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Late Cretaceous radiolarians from a bentonite-rich interval at the base of the Niobrara Formation, southwestern Saskatchewan, Canada: biostratigraphic and paleoenvironmental implications

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Abstract

A radiolarian assemblage containing eleven species of both nasellarians and spumellarians was recovered from the Upper Cretaceous Niobrara Formation in southwestern Saskatchewan, Canada. This assemblage represents the first report of Coniacian radiolarians in the entire Western Interior Basin and one of the few reports for the Upper Cretaceous in North America. The presence of radiolarians and the partial disappearance of foraminifera in the only bentonitic interval in this formation suggests that high silica concentrations supplied by volcanic events favored ecological conditions for radiolarians to thrive and or enhanced their preservation before and after deposition. Correlation of this assemblage with other Upper Cretaceous radiolarian assemblages in North America shows a close affinity with the microfauna recovered in the Sverdrup Basin (Canadian Arctic).

Keywords: Radiolarians, Niobrara Formation, Southwestern Saskatchewan, Bentonites, Upper Cretaceous
Introduction

Radiolarians are marine, planktic siliceous microorganisms that have spanned an evolutionary history of more than 500 million years (Cambrian-Recent). In spite of their wide distribution in the oceans throughout the Phanerozoic, radiolarians are often poorly preserved as fossils due to the high solubility of silica in sea water (Kling, 1998, Armstrong and Brasier, 2005). During the Cretaceous, the number of radiolarian families reached its peak probably as a result of strengthened circulation produced by the partitioning of the world’s oceans (De Wever et al., 2003). Radiolarian assemblages from this period have been reported from several localities around the world (e.g. O’Dogherty, 1994; Packer and Hart, 2005; Popova-Goll et al., 2005; Bandini et al., 2006) allowing a better understanding of their distribution and evolutionary processes during that time.

Unlike other microfossil groups such as foraminifera, calcareous nanofossils or dinoflagellates cysts, radiolarians have been reported only from a few Cretaceous localities in North America (Fig. 1). Due to their scarcity and discontinuity through the sedimentary record, Cretaceous radiolarian zonations are almost non-existent except for the ones proposed by Pessagno (1976) in California and Pugh et al. (2014) in the Sverdrup Basin. In the Western Interior Basin, radiolarians have been recovered mainly from the Campanian Pierre Shale Formation (e.g. Schultz et al., 1980; Bergstresser, 1983; Young and Moore, 1994), and the Albian Mowry Shale and Loon River formations (e.g. Davis, 1970; Wall, 1975) (Fig. 1). Other reports of Cretaceous radiolarians in North America include only one species (e.g. Nauss, 1947; Kent, 1967) or do not provide descriptions or illustrations of the specimens found (McNeil and Gilboy, 1999; McNeil and Zonneveld, 2004).
The radiolarian assemblage analyzed in this study was recovered from a bentonitic interval in the lower part of the Niobrara Formation (Govenlock Member) in well 14-26-015-27W3, southwestern Saskatchewan (Fig. 2). Except for some individuals of the species *Dictyomitra multicostata* identified by Kent (1967) in the state of Colorado (USA), no radiolarians had been described from this unit in the Western Interior Basin of North America. The microfauna identified in this study is therefore crucial to understand the environmental conditions that took place during the first stage of the regressive Niobrara Cycle in the Western Interior Basin. The analysis of radiolarians is also key to determine the oceanic circulation patterns of the Western Interior Seaway during the Late Cretaceous as well as to correlate biostratigraphic units in areas where calcareous microorganisms are missing.

