolite steinkerns; the results provide new evidence on the taxonomic classification of these graptolites.

Materials and methods

The specimens used in this study were collected from the Upper Ordovician Wufeng Formation in the Daheba section, Yongshun County, Hunan Province, South China (Fig. 1). The micro-CT scans were performed on a Bruker-microCT system SkyScan 1172F at the State Key Laboratory of Biogeology and Environmental Geology, China University of Geosciences, Wuhan, China. Analysis and reconstruction of tomographic slices was performed using Avizo fire (v. 8.1.1). The imaged specimens are permanently deposited in the Laboratory of Palaeontology, School of Geosciences and Info-Physics, Central South University, Changsha, China.

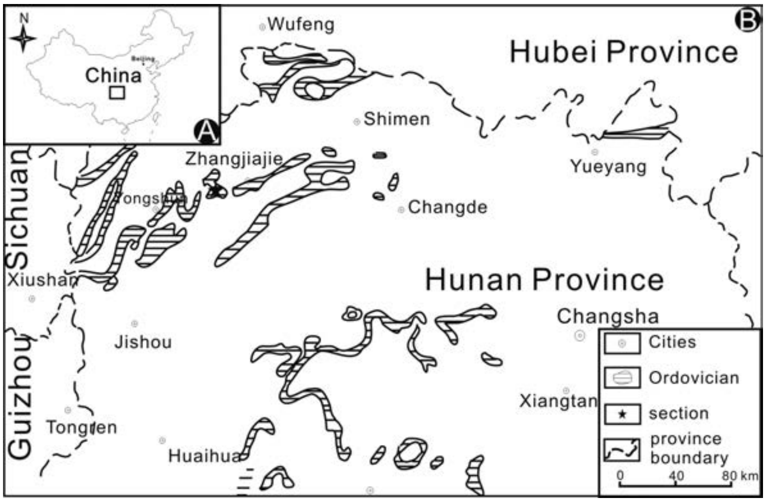

Fig. 1. Location of the study area within China (A) and a map of the study area in Hunan Province (B) showing the distribution of Ordovician outcrops, with the position of the Daheba section indicated by the black star.

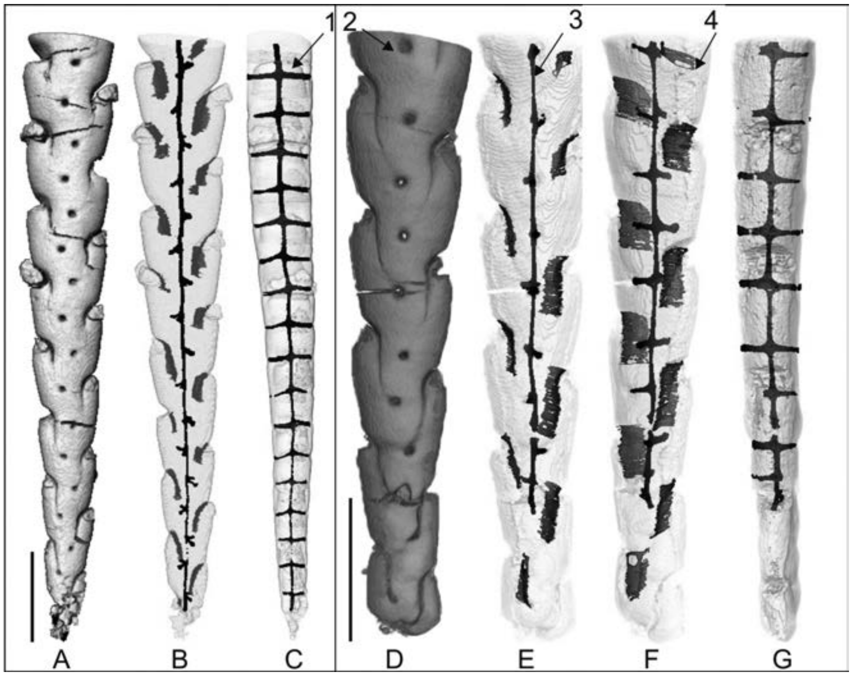

Fig. 2. *Styracograptus putillus* (Hall, 1865).
A, D – Micro-CT reconstruction, note the pits (2) in the internal mould of graptolite in obverse (D) view; B, E–F – Reconstructions of internal structures, including internal cross-bars (1) joined to the central nema (3) with transparent tubarium (light gray) and interthecal septa (4); C, G – scalariform-view reconstruction of internal cross-bars; Specimen number: CSU 10047, CSU10165; Scale bars in A–C and D–G represent 1 mm. Rounded masses of pyrite extend from the apertures of almost all thecae (A). Such masses were not detected in other graptolites from the same beds, and so are not part of the "normal" preservational style in this rock. These structures may reflect a higher content of pyrite in this specimen.

Results

Pea-shaped pits in internal pyritized moulds are distributed in two parallel lines proximally and in one line distally (Fig. 2). The pits, which can only be observed in pyrite-filled specimens, represent the surface expression of the junction between the lateral walls and the isolated thickened internal cross-bars that support the nema (Goldman et al., 2011). Other internal structures visible in the micro-CT reconstructions can thus be identified as the interthecal septa and nema (Fig. 2).

In some graptolites, the aboral list together with the cross-bars (also termed lists, Bulman, 1970, Figs 46-2) can form a horizontal ring through which the next theca emerges. However, connection of the aboral list and the crossbars in the interior of the tubarium has not been observed in the present internal-mould specimens. In the reconstruction, no thickening (aboral list) at the beginning of each interthecal septum is present. In the first two thecal pairs, the pits are connected to the beginning of each interthecal septum above a pattern E astogeny (Fig. 2D). It is still uncertain whether there is no "ring" connecting the interthecal septa and cross-bars, or the ring is too weak to be observed, as in some isolated specimens illustrated by Štorch et al. (2011, Fig. 17C, H) and Goldman et al. (2011, Fig. 1H). However, it is certain that these specimens with pits cannot be attributed to *Styracograptus*, which bears cross-bars but also possesses a pattern D astogeny.

Cross-bars are not confined to advanced climacograptoids (*Climacograptus, Styracograptus* and *Appendispinograptus*), but are also present in more derived 'amplexograptid'-like species; thus, there is parallelism in structural details. This may result from constructional restrictions of the graptolite tubarium.

Conclusions

Pits in pyritized graptolite steinkerns recovered from the Upper Ordovician Wufeng Formation correspond to subtle cross-bars in the original tubarium, which extended into the tubarium as cross-bars connected to the nema. The studied specimens, which possess both pits and pattern E astogeny, can be separated from *Styracograptus*. Further investigation of the taxonomy of these graptolites is required.

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NEW DATA ON ORDOVICIAN–SILURIAN BOUNDARY OF THE WESTERN SLOPE OF SOUTH URALS, RUSSIA

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Key words: *Ordovician, Silurian, isotopy, biostratigraphy, graptolites, South Urals.*

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New data on graptolites and carbon isotopes from the Ordovician-Silurian boundary in the carbonate-terrigenous section of the West-Zilair Zone of the Southern Urals are presented. According to carbon isotopes, the dolomites of the Nabiullino Formation in the Nabiullino-3 section belong to the upper part of the Hirnantian Stage. At the base of the overlying Yuzhno-Baynazar dolomites, an assemblage of presumably Hirnantian graptolites has been discovered. This allows re-consideration of previously assumed Silurian (Llandovery) succession as the uppermost Ordovician.

The Ordovician and Silurian of the South Urals western slope were studied since 1930-s. There are two types of key section: siliciclastic-carbonate unit in the West-Zilair Zone, and clastic-siliceous in the East-Zilair Zone and Uraltau. By the early 1960s the Late Ordovician – Early Silurian sedimentation in the region was thought to be a continuous. A regional stratigraphic scheme, created by this time (Ozhiganov, 1955; Krauze, Maslov, 1961) was followed by the Regional stratigraphic scheme of the Urals (Stratigraphic Schemes, 1993). According to both schemes, the Ordovician – Silurian boundary coincide with the level of lithological changes from carbonates to fine siliciclastics. The subsequent study of the Uraltau sections and finds of conodonts and chitinozoans have changed the age estimations of a number of formations (Chibrikova, Olli, 1997; Yakupov, 2008; Mavrinskaya, Yakupov, 2016). However, a position of the Ordovician-Silurian boundary on the western slope of the Southern Urals have not been changed for a long time: it was traditionally suggested according to lithology. The boundary position was not sufficiently supported by fauna. In the last decade a detailed study of well-known Ordovician-Silurian boundary sections and search for a new ones were actively carried out in order to determine the Silurian lower boundary in the region (Fig. 1).

The Nabiullino section is the most complete and well exposed section of the Upper Ordovician and Lower Silurian. It is the Nabiullino Formation stratotype, known since the 1940s. (Fig. 1). Studies of conodonts and carbon isotopes (d^{13}C) in two cross-sections of this extensive outcrop, allowed us to define the Hirnantian age of the carbonates, underlying the siliciclastic part of the section (Mavrinskaya, Yakupov, 2016; Yakupov, 2018). The Hirnantian deposits here are c. 7–8 m thick and comprise dolomitic limestones and dolomites. Their Hirnantian age was confirmed by conodonts *Gamachignathus ensifer*, as well as by a well-defined positive δ^{13}C anomaly, which is comparable to the well-known HICE anomaly (Yakupov et al., 2018).

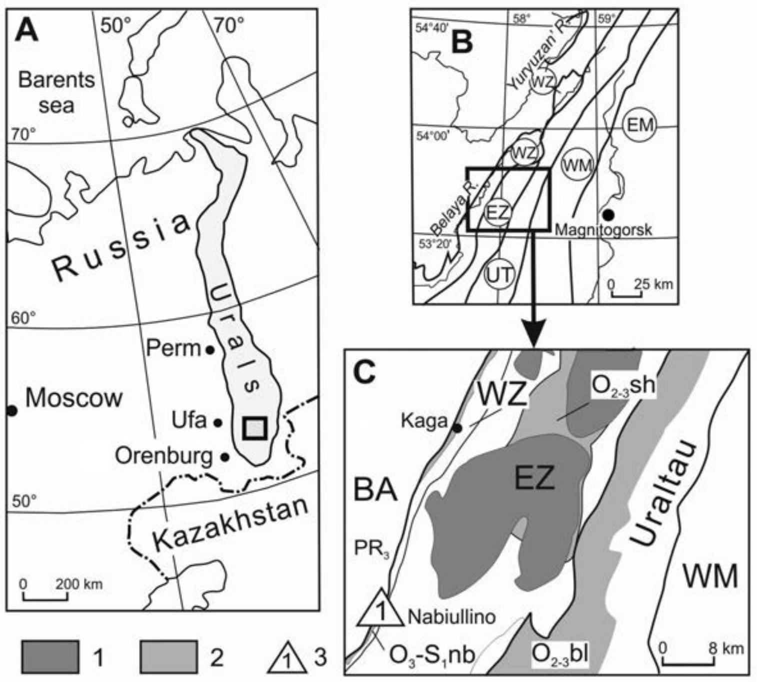


Fig. 1. Section location and geological sketch map.
A – geographical location of the study area; B – fragment of the structural zoning scheme; C – geological scheme. WZ – West Zilair Zone; EZ – East Zilair Zone; UT – Uraltau Zone; WM – West Magnitogorsk Zone. 1 – Kraka ultramafic Massifs; 2 – Ordovician; 3 – Nabiullino section.

