



# NEW AND REVISED INANIGUTTID RADIOLARIA AND ASSOCIATED TRILOBITES FROM THE UPPER DARRIWILIAN (ORDOVICIAN) SHUNDY FORMATION OF KAZAKHSTAN

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**ABSTRACT**—Representatives of the family Inaniguttidae dominate a diverse and well-preserved radiolarian assemblage from Kazakhstan. The fauna was extracted from a limestone sample of the Shundy Formation, a limestone sequence that accumulated on the slope of a carbonate platform and which crops out in the Aksuran Mountains (North Balkhash Region). The family Inaniguttidae is represented in the studied assemblage by five genera and 14 species (including two new species, *Triplococcus aksuranensis* and *Inanibigutta maletzi*). The genus *Triplococcus* is particularly abundant, representing half of the Inaniguttids in the studied assemblage. Based on the presence of species *Haplentactinia juncta*, the fauna can be correlated with the upper Darriwilian *Haplentactinia juncta*–*Inanigutta unica* assemblage. Identified trilobites (*Endymionia semielliptica* and *Porterfieldia* sp. aff. *P. delicata*) found in the same sample also suggest a late Darriwilian age, which agrees with the age suggested previously by graptolites.

## INTRODUCTION

KAZAKHSTAN HAS been historically crucial to the understanding of Ordovician Radiolarian biodiversity. A number of localities around Lake Balkhash have yielded relatively well-preserved Radiolaria from Middle–Upper Ordovician carbonate rocks (Nazarov, 1975, 1988; Nazarov et al., 1975, 1977; Nazarov and Popov, 1980; Nazarov and Ormiston, 1993; Danelian and Popov, 2003). Coeval sequences represented by radiolarian cherts (e.g., Scotland: Danelian and Clarkson, 1998; Danelian and Floyd, 2001; China: Buckman and Aitchison, 2001) reveal some species in common, but the assemblages are less diverse, possibly because they are more affected by taphonomic bias. The family Inaniguttidae Nazarov and Ormiston, 1984 represents one of the major faunal components of Ordovician radiolarian assemblages (Nazarov and Ormiston, 1993; Noble and Aitchison, 1995; Noble and Danelian, 2004; Maletz, 2011). Its earliest known representatives date from the early Ordovician (late Dapingian?, Maletz, 2007); the family diversified substantially during the Middle Ordovician (Noble and Danelian, 2004; Maletz, 2011). Although first described nearly 30 years ago (Nazarov and Ormiston, 1984), the family Inaniguttidae is nevertheless still poorly understood in terms of its inner test construction and diversity (see De Wever et al., 2001). This preliminary report on the radiolarians yielded from a carbonate sample from the Shundy Formation in Kazakhstan contains a large number of relatively well-preserved specimens and in some cases allows observation of the most internal parts of the skeleton. This paper focuses essentially on the taxonomic study of Inaniguttidae including the description of two new species and emendation of the genus *Triplococcus* Danelian and Popov, 2003. It also describes the trilobites found at the same level, which provide additional biochronological and paleoenvironmental constraints.

## GEOLOGICAL SETTING

The Kazakhstani mountain belt is a complex agglomerate of pre-Cambrian and lower Paleozoic microplates and

intraoceanic island arc terranes (Yakubchuk, 1990; Zonenshain et al., 1990; Sengör et al., 1993; Popov et al., 2009). The Atasu-Zhamshy region (Popov et al., 2009) is located north-west of Lake Balkhash (Fig. 1). The sedimentary rocks in the area are mainly composed of lower Paleozoic limestones and dolomites exposed in numerous scattered outcrops. These sedimentary sequences accumulated on a carbonate platform, situated on the passive continental margin of a lower Paleozoic microplate (Apollonov, 2000). Outlines of the lower Paleozoic geology and stratigraphy of the area have been published by Alperovich et al. (1971), Pupyshv (1974) and Apollonov et al. (1990).

The Middle to Upper Ordovician (Darriwilian to Sandbian) Shundy Formation, in which radiolarians occur sporadically, represents a carbonate sequence that accumulated in deep-waters, possibly at the base of a slope. The Shundy Formation is divided into four informal stratigraphic units (Fig. 2; Apollonov et al., 1990).

Sample 112 was collected from a locality of the Atasu-Zhamshy Region (N 47°32′40.77″, E 73° 2′47.34″) situated about 1,100 m west-southwest from the Aksuran Mountain (northwest of Lake Balkhash). It was sampled from the pelagic limestones situated in the middle part of Unit 2 of the Shundy Formation.

## MATERIAL AND METHODS

More than 450 specimens were extracted from a black to dark-gray micritic limestone sample after treatment with diluted acetic acid. The sample was crushed into 1–5 cm size blocks and immersed in 30% diluted acetic acid for a maximum of 12 hours. After washing away the acid, the sample residues were sieved through a 50 µm sieve and were mounted on SEM stubs.

Some specimens have been sectioned by using Dumitrica’s method (e.g., De Wever et al., 2001), but very few clear images were obtained, given the fragility of the radiolarian specimens in our material, most of which are highly recrystallized.

Trilobites were collected from the same level as the radiolarian-bearing sample 112.



FIGURE 1—Schematic map of central Kazakhstan indicating the location of the radiolarian and trilobite bearing strata of this study in the Atasu-Zhamshy region (modified after Danelian and Popov, 2003).

All the types described here are housed in the public paleontological collections of the Earth Sciences Department (SN5) of the University of Lille 1 (France).

#### SYSTEMATIC PALEONTOLOGY

RADIOLARIA by L. Pouille and T. Danelian

Family INANIGUTTIDAE Nazarov and Ormiston, 1984

INANIGUTTA Nazarov and Ormiston, 1984

*Remarks.*—The family Inaniguttidae is characterized by spherical radiolarians composed of one or several latticed to irregularly porous concentric cortical shells bearing six or more rod-like spines. Their most internal structure consists of a small hollow sphere (the microsphere) or a polyhedron from which the rod-like outer spines radiate. Following the initial taxonomic scheme of Nazarov and Ormiston (1984), genera in this family are distinguished by two major criteria: the number of shells and the number of outer spines that can range from six to 20. The internal structure of the siliceous skeleton is difficult to decipher as the fragile inner structure is rarely preserved and it is difficult to examine the inner shell and microsphere without breaking the specimen. Moreover, as mentioned by a number of authors (i.e., Maletz, 2011), the number of shells as a genus diagnostic character needs to be re-evaluated as it may also depend on the

ontogenic stage of the specimen. The inner framework was described initially by Nazarov (Nazarov and Ormiston, 1984, 1993; Nazarov, 1988) as an internal structure in the form of a polyhedron that is located in the center of the test. Only a few species with a central skeletal structure in the form of a microsphere have been described so far, such as *Triplococcus acanthicus* Danelian and Popov, 2003, *Inanigutta penrosei* (Ruedemann and Wilson, 1936), *Kalimnasphaera maculosa* Webby and Blom, 1986, *Inanigutta complanata* (Nazarov, 1975) and species belonging to the genus *Plussatispila* MacDonald, 2006 (Danelian and Popov, 2003; MacDonald, 2006; Maletz and Bruton, 2007; Noble and Webby, 2009).

Genus *TRIPLOCOCUS* Danelian and Popov, 2003

2003 *Triplococcus* DANELIAN AND POPOV, p. 333

*Type species.*—*Triplococcus acanthicus* Danelian and Popov, 2003.

*Diagnosis.*—Inaniguttidae composed of three (possibly four) shells placed around a small microsphere from which originate five to 12 outer spines. The latter emerge from the bars of the microsphere as thin spines, becoming thicker rod-like spines from the median shell (second after the microsphere) onwards. Inner

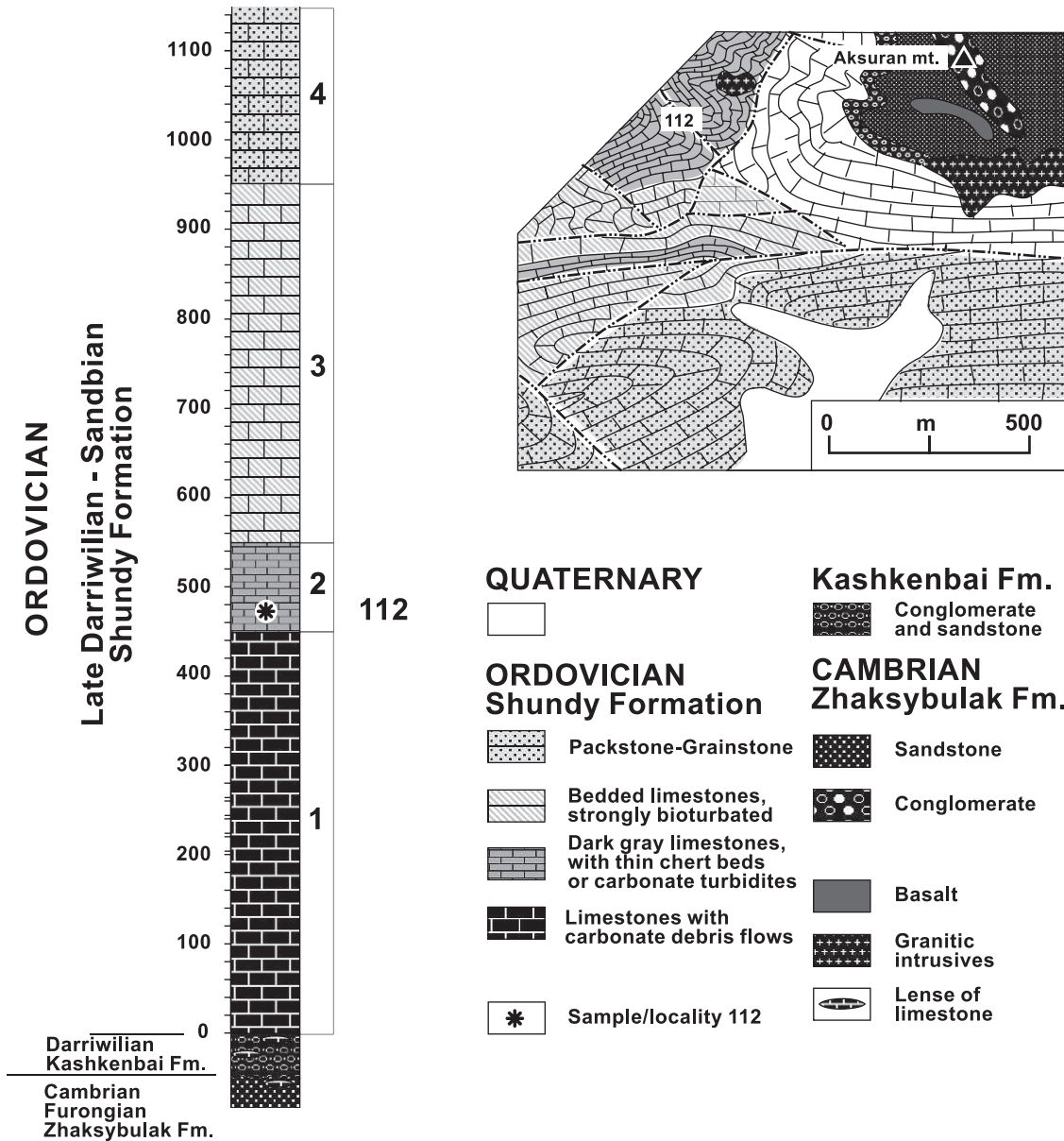


FIGURE 2—Schematic geological map of the Atasu-Zhamshy region (upper right) indicating the location of sample 112 and simplified stratigraphic column of the Shundy Formation (Middle to Upper Ordovician).

and median shells are rather closely spaced. The microsphere and inner shell’s wall structure consist of a thin layer, pierced irregularly, whereas the median and outer shells are regularly perforated. Numerous beams originate either from the surface of the inner or from the median shell. Outer spines may bear some apophyses indicating the possible presence of a fourth shell.