**Geological setting**

The Niobrara Formation in southwestern Saskatchewan is subdivided into three formal units: the Govenlock, Medicine Hat, and First White Specks members, in ascending order (Gilboy, 1996; Nielsen et al., 2003; Diaz and Velez, 2015) (Fig. 3). The lower Govenlock Member (stratigraphic equivalent of the Verger Member of southern Alberta) is about 33 m thick at well 14-26-015-27W3 and comprises non-calcareous mudstones at the base grading into calcareous mudstones and siltstones at the top. The basal part of the Govenlock Member, which corresponds to the base of the Niobrara Formation is a non-calcareous, grey, silty mudstone interbedded with more than 20 bentonite beds. This bentonitic interval is an important lithostratigraphic marker in southwestern Saskatchewan and southeastern Alberta as it indicates the contact between the Carlile and Niobrara formations (Nielsen et al., 2003; Diaz and Velez, 2015; Diaz 2017).
Nielsen et al. (2008) placed the base of the Verger Member (Govenlock equivalent) within the foraminiferal *Marsonella oxycona* Subzone (Fig. 3). This subzone is early to middle Coniacian in age based on its correlation with the molluscan assemblages described by Jeletzky (1971), Kauffman et al. (1993) and Cobban et al. (2006). Additionally, this age is supported by radiometric dating (\(^{40}\text{Ar} -^{39}\text{Ar}\)) of two bentonites at the base of the Verger Member in southern Alberta that provides an age of 89.19 Ma ±0.51 and 89.40 Ma ±0.31 (close to the Turonian-Coniacian boundary defined by Gradstein et al., 2012) (Nielsen et al., 2003). The lowermost part of the *Marsonella oxycona* Subzone, which is coincident with the bentonitic interval at the base of the Govenlock Member yields a few foraminiferal species, but holds a significant number of radiolarians. The lack of foraminifera within this interval was also reported by Elberdak (2004) and Nielsen et al. (2008) in the plains of southeastern Alberta.

The deposition and patterns of sedimentation of the Niobrara Formation across the Western Interior Basin are closely linked to lithosphere deformation caused by static and dynamic loads, and eustatic sea level changes occurred during the Late Cretaceous (Monger, 1993; Kauffman and Caldwell, 1993; Miall et al., 2008). Physiographic and oceanographic changes occurred during the Late Cretaceous also affected the composition and distribution of the different floral and faunal groups (McNeil and Caldwell, 1981). In general, the siliciclastic content of the Carlile and Niobrara formations is higher in the foothills and plains of Alberta due to their proximity to the major detrital source of the rising orogen and decreases further east within the provinces of Saskatchewan and Manitoba (McNeil and Caldwell, 1981; Diaz, 2017).
Material and methods

Samples from the 4-meters bentonitic interval at well 14-26-015-27W3 (Fig. 2) were taken approximately every fifteen to thirty centimetres; a total of 21 samples were collected and prepared using a modified version of the method proposed by Kennedy and Coe (2014), (For further details see Diaz and Velez, in press). Foraminiferal tests were also recovered from this interval and are included in the quantitative analysis. Twenty five slides for diatom analysis were also prepared following the method described in Diaz (2017). However, no diatoms were found.

Radiolarian abundance is reported in four categories: Barren, low (1 to 50 individuals), moderate (51 to 300 individuals), and high (> 300 individuals). Samples barren of radiolarians normally yielded foraminifera and vice versa. Microfossil counting and preliminary classification was made using a binocular microscope (Nikon SMZ-2T). Radiolarian classification was refined subsequently using SEM imaging. For this, carbon coated radiolarian tests were examined with a Jeol JSM-6360 microscope housed in the Department of Geology, University of Regina. Samples were subjected to high vacuum during both sample preparation (carbon-coating) and observation under the SEM. Examination of samples was undertaken with both the secondary electron (SEI), and back-scattered electron (BSE) detectors fitted to the Jeol instrument.

Radiolarians were classified using the Interrad-Mesozoic Radiolaria Database (2016) and some publications of Cretaceous radiolarians including: Dumitrica (1970); O’Dogherty et
al. (2009), O’Dogherty (1994), Campbell and Clark (1944), Empson Morin (1981), Packer and Hart (2005), Pessagno (1976), Pugh et al. (2014), and others.