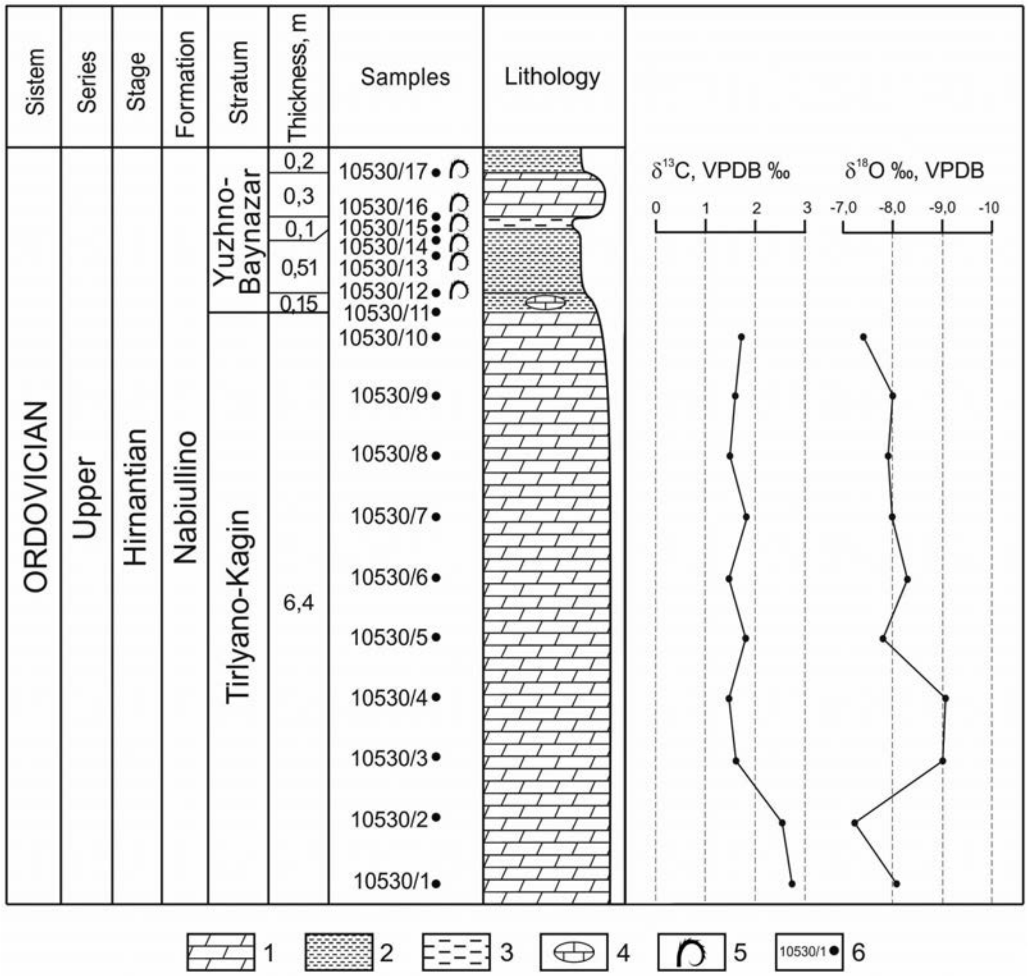


Fig. 2. Stratigraphy of the Nabiullino-3 section, δ^{13}C curve.
1 – dolomites and dolomitic sandstones; 2 – siltstones; 3 – black mudstones; 4 – carbonate lens; 5 – graptolites; 6 – sample numbers.

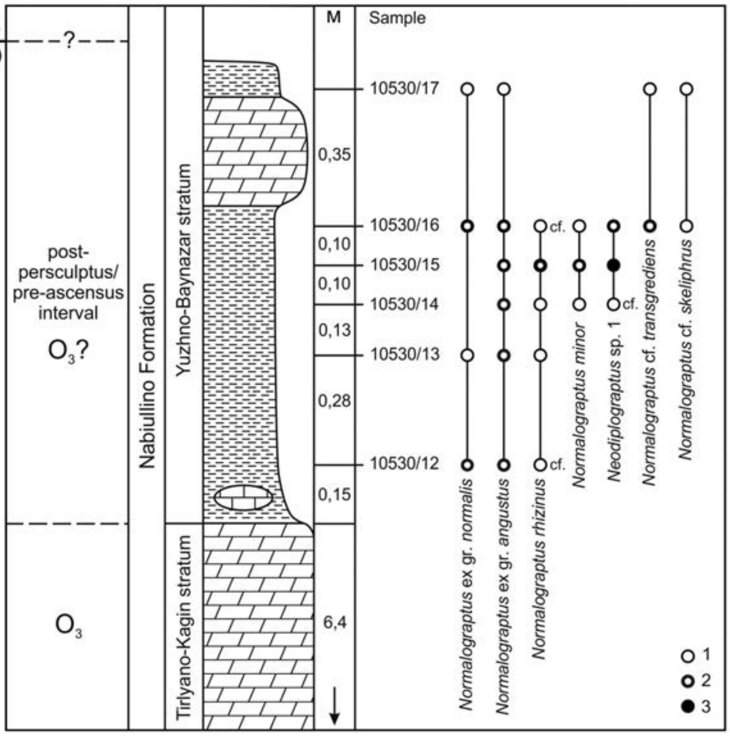
The lithology of Hirnantian carbonates of the Nabiullino section, with inherent horizontal stratification, combined with a large ("hammocky") type indicate their deposition at depths from below a basis of wave activity to a level of storm waves (50–100 m).

In the Nabiullino cross-section 1, the top of the Hirnantian is covered by a 2.5-meter thick soil layer, above which occur the clastic-carbonate sediments bearing the Llandovery graptolites (determinations by T. Koren' in Krause, Maslov, 1961; Yakupov et al., 2002). Thus, the exact position of the Ordovician-Silurian boundary in this section remains unclear. In 2018 field season, the Ordovician-Silurian transition interval was studied in a new outcrop – Nabiullino-3. The new well-exposed and sub-horizontal section is located 100 m up the slope of the stratotype of the Nabiullino Formation. Unlike sections 1 and 2, the contact of the upper part of the Ordovician dolomites (Tirlyano-Kagin stratum) with the overlapping graptolite-bearing siltstone (Yuzhno-Baynazar stratum) crops out here. A bed of carbonaceous-siliceous siltstone 1.1 m as thick conformably overlies massive dolomites (6.5 m thick). The dolomite part of the section has been sampled for microfossils, C isotopes and geochemistry (sample 10530 / 1-10530 / 10); graptolites were collected in siltstones (sample 10530/ 12-10530/17) (Fig. 2).

Since microfossils in the dolomites have not yet been detected, an attempt was undertaken to correlate it with the main Nabiullino section using δ^{13}C data. Upwards the section the δ^{13}C plunges consistently down in the upper part of the dolomite sequence from 2.69 % (sample 15030/1) to 1.75 % (sample 10530 / 10) at the contact with the overlapping siliceous-clastic bed (Fig. 2). Taking into account the data on the Nabiullino-1 section, where the HICE event is truncated in its upwardly trend (Yakupov, 2018), it can be assumed that the Nabiullino-3 section contains the trend lower part. Thus, the new section expands the sequence-studied range, unexposed the Nabiullino-1 and -2 sections and shows a direct transition from the uppermost Ordovician to the Silurian deposits.

From siltstones overlying the dolomites we sampled six graptolites-bearing specimens. Graptolites are relatively numerous, flattened, their preservation is complicated by linear deformation. In the deformed graptolite colonies, the sizes and proportions are distorted, making exact diagnostics difficult. From one level (sample 10530/15) a layer with abundant graptolites has been found.

Fig. 3. Distribution of graptolite taxa in Nabiullino-3 section.
1 – Graptolites are rare, 2 – numerous, 3 – abundant. See Legend on the fig. 2.



The graptolite assemblages is dominated by normalograptids: *Normalograptus angustus* (Perner), *N.* ex gr. *normalis* (Lapw.), *N. rhizinus* (Li et Yang), *N. minor* (Huang), *N.* cf. *transgrediens* (Waern), *N.* cf. *skeliphrus* Koren’ et Melchin. A thin interval (0.1 m) contains abundant *Neodiplograptus* sp. 1. Severe deformation complicates the study of its morphological features; it might be a new species characteristic to this region, bloomed in a short time interval (Figs 3, 4).

The studied graptolite fauna does not include species that are typical only to the Hirnantian. At the same time an unambiguously Silurian taxa marking basal Akidograptus ascensus Biozone are also absent. *N. rhizinus* and *N. minor* are stratigraphically significant species typical of the upper Hirnantian, but they also known to associate with early akidograptids in the lowermost Silurian (Storch et al., 2018). *N. skeliphrus* and *N. transgrediens* are species that are not widely distributed. *N. skeliphrus* is described from the N. lubricus Biozone (below appearance of akidogaptids) in Uzbekistan (Koren ‘, Melchin, 2000). *N. transgrediens* is found above and below of akidogaptids in some regions. Both species are present in the pre–ascensus interval (avitus s.s. Fauna) in Sweden (Koren’ et al., 2003), which is very similar to the Nabiullino by taxonomic composition of the graptolite assemblages. The age of the studied graptolite assemblages is defined as the “post-persculptus/pre-ascensus interval” and is tentatively attributed to the Hirnantian stage of the Upper Ordovician.

By now, the transitional graptolite assemblages are recognized at the Ordovician-Silurian boundary interval in many

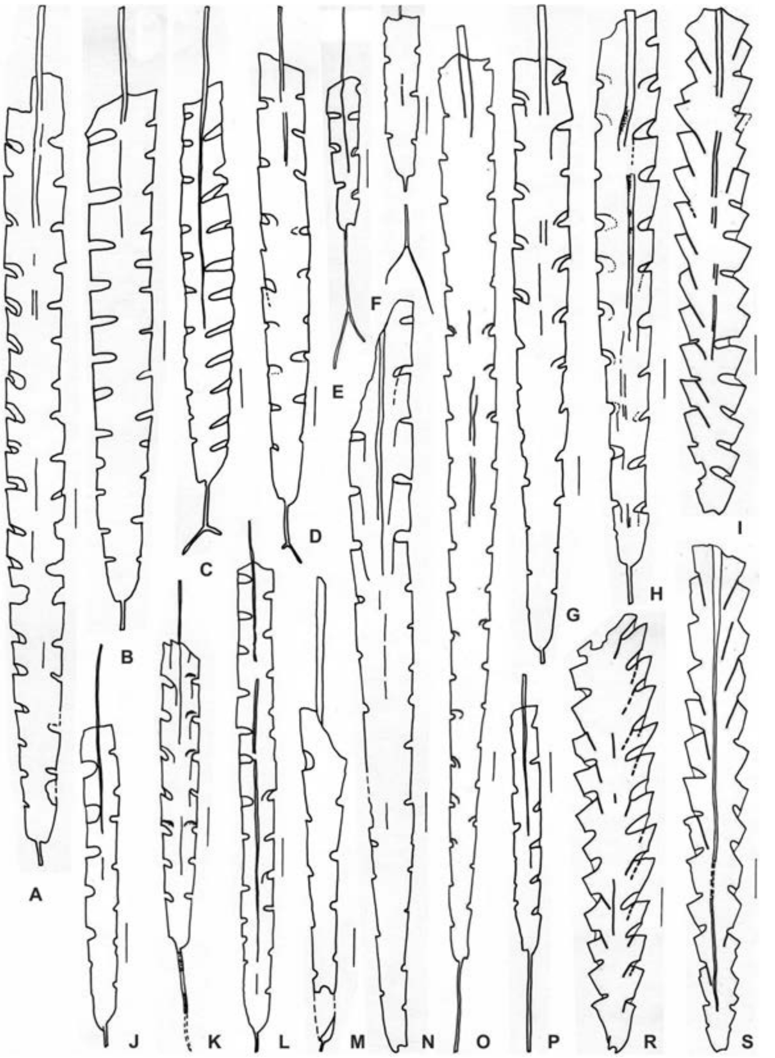


Fig. 4. Graptolites from Nabiullino-3 section, the post-persculptus/pre-ascensus interval, Hirnantian(?).
A-B – *Normalograptus* ex gr. *normalis* (Lapw.); **C-F** – *Normalograptus minor* (Huang); **G-H** – *Normalograptus* cf. *transgrediens* (Waern); **I, R-S** – *Neodiplograptus* sp. 1; **J-L** – *Normalograptus angustus* (Perner); **M-O** – *Normalograptus rhizinus* (Li et Yang); **P** – *Normalograptus* cf. *skeliphrus* Koren ‘et Melchin. Skale bar represent 1 mm.

regions of the World (China, Uzbekistan, Sweden, Spain, Mauritania, Iran, Arctic Canada, Taimyr, etc.). The presence of a transition period in the evolution of graptoloids after extinction of *Metabolograptus persculptus* and before the appearance of akidograptid fauna is confirmed by a numerous date. However, this interval does not yet have an official status and an approved stratigraphic position relative to the systems boundary, thus for researchers it is often difficult to determine its age, especially in absence of akidograptids. The interval has a small thickness (up to 3 m) and is not always observed in a section, which may be related to sedimentation conditions, geological structure of a particular section, etc. (Storch et al., 2018, p. 16). A small thickness of the shale transitional part of the Nabiullino-3 section (1.1 m) and the graptolite assemblages, suggest that the Silurian boundary is stratigraphically higher the studied interval.

Thus, a detailed, comprehensive study of the Nabiullino-3 section showed: (1) the mudstones at the base of the Yuzhno-Baynazar stratum contain a transitional graptolite assemblage, presumably of the Hirnantian age; (2) carbon isotope data allow to assign dolomites to the Upper Hirnantian; (3) the Silurian boundary is assumed to be stratigraphically higher the studied interval and is not associated with a change in the lithology; (4) the age interval of the Silurian (Llandovery) Yuzhno-Baynazar stratum may be extended to include the Upper Ordovician.

The obtained results allow to suggest a new position of the Ordovician-Silurian boundary and reconsider a stratigraphic volume of some Silurian strata in the West Zilair Zone in the Southern Urals. It is necessary to continue studies of the Nabiullino sections as well as the other promising sections in order to establish an exact position of the Ordovician–Silurian boundary in the region.

This is a contribution to IGCP 653 project.