*Occurrence.*—Upper Dapingian? to upper Darriwilian from Kazakhstan, China and Argentina.

*Remarks.*—In the above emended diagnosis the term “microsphere” is used in the sense of Maletz and Bruton (2007) for the innermost hollow sphere ( $\varnothing$ : ~40–55  $\mu\text{m}$ ) that is located in the center of the test. The number of outer spines may be up to 12 (instead of six in the original definition). Beams originate from the surface of the inner or the median shell.

Based on material from the lower Silurian Canadian Arctic, MacDonald (2006) compared *Triplococcus* with *Plussatispila* and he established a number of new species based essentially on the

number of cortical shells: *Plussatispila delicata* MacDonald, 2006 which possesses a microsphere and two additional shells (Fig. 3.9), *Plussatispila cornwallisensis* MacDonald, 2006 for forms with three shells (Fig. 3.11) or *Plussatispila magnilimax* MacDonald, 2006 for forms with four concentric shells (Fig. 3.12).

He distinguished the two genera based on the fact that *Triplococcus* was described as possessing only five or six spines, while *Plussatispila* displays seven or more spines. The material of this study contains specimens with up to 12 spines and thus casts doubt on MacDonald’s argument. However, *Triplococcus* can still be distinguished from three to four-shelled *Plussatispila* by its shell-wall structure and by its smaller dimensions compared with three to four-shelled *Plussatispila* (outer shell  $\varnothing$ : ~290–330  $\mu\text{m}$  for *Triplococcus* in our material; 414–475  $\mu\text{m}$  for *P. magnilimax*; 384–495  $\mu\text{m}$  for *P. cornwallisensis*). *Triplococcus* bears a thinly layered inner shell and a thick outer

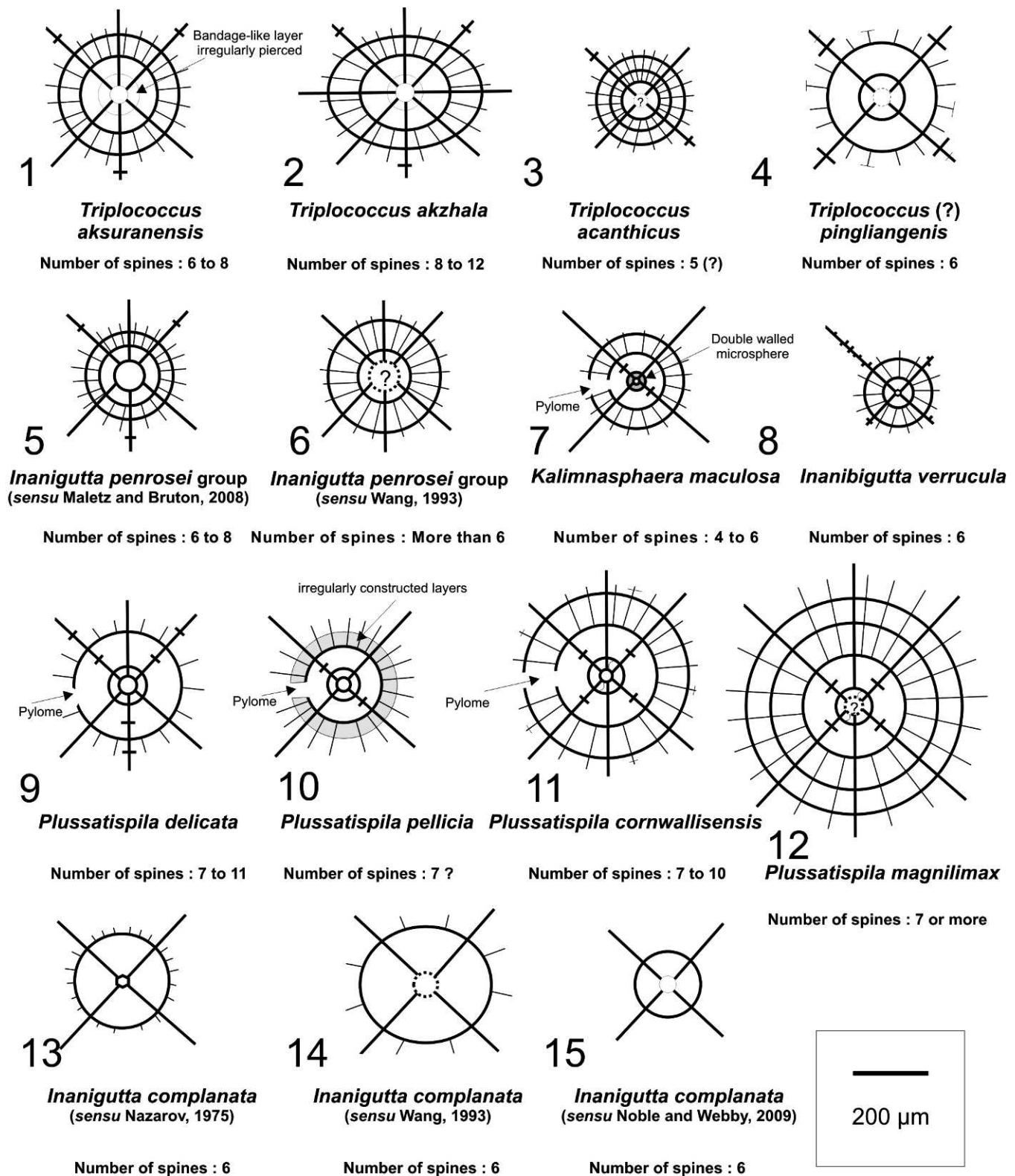


FIGURE 3—Schematic drawings of a number of Inaniguttid species compared with *Triplococcus aksuranensis* in the species discussion. Scale bar=200 μm for all drawings. 1, *Triplococcus aksuranensis* Pouille and Danelian n. sp.; 2, *Triplococcus akzhala* (Danelian and Popov, 2003); 3, *Triplococcus acanthicus* Danelian and Popov, 2003; 4, *Triplococcus? pingliangensis* (Wang, 1993); 5, *Inanigutta penrosei* group (Ruedemann and Wilson, 1936) drawn after the material of Maletz and Bruton (2008); 6, *Inanigutta penrosei* group (Ruedemann and Wilson, 1936) drawn after the material of Wang (1993); 7, *Kalimnasphaera maculosa* Webby and Blom, 1986; 8, *Inanigutta verrucula* (Nazarov, 1975); 9, *Plussatispila delicata* MacDonald, 2006; 10, *Plussatispila pellicia* MacDonald, 2006; 11, *Plussatispila cornwallisensis* MacDonald, 2006; 12, *Plussatispila magnilimax* MacDonald, 2006; 13, *Inanigutta complanata* (Nazarov, 1975) drawn after the material of Nazarov (1975); 14, *Inanigutta complanata* (Nazarov, 1975) drawn after the material of Wang (1993); 15, *Inanigutta complanata* (Nazarov, 1975) drawn after the material of Noble and Webby, 2009.

shell, whereas *Plussatispila* is made of a latticed inner shell and a latticed to “gossamer” outer shell. Moreover, a greater distance separates the inner shell from the median shells of *Plussatispila* while in *Triplococcus* they are more closely spaced. Finally, *Plussatispila* may be also distinguished from *Triplococcus* by the occasional presence of apophyses on the rays between the inner and median shells.

The number of shells and spines are often taken as genus-level character in radiolarian taxonomy (Nazarov and Ormiston, 1984, 1993; Nazarov, 1988; Furutani, 1990; Noble, 1994; Danelian and Popov, 2003) and *Triplococcus* is distinguished from other genera of the family Inaniguttidae chiefly by its greater number of shells. However, the significance of using the number of shells as a genus-level diagnostic character is still under debate (see discussion in MacDonald, 2006); in addition some recent ontogenetic studies on Cenozoic radiolarians revealed that the number of concentric shells can vary with the ontogenic stage (Suzuki, 2006). It has also been observed that some three-shelled actinommid species developed into four-shelled specimens during growth (Cleve, 1899; Petrushevskaya, 1967; Björklund, 1974; Itaki et al., 2003; Nishimura, 2003; Suzuki, 2006). In 2006, MacDonald included all Inaniguttidae present in his Silurian material of the Cape Phillips Formation in a single genus (*Plussatispila*), independent of their number of shells (two to four). However, since the ontogenetic growth of Ordovician Inaniguttids is not yet fully understood, for the moment we prefer to use a more traditional (although imperfect) taxonomic scheme. Thus, *Triplococcus* can still be distinguished from other genera of the family Inaniguttidae by the number of its shells or its dimensions. For example, although its features are fairly close to the ones of *Inanihella* Nazarov and Ormiston, 1984, the two genera can be differentiated by their shell number and dimensions.

TRIPLOCOCCLUS AKSURANENSIS new species  
Figure 4.1–4.14

**Diagnosis.**—Fairly large *Triplococcus* with six to eight outer spines that originate as thin spines from the microsphere to become rod-like spines starting from the median shell. Numerous beams are present between the almost perfectly spherical median and outer shells.

**Description.**—The internal frame consists of a microsphere (~40–55  $\mu\text{m}$  in diameter) from which six to eight outer spines originate. The test surrounding the microsphere consists of three encapsulated shells that are called inner ( $\text{\O}$ : 90–130  $\mu\text{m}$ ), median ( $\text{\O}$ : 180–230  $\mu\text{m}$ ), and outer ( $\text{\O}$ : 290–330  $\mu\text{m}$ ), shells. The thin outer spines turn into thicker rod-like spines starting from the outer surface of the median shell. They emerge as straight (more rarely curved) rod-like spines from the surface of the outer shell. Both the inner shell and the microsphere are thin-layered and pierced irregularly by uneven pores. The median and outer shells are made of a thick pore-frame which is regularly perforated with numerous hexagonal to sub-circular pores ( $\text{\O}$ : 5–15  $\mu\text{m}$ ). Numerous needle-like beams originate from the pore-frame junctions of the median shell to connect to the outer shell. Beams joining the inner to the median shell may be present on some specimens. Very thin and short secondary spines originate from the pore-frame of the outer shell and taper sharply. Rod-like outer spines emerge from the surface of the outer shell surface; they are nearly 200  $\mu\text{m}$  long when well-preserved. They often display weakly developed apophyses.

**Etymology.**—Named after the Aksuran mountains of Kazakhstan, where sample 112 is located.

**Material.**—Eighty-three (83) specimens. Holotype, USTL1173/048; paratypes: USTL1178/035, USTL1142/011, USTL1142/075, and USTL1142/031.