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UPPER LOWER TREMADOCIAN (LOWER ORDOVICIAN) CONODONTS FROM THE UPPER YELI FORMATION OF DAYANCHA, JILIN PROVINCE, NORTH CHINA

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Key words: *upper lower Tremadocian, conodonts, Yeli Formation, Dayangcha, North China.*

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Lower Ordovician (mid-Tremadocian) conodonts are recorded from carbonate sedimentary rocks of the Yeli Formation in eastern North China. The low-latitude Cambro-Ordovician carbonate sediments accumulated on the platform next to the continental margin of eastern North China. The conodont fauna briefly presented here is recovered from the Xiaoliaohuangdi section (42°03′17″N, 126°42′13″E), Dayangcha, Baishan city, Jilin Province, NE China, which is situated along the national road from Dayangcha to Wangou, which is ca. 400 m SSE of the famous Xiaoyangqiao section (Fig. 1).

The Yeli Formation comprises two lithological units: Unit 1 is composed of limestone and limestone breccia, and Unit 2 interbedded shale-limestone with minor silt and sandstone beds. The units represent two depositional intervals that reflect cyclic changes of the shallow water platform sedimentation and deeper water shale deposition. The Yeli Formation overlies the ‘Dayangcha beds’, which are exposed at the famous Xiaoyangqiao section with the Cambrian-Ordovician Boundary transition (Chen, 1986; Wang et al., 2019), and is overlain by the Liangchiashan Formation.

Chen and Gong (1986) recorded conodonts from the lower carbonate unit of the Yeli Formation within the district and assigned this lower carbonate unit to the *Cordylodus angulatus-Chosonodina herfurthi* conodont Zone. The conodont zonation for North China, which was established previously by An et al. (1983), is not applied here as Wang et al. (2016) have revised it. Within the district the zonation of Chen and Gong (1986) is not followed, but revised to consist of the *Cordylodus angulatus* conodont Zone and the *Chosonodina herfurthi* conodont Zone. The two interbedded shale-limestone intervals of the Yeli

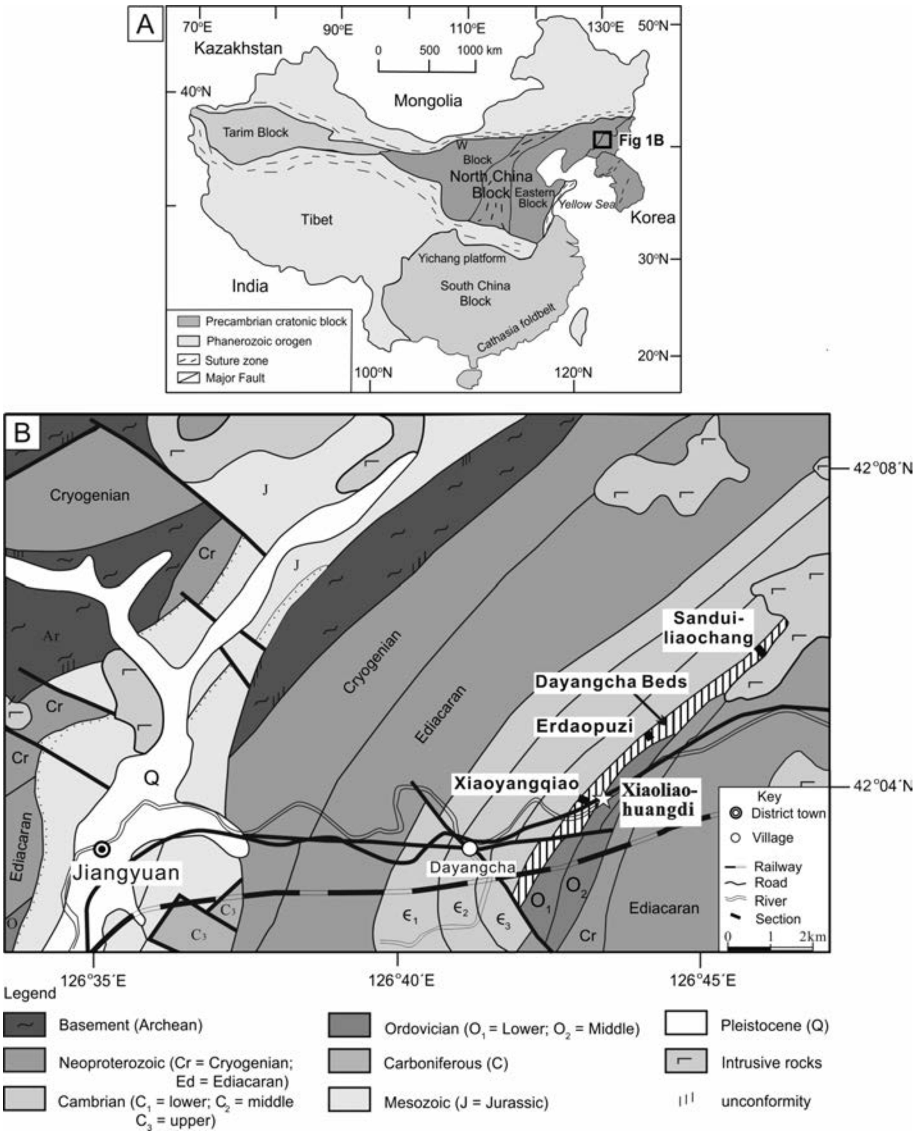

Fig. 1. A. Simplified tectonic map of the three main China plates (Tarim, North China and South China). B. Geological and location map of the study area (modified from Wang et al., 2019).

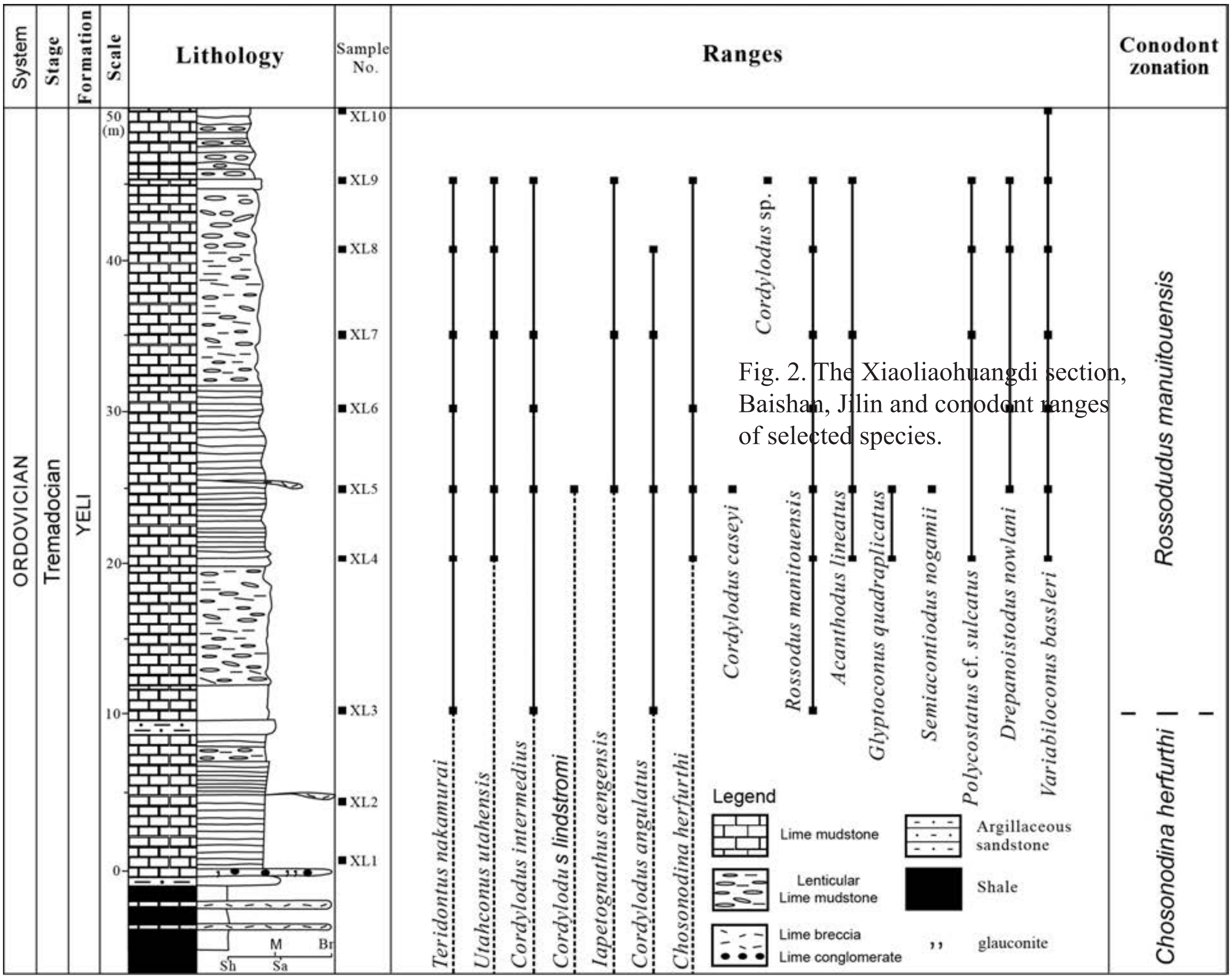

Fig. 2. The Xiaoliaohuangdi section, Baishan, Jilin and conodont ranges of selected species.

Formation contain important graptolite species, and the *Psigraptus jacksoni* Zone is identified from the lower shale-limestone unit and the *Aorograptus victoriae* graptolite Zone is present in the upper shale-limestone unit (Zhang and Erdtmann 2006).

The newly recovered conodont fauna recorded from 10 limestone samples were collected from the upper carbonate unit of the Yeli Formation at the Xiaoliaohuangdi section. The conodont specimens are well preserved (CAI = 2–3), representing a diverse fauna and both diagnostic and characteristic taxa are recorded (Figs 2, 3).

The conodont fauna includes a.o. *Acanthodus uncinatus* Furnish (Fig. 3H), *Chosonodina herfurthi* Müller (Fig. 3L, M), *Cordylodus angulatus* Pander (Fig. 3B), *C. caseyi* (Fig. 3C), *C. intermedius*, Furnish (Fig. 3A), *Cordylodus* sp. A., *Drepanoistodus nowlani* Ji and Barnes (Fig. 3F), *Glyptoconus quadraplicatus* (Branson and Mehl) (Fig. 3H), *Iapetognathus aengensis* (Lindström) (Fig. 3D), *Laurentoscandodus triangularis* (Furnish), *Rossodus manitouensis* Repetski and Ethington (Fig. 3N–P, U-V), *Utahconus utahensis* (Miller) (Fig. 3J, K) and *Variabiliconus bassleri* (Furnish) (Fig. 3S, T). The first appearance in the section of the eponymous species *R. manitouensis* is in sample XL-03, 10 m above the base (Fig. 2), and it ranges to the top of the limestone unit. The conodont fauna clearly represents the *Rossodus manitouensis* conodont Zone. (Abbreviations used for grainsize: M = lime mudstone; Br = lime breccia and conglomerate; Sh = shale; Si = siltstone)

The common occurrence of conodonts and graptolites recorded in the district suggest that the *Chosonodina herfurthi* conodont Zone corresponds largely to the *Psigraptus jacksoni* graptolite Zone and the *Aorograptus victoriae* graptolite Zone corresponds to the *Rossodus manitouensis* conodont Zone (mid-Tremadocian).

Ethington and Clark (1971) named the same assemblage Fauna C from USA and considered it characteristic of the Midcontinent ‘Province’. Today and internationally, the *R. manitouensis* fauna allows a precise correlation with other regions such as South China, Malaysia, North America, Argentina and Australia and the index species is known from widely distributed locations representing low latitude shallow water deposition. This depositional and palaeogeographic setting is in perfect agreement with the conodont fauna recorded from the Yeli Formation of eastern North China.

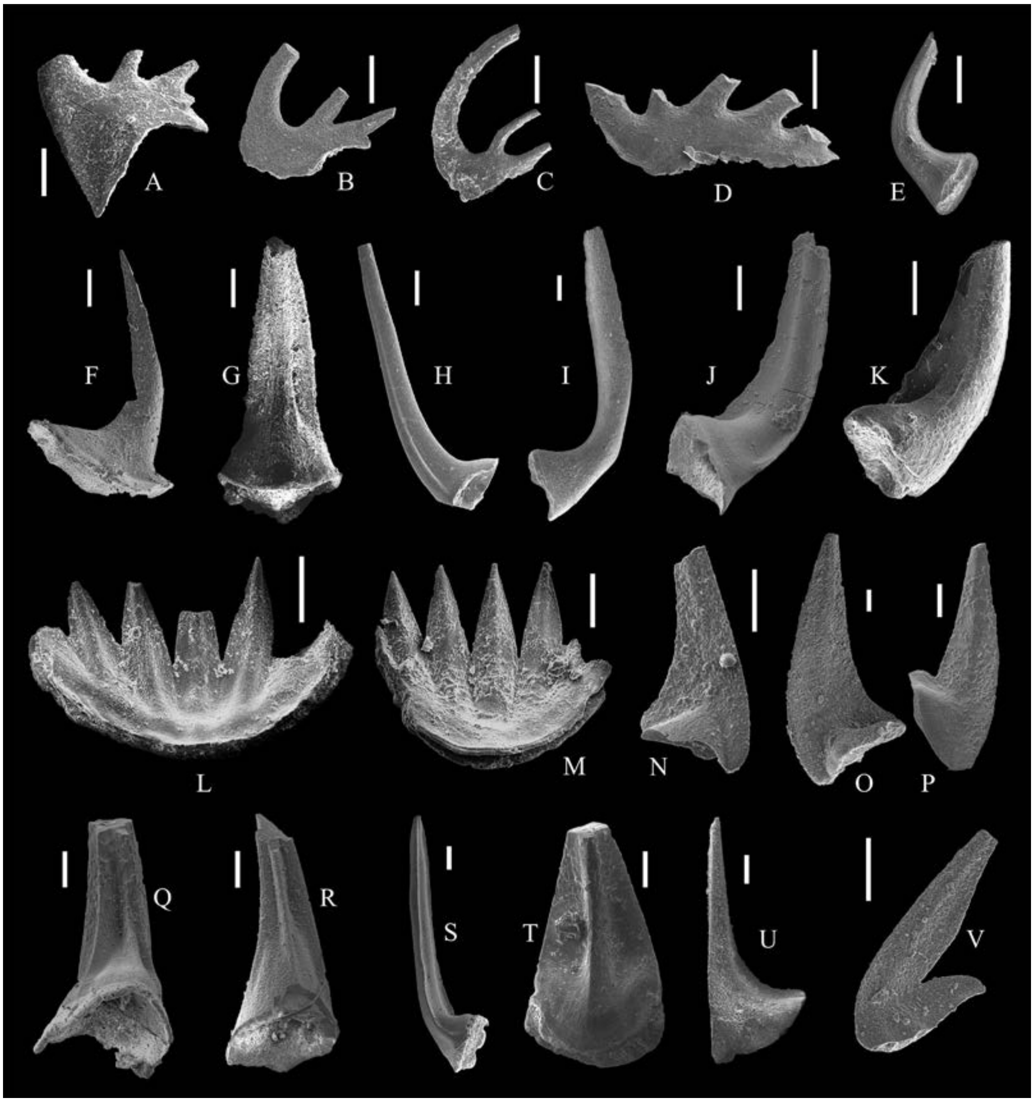

Fig. 3. SEM photos of conodonts from the (mid-Tremadocian (Lower Ordovician) Yeli Formation, exposed at the Xiaoliaohuangdi section.

A – *Cordylodus intermedius* Furnish; lateral view, sample XL03, 1901XL004. **B – *Cordylodus angulatus*** Pander; lateral view, sample XL05, 1901XL042. **C – *Cordylodus caseyi*** Druce and Jones; lateral view, sample XL03, 1901XL043. **D – *Iapetognathus aengensis*** (Lindström); lateral view, sample XL09, 1902XL026. **E – *Teridontus nakamurai*** (Nogami); lateral view, sample XL05, 1901XL064. **F – *Drepanoistodus nowlani*** Ji and Barnes (*pars*); lateral view, sample XL06, 1901XL029. **G – *Semiacontiodus nogamii*** Miller *sensu* Ji and Barnes; posterior view, sample XL05, 1901XL051. **H – *Glyptoconus quadraplicatus*** (Branson and Mehl); lateral view, sample XL05, 1901XL058. **I – *Acanthodus lineatus*** Furnish; lateral view, sample XL05, 1901XL061. **J, K – *Utahconus utahensis*** (Miller); lateral view, sample XL09 and XL05, 1902XL030 and 1901XL046. **L, M – *Chosonodina herfurthi*** Müller; lateral view, samples XL05 and XL09, 1901XL038 and 1902XL023. **N–P, U-V – *Rossodus manitouensis*** Repetski and Ethington; lateral views, samples XL06, XL07, XL08, XL08 and XL05, 1901XL026 1901XL026 1901XL026, 1902XL005 and 1901XL026. **Q-R – *Polycostatus* cf. *sulcatus*** (Furnish) *sensu* Ji and Barnes, posterior view, samples XL09 and XL08, 1902XL014 and 1902XL041. **S-T – *Variabiloconus bassleri*** (Furnish), posterior and lateral view, samples XL05 and XL09, 1901XL048 and 1902XL028. Scale bars represent 100 µm. All specimens are kept in the collections of the Wuhan Center of China Geological Survey, Wuhan, Hubei Province, P.R. China.

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TREMADOCIAN ACRITARCH ASSEMBLAGES FROM SOUTH CHINA: BIOSTRATIGRAPHIC AND PALAEOGEOGRAPHIC IMPLICATIONS

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The Great Ordovician Biodiversification Event (GOBE) is one of the most significant radiations of marine organisms during Earth history, showing a rapid increase in biodiversity. As the representative of primary producer of the marine trophic chain in the Palaeozoic, acritarchs increased its biodiversity and disparity rapidly during the Ordovician and probably indicated the onset of the 'Ordovician Plankton Revolution' took place in the late Cambrian – Tremadocian (Servais et al., 2016).

Most Ordovician acritarch assemblages described from South China concentrated on the Floian to Darriwilian (e.g. Li, 1987; Xu, 2001; Tongiorgi et al., 2003). Only few researches have been done on Tremadocian acritarch assemblages of South China, such as Fang (1986), Hu (1986), Yin (1995), Wang et al., (2013). Seven sections have been restudied or studied from South China that represents different lithological facies herein.

The Xiangshuidong section yields the Nantsinkuan, Fenhsiang, Hunghuayuan, Zitai, Kuniutan and Pagoda formations in ascending order representing Ordovician sediments. Our materials from the Nantsinkuan and Fenhsiang formations attributed to the Tremadocian. The acritarch assemblage of the Nantsinkuan Formation consists of 39 species assigned to 26 genera, dominated by *Cymatiogalea*, *Polygonium* and *Aryballomorpha*. The acritarch assemblage of the Fenhsiang Formation is composed of 35 species attributed to 22 genera, and is dominated by *Lophosphaeridium*, *Polygonium*, *Cymatiogalea*/*Stelliferidium* and *Peteinosphaeridium*. The Tremadocian acritarch assemblages yield 50 species assigned to 32 genera.

A series samples collected from the Tangchi Formation in Liujiang section, Luquan and Erchun section, Kunming. The acritarch assemblages contain 31 species assigned to 25 genera and is dominated by *Leiosphaeridia*, *Dactylofusa velifera*, *Rhopaliophora* and *Pterospermella*.

43 species attributed to 22 genera acritarchs are identified from the Early Ordovician Fenghsiang Formation in the Gudongkou section, Xingshan, Hubei province, South China. The assemblage is dominated by *Polygonium*, *Rhopaliophora* and *Stelliferidium* and their relative abundant reaches 78.4 % in total. Three samples also collected from the Fenghsiang Formation in the Jianyangping section, Xingshan, which about 10km south to the Gudongkou section. Almost no acritarchs have been found from the Jianyangping section.

Another two sections are the Huanghuachang and Daping (Chenjiahe) sections. 18 species assigned to 12 genera acritarchs have been identified from the Huanghuachang section in the Fenghsiang Formation and this assemblage is dominated by *Comasphaeridium* and *Leiosphaeridia*. The acritarch assemblage yields 35 species attributed to 19 genera, dominated by *Leiosphaeridia*, *Stelliferidium* and *Polygonium* in the Fenghsiang Formation.

Servais et al. (2018) selected 19 acritarch taxon to review their stratigraphic implications. According to the conodonts biostratigraphic results (Wu, pers. comm., 2019), the Nantsinkuan Formation represented sediments of the upper most Tr1 to Tr2 (Bergström et al. 2009) or 1b (Webby et al., 2004) and the Fenghsiang Formation represented sediments of the Tr3 or 1c and 1d. Our new materials should update some taxon FADs in South China or even worldwide. *Rhopaliophora* was first found in the Nantsinkuan Formation which was younger than the previous presence in South China, and probably also presents its global FADs. *Coryphidium* is also first present in the Nantsinkuan Formation and presents its global FADs. Although without the graptolite and conodont biostratigraphic control, the present of *Arbusculidium filamentosum*, *Aureotesta clathrata* var. *simplex*, *Coryphidium* cf. *elegans*, *Dactylofusa velifera*, *Dasydorus cirritus* and *Rhopaliophora* together with trilobite (Luo et al., 2014) implied that the Tangchi Formation probaly represent the sediment of the Upper Tremadocian (1d)-Middle Floian (2b).

Volkova (1997) defined a warm-water acritarchs assemblage by presents of *Aryballomopha-Athbascaella-Lua*, and absence of diacromopha acritarchs, including acritarch assemblages of North America and North China. In resent years, several acritarch assemblage with *Aryballomopha-Athbascaella-Lua* have been found in Australia (Foster and

Wicander, 2016). We recognized *Aryballomopha-Athbascaella-Lua* in the Xiangshuidong section with *Coryphidium* and diacromopha acritarchs that possibly shows a mixed acritarch assemblage in South China during Tremadocian.

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COLD TONGUE: ENGINE OF THE GREAT ORDOVICIAN BIODIVERSIFICATION EVENT IN SOUTH CHINA

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There is a phenomenon that has been puzzling geologists for generations in South China. During the Early Ordovician, the geological record in South China refers to a warm or even hot environmental background (Zhang, 1962; Lai, 1982; Chen et al., 1995). Dolomites, various kinds of microbialites including stromatolites, oolites, oncolites, and even evaporites developed extensively on the vast area of the Yangtze Platform for more than 3000 km from east to west and more than 800 km from north to south (Chen et al., 2001). Within these rocks are typical warm water benthic shelly faunas discovered, such as the *Finkelburgia* fauna, the *Tritoechia* fauna, and the *Sinorthis* fauna (Rong Jiayu *in* Chen et al., 1995). Starting from the Darriwilian (late Middle Ordovician), those warm water deposits disappeared completely in South China, and instead cool water sediments became widespread, such as the Pagoda Limestone, typical cool water carbonate with abundant and regularly distributed meandering network structure (Zhan et al., 2016). Microbialites, oolites and oncolites were replaced by metazoan shell beds, burrows or even reefs. The brachiopod *Foliomena* fauna (middle Sandbian-late Katian), a typical cool and deep/deeper water benthic fauna (Rong et al., 1999), became widespread everywhere on the Yangtze Platform, or even in the world. The *Saucrorthis* fauna (before the *Foliomena* fauna) and the *Altaethyrella* fauna (after) are both typical regional brachiopod faunas representing the second and the third diversity acmes of the Ordovician brachiopod radiation in South China (Zhan and Cocks, 1998; Zhan and Jin, 2008; Zhan et al., 2013, 2014). All of which are cool water brachiopod faunas. But, it is commonly accepted that, commencing from the beginning to the end of the Ordovician Period, South China paleoplate was moving northward from the middle latitude (about 30-40°S) to the equator along the eastern margin of the Gondwana supercontinent. It was straddling the equator during the Hirnantian (late Late Ordovician). So, the puzzle is that the latitude of South China became lower and lower to the equator while the geological (including biological) records indicating a reverse trend from warm to cool or even cold environmental backgrounds (Jin et al., 2018).

To tackle this puzzle, we introduce the concept of cold tongue. This is a usage in modern climatology, i.e. the cold water mass forming in the Antarctic zone, sinking into the sea, moving northward along the west coast of South America, and emerging to the water surface in the equatorial eastern Pacific, behaving as a tongue shaped cold current. Just such cold tongue affects the global climate including the El-Nino and La Nina, and makes the Galapagos Islands, exactly in the area of the cold tongue, a diversity hot spot of the world (James, 1997). We assume that the ice cap started near the south pole during the Middle Ordovician, and the cold water mass had formed then, sunk into the sea and moved northward along the eastern coast of the Gondwana supercontinent, just like today's South America. South China paleoplate, a typical peri-Gondwana terrane moving northward gradually during the entire Ordovician (Cocks and Torsvik, 2013; Torsvid and Cocks, 2017), was just in the way of the cold water mass, making it cooling down ahead of the global trend. This is also why the Great Ordovician Biodiversification Event (GOBE) in South China was much ahead of the global trend. And South China was behaving as a diversity hot spot during the GOBE with many taxa having their earliest known occurrences here covering all major fossil groups like brachiopods, trilobites, graptolites, etc. (Zhan et al., 2013).