**Occurrence.**—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

**Remarks.**—The entire microsphere is rarely preserved in this material. It is often found as relic fragments at the end of the outer spines and there is no evidence of a continuity of these spines into the microsphere. The rarity of the microsphere could be attributed to preferential dissolution due to its fragility and small size. *Triplococcus aksuranensis* (Fig. 3.1) differs from *T. acanthicus* (Fig. 3.3) in having six or eight outer spines (*T. acanthicus* is described as having five to six outer spines) and in bearing numerous beams that originate at the surface of the median shell rather than the surface of the inner shell. However, it should be emphasized that rare beams may be present on the most internal shell of some specimens of *T. aksuranensis*. It also differs from *T. acanthicus* in its larger size (outer shell  $\text{\O}$ : ~290–330  $\mu\text{m}$  for our material; 214–257  $\mu\text{m}$  for *T. acanthicus*). It is worth noting that quantitative studies from modern spherical Radiolaria establish that two fairly similar morphotypes which belong to different size clusters may be considered as separate species (Cortese and Björklund, 1998). In the same way, and in spite of some morphological similarities, *Triplococcus? pingliangensis* (Wang, 1993) (Fig. 3.4) may be distinguished from *T. aksuranensis* in its larger size. Indeed, even though their inner shells are of approximately the same size ( $\text{\O}$ : 100–140  $\mu\text{m}$  for *T.? pingliangensis* and 90–130  $\mu\text{m}$  for *T. aksuranensis*), the median shell of *T.? pingliangensis* ( $\text{\O}$ : 220–360  $\mu\text{m}$ ) is much larger than in *T. aksuranensis* ( $\text{\O}$ : 180–230  $\mu\text{m}$ ). Moreover, the dimensions of *T.? pingliangensis* median shell are closer to the dimensions of *T. aksuranensis* outer shell ( $\text{\O}$ : 290–350  $\mu\text{m}$ ). Therefore, *T.? pingliangensis* inner and median shells are not as closely spaced as in *T. aksuranensis*.

Some of the *Triplococcus* specimens encountered in our material possess only two shells (certainly due to poor preservation) but can still be distinguished from other two-shelled Inaniguttids (i.e., *Inanihella*) by their larger size (outer shell  $\text{\O}$ : 270–350  $\mu\text{m}$ , median shell  $\text{\O}$ : 180–260  $\mu\text{m}$ ).

*Triplococcus aksuranensis* differs from all species of *Plussatispila* in its shell structure and dimensions (e.g., discussion under the genus *Triplococcus*) and in the relative arrangement of its inner and median shells which are more closely spaced than in any species of *Plussatispila* (distance between inner and median shells of a minimum of 160  $\mu\text{m}$  for *Plussatispila magnilimax*, of 142  $\mu\text{m}$  for *Plussatispila cornwallisensis*, of 162  $\mu\text{m}$  for *Plussatispila delicata*, of 118  $\mu\text{m}$  for *Plussatispila pellicia* MacDonald, 2006 and 50  $\mu\text{m}$  for *T. aksuranensis*). *Triplococcus aksuranensis* also differs from *P. cornwallisensis*, *P. delicata* and *P. pellicia* (Fig. 3.10) in the absence of a pylome.

Unlike *Triplococcus acanthicus*, *T.? pingliangensis* and the *Plussatispila* species the microsphere and inner shell of *T. aksuranensis* are very thin and irregularly porous, while the median and outer shells are thick and regularly porous.

*Triplococcus aksuranensis* displays some morphological similarities with the *Inanigutta penrosei* group sensu Maletz and Bruton (2008) (Fig. 3.5, 3.6) by the presence of two to three shells and a microsphere. However, *I. penrosei* possesses a microsphere of a wide mesh made of bars nearly twice as large as those found in our material (~80  $\mu\text{m}$   $\neq$  40–55  $\mu\text{m}$ ). Moreover, all the spheres in *I. penrosei*, including the inner shell, are produced from thin, cylindrical bars forming an irregular to hexagonal meshwork. Forty specimens of *I. penrosei* have also been identified by Wang (1993) from Chinese material but as the shape of their outer shell varies from spherical to sub-spherical and their dimensions range from 240 to 440  $\mu\text{m}$  (a gap of 200  $\mu\text{m}$  while in Maletz and Bruton’s material outer shells range from 220 to 240  $\mu\text{m}$ ) Wang may have included within the *I. penrosei* larger species such as *T. aksuranensis* or *Triplococcus akzhala* (Danelian and Popov,

2003) (Fig. 3.2) which are difficult to differentiate from *I. penrosei* when complete.

The species *Inanigutta complanata* (described initially by Nazarov, 1975 and reported by Nazarov and Popov, 1980; Nazarov and Ormiston, 1984; Wang, 1993; Noble and Webby, 2009) (Fig. 3.13–3.15) currently incorporates great morphological differences from one description to another. They are all described with different dimensions (outer shell  $\text{\O}$ : 250–253  $\mu\text{m}$  for Nazarov's material; 310–350  $\mu\text{m}$  for Wang's material and 165–185  $\mu\text{m}$  for Noble and Webby's material). Nazarov described his material as mostly spherical, sometimes slightly flattened, with small spines in the form of a trihedral pyramid on the outer shell and inner framework consisting of a hexahedron. Wang's material is described as more usually elliptical and rarely spherical and with many slender spines emerging from the outer shell. Nothing is mentioned concerning the internal framework. Noble and Webby's material has, on the contrary, no spines radiating from the outer shell and an inner framework consisting of a spherical microsphere. The morphotype illustrated by Noble and Webby (2009) as *I. complanata* displays the same internal structure as our *Triplococcus* specimens. It is composed of a small microsphere (35–55  $\mu\text{m}$ ) of a single layer. However, these *I. complanata* cannot be confused with juvenile forms of *T. aksuranensis* because the shell dimensions do not correspond and their inner shells display a rounded pore-frame while in our material the inner shell also consists of a single layer.

*Kalimmasphaera maculosa* (Fig. 3.7) has been described by Webby and Blom (1986) as a spherical to subspherical radiolarian composed of three to four concentric shells. In fact, the two innermost shells, termed by Webby and Blom as first and second medullary shells can be confused with a microsphere due to their very small size (respectively, 13 and 40  $\mu\text{m}$ ). Those two medullary shells were later described by Noble and Webby (2009) from Katian material as one "double walled latticed medullary shell." Measurement of the illustrated figures indicates that this double walled medullary shell ranges from 20 to 55  $\mu\text{m}$  in size. Therefore, *K. maculosa* corresponds to a two-shelled radiolarian with a double walled microsphere and so cannot be confused with *Triplococcus*. Besides its peculiar inner framework consisting of a double walled microsphere, *K. maculosa* also differs from *T. aksuranensis* in having a microsphere of pore-bars with rounded cross section and slightly polygonal in outline, in the presence of a large pylome on the outer shell, in the presence of apophyses between the microsphere and the inner sphere and in its smaller dimensions (outer shell  $\text{\O}$ : 198–307  $\mu\text{m}$  and inner shell: 111–189  $\mu\text{m}$  in *K. maculosa*; outer shell  $\text{\O}$ : 270–350  $\mu\text{m}$ , median shell 180–260  $\mu\text{m}$  and inner shell: 90–130  $\mu\text{m}$  in *T. aksuranensis*).

Juvenile or broken morphotypes of *T. aksuranensis* composed of only two shells (inner and median shell) that were found in our material can still be differentiated from other Inaniguttidae by the peculiar layered-like structure of their microsphere and inner sphere. However, some unbroken specimens showing only the

median shell can be easily confused with *Inanibigutta verrucula* (Nazarov, 1975) (Fig. 3.8). The dimensions of *T. aksuranensis* median shell ( $\text{\O}$ : 180–230  $\mu\text{m}$ ) are very similar to the outer shell dimensions of *I. verrucula* ( $\text{\O}$ : 180–260  $\mu\text{m}$ ) as described by Wang (1993). Four unbroken specimens in our material display some morphological similarities with *I. verrucula* having one or two long, straight or gently curved outer spines from which branch randomly distributed apophyses (Fig. 4.13, 4.14). However, rare small fragments of a porous shell also branch on some spines, testifying to the presence of a third shell of the same dimensions as *T. aksuranensis* outer shell ( $\text{\O}$ : 280–326  $\mu\text{m}$  herein; 290–350  $\mu\text{m}$  for *T. aksuranensis*).

#### TRIPLOCOCCUS AKZHALA (Danelian and Popov, 2003)

Figure 5.1–5.8

- 2003 *Inanihella? Akzhala* DANELIAN AND POPOV, p. 333, fig. 5n–r.  
 2009 *?Inanihella? akzhala* Danelian and Popov. MALETZ ET AL., p. 59, fig. 4.1–4.12.

*Diagnosis.*—Fairly large *Triplococcus* with a sub-spherical to strongly ellipsoidal outer shell and eight to 12 outer spines. Most internal shell surrounding the microsphere consists of a thin layer irregularly pierced. Median and outer shells display a thick pore-frame regularly perforated by polygonal to oval pores. Outer shell varies from sub-spherical to strongly ellipsoidal shape. Outer spines can bear small apophyses. Numerous beams are present between the median and outer shell.

*Material.*—Sixty-seven (67) specimens.

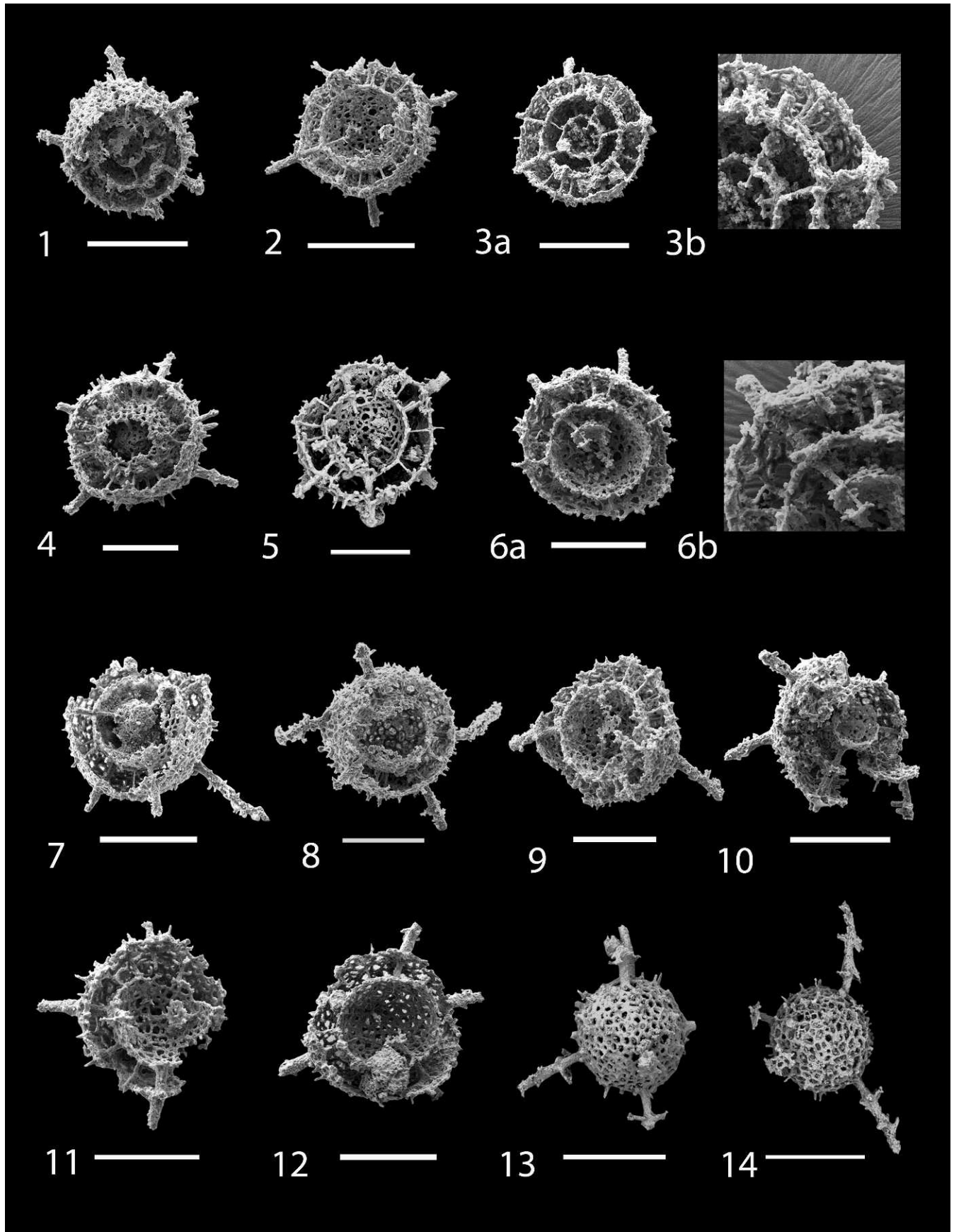
*Occurrence.*—Upper Dapingian? of the Akzhala Mountains, Balkhash Region, Kazakhstan; upper Darriwilian Shundy Formation, Aksuran Mountains, Balkhash Region, Kazakhstan; upper Darriwilian Yerba Loca Formation, western Precordillera, Argentina.