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PALEOGEOGRAPHIC EVOLUTION OF SOUTH CHINA IN THE ORDOVICIAN AND ITS RELATIONSHIP WITH BIODIVERSIFICATION EVENT

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Key words: *GOBE, paleobiogeography, biodiversity, correlation analysis, TIN polygon.*

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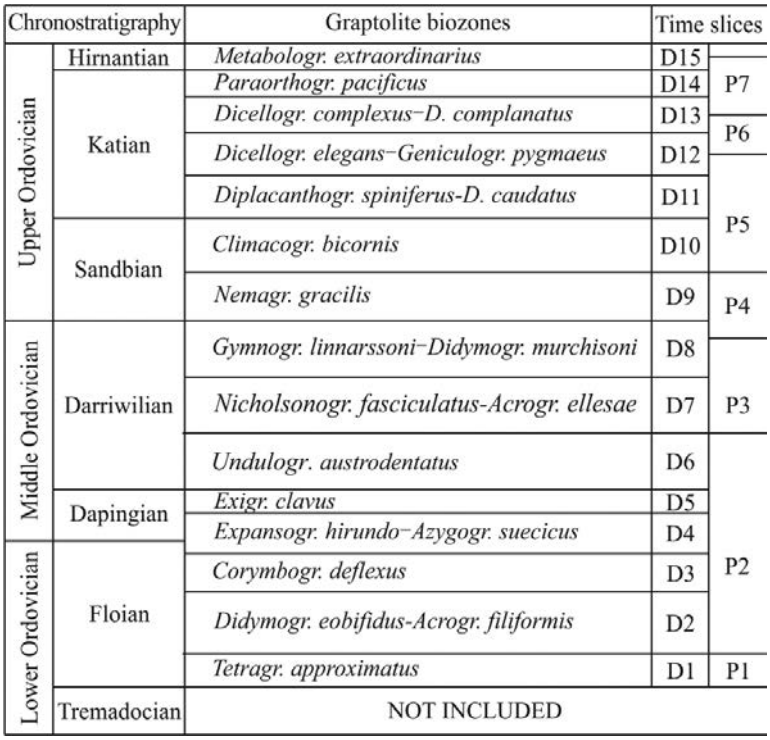
1. Introduction

The great Ordovician biodiversification event (GOBE; Webby et al., 2004) is one of the most significant biological radiation events during the Phanerozoic, which was remarkably well recorded in South China and indicated by several major marine fossil groups. It not only presented a stepped increase in biodiversity at different taxonomic levels, but also affected the paleobiogeographic evolutionary pattern and the marine ecosystem (Servais et al., 2009; Zhan et al., 2013). Previous studies mostly focused on marine biodiversity changes during the GOBE, but rarely on the paleobiogeographic evolution. In the presented study, we calculated the distribution area of seven fossil groups through the Ordovician in South China and examined the relationship between biodiversity and paleobiogeography during the GOBE.

2. Data and methods

Based on the time slices designed by Webby et al. (2004) and the graptolite biozones recognized in South China (Zhang and Chen, 2003; Chen et al., 2006), we divide the time interval from Floian to Hirnantian (Ordovician) into fifteen time slices for the estimation of biodiversity (D1-D15 in Fig. 1), which correspond to seven time intervals for paleogeographic reconstruction (P1-P7 in Fig. 1). The Tremadocian was not included due to the scarcity of fossil records and poor biostratigraphical constraint in South China.

In Chen's paper (Chen et al., 2019), the biodiversity of seven fossil groups (graptolite, conodont, chitinozoan, acritarch, brachiopod, trilobite and bivalve) from D1 to D15 have been calculated. Here we mainly discussed the backgrounds of paleogeography and paleobiogeography through Ordovician in South China. Seven litho-paleogeographic maps were reconstructed over intervals from Floian to Hirnantian (P1-P7), and each of them was based on more than 300 sections. Some characteristic parameters of the lithofacies were calculated based on these maps, including the number of facies types, the evenness of distribution areas of different facies, and the percentage of distribution areas of carbonate rocks (Chen et al., 2019). The distribution area of seven fossil groups are indicated by total distribution area of litho-stratigraphic units that yielded corresponding taxon in order to avoid the incompleteness of the fossil records. After that, correlation analysis were made using the PAST software among the biodiversity, lithofacies (paleogeography) and paleobiogeography to study their relationships during the biodiversification event.



Chronostratigraphy		Graptolite biozones	Time slices	
Upper Ordovician	Hirnantian	*Metabologr. extraordinarius*	D15	
	Katian	*Paraorthogr. pacificus*	D14	P7
		Dicellogr. complexus–D. complanatus	D13	P6
		Dicellogr. elegans–Geniculogr. pygmaeus	D12	
		Diplacanthogr. spiniferus-D. caudatus	D11	P5
	Sandbian	*Climacogr. bicornis*	D10	
		Nemagr. gracilis	D9	P4
Middle Ordovician	Darriwilian	*Gymnogr. linnarssoni–Didymogr. murchisoni*	D8	P3
		Nicholsonogr. fasciculatus-Acrogr. ellesae	D7	
		Undulogr. austrodentatus	D6	P2
	Dapingian	*Exigr. clavus*	D5	
		Expansogr. hirundo–Azygogr. suecicus	D4	
Lower Ordovician	Floian	*Corymbogr. deflexus*	D3	
		Didymogr. eobifidus-Acrogr. filiformis	D2	
		Tetragr. approximatus	D1	P1
	Tremadocian	NOT INCLUDED		

Fig. 1. Time slices for biodiversity estimation (D1-D15) and paleogeographic reconstruction (P1-P7) in South China (modified from Chen et al., 2019).

3. Paleogeography and paleobiogeography

In time slice P1, South China showed a typical “platform-slope-basin” paleogeographic pattern, i.e. Yangtze platform, Jiangnan Slope and Zhujiang Basin. The Yangtze platform was mainly covered by carbonate rocks and yielded abundant shelly fossils. The Jiangnan Slope was mainly deposited with shale and siltstone, and yielded a mixed biofacies of graptolites and shelly fossils. The Zhujiang Basin was deposited with black siliceous and carbonaceous shale and slate with abundant graptolites. In time slice P2, it showed apparent changes in the platform, which was deposited with the mixture of carbonate rocks and clastic rocks with mixed biofacies of graptolites and shelly fossils. In time slice P3, the Yangtze Platform was mostly deposited with carbonate rocks again, with abundant shelly fossils. In time slice P4, the lands in the southwestern Yangtze Platform gradually expanded and connected. Carbonate rocks were widely distributed on the Yangtze Platform with two black shale depressions embedded in it. The strata of the slope and basin were similar with P3, which were still deposited with graptolite-bearing clastic rocks. In time slice P5, the Yangtze Platform was deposited with the Pagoda limestone contained abundant cephalopods. In time slice P6, the Yangtze Platform still deposited with carbonate rocks with shelly fossils, while the sediments of Jiangnan Slope changed from nodular limestone to calcareous mudstone with shelly fossils, but Zhujiang Basin was deposited with flysch strata of sandstone, siltstone and shale with a few graptolites. In time slice P7, the “platform-slope-basin” paleogeographic pattern of South China were completely destroyed (Chen et al., 2018), it became a semi-enclosed, limited, anoxic sea with a series of lands surrounded. The Yangtze Platform was deposited with the Wufeng black shales with abundant graptolites, and there were two local depressions remained to the south of the platform, which were deposited with thick, nearshore clastic rocks with few fossils.

4. Calculation and correlation analysis

According to the curves of geographic distribution of these fossil groups (Fig.2), their distribution areas were not always increased, but constantly fluctuated, just like their biodiversity curves (see in Chen et al., 2009), which was clearly influenced by the lithofacies. We can see that distribution areas of graptolites, chitinozoans and acritarchs obviously decreased from D7 to D12, when South China was mainly deposited with the Pagoda and some other carbonate rocks. After that, their distribution areas increased sharply with the appearance of the Wufeng clastic rocks from D13 to D15, while the distribution areas of the other four fossil groups decreased conversely.

The correlation analysis shows that the types of lithofacies is highly positive correlated with the diversities (Chen et al., 2019) and geographic distribution of pelagic organisms, while the evenness of lithofacies influenc the

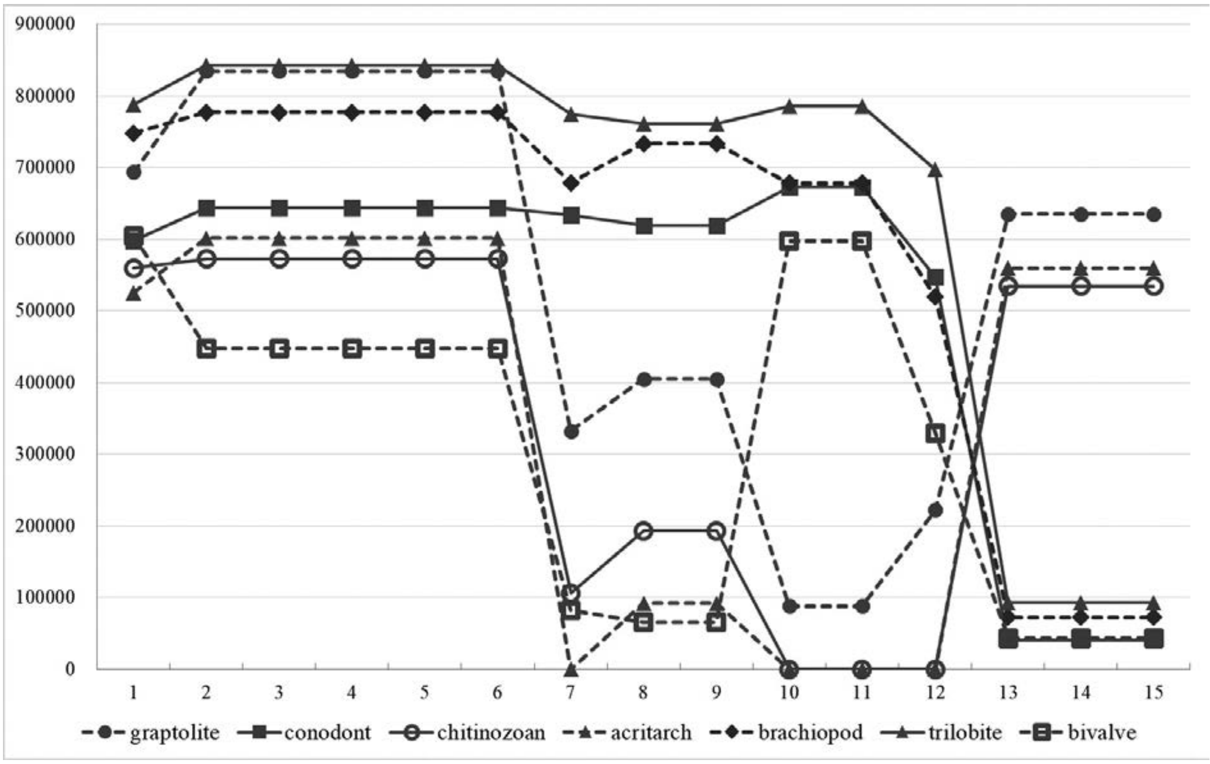


Fig. 2. Geographic dynamic of the major fossil groups during the GOBE

benthic organisms more intensively (Table). It seems possible that the increasing types of lithofacies in the Ordovician suggested the diversification of hydrodynamic and hydrochemical conditions, which created more pelagic habitats for higher biodiversity and geographic distribution. On the other hand, the higher evenness of lithofacies indicated more diversified living and sedimentary environments, which might benefit the living and bury for marine benthic organisms. The percentage of the distribution areas with carbonate rocks has a strongly positive correlation with distribution area of fossil groups (conodonts, brachiopods, trilobites, and bivalves) that are mainly preserved in limestones, and is weekly or negatively correlated with the distribution area of fossils that are not preserved in limestones.

Table

Correlation coefficients among lithofacies paleogeographic parameters and paleobiogeographic distribution areas of major fossil groups

lithofacies	Paleobiogeography								
	Gr	Co	Ch	Ac	Br	Tr	Bi	Pe	Be
N	0.71	0.46	0.99	0.77	0.32	0.53	-0.57	0.87	0.54
E	0.03	0.62	0.99	0.78	0.47	0.67	0.28	0.34	0.64
C	-0.73	0.75	0.76	0.05	0.92	0.69	0.87	-0.56	0.68

Abbreviations: N=number of formations, indicates types of lithofacies; E=evenness of lithofacies; C=percentage of the distribution areas with carbonate rocks; Gr=graptolite, Co=conodont, Ch=chitinozoan, Ac=acritarch, Br=brachiopod, Tr=trilobite, Bi=bivalve, Pe=pelagic, Be=benthic.

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THE DISCOVERY OF A LATE ORDOVICIAN SHALLOW WATER BRACHIOPOD FAUNA IN WUSHI, NORTHWESTERN TARIM OF XINJIANG, CHINA, AND ITS IMPLICATIONS

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Tarim Basin is one of the largest inland basins of China, lying in the southern part of the Xinjiang Autonomous Region, northwestern China. Most of the Ordovician rocks are covered by desert, whereas some Late Ordovician strata crop out near the southern, northwestern, and northeastern margins of the basin with a very limited distribution.

Late Ordovician is one of the most important time intervals for the brachiopod macroevolution during the Great Ordovician Biodiversification Event (GOBE). Previous investigations reported the distribution of shallow-water brachiopod fauna (i.e. *Altaethyrella* fauna, Sproat and Zhan 2018) and deep-water brachiopod fauna (i.e. *Foliomena* fauna, Zhan et al. 2014; Zhang et al., 2017) in the Kuruktag region, northeastern Tarim.

The studied section lies at Mengdalek (79°20.491'E, 41°09.720'N), about 10 km southeast of Wushi county town, northwestern Tarim. The Upper Ordovician sequence contains greyish green silty mudstones intercalated with thin to medium-bedded silica-rich siltstones, yielding a few brachiopod shells and crinoid fragments. The sequence is overlain by the Lower Carboniferous Mengdalek Formation with an angular unconformity.

Around 40 brachiopod shells were collected from the upper part of the Upper Ordovician. Shells are generally well preserved with two conjoined valves, revealing the *in situ* preserving condition or the limited transporting process before being buried by sediments. After laboratorial shell repairing and serial sectioning, 5 genera are recognized (i.e. *Altaethyrella*, *Christiania*, *Schachriomonia*, *Sowerbyella*, and *Mimella*?). Besides, a unique rhynchonellid brachiopod was identified by detailed serial sectioning and cellulose acetate peel replicating, which is similar to *Altaethyrella* in external morphology but characteristic for the existence of septalium and prominent median septum in its dorsal interior. It might be a representative of the genus *Rhynchotrema*. However, further taxonomical study is still going on.

It is the first report of the Katian (Late Ordovician) *Altaethyrella* fauna in northwestern Tarim, which is characteristic for the brachiopod genus *Altaethyrella*. The fossil assemblage in this region shows a clear affinity with those in South China (e.g. the Sanqushan Formation of JCY area, and the Shiyanhe Formation of Xichuan County), North China (e.g. the Beiguoshan Formation of Longxian County), Qilian Mountains (e.g. the Koumenzi Formation of Menyuan County), northeastern Tarim (the Hadabulatage Formation of Kuruktag region), and different terranes in Kazakhstan, indicating a close paleogeographical relationship among the above regions in Late Ordovician. The *Altaethyrella* fauna has also been well understood to inhabit the shallow marine environment (corresponding to benthic assemblage 3, BA 3) during the Katian (e.g. Sproat and Zhan, 2018).

There is a long debate on the stratigraphic subdivision of the Upper Ordovician in this region. The studied sequence was recognized as the Kalpintag Formation and assigned to early Silurian in age (Zhang et al., 1991). In the nearby Kalpin area, Huang et al. (2009) subdivided the Kalpintag Formation and established a new lithostratigraphic unit in its lower part, i.e. the Tierekeawati Formation. According to chitinozoans, this newly named Tierekeawati Formation is of Katian (Late Ordovician) age (Tang et al., 2012).

The brachiopod fauna reported in this study provides an additional evidence for the age of the Tierekeawati Formation, i.e. Late Ordovician rather than early Silurian. The fauna also indicates that shallow marine depositional environment existed in this region during the Late Ordovician, while the Silurian Kalpintag Formation, containing a sequence of thick-bedded or blocky sandstone, is thought to be deposited in a delta environment.

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AN INTEGRATIVE STRATIGRAPHY FOR THE ORDOVICIAN SYSTEM OF CHINA: FRAMEWORK AND QUESTIONS

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1. Chronostratigraphic framework

The Ordovician System is one of the Phanerozoic systems for which the Global Stratotype Sections and Points (GSSPs) for all of its stages had been established by 2007 (Cooper & Sadler, 2012). The “Three Series and Seven Stages” scheme, i.e. the Lower Ordovician Series (Tremadocian and Floian stages), the Middle Ordovician Series (Dapingian and Darriwilian stages), and the Upper Ordovician Series (Sandbian, Katian and Hirnantian stages), has been widely agreed and adopted, and has significantly improved interregional and intercontinental correlations. In defining the bases of these stages, graptolites and conodonts have played important roles as leading groups, as evidenced by the fact that five of the stages are defined by the first appearance datum (FAD) of a specific graptolite species, and two by FADs of conodont species. Three of the seven approved GSSPs are established in South China, making this block and the paleogeographically adjacent blocks a critical region as a reference standard for the global Ordovician stages (Fig. 1).

The currently adopted Ordovician chronostratigraphic system of China is almost identical to the global official framework, but with some specific differences (Fig. 2). The evolution of the chronostratigraphic system in China has had a long and complex history since the 1920s, when Lee & Chao (1924) first subdivided the Ordovician succession in the Three Gorges area into, in ascending order, the Yichang Limestone, the *Yangtzeella* Bed (the genus was originally called *Triplesia*), and the Pagoda Limestone. Subsequently, the Ordovician System of China underwent either a bipartite or a tripartite subdivision, and commonly was defined differently by different scholars (Zhang et al., 2019). In the 1960s and 1970s, the “Lower Ordovician” corresponded approximately to the Tremadocian to middle Darriwilian of the current scheme, and the “Upper Ordovician” was equal to the upper Katian and Hirnantian. In the 1980s and 1990s, a quinquepartite framework, a modification of the traditional British scheme, was adopted provisionally (Chen et al., 1995), and meanwhile a bipartite subdivision was proposed, with the boundary placed at or near the current base of the Upper Ordovician (Lai & Wang, 1982; Wang et al., 1992). Since the year 2000, the officially approved “Three Series and Six Stages” and later “Three Series and Seven Stages”, defined by GSSPs, have been followed widely. However, a Chinese scheme has been retained in parallel to the global scheme, based on the geological history and characteristics of China, especially South China. The scheme also subdivides the Ordovician into three series and seven stages, but uses the Neichiashanian Stage to represent the Sandbian and lower Katian interval, and the Chientangkiangian Stage for the upper Katian (Fig. 2). The base of the Neichiashanian Stage is defined at the base of the *Nemagraptus gracilis* graptolite Biozone, and the base of the Chientangkiangian Stage at the base of the *Dicellograptus complanatus* graptolite Biozone (roughly

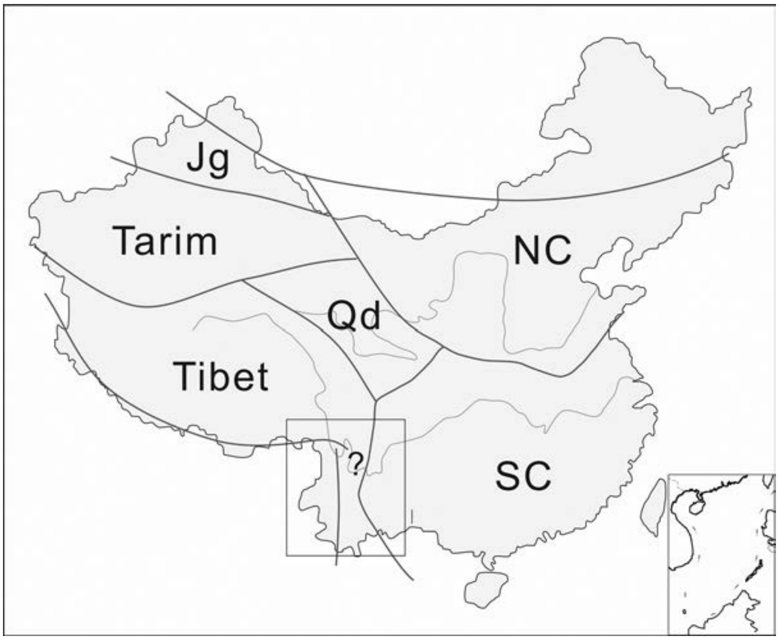

Fig. 1. Major tectonic blocks comprising China. Jg, Junggar; NC, North China; Qd, Qaidam; SC, South China.

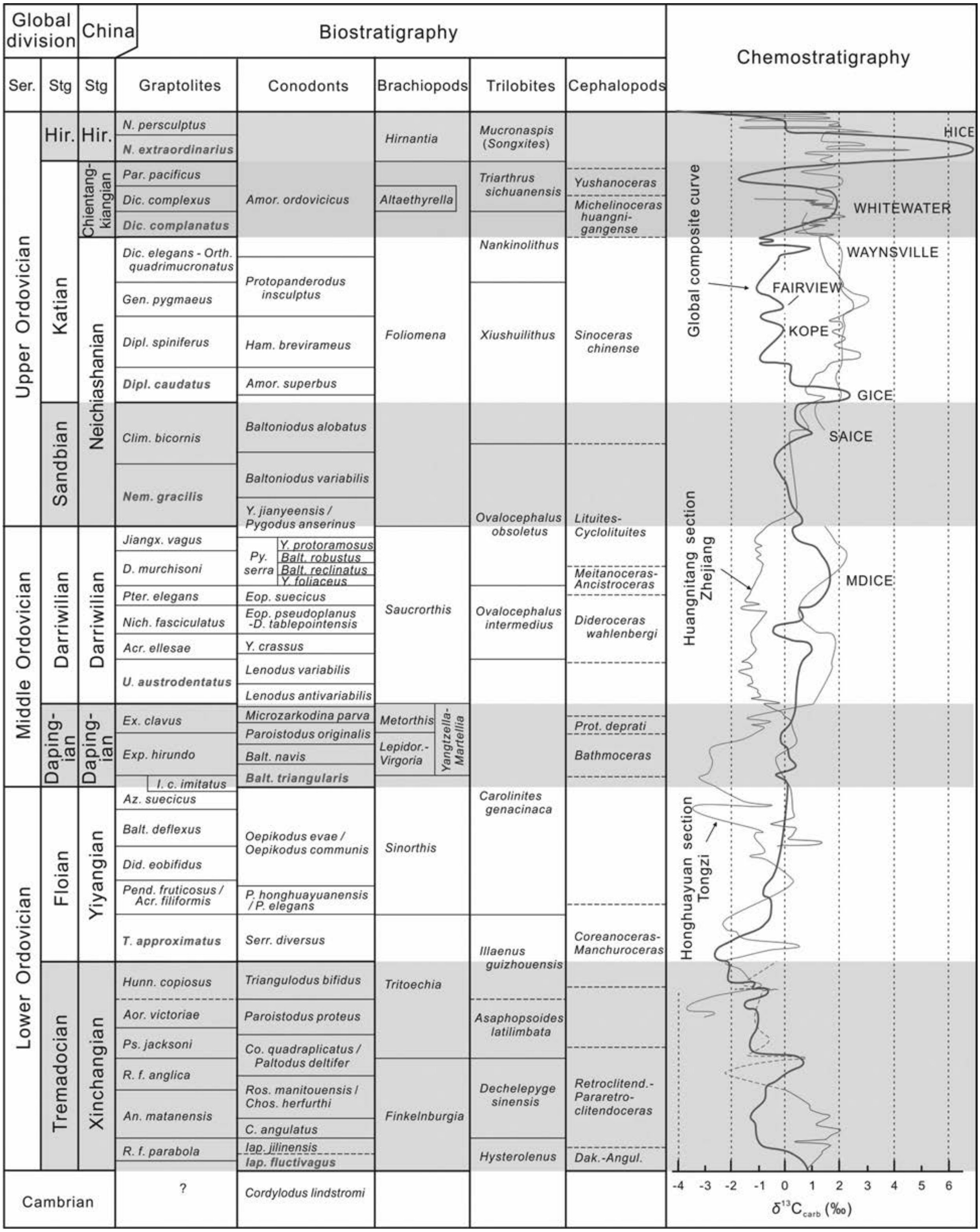

Fig. 2. An integrative stratigraphic framework for the Ordovician of China.

Carbon isotope curves: Global composite curve—Bergström et al. (2009a); Honghuayuan section in Tongzi—Zhang T.G. et al. (2010), Munnecke et al. (2011); Huangnitang section in Changshan—Munnecke et al. (2011).

corresponding to the *Nankinolithus nankinensis* trilobite Biozone). Xinchangian and Yiyangian stages are defined to represent the same intervals as the Tremadocian and Floian stages, respectively.

2. Identifications of basal boundaries for the Tremadocian, Dapingian and Katian stages

Although the global scheme for the Ordovician has been widely adopted in China, there are still considerable difficulties in identifying the basal boundaries of three specific stages, i.e. the Tremadocian, Dapingian and Katian. A precise identification of the base of the Tremadocian is difficult in China, largely due to the rare occurrences of the defining conodont species *Iapetognathus fluctivagus*. In South China, reliable occurrences of *I. fluctivagus* have been recorded only in western Hunan Province of the marginal platform to slope facies (Dong et al., 2004; Dong and Zhang, 2017), and the species has not been reported from anywhere on the Yangtze Platform. In North China, possible *I. fluctivagus* was reported from Wushan of Lulong in Hebei Province and in Qingzhou, Shandong Province (Nicoll et al., 1999; Wu et al., 2005), but these occurrences require further taxonomic confirmation. At the classical Dayangcha section, and at the Zhaogezhuang section, the first occurrence of *Iapetognathus jilinensis* was used to mark the approximate base of the Ordovician System (Wang et al., 2014), but the FAD of this species seems to be significantly higher than that of *I. fluctivagus* (Zhang et al., 2019, Wang et al., 2019).