*Remarks.*—The internal structure of *Inanihella? akzhala* had never been observed before. The new material allows observation of three encapsulated porous shells surrounding a microsphere ( $\text{\O}$ : 45–55  $\mu\text{m}$ ) which is characteristic of the genus *Triplococcus*. The microsphere is broken in every observed specimen but relic fragments still present at the innermost ends of the outer spines testify to its former presence. The presence of apophyses at the outermost ends of the outer spines may indicate the presence of an incomplete fourth shell.

The observed material shows that an inner sphere ( $\text{\O}$ : 90–100  $\mu\text{m}$ ) consists of a thin layer irregularly pierced while median ( $\text{\O}$ : 180–260  $\mu\text{m}$ ) and outer ( $\text{\O}$ : 270–330 and 370–450  $\mu\text{m}$  along the minor and major axes, respectively) shells are made of a thick pore-frame that is regularly pierced by polygonal, rounded or strongly elongated pores. It differs from the material described by both Danelian and Popov (2003) and Maletz et al. (2009) in its larger size (outer shell  $\text{\O}$ : ~216–268  $\mu\text{m}$  for Danelian and Popov's material; 220–300  $\mu\text{m}$  for Maletz's material; 270–450  $\mu\text{m}$  here). Like the Argentinian material recovered by Maletz et

FIGURE 4—Scanning electron micrographs of *Triplococcus aksuranensis* Pouille and Danelian n. sp. radiolarian specimens yielded from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region. Scale bar=200  $\mu\text{m}$  for all figures. 1, 4, 6a, 10, paratypes of *Triplococcus aksuranensis* (USTL1178/035; USTL1142/011; USTL1142/075; USTL1142/031); 1, broken specimen showing the thin layer of the inner shell; 6b, magnified view of the three shells and the microsphere of 6a; 10, note the thin layered framework composing the microsphere and the inner shell; 2, broken specimen bearing relic fragments of the inner shell and the microsphere (USTL1157/004); 3a, holotype of *Triplococcus aksuranensis* (USTL1173/048); 3b, magnified view of the internal structure of the holotype, showing the inner sphere and relic fragments of the microsphere from which two of the secondary spines originate; 5, (USTL1140/065); 7–9, (USTL1173/002; USTL1141/015; USTL1183/024); 11, 12, (USTL1142/074; USTL1184/033); 13, 14, juvenile or broken specimens of *Triplococcus aksuranensis*, lacking the third shell (USTL1180/063; USTL1185/010).

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al. (2009), the shape of our specimens ranges from sub-spherical to strongly ellipsoidal.

Maletz suggested that the elongated specimens could have been distorted by partial compaction of the sediment. However, in this case, all specimens would have been distorted, regardless of their genus assignment. Yet, on over 450 specimens recovered in our material, only those that can be assigned to *Triplococcus akzhala* display such an elongated shape. The peculiar shape of the shell should therefore be considered as characteristic for this species.

*Triplococcus akzhala* bears the same inner wall structure as *T. aksuranensis* with its layered microsphere and inner sphere. However, it differs from *T. aksuranensis* in its ellipsoidal shape, its larger size ( $\emptyset$ : up to 350  $\mu\text{m}$  for *T. aksuranensis*; up to 450  $\mu\text{m}$  for *T. akzhala*) and its greater number of spines (max. eight outer spines in *T. aksuranensis*, max. 12 outer spines in *T. akzhala*)

TRIPLOCOCCLUS sp. cf. *T. AKZHALA* (Danelian and Popov, 2003)  
Figure 5.8–5.10

cf. 2003 *Inanihella? akzhala* DANELIAN AND POPOV, p. 333, fig. 5n–r.

**Description.**—Outer shell ( $\emptyset$ : 190–240  $\mu\text{m}$ ) oval to sub-spherical, irregularly perforated by oval to elongated pores. Eight to 12 outer spines are arranged radially. Internal frame consists of a microsphere from which the outer spines originate. Beams are present between the median and outer shell. Numerous short beams emerge at the surface of the outer shell.

**Material.**—Twelve (12) specimens.

**Occurrence.**—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

**Remarks.**—It differs from *Triplococcus akzhala* in its very small dimensions (outer shell  $\emptyset$ : 190–240  $\mu\text{m}$  for *Triplococcus* sp. cf. *T. akzhala* against 270–450  $\mu\text{m}$  for *T. akzhala*), by having a more loosely outer shell structure with wider and more elongated pores and by having more beams emerging from the surface of the outer shell. *T.* sp. cf. *T. akzhala* might possibly be a juvenile form of *T. akzhala* as the dimensions of *T.* sp. cf. *T. akzhala* outer shell ( $\emptyset$ : 190–240  $\mu\text{m}$ ) are the same as *T. akzhala* median shell ( $\emptyset$ : 180–260  $\mu\text{m}$ ) and some specimens have been found bearing relic fragments of a third shell on their outer spines.

TRIPLOCOCCLUS sp. A  
Figure 5.11, 5.12

**Description.**—The test surrounding the microsphere ( $\emptyset$ : 55–60  $\mu\text{m}$ ) consists of three encapsulated spherical shells. The inner shell ( $\emptyset$ : 100–105  $\mu\text{m}$ ) and the microsphere are delicate and thinly latticed. The median shell ( $\emptyset$ : 222–241  $\mu\text{m}$ ) is regularly porous and displays sub-circular to angular pores. Ten thin outer rays originate from the microsphere; they turn into rod-like spines starting from the external surface of the median shell. Relic fragments of a third outer shell ( $\emptyset$ : 265–285  $\mu\text{m}$ ) can still be observed at the distal ends of the outer spines. Numerous beams originate from the pore-frame junctions of the median shell to connect to the outer shell.

**Material.**—Seven (7) specimens.

**Occurrence.**—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

**Remarks.**—It differs from *Triplococcus aksuranensis* and *Triplococcus acanthicus* in a greater number of outer spines and dimensions (outer shell  $\emptyset$ : 265–285  $\mu\text{m}$  vs. 290–350  $\mu\text{m}$  in *T. aksuranensis* and 214–257  $\mu\text{m}$  in *T. acanthicus*) but also by its more closely spaced median and outer shell (distance between outer and median shell a maximum of 63  $\mu\text{m}$  for *Triplococcus* sp. A; 170  $\mu\text{m}$  for *T. aksuranensis*; and 102  $\mu\text{m}$  for *T. acanthicus*). It also differs from *Triplococcus? pingliangensis* in its greater number of outer spines and its smaller dimensions (median shell  $\emptyset$ : 222–241  $\mu\text{m}$  versus 220–360  $\mu\text{m}$  in *T.? pingliangensis*).

Genus INANIELLA Nazarov and Ormiston, 1984

**Type species.**—*Entactinia unica* Nazarov, 1975.

INANIELLA BAKANASENSIS (Nazarov, 1975)  
Figure 5.13–5.15

1975 *Helioentactinia? bakanasensis* NAZAROV, p. 89, pl. 19, fig. 9–13.

1980 *Helioentactinia bakanasensis* NAZAROV; NAZAROV AND POPOV, p. 48, pl. 16, figs. 7, 8.

1993 *Inanihella bakanasensis* (Nazarov); NAZAROV AND ORMISTON, pl. 2, fig. 3.

2003 *Inanihella bakanasensis* (Nazarov); DANELIAN AND POPOV, p. 332, fig. 5a–f.

**Description.**—Our material displays two spherical shells closely connected by numerous beams; the inner shell ( $\emptyset$ : 210–250  $\mu\text{m}$ ) is irregularly perforated with rounded to angular pores distributed evenly on the shell surface. Numerous spines emerge from the outer shell surface as short thin outer spines. Small conical secondary spines, which may be the prolongation of connecting beams between the two shells, emerge sporadically from the surface of the outer shell ( $\emptyset$ : 290–320  $\mu\text{m}$ ), which is often not preserved.

**Material.**—Twenty-three (23) specimens.

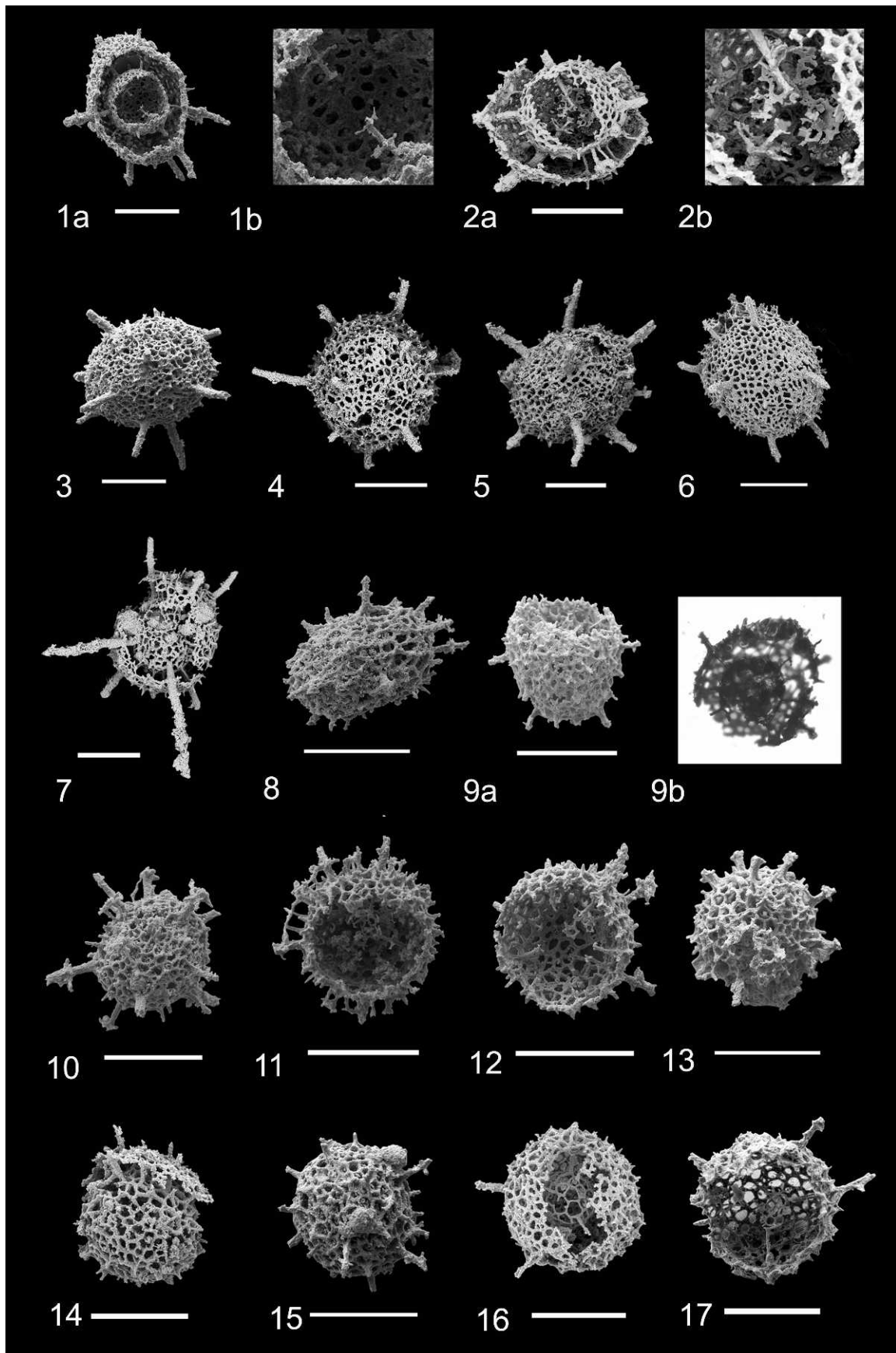
**Occurrence.**—Upper Dapingian? of the Akzhal Mountains, Balkhash Region, Kazakhstan; upper Darriwilian of the Shundy and Bestamak Formations, Balkhash Region, Kazakhstan; upper Darriwilian of the Yerba Loca Formation, western Precordillera, Argentina.

**Remarks.**—Our material differs from the material described by Nazarov (1975) in its larger size (outer shell  $\emptyset$ : 115–169  $\mu\text{m}$  and inner shell  $\emptyset$ : 86–131  $\mu\text{m}$  for Nazarov's material; outer shell  $\emptyset$ : 270–320  $\mu\text{m}$  and inner shell  $\emptyset$ : 210–250  $\mu\text{m}$  here). The specimens in our material are of approximate size to those of Danelian and Popov (2003) and Nazarov and Popov (1980) (outer shell  $\emptyset$ : 292–332  $\mu\text{m}$  and inner shell  $\emptyset$ : 220–263  $\mu\text{m}$  for Nazarov and Popov's material; outer shell  $\emptyset$ : 300–344  $\mu\text{m}$  and inner shell  $\emptyset$ : 171–275  $\mu\text{m}$  for Danelian and Popov's material). However, our material is much smaller than the *Inanihella* sp. cf. *Inanihella bakanasensis*

FIGURE 5—Scanning electron micrographs of Inaniguttidae radiolarian specimens yielded from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region. Scale bar=200  $\mu\text{m}$  for all figures. 1–8, *Triplococcus akzhala* (Danelian and Popov, 2003): 1a, 2a, broken specimens showing the internal structure of *Triplococcus akzhala* (USTL1157/036; USTL1184/027); 1b, magnified view of 1a internal structure showing relic fragments of the inner sphere and the microsphere; note that the secondary spines do not spread inside the microsphere; 2b, magnified view of 2a internal structure showing the thinly-layered inner shell wall structure; 3–7, complete specimens showing an oval shape and numerous outer spines (USTL1144/005; USTL1143/002; USTL1180/053; USTL1143/020; USTL1145/033); 8–10, *Triplococcus* sp. cf. *T. akzhala* (Danelian and Popov, 2003) (USTL1160/001; USTL1144/001; USTL1173/036); 9b, view under the optical microscope of the sectioned specimen illustrated in 9a; two shells can be clearly observed and the microsphere is only faintly visible; 11, 12, *Triplococcus* sp. A (USTL1142/072; USTL1170/008); 13–15, *Inanihella bakanasensis* (Nazarov, 1975) (USTL1140/53; USTL1146/014; USTL1147/007); 16, 17, *Inaniguttia* sp. A (USTL1146/006; USTL1179/002).

→





species described by Maletz et al. (2009) from Argentina (outer shell  $\text{\O}$ : ~350–420  $\mu\text{m}$ ).

INANIHHELLA HIRTA (Nazarov in Nazarov and Popov, 1980)  
Figure 6.16–6.18

1980 *Entactinosphaera? hirta* NAZAROV in Nazarov and Popov, p. 39, pl. 16, figs.1–3.

1988 *Inanibigutta? hirta* (Nazarov); NAZAROV pl. 9, fig. 15.

*Material*.—Twenty-seven (27) specimens.

*Measurements*.—In micrometers ( $\mu\text{m}$ ): diameter of the outer shell: 220–308 (average: 230–250); diameter of the inner shell: 86–97; diameter of the mesh: from 6 to 40  $\mu\text{m}$ ; length of outer spines: up to 13.

*Occurrence*.—Lower Darriwilian of the Kurchilik Formation, Kazakhstan; upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks*.—Nazarov in Nazarov and Popov (1980) described the outer shell structure as “sponge-like.” However, we prefer to use the term “three-dimensional meshwork” as the meshes are widely spaced and distinct. The inner framework had not been observed by Nazarov who discussed the possible presence of a six-rayed or a multi-rayed primary spicule inside the inner shell. The fragment of a microsphere at the end of an outer ray protruding into the inner shell in one of our specimens argues in favor of a small microsphere as internal structure (Fig 6.16b). The exact number of outer spines is still unclear as outer spines cannot be easily distinguished from secondary spines or beams. Indistinct outer and secondary spines are a common feature in *Inanihella* (*I. magnifica* Maletz and Bruton, 2008, *I. bakanasensis*, *I. sp. A* and *I. sp. B*). Therefore, as it stands, this species is assigned to *Inanihella*.

INANIHHELLA MAGNIFICA (Maletz and Bruton, 2008)  
Figure 6.4

2008 *Inanigutta magnifica* MALETZ AND BRUTON, fig. 7N, R–U.

*Material*.—Two (2) specimens.

*Occurrence*.—Lower Darriwilian of the Valhallfonna Formation, Spitsbergen; upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks*.—Our material displays an inner and outer shell ( $\text{\O}$ : 90–100  $\mu\text{m}$  and 202–211  $\mu\text{m}$ , respectively) formed by a mesh of widely spaced bars ( $\text{\O}$ : 4–6  $\mu\text{m}$ ). The diameter of the mesh width of the outer sphere ranges between 16 and 30  $\mu\text{m}$  (exceptionally up to 45). The peculiar arrangement of the outer shell mesh, which consists of bars that are occasionally curved and sometimes arranged in a three-dimensional fashion, gives the impression of a spiral arrangement. Maletz and Bruton (2008) also mentioned that in their material the outer sphere often appears slightly spirali-form. Our material differs from Maletz and Bruton by the absence of outer spines. However, this is most likely due to bad preservation as the bars are covered with recrystallized material and the presence of numerous outer rays (up to 20) is clearly visible.

*Inanigutta magnifica* has been assigned here to the genus *Inanihella* because of the presence of the two adjacent spherical shells and numerous outer spines, as described by Maletz and Bruton.

INANIHHELLA sp. A  
Figure 6.5

*Description*.—Skeleton consists of two encapsulated spherical shells and a microsphere from which eight to 12 outer rays originate. Inner shell ( $\text{\O}$ : 115–125  $\mu\text{m}$ ) formed of irregularly porous widely spaced bars. Outer shell ( $\text{\O}$ : 195–230  $\mu\text{m}$ ) differs from the inner shell by having more regular and smaller pores. Numerous tiny outer spines are present (from 12 to 16), tapering slightly on the distal part. They originate either from the microsphere ( $\text{\O}$ : 50–65  $\mu\text{m}$ , outer spines) or from the inner shell surface (secondary spines). They can be up to 80  $\mu\text{m}$  and are often slightly curved. Inner and outer shells are connected by the outer and secondary spines. Occasional beams are present. Some spines emerge from the surface of the outer shell.

*Material*.—Two (2) specimens.

*Occurrence*.—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks*.—It differs from *Inanihella magnifica* in the smaller pore-frame of the outer shell, in the size of the microsphere ( $\text{\O}$ : 50–60  $\mu\text{m}$  vs. 80  $\mu\text{m}$  for *I. magnifica*) and in the absence of any three-dimensionally organized meshwork. It differs from *Inanihella bakanasensis* in the structure of its inner shell, in its greater number of outer spines and in its shell size (*Inanihella sp. A* outer shell  $\text{\O}$ : 195–230  $\mu\text{m}$ ; *I. bakanasensis* outer shell  $\text{\O}$ : 115–169  $\mu\text{m}$  for Nazarov’s [1975] material; 220–263  $\mu\text{m}$  for Nazarov and Popov’s [1980] material and 300–344  $\mu\text{m}$  for Danelian and Popov’s [2003] material). In general, it differs from other Inaniguttidae in the very high number of outer spines (12 to 16) and in its inner shell structure.

INANIHHELLA sp. B  
Figure 6.13–6.15

*Description*.—Small spherical shell (outer  $\text{\O}$ : 202–220  $\mu\text{m}$ ), bearing numerous outer spines. Very well-developed apophyses branch out of the distal end of the outer spines and join to form a second shell. On some specimens, broken fragments of a former porous cortical shell are still present. Pores can be rounded or angular and vary in size.

*Material*.—Forty-six (46) specimens.