The base of the Dapingian Stage has been defined at the FAD of the conodont *Baltoniodus triangularis*, with the GSSP at the platform-facies Huanghuachang section. However, the species has not yet been recorded in slope and basinal facies of South China; thus, precise interregional correlation of this boundary would require the use of associated graptolites or chitinozoans.

For the base of the Katian Stage, defined at the FAD of the graptolite *Diplacanthograptus caudatus*, the main problem is the rarity of sections yielding the species in China. Until now, the species has been identified in only three sections: the Longmendong section in Longxian, Shaanxi (Chen et al., 2016); the Shuangjiakou section in Qidong, Hunan (Liu & Fu, 1989a, b); and the Dawangou section in Kalpin, Xinjiang (Chen et al., 2000; Zhang & Munnecke, 2016). For extensive areas of platform facies, this boundary can only be identified approximately by using conodonts from carbonate rocks. The boundary is placed within the upper *Baltoniodus alobatus* Biozone or the basal *Amorphognathus superbus* Biozone in South China (Bergström et al., 2016), and roughly at the base of the *Belodina confluens* conodont Biozone in the platform facies of North China (Zhen et al., 2016) and Tarim (Chen et al., 2016).

3. Carbon isotope curves in the Darriwilian and lower Katian

The Ordovician carbon isotope curves of China largely match the composite curve of Bergström et al. (2009a), especially in the successful recognition of the Guttenberg Isotope Carbon Excursion (GICE; Bergström et al., 2009b; Zhang & Munnecke, 2016) and the Hirnantian Isotope Carbon Excursion (HICE; Fan et al., 2009; Munnecke et al., 2011). However, there are two segments, in the Darriwilian and lower Katian, that exhibit significant deviations from the global composite curve (Zhang et al., 2019). The Darriwilian curve from the slope-facies Huangnitang section displays a largely negative excursion, in which no clear Middle Darriwilian Isotope Carbon Excursion (MDICE) has been identified, but in the Honghuayuan section of the platform facies a probable truncated MDICE was recognized (Zhang TG et al., 2010; Munnecke et al., 2011). For the lower Katian interval, the carbon isotope curves of both the Honghuayuan and Huangnitang sections show significantly prolonged positive excursions relative to the short-lived GICE identified in USA. At the Dawangou section, the identified GICE appears to span the uppermost Sandbian (upper *C. bicornis* Biozone) to the lower Katian (*Diplacanthograptus lanceolatus* Biozone, roughly equivalent to the *D. caudatus* Biozone; Zhang & Munnecke, 2016), and is well correlated to the GICE recognized elsewhere.

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CONODONT BIOSTRATIGRAPHY OF THE HORN VALLEY SILTSTONE, AMADEUS BASIN IN CENTRAL AUSTRALIA

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Key words: *Ordovician, conodonts, Horn Valley Siltstone, Amadeus Basin, Australia.*

Introduction

A diverse conodont fauna represented by some 46 species belonging to 31 genera has recently been documented from the Horn Valley Siltstone of the Amadeus Basin, central Australia (Zhen et al., in press). This study based on a extremely large collection obtained over several decades from numerous outcrop localities and subsurface drillcores has recognized four conodont biozones that indicate an age ranging from latest Tremadocian to Dapingian (or even possibly into earliest Darriwilian) for the Horn Valley Siltstone. These new data provide the basis for precise regional biostratigraphic correlation of Floian (Early Ordovician) and Dapingian (early Middle Ordovician) rocks within the Amadeus Basin and other intracratonic sedimentary basins developed on the eastern Gondwana. Although part of the fauna was previously reported by Cooper (1981), Nicoll (1992), Nicoll & Ethington (2004) and Nicoll & Kelman (2004), the new study represents the first comprehensive revision and documentation of the entire fauna from this well-known stratigraphic unit, which not only yielded a highly diverse Ordovician conodont fauna with excellent preservation, but was also the source of the first Australian conodont record (Crespin, 1943).

Regional geological settings

The Amadeus Basin (Fig. 1) comprises an area (extending approximately 800km EW and 300 km NS) occupying much of the southern Northern Territory and extending westward into Western Australia. The Amadeus Basin has a Palaeo–Mesoproterozoic basement (a complex of igneous and moderately to highly metamorphosed rocks) and a cover consisting of a thick, shallow-marine to terrestrial sedimentary succession (with a maximum preserved thickness of 14,000m) of Neoproterozoic to Late Devonian (or early Carboniferous) age. The basin development and sedimentation of the Amadeus Basin can be summarised as comprising three broad episodes, namely Neoproterozic, Cambrian–Ordovician and Devonian–Carboniferous (Lindsay & Korsch, 1991). The lower Palaeozoic marine shelf deposits are represented by the Ediacaran–Cambrian Pertaoorrta and Cambro-Ordovician Larapinta groups. The Larapinta Group includes five formations, in ascending order the Pacoota Sandstone, Horn Valley Siltstone, Stairway Sandstone, Stokes Siltstone and Carmichael Sandstone, with a maximum total thickness of 2100m. The Horn Valley Siltstone consists of thinly bedded graptolite-bearing siltstone, shale and mudstone with minor limestone, sandstone, sandy siltstone and silty dolostone with a maximum presered thickness of *ca* 422m. Outcrop is generally poor and is commonly confined to strike valleys. Along the present northern margin of the basin, the Horn Valley Siltstone may

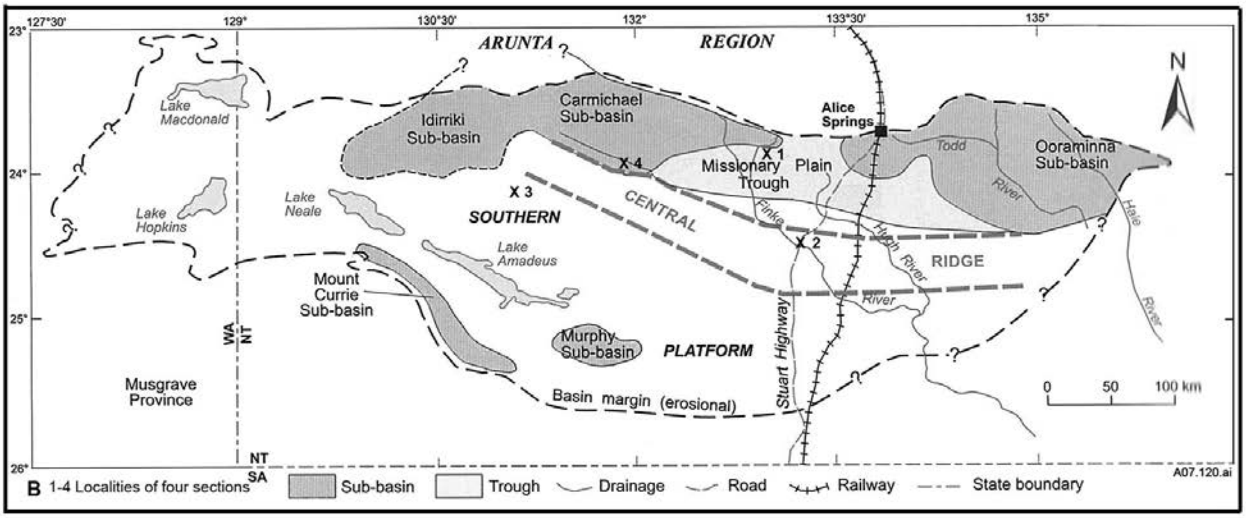

Fig. 1. Locality Map (modified from Edgoose 2013) showing outline of Amadeus Basin and locations of major Horn Valley Siltstone sections sampled for conodonts (1-4).

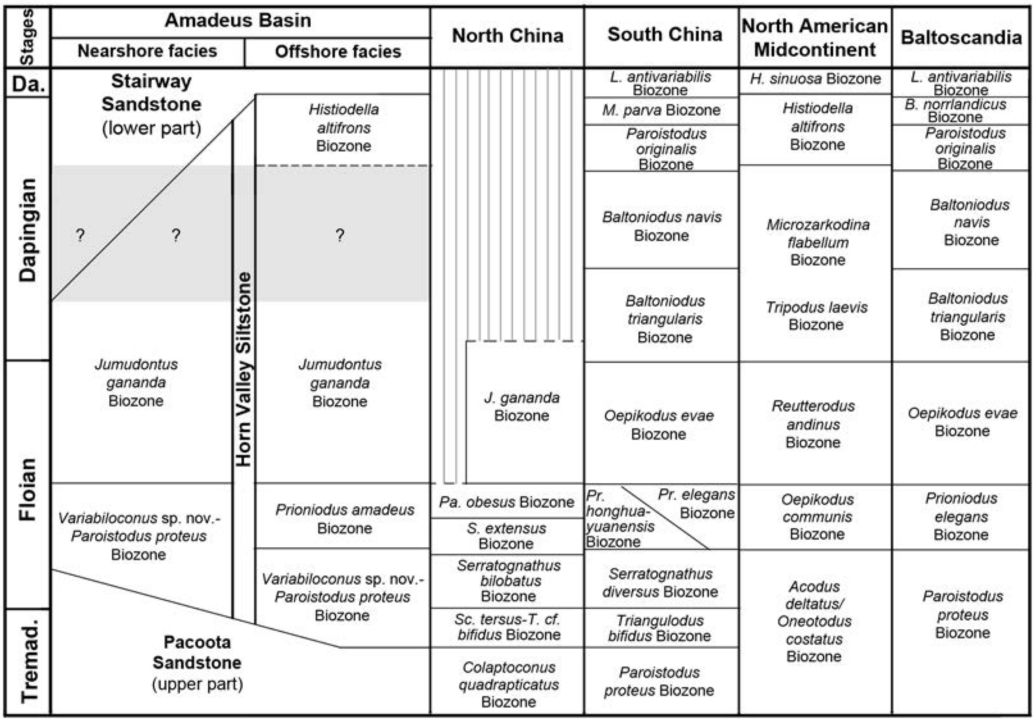

Fig. 2. Conodont biozones recognized from the Horn Vally Siltstone and their correlation with those established in North China, South China, North American Midcontinent and Baltoscandia.
Abbreviations: *B. = Baltoniodus, H. = Histiodella, J. = Jumudontus, L. = Lenodus, M. = Microzarkodina, Pa. = Paraserratognathus, Pr. = Prioniodus, S. = Serratognathus, Sc.= Scalpellodus, T. = Triangulodus.*

be conformable with both the underlying Pacoota Sandstone and the overlying Stairway Sandstone, but in the southern and eastern parts of the basin, it is in unconformable contact relationship with the underlying Pacoota Sandstone and overlying Stairway Sandstone. Lithologically the Horn Valley Siltstone is dominated by beds of shale and siltstone interspersed with fossiliferous coquinas that have a carbonate cement with a low silt component, which may represent storm deposits. The abundance of a mixed shelly biota and the common presence of horizontal burrows suggest that the sedimentary environment was predominantly oxygenated, although intervals of organic-rich black shales imply periods of anoxic conditions. It was mainly deposited in quiet offshore settings, probably in relatively deeper water environments than those of other lithological units of the Larapinta Group.

Conodont biostratigraphy

Four conodont biozones, the *Variabiloconus* sp. nov.–*Paroistodus proteus*, *Prioniodus amadeus*, *Jumudontus gananda* and *Histiodella altifrons* biozones, have been recognized to suggest a maximum age ranging from early Floian (or latest Tremadocian) to earliest Darriwilian for the Horn Valley Siltstone, although in most parts of the basin, only the middle part of the formation, confined to the *P. amadeus* and *J. gananda* biozones of the middle Floian to early Dapingian, is preserved (Fig. 2).

***Variabiloconus* sp. nov.–*Paroistodus proteus* Biozone** contains a distinctive assemblage that consistently occurs in the basal part of the Horn Valley Siltstone. It is characterised by the presence of *Paroistodus proteus*, *Aloxoconus* sp. nov., *Variabiloconus* sp. nov., *Scolopodus multicostatus*, *Scolopodus* sp. cf. S. *striatus* and *Oneotodus* sp. It exhibits strong endemism, being dominated by several new species as well as long-ranging cosmopolitan species such as *D. arcuatus* and *C. longibasis*. The only age-diagnostic species is *P. proteus*, which is a zonal index species characterising the latest Tremadocian to early Floian in the Baltoscandian conodont succession. Therefore this biozone is considered as early Floian and likely ranges from the latest Tremadocian. All 13 species occurring in this biozone of a relatively low diversity are simple coniform species, except for *Bergstroemognathus kirki*.

***Prioniodus amadeus* Biozone** is characterised by the occurrence of the nominal species and can be correlated with the *Prioniodus elegans* Biozone of the Baltoscandian conodont succession and with the *Oepikodus communis* Biozone of the North American Midcontinent succession (Fig. 2). Its base is marked by the First Appearance Datum (FAD) of *Prioniodus amadeus*, which more or less coincides with the first appearances of *Cooperignathus nyinti*, *Cooperignathus aranda*, *Drepanoistodus pitjanti*, *Triangulodus larapintinensis* and *Triangulodus emanuelensis*. Both

C. nyinti and *C. aranda* have a wide distribution in central and eastern Australia, eastern Asia, the Argentine Precordillera and Laurentia. Other distinctive species occurring in this biozone include *Oepikodus communis* and *O. cleftus*, which provide a direct correlation with other middle Floian conodont faunas known from New South Wales, Arafura Basin and Canning Basin in Australia.