*Occurrence*.—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

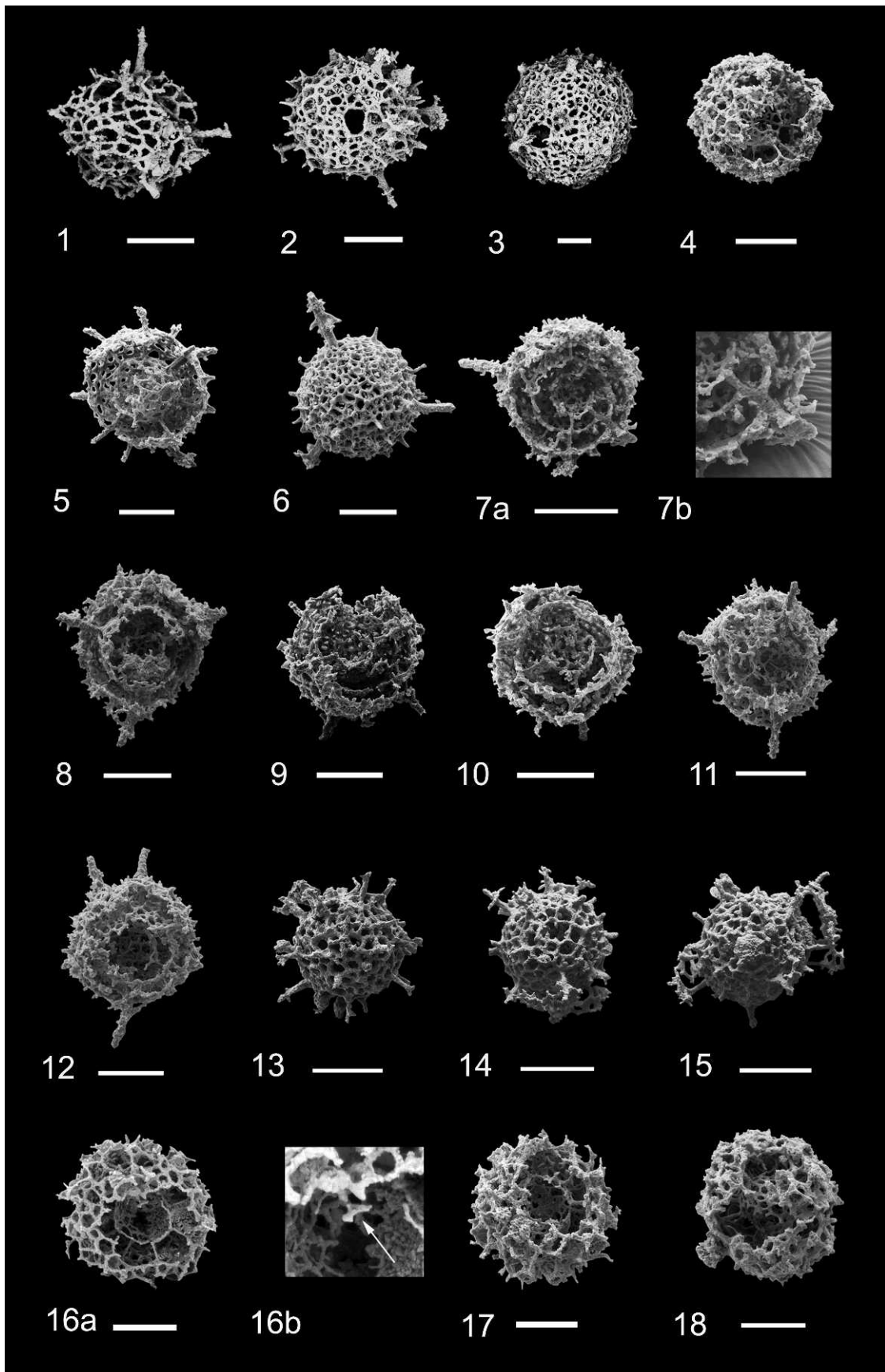
*Remarks*.—Our material is assigned to genus *Inanihella* because of the high number of outer spines and the presence of two shells. When apophyses are not present, this species can be easily confused with *Oriundogutta miscella miscella*, which has an outer shell of nearly the same size ( $\text{\O}$ : 140–180  $\mu\text{m}$ ) as the inner shell of *Inanihella sp. B* ( $\text{\O}$ : 130–168  $\mu\text{m}$ ). Because the internal framework is not accessible, it is difficult to determine whether a smaller internal shell is present or not.

Genus INANIBIGUTTA Nazarov, 1988

*Type species*.—*Inanibigutta aksakensis* (Nazarov, 1975)

FIGURE 6—Scanning electron micrographs of radiolarian specimens yielded from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region. Scale bar=100  $\mu\text{m}$  for all figures. 1, *Haplentactinia juncta* (Nazarov, 1975) (USTL1142/071); 2, *Kalimnaspheera sp. aff. K. aperta* (Nazarov, 1975) (USTL1146/012); 3, *Kalimnaspheera sp. A* (USTL1180/052); 4, *Inanihella magnifica* (Maletz and Bruton, 2008) (USTL1142/082); 5, *Inanihella sp. A* (USTL1142/027); 6, *Inanigutta gansuensis* Wang, 1993 (USTL1152/003); 7–12, *Inanibigutta maletzi* Pouille and Danelian n. sp.: 7a, holotype of *Inanibigutta maletzi* (USTL1178/025); 7b, magnified view of the holotype; spiraliform arrangement showing the dissymmetrically arranged apophyses forming the shells; 8–10, paratypes of *Inanibigutta maletzi* (USTL1142/026; USTL1142/035; USTL1173/040); 11, 12, (USTL1173/042; USTL1183/020); 13–15, *Inanihella sp. B* (USTL1184/024; USTL1140/079; USTL1140/069); 16–18, *Inanihella hirta* (Nazarov in Nazarov and Popov, 1980): 16b, magnified view of 16a internal structure, arrow showing relic fragments of the microsphere at the end of an outer ray protruding inside the inner shell (USTL1173/042; USTL1183/020).

→



## INANIBIGUTTA MALETZI new species

Figure 6.7–6.12

*Diagnosis.*—Skeleton consists of two porous shells surrounding a large latticed microsphere formed of loosely spaced bars. Six outer spines originate from the microsphere. Apophyses forming the shells are sometimes staggered along the outer spine. Shell displays an irregular outline. Additional spongy meshwork of latticed bars may interweave three-dimensionally on the outer shell.

*Description.*—The frame consists of two spherical shells surrounding a large latticed microsphere ( $\text{\O}$ : 60–70  $\mu\text{m}$ ). The latter is formed of loosely spaced bars, at which six outer spines originate. The microsphere may be eccentrically placed on some specimens. No beams are present between the microsphere and the inner shell. The inner and outer shells are regularly perforated with rounded to oval pores. The pores of the outer shell are usually small (8–15  $\mu\text{m}$ ) but can be very wide (up to 30  $\mu\text{m}$ ). The inner and outer shells ( $\text{\O}$ : 120–130  $\mu\text{m}$  and 190–220  $\mu\text{m}$ , respectively) are interconnected by tiny beams. The shell is rarely a perfect sphere; it often displays an irregular outline. Apophyses that originate from the outer spines to form the median and outer shells are occasionally staggered along the spine, leading to a spiraliform arrangement of the shell (Fig. 6.7b). At some places on the outer shell surface, a meshwork of latticed bars may interweave three-dimensionally, giving the outer shell a sponge-like aspect. It usually branches from the outer spines and may develop into an additional irregular layer. Simple apophyses can branch from the outer spines to join the outer shell surface. On some specimens small secondary spines emerge from the wall surface.

*Etymology.*—Named in honor of Jörg Maletz for his contribution to the knowledge of Ordovician Radiolaria.

*Material.*—Twelve (12) specimens. Holotype, USTL1178/025; paratypes, USTL1142/026, USTL1142/035, and USTL1173/040.

*Occurrence.*—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks.*—This species is assigned to the genus *Inanibigutta* because of its two distinct porous shells which enclose a latticed microsphere. However, the asymmetrically arranged apophyses on both sides of the outer spines on some specimens separate it from other species. This character is more similar to the shell structure of *Gyrosphaera* (Noble and Maletz, 2000). *Gyrosphaera* has been synonymized with the genus *Haplotaeniatum* in 2006 by MacDonald but Jones and Noble (2006) chose to keep the two genera separate as *Gyrosphaera* can be distinguished from *Haplotaeniatum* in its well-defined spiraliform layering and its wall structure. *Gyrosphaera* possesses an irregularly porous wall structure forming three or more strongly spiraled layers. This spiraliform layering of the shell has been well illustrated by the figures of *Gyrosphaera cavea* (Jones and Noble, 2006; pl. 4.2, 4.3), *Gyrosphaera raneatela* (Noble and Maletz, 2000; pl. 2.1–2.3) and *Gyrosphaera siljanensis* (Noble and Maletz, 2000; pl. 2.4, 2.5). The three-dimensional spongy meshwork, developed partly on the outer shell of *Inanibigutta maletzi*, recalls to some extent the outer shell structure of *Haplotaeniatum* Nazarov and Ormiston, 1993.

## INANIBIGUTTA sp. A

Figure 5.16, 5.17

*Description.*—Two-shelled radiolarian with a perfectly spherical inner latticed shell ( $\text{\O}$ : 110–121  $\mu\text{m}$ ) which consists of widely spaced bars forming a mesh of large polygonal pores ( $\text{\O}$  7–30  $\mu\text{m}$ , mostly 23–30). The outer shell ( $\text{\O}$ : 277–309  $\mu\text{m}$ ) is formed of a spherical mesh of small sub-circular pores (average  $\text{\O}$ : 8–15  $\mu\text{m}$ ; exceptionally up to 34). At some places, the bars interweave. Numerous thorn-like small beams are present at the outer shell surface. They possess a bifurcated or trifurcated base. Six outer

rays originate from the inner framework and emerge from the surface of the outer shell as thin rod-like outer spines. Numerous apophyses branch from the base of the outer spines and merge into the latticed shell. Simple apophyses can be present on the outer spines and rare beams connect the inner and outer shell. The innermost framework is not preserved in any of the specimens.

*Material.*—Eight (8) specimens.

*Occurrence.*—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks.*—It differs from other *Inanibigutta* species by the large pore-size of the inner shell, by the presence of numerous bifurcated and trifurcated beams and the presence of numerous apophyses branching from the base of the outer spines.

## Genus INANIGUTTA Nazarov and Ormiston, 1984

*Type species.*—*Entactinia unica* Nazarov, 1975.

## INANIGUTTA GANSUENSIS Wang, 1993

Figure 6.6

1993 *Inanigutta gansuensis* WANG, p. 99, pl. 7, figs. 1–8; pl. 8, figs. 1–11.

*Material.*—Twelve (12) specimens.

*Occurrence.*—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan; lower Sandbian of the Pingliang Formation, Gansu Province, China.

*Remarks.*—The specimens found in our material (outer shell  $\text{\O}$ : 200–240  $\mu\text{m}$ ) bear a greater number of secondary spines than the species described by Wang (1993). The six rod-like spines emerging out of the spherical outer shell are often broken (length:  $\leq$  100  $\mu\text{m}$ ). Short branch apophyses are common on the pore-bar junctions. Pores are rounded to oval, rarely angular.

## Genus KALIMNASPHAERA Webby and Blom, 1986

*Type species.*—*Kalimnasphaera maculosa* Webby and Blom, 1986.

*Remarks.*—As discussed in Noble and Webby, 2009, *Cessipylorum* Nazarov and Ormiston, 1984 should be considered as *nomen nudum* and *Cessipylarum* Nazarov in Afanasieva, 1986 as a junior synonym.

## KALIMNASPHAERA sp. aff. K. APERTA (Nazarov, 1975)

Figure 6.2

aff.1975 *Pylentonema aperta*; NAZAROV in NAZAROV, POPOV AND APOLLONOV, p. 102, figs. 1, 2.

aff.1988 *Cessipylorum apertum* (Nazarov); NAZAROV, p. 70, pl. 10, fig. 6.

*Description.*—Test made of a spherical to subspherical pylomate cortical shell (outer shell  $\text{\O}$ : 210–250  $\mu\text{m}$ ) with seven or more rod-like outer spines. Two of them are located around the pylome which has a sub-circular opening ( $\text{\O}$ : 32–42  $\mu\text{m}$ ). The rim of the pylome opening is fringed with a small ridge (5–7  $\mu\text{m}$  thick). The cortical shell is thick and irregularly latticed with oval to angular-oval pores (more rarely rounded). The size of the pores is variable (3–30  $\mu\text{m}$ ). The latticed bars are thick and irregular and interweave in some places. Straight or curved rays may branch from the base of the outer spine and merge into the latticed shell. Numerous small conical secondary spines (up to 30  $\mu\text{m}$  long) emerge from the pore-bar junction. The outer spines often bear well-developed apophyses. The inner framework is not visible.

*Material.*—Six (6) specimens.

*Occurrence.*—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

*Remarks.*—Presently only three species of *Kalimnasphaera* are known from the Darriwilian of Kazakhstan: *Kalimnasphaera*

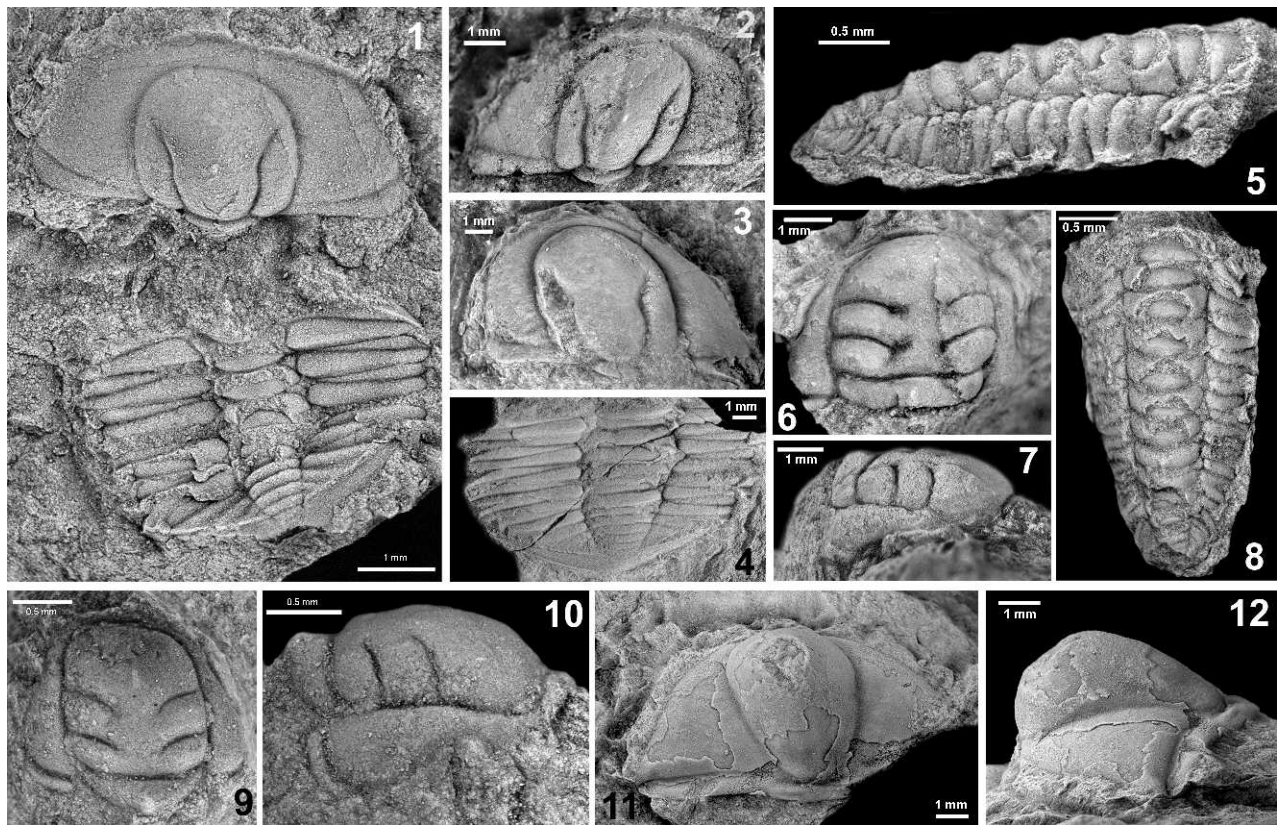


FIGURE 7—All trilobite specimens from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region. 1–4, *Endymionia semielliptica* Chang and Fan, 1960: 1, NMW 2012.5G.8, disarticulated exoskeleton; 2, NMW 2012.5G.9, cranium; 3, NMW 2012.5G.10, cranium; 4, NMW 2012.5G, pygidium with attached thorax; 5–10, *Porterfieldia* sp. aff. *P. delicata* Kolobova in Klishevich and Kolobova, 1990: 5, 8, NMW 2012.5G.1, pygidium with attached thorax, dorsal and lateral views; 6, 7, NMW 2012.5G.2, cranium, dorsal and lateral views; 9, 10, NMW 2012.5G.3, cranium, dorsal and lateral views; 11, 12, *Nambeetella?* sp., NMW 2012.5G.12, cranium, dorsal and lateral views.

*insueta* (Nazarov and Popov, 1980), *Kalimnasphaera rimata* (Nazarov and Popov, 1980) and *Kalimnasphaera aperta* (Nazarov, 1975). Our material resembles *K. aperta* morphologically though it differs from it by having a smaller outer shell ( $\text{\O}$ : 210–250  $\mu\text{m}$  vs. 260–290  $\mu\text{m}$  in *K. aperta*) and a slightly thinner pylome ridge (5–7  $\mu\text{m}$  vs. 8–10  $\mu\text{m}$  in *K. aperta*). It differs from *K. insueta* by having mostly oval or angular-oval pores, in the smaller dimensions of its outer shell ( $\text{\O}$ : 210–250  $\mu\text{m}$  vs. 260–300  $\mu\text{m}$  in *K. insueta*) and in the size of its pylome opening ( $\text{\O}$ : 32–42  $\mu\text{m}$  vs. 45–80  $\mu\text{m}$  in *K. insueta*). They also differ in the thickness of the pylome ridge (5–7  $\mu\text{m}$  vs. 10–20  $\mu\text{m}$  in *K. insueta*). *Kalimnasphaera* sp. aff. *K. aperta* shares nearly the same dimensions as *K. rimata* ( $\text{\O}$ : 210–250  $\mu\text{m}$  for *K. sp.* aff. *K. aperta*; 245–260  $\mu\text{m}$  for *K. rimata*). Yet, it differs from it by having smaller secondary spines but mostly by the more varied shape of its pores (pores  $\text{\O}$ : 3–30  $\mu\text{m}$  in *K. sp.* aff. *K. aperta*; 2–12  $\mu\text{m}$  in *K. rimata*). It also differs from all *Kalimnasphaera* species in the presence of apophyses branching from the outer spines which occasionally might develop into a second outer shell. This feature is present in *Kalimnasphaera maculosa* (Katian) (Webby and Blom, 1986; Noble and Webby, 2009). However, our material differs from *K. maculosa* in the greater number of outer spines, the larger size of its outer shell ( $\text{\O}$ : 204–225  $\mu\text{m}$  in our material; 111–189  $\mu\text{m}$  in *K. maculosa*) and the pores shape (rounded in *K. maculosa*; angular to oval in this material).

KALIMNASPHAERA sp. A  
Figure 6.3

**Description.**—Test made of a spherical pylomate cortical shell (outer shell  $\text{\O}$ : 354–360  $\mu\text{m}$ ) from which rod-like outer spines emerge. Two of the spines are located around the pylome which has a large irregularly circular opening (60–70  $\mu\text{m}$  width). The rim of the pylome opening is fringed with a small ridge of 5 to 10  $\mu\text{m}$  thick. The cortical shell is thick and regularly latticed with rounded to angular-oval pores ( $\text{\O}$ : 6–40  $\mu\text{m}$ ). The pores are mostly uniform in size. A few tiny conical secondary spines (up to 18  $\mu\text{m}$  long) emerge from the pore-bar junction. The outer spines are all broken in the specimen.

**Material.**—One specimen.

**Occurrence.**—Upper Darriwilian of the Shundy Formation, Balkhash Region, Kazakhstan.

**Remarks.**—This specimen differs from other *Kalimnasphaera* species in its very large size and large pylomate opening (outer shell  $\text{\O}$ : 354–360  $\mu\text{m}$ ; pylomate opening  $\text{\O}$ : 60–70  $\mu\text{m}$ ). It also differs from other species by having tiny secondary spines.

#### TRILOBITES

by M. Ghobadi Pour and L. E. Popov

The studied and illustrated trilobite specimens are deposited in the Department of Geology, National Museum of Wales, Cardiff (NMW). Abbreviations for parameters measured on specimens are (in millimeters): Cl, Cw=maximum cranium length and width; Gl, Gw=maximum glabella length and width; GTw=width of glabella tongue; ORI=length (sag.) and width of occipital ring; Pl, Pw=maximum pygidial length and width; Al, Aw=length and width of pygidial axis; sag.=sagittal, exsag.=exsagittal, tr.=transverse.

Family OLENIDAE Burmeister, 1843  
 Subfamily TRIARTHRIINAE Ulrich, 1930  
 Genus PORTERFIELDIA Cooper, 1953

*Type species.*—*Triarthrus caecigenus* Raymond, 1920, Upper Ordovician, Sandbian, Athens Shale, north of Salem, Virginia, U.S.A.

PORTERFIELDIA sp. aff. *P. DELICATA* Kolobova  
 in Klishevich and Kolobova, 1990  
 Figure 7.5–7.10

*Material.*—NMW 2012.5G.2 (Cl=3.7, Gl=2.9, Gw=3.5, ORI=0.65), NMW 2012.5G.3, (Cl=1.7, Cw~1.9, Gl=1.3, Gw=1.25, ORI=0.3), NMW 2012.5G.4–7, cranidia; NMW 2012.5G.1, pygidium with attached thorax; all specimens from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region, Kazakhstan.

*Remarks.*—Specimens from the Shundy Formation show very close similarity to *Porterfieldia delicata* Kolobova in Klishevich and Kolobova, 1990 from the lower part of the Zyndan Formation (Middle Ordovician, upper Darriwilian) of the North Tien Shan, Kyrgyzstan, but differ in having more arcuate glabellar furrows, a more strongly impressed furrow delineating the sutural ridge, and probably a fewer number of the axial rings and pleural ribs on the pygidium. The studied Kyrgyz specimens are preserved in argillite and they are strongly flattened, therefore differences in convexity of the cranidium and glabella are mainly due to their distortion.

*Porterfieldia* sp. aff. *P. delicata* differs from *Porterfieldia sinensis* (Chang and Fan, 1960), known from the upper part of the Yinggou Group (middle Darriwilian, *Amplexograptus confertus* Biozone), Angzanggou, southwest Yumen, Gansu Province, South China, in the complete absence of preglabellar field and eye ridges. The pygidial morphology cannot be compared due to any report on the pygidium in the original description of the species.

The specimens from the Shundy Formation closely resemble *Porterfieldia goldwyerensis* (Legg, 1976) from the Middle Ordovician, Darriwilian, Goldwyer Formation, Canning Basin, Western Australia in their general cranidial morphology, shape and outline of the glabella and characters of the glabellar furrows. The main differences lie with the complete absence of preglabellar field and interpleural furrows on the pygidium; the latter has also fewer axial rings and pleural ribs.