Jumudontus gananda **Biozone** is characterized by the occurrence of the nominal species in the middle part of the Horn Valley Siltstone and has age ranging from late Floian to early Dapingian. In the Horn Valley Silstone it succeeds the *P. amadeus* Biozone, with its base marked by the FAD of *J. gananda*. *Jumudontus gananda* is a morphologically distinctive and geographically widely distributed pandemic species, reported from central and eastern Australia, North America, Argentine Precordillera, North China, Greenland and Baltoscandia.

Histiodella altifrons **Biozone** is recorded from the very top of the Horn Valley Siltstone and characterized by the occurrence of the nominal species along with *Histiodella minutiserrata*, *Fahraeusodus* sp., *Jumudontus* sp. and a number of species continuing from the underlying *J. gananda* Biozone. It can correlate to the stratigraphical interval in the Joins Formation of southern Oklahoma corresponding to the upper Dapingian to the basal Darriwilian in the North American Midcontinent conodont succession (*Histiodella altifrons* Biozone, *H. minutiserrata* Biozone, and the basal part of the *H. sinuosa* Biozone; see Bauer, 2010).

Conodont biofacies and palaeobiogeography

Two distinct conodont biofacies, namely the *Erraticodon–Triangulodus* biofacies and the *Periodon–Oepikodus* biofacies have be recognised within the Horn Valley Siltstone (Zhen et al in press), indicating respectively shallow-water nearshore and the low-energy, offshore settings. The former is characterized by domination of the endemic forms present in the unit, while the latter is characterized by the appearance of a number of species of *Periodon*, *Paroistodus*, *Oepikodus* and *Prioniodus* that were predominantly inhabited off-shore to deep-water (Open-Ocean Realm) conditions. The strong endemism of the Horn Valley Siltstone fauna is also demonstrated by the occurrence of a large number of taxa so far only reported from the Amadeus Basin.

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REVISED ORDOVICIAN LITHOSTRATIGRAPHY AND CONODONT BIOSTRATIGRAPHY OF SOUTHERN-CENTRAL XIZANG (TIBET)

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Key words: *Ordovician, conodonts, Himalaya Terrane, Lhasa Terrane, Xizang (Tibet), China.*
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Introduction

Our regional reassessment of the Ordovician stratigraphy and conodont biostratigraphy of southern-central Xizang (Tibet), China has demonstrated urgent needs in clarifying or revising the definitions of several lithostratigraphic units that have been widely but variably used in the scientific literatures and regional geological maps. Misuse and inconsistencies in the stratigraphic nomenclature of these units has unnecessarily complicated our understanding of the regional geological history. Therefore, a clearly defined lithostratigraphy updated with new biostratigraphical data will be crucial in correlating the Ordovician rocks of the Qinghai-Xizang Plateau. The Ordovician lithostratigraphic units redefined include the Chiatsun Group exposed in the Nyalam County of the Himalaya Terrane in southern Xizang, and the Xainza Formation and Keerduo Group in the Xainza region, and the Sangqu Formation in the Zayu region of the Lhasa Terrane in central Xizang (Fig. 1).

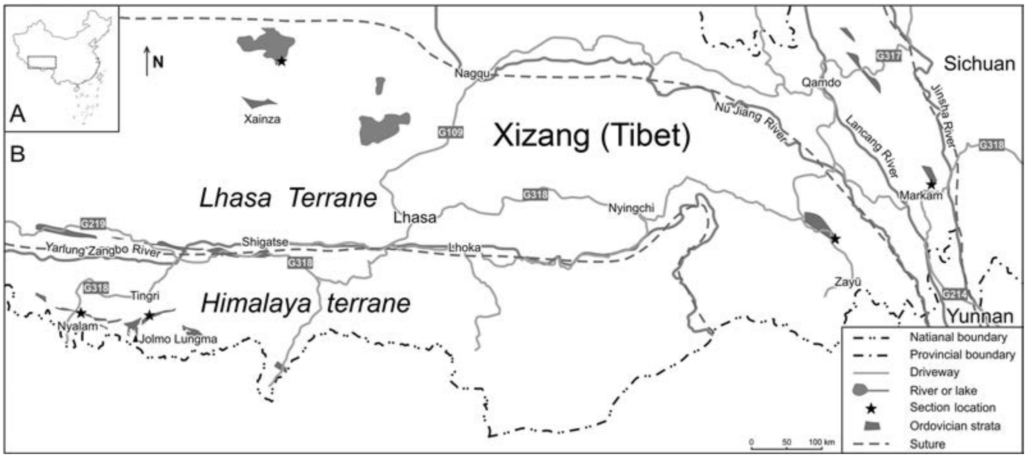

Fig. 1. Location map showing the study areas in southern-central Xizang (Tibet), China.

Revised lithostratigraphy

The Chiatsun Group has been variably used either being subdivided into two formations (Zhan et al., 2014) as originally proposed or substituted by one (e.g. Wang et al., 2014), two (e.g. Lin & Qiu, 1982) or three formations (e.g. Chen, 1984) since its initial recognition by Mu et al. (1973). This stratigraphic unit accommodating the undeformed Ordovician carbonate succession exposed in southern Xizang has now been subdivided into three formations, which can be distinguished from each other by their distinctive and mappable lithological characters. They are, in descending order, the Jiaqu Formation consisting of purple-brownish, thin- to thick-bedded limestone and marlstone (argillaceous limestone), the Alai Formation of the dark-grey or greyish medium- to thick-bedded nautiloid limestone, and the unnamed Lower Formation of medium- to thick-bedded limestone intercalated with thinly bedded sandy limestone, siltstone, sandstone and dolomitic limestone interlayers.

The Xainza Formation was named based on the discovery of the *Hirnantia* fauna and the youngest Ordovician graptolite fauna in the top part of the Gangmusang Formation (Ni et al., 1981). Due to its minor thickness (varying from 14 m to <2.5 m) and difficulties to recognize in the field with a lithology transitional from the underlying Gangmusang Formation to overlying Dewukaxia Formation, it has been variably treated as a valid stratigraphic unit (Ni et al., 1981; Wang et al., 2014) or as part of either Dewukaxia Formation (Qu et al., 2011) or Gangmusang Formation (Zhang et al., 2004). It is considered herein as a separate lithological unit consisting of the upper dark-grey muddy limestone and

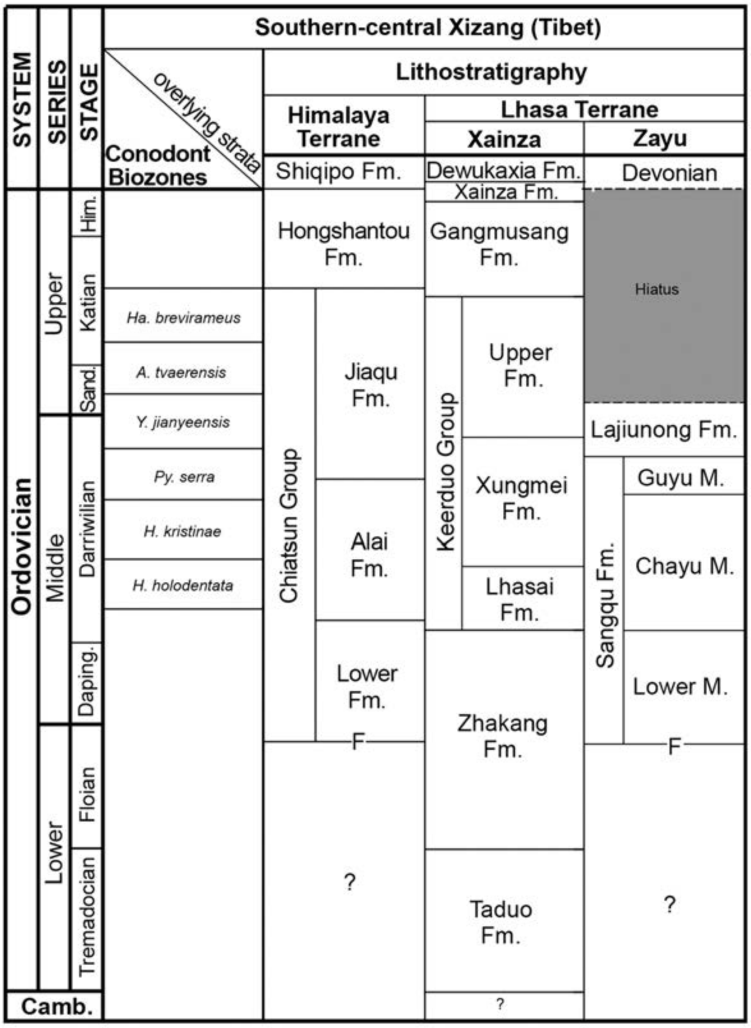

Fig. 2. Lithostratigraphy and conodont biostratigraphy of the Ordovician System in southern-central Xizang (Tibet), China.

lower yellowish calcareous or silty graptolitic mudstone. It is in conformable contact with the overlying graptolitic black shale of the Silurian Dewukaxia Formation and the underlying Ordovician Gangmusang Formation of the mixed siliciclastic-carbonate succession. However, the basal part of the Dewukaxia Formation below the black shale is included herein in the underlying Xainza Formation. Thus, the Ordovician–Silurian boundary is now within the revised Xainza Formation (Fig. 2).

The Keerduo Group was named by Xia (1979) in an unpublished manuscript and was formally introduced in the literature by the Xizang Geological Survey (1980) for the carbonate succession conformably underlying the Gangmusang Formation in the Xainza region. Subsequently it has been widely used as a formation, but with varied lithological definitions. Moreover, several lithological units that are equivalent to parts of the Keerduo Group, e.g. the Xungmei Formation of Chen (1986) and the Lhasai Formation of Zhang (2003), have also been erected from this region, created uncertainty for precise correlation. Therefore, the original definition for the Keerduo Group given by the Xizang Geological Survey (1980) is accepted herein for the carbonate-dominated succession overlying the Zhakang Formation of the weakly to moderately metamorphosed siliciclastic succession and underlying the Gangmusang Formation of the mixed siliciclastic-carbonate succession. The Keerduo Group defined herein can be subdivided into three formations, i.e. the unnamed Upper Formation (=thin-bedded grey limestone with mud stripped limestone of the upper Keerduo Formation defined by Xia, 1983), the Xungmei Formation (=thin- to thick-bedded purple-greyish-green mud stripped limestone of the lower Keerduo Formation defined by Xia, 1983) and the Lhasai Formation (grey-dark grey, thin- to medium-bedded nautiloid bioclastic limestone, micrite and calcirudite) forming the lower part.

The Sangqu Formation was named by Chen et al. (1982) for the Ordovician carbonates exposed in the Zayu County, where it is in fault contact with the Guqin Group (= Bomi Group) of the Neoproterozoic-early Cambrian age and conformably overlain by the Early Devonian red beds. The Chayu and the Guyu formations named by Chen et al. (1986) from the same area are equivalent to the middle and upper part of the Sangqu Formation and treated herein as the two members of the Sangqu Formation (Fig. 2). The upper part (dolomitic limestone and dolostone) of the Gujin Group defined by Chen (1986) is correlative to the lower part of the Sangqu Formation (= unnamed Lower Member), and the lower part (shale, sandstone and quartzite) of the Gujin Group is equivalent to the Guqin Group defined by Chen et al. (1982). Therefore, the Gujin Group is redundant as a junior synonym of the Guqin Group.

Regional biostratigraphic correlation

The stratigraphic age for the Jiaqu and Alai formations of the Chiatsun Group has been confirmed ranging from the middle Katian (the *Hamarodus brevirameus* Biozone) to middle Darriwilian (the *Histiodella holodentata* Biozone), but its Lower Formation is still poorly dated and may extend to Dapingian or even Floian based on nautiloids (Fig. 2). A more complete biostratigraphic succession has been recognized in the Xainza region of the Lhasa Terrane extending from the Hirnantian fauna (brachiopods and graptolites) recovered from the Xainza Formation to the basal Floian graptolite fauna (*Tetragraptus approximatus* Biozone) from the Zhakang Formation. Conodonts of the middle-late Katian age (the *Amorphognathus superbus* Biozone) were recovered from the lower part of the Gangmusang Formation (Qiu, 1988) and conodonts and nautiloids from the Keerduo Group suggested an age ranging from the middle Katian to at least lower Darriwilian. Therefore, the lower Gangmusang Formation and the Keerduo Group in the Xainza region of the Lhasa Terrane can correlate approximately with the Chiatsun Group of the Himalaya Terrane (Fig. 2). Conodonts and other fossil records from the Sangqu Formation of the Zayu region indicated a minimum age of the late Darriwilian (the *Pygodus serra* Biozone) and a maximum age of possibly Floian (Fig. 2).

Acknowledgments

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