There are two other species of *Porterfieldia* presently documented from the Darriwilian of neighboring Northern Kyrgyzstan (Weber, 1948; Klishevich and Kolobova, 1990), but they are definitely not conspecific. *Porterfieldia turkestanica* (Weber, 1948) differs in having a wider (sag.), a strongly swollen medially anterior cranidial border and a spine on the occipital ring. *Porterfieldia sponisa* Kolobova in Klishevich and Kolobova, 1990, unlike Kazakhstani specimens, have almost straight, converging closely, but not merging glabellar furrows, and a prominent median spine in front of the cranidium.

Family RAPHIOPHORIDAE Angelin, 1854  
 Subfamily RAPHIOPHORINAE Angelin, 1854  
 Genus NAMBEETELLA Legg, 1976

*Type species.*—*Nambeetella firroyensis* Legg, 1976, Lower Ordovician, Floian, Emanuel and Namber formations, Canning Basin, West Australia.

NAMBEETELLA? sp.  
 Figure 7.11, 7.12

*Material.*—NMW 2012.5G.12, cranidium, NMW 2012.5G.13, external mold of pygidium and incomplete thorax.

*Remarks.*—A single cranidium that recalls *Nambeetella* (Legg, 1976) in its subsemicircular shape and the absence of an anterior border with a strongly convex, flask-shaped glabella; the latter is slightly overhanging above a steeply inclined preglabellar field, but it is not crossing the anterior cranidial margin. An anterior part of the glabella is slightly damaged, thus the absence of a glabellar spine cannot be proved, which explains the tentative identification of the specimen.

Subfamily ENDYMIONIINAE Raymond, 1920  
 Genus ENDYMIONIA (Billings, 1865)

*Type species.*—*Endymion meeki* Billings, 1862, Middle Ordovician, Levis Formation, Quebec Canada.

ENDYMIONIA SEMIELLIPTICA Chang and Fan, 1960  
 Figure 7.1–7.4

- 1960 *Endymionia semielliptica* CHANG AND FAN, p. 129, pl. 7, figs. 5–7.  
 1965 *Endymionia semielliptical* Chang and Fan; LU ET AL., p. 609, pl. 127, figs. 11–13.  
 1990 *Endymionia kazakhstanica* Balashova (*nomen nudum*); APOLLONOV ET AL., 1990, p. 15.

*Description.*—The cranidium is semioval in outline, about three-fifths as long as wide, with an evenly curved anterior margin. The glabella is gently convex (trans.), subcircular to subquadrate in outline, and almost as long as wide (including occipital ring); it is bounded by equally deep axial and preglabellar furrows, which occupy approximately 85% of the cranidial length and slightly less than half of the cranidial width. A median tubercle is situated slightly posteriorly to the glabellar mid length. The glabellar lateral lobes taper outwards; they are separated from the median glabellar lobe by deep, sigmoidal glabellar furrows sharply terminated anteriorly, at a short distance from the axial furrows. The occipital ring is narrow and bordered by a deep occipital furrow running almost parallel to the cranidial margin.

The fixigena is broad and tapers gently outwards, but more sharply at the proximity of the facial sutures.

The preglabellar field is fairly broad and it is slightly widened (exsag.) laterally. The anterior border is very narrow and defined by a shallow border furrow. The posterior border is narrow (trans.) adaxially, to widen gradually (trans.) abaxially, to narrow slightly at its lateral extremity. The posterior border is furrowed, narrow, well-defined and slightly curved forward abaxially. The librigena is unknown. Facial sutures are gently curved and converge anteriorly.

The thorax axis is about one-fourth as long as the thoracic width; pleural furrows are deep and curved slightly forward. The posterior pleural band is more prominent and becomes wider adaxially.

The pygidium is three to four times as wide as long, with its axis occupying 25–30% of the pygidial width at the anterior margin. The axis is truncated conical tapering posteriorly, with five axial rings of approximately equal length (sag.) and a short (sag.) terminal piece crossing the margin of the posterior border. The pleural fields are almost flat, bordered by a distinct rim, with three pairs of pleural ribs, separated by broad, straight pleural furrows that are slightly inclined posteriorly abaxially. The posterior border is flattened and tapers strongly downwards; it is ornamented by faint subparallel terrace lines.

*Holotype.*—Cranidium figured by Chang and Fan (1960, pl. 7, fig. 5), Ordovician, Darriwilian, Datouyanggou, Da Qaidam, northwest China.

*Material.*—NMW 2012.5G.8 (Cl=2.6, Cw=4.9, Gl=2.1, Gw=2.1, Pl=1.2, Pw=3.6, Al=0.95, Aw=0.85), disarticulated

exoskeleton lacking free cheeks; NMW 2012.5G.9 (Cl=4.0, Cw=6.8, Gl=3.35, Gw=3.3); NMW 2012.5G.10 (Cl=4.6, Cw=7.3, Gl=4.2, Gw=3.9); cranidia; NMW 2012.5G.11 (Pl=2.7, Pw=10.5, Al=2.2, Aw=3.2), pygidium with attached thorax; all specimens from Shundy Formation, locality 112, Shundy Mountains, North Balkhash Region, Kazakhstan.

*Remarks.*—The specimens from the Shundy Formation show close similarity in their cranidial morphology to *Endymionia semielliptica* Chang and Fan, 1960 known from the Darriwilian of northern Qinghai; in particular, they have a subcircular to subquadrate glabella with sigmoidal glabellar furrows that are not merged anteriorly with axial furrows; they also have strongly impressed posterior border furrows that are not fading adaxially. The sigmoidal glabellar furrows are not merged anteriorly and the axial furrows can be considered as the most distinctive feature of *E. semielliptica*, which is unknown from any other species referred to the genus (e.g., Fortey, 1975; Whittington, 1965). The thoracic and pygidial morphology of *E. semielliptica* was not documented in the original description of the species. The closest species is *E. canningi* Legg, 1976, known from the Darriwilian, Goldwyer Formation, Canning Basin of Western Australia; it has similar proportions and shows a similar cranidial and glabellar outline. However, unlike *E. semielliptica*, the glabellar furrows present in the Australian species are only slightly curved and they almost reach the axial furrows; moreover, Kazakhstani specimens have a significantly wider pygidium with only five axial rings (instead of 12) and three pleural ribs (instead of five). Our specimens differ from the type species *Endymionia meeki* (Billings, 1862) in cranidial morphology, including sigmoidal glabellar furrows, which do not approach the axial furrows and a less rounded glabella.

#### DISCUSSION

The studied radiolarian assemblage is dominated by the family Inaniguttidae, which is represented by five genera and 14 species: *Triplococcus aksuranensis* n. sp., *T. akzhala*, *Triplococcus* sp. cf. *T. akzhala*, *T. sp. A*, *Inanihella bakanasensis*, *I. hirta*, *I. magnifica*, *I. sp. A*, *I. sp. B*, *Inanigutta maletzi* n. sp., *I. sp. A*, *Inanigutta gansuensis*, *Kalimnaspheera* sp. aff. *K. aperta* and *K. sp. A*. Representatives of genus *Triplococcus* are particularly abundant, representing half of the Inaniguttidae found in this fauna. Ordovician Radiolarian biostratigraphy is still in its infancy. Based on the Inaniguttid species discussed here, the radiolaria of sample 112 could be correlated with the *Triplococcus akzhala*–*Inanihella bakanasensis* assemblage described by Danelian and Popov (2003) from upper Dapingian? (e.g., Maletz, 2011) limestones in Kazakhstan and possibly with the radiolarian assemblage described by Maletz et al. (2009) from lower Darriwilian carbonates in Argentina. Based on the low diversity of this assemblage Maletz (2011) suggested that it may represent “a depauperate fauna” of the lower Darriwilian *Proventocitum procerulum* assemblage. We also report the presence of *Haplentactinia juncta* (Fig. 6.1) in the fauna studied here, which is one of the characteristic species of the *Haplentactinia juncta*–*Inanigutta unica* assemblage, correlated with the uppermost Darriwilian (e.g., discussion in Nazarov and Ormiston, 1993; Danelian and Popov, 2003; Maletz, 2011). Moreover, pyromate radiolaria of the genus *Kalimnaspheera* are known to first occur in this assemblage (Nazarov and Popov, 1980).

In addition to the radiolarian assemblage, sample 112 also contains three species of trilobites (*Endymionia semielliptica*, *Nambeetella?* sp., and *Porterfieldia* sp. aff. *P. delicata*), which form an oligotaxitic association characteristic of the deep water olenid biofacies (Fortey in Webby et al., 2004), reflecting a basinal, offshore depositional environment, below the strongest

storm wave base. *Endymionia semielliptica* was originally described from the uppermost part of the Duoquanshan Formation (Ordovician, Darriwilian) of the Qaidam Terrane in north-west China, where argillites, overlying the trilobite-bearing unit, contain the mid-Darriwilian graptolites of the *Pterograptus elegans* Subzone of the *Didymograptus murchsoni* Biozone (Chang and Fan, 1960; Zhou and Dean, 1996). *Porterfieldia* sp. aff. *P. delicata* from the Shundy Formation is fairly similar and possibly conspecific to specimens described by Klishevich and Kolobova (1990) from the Upper Member of the Zyndan Formation of the Toluk river valley in North Tien Shan (Kyrgyzstan), which also contains a graptolite assemblage (*Cryptograptus* sp. cf. *C. tricornis* [Carruthers, 1858], *Glossograptus* sp. cf. *C. hincksii* [Hopkinson, 1872], *Hustedograptus* ex gr. *teretiusculus* [Hisinger, 1840] and *Pseudoclimacograptus* ex gr. *scharenbergi* [Lapworth, 1876]) transitional in age from the late Darriwilian to the Sandbian. Finally, the stratigraphic level from which sample 112 was collected also contains the graptolite species *Hustedograptus* ex gr. *teretiusculus* (identification by Tsai in Apollonov et al., 1990), which confirms and further narrows the age of the radiolarian-bearing sample to the uppermost Darriwilian.

In conclusion, the fossil record taken as a whole suggests an upper Darriwilian age for radiolarian sample 112. It appears to be somewhat older than the radiolarian-bearing beds of the Bestomak Formation in the Chingiz Range (sample 553a), which are overlain by graptolites of the *Nemagraptus gracilis* biozone (lower Sandbian) and from which Nazarov and Popov (1980) described the diverse radiolaria that defined the *Haplentactinia juncta*–*Inanigutta unica* assemblage. Radiolarian sample 112 of this study is also older than the radiolarian assemblage described by Wang (1993) from the Pingliang Formation of Gansu Province, China which is of an early Sandbian age dated by the presence of graptolites belonging to the *Nemagraptus gracilis* to *Climacograptus bicornis* biozones (Maletz, 2011).

#### CONCLUSION

A rich and well-preserved radiolarian assemblage from a Middle Ordovician sample from Kazakhstan is composed essentially of representatives of the family Inaniguttidae. They are represented by five genera and 14 species, two of which are new. The Trilobite fauna found in the sample suggests a late Darriwilian age which is supported by graptolite species found previously. The presence of the radiolarian species *Haplentactinia juncta* corroborates this age. The trilobite fauna is characteristic of the deep water olenid facies. This work provides a significant contribution regarding the family Inaniguttidae, especially by providing a more detailed examination of the internal structure of *Triplococcus*. It also refines our knowledge of Ordovician radiolarian biostratigraphy using the identification of co-occurring trilobites and graptolites which provide a reliable age constraint for the assemblage.

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