**Results**

The bentonitic interval at the base of the Niobrara Formation is composed of non-calcareous, grey, silty mudstone interbedded with more than 20 bentonite beds (Fig. 4). Bentonite beds range in thickness from 0.5 to 15 cm and are commonly bioturbated. Trace fossils include *Chondrites* and *Planolites*. The contact with the underlying Carlile Formation is placed 1.5 meters below the bentonitic interval, where the lithology changes from calcareous, fossiliferous and moderately bioturbated mudstones in the upper part of the Carlile Formation to non-calcareous mudstones in the basal part of the Niobrara Formation (Diaz and Velez, 2015; Diaz 2017). The contact between these two units is also marked by a change in foraminiferal assemblages. Diaz (2017) placed the upper part of the Carlile Formation within the *Gavelinella kansasensis* Subzone and the lower Govenlock Member of the Niobrara Formation within the *Marsonella oxycona* Subzone (both belonging to the *Trochammina* sp. Zone). Although, preliminarily Diaz and Velez (2015) reported the base of the Niobrara Formation as barren of foraminifera, more than ten different species were recovered in this study.

From the 21 samples analyzed only eight yielded radiolarian tests (Fig. 4). Samples rich in radiolarians are concentrated in the central part of the bentonitic interval, where the thickness and number of bentonite beds is higher. The radiolarian assemblage includes 11 genera and species (Figs. 5, 6). Most specimens belong to the species *Dictyocephalus* cf. *cayeuxi* (Squinabol), *Cryptamphorella conara* (Foreman), and *Dictyomitra multicostata* (Zittel). Specimens of *Dactyliodiscus* cf. *lenticulatus* (Jud), *Xitus* sp., *Paronaella* sp.,...
Pessagnobrachia cf. fabianii (Squinabol), Crucella cf. messinae Pessagno, Orbiculiforma? sp., Praeconocaryomma sp., and Spongodiscus? multus Koslova were also recovered (Figs. 5 and 6). Radiolarians abundances range from just a few specimens to more than one thousand individuals per sample (Fig. 5). Some individuals of these species were also recovered from the same stratigraphic interval at well 05-08-018W3 (28 km NW of the core analyzed, see Fig. 2) but in lower numbers.

The foraminiferal fauna recovered from this interval is dominated by the benthic species Pseudobolivina rollaensis, Dorothia smokyensis and Neobulimina sp. A few specimens of the marker species Marsonella oxycona were identified in samples A2, A3 and A19. Samples which hold radiolarians were barren of foraminifera except for sample A12 that hold a few individuals of both microfossil groups. The presence of radiolarians in the Niobrara Formation seems to be restricted only to the westernmost part of the province of Saskatchewan (Diaz, 2017). However, more detailed micropaleontological analyses of this unit throughout the Western Interior Basin are needed in order to draw such conclusion.

Discussion

The limited radiolarian fauna analyzed in this study precludes the definition of a radiolarian zonation for the Upper Cretaceous units of southern Saskatchewan. However, it allows for comparison with the biozones described from the California coast (Pessagno, 1976) and the Sverdrup Basin (Pugh et al., 2014) which are the nearest localities where Coniacian radiolarians have been reported. The radiolarian species identified here bear a close resemblance to the species recovered by Pugh et al. (2014) in their Coniacian-Santonian Dictyomitra multicostata partial range zone. The most important elements in common are Dictyocephalus cf. cayeuxi (Squinabol), Dictyomitra multicostata (Zittel) and Xitus sp.
Pugh et al. (2014) assigned a Coniacian age to the lower part of this zone which coincides with the age proposed by Nielsen et al. (2003) for the Verger Member (Govenlock equivalent) in southern Alberta. In contrast, the radiolarian species described in this study differ almost entirely from the species recovered by Pessagno (1976) in the Upper Cretaceous strata in the Great Valley sequence of the California coast. For example, diagnostic species of the Coniacian *Alievium praegallowayi* Zone (Pessagno, 1976) were not recovered in this study except for some specimens of the genus *Patulibrachium* and one medullary shell of *Praeconocaryomma* sp. which resembles *P. californiaensis* as illustrated by Pessagno (1976). The species *Dictyomitra multicostata* was also recovered by Pessagno (1976) in California, but from the Campanian *Crucella espartoensis* Zone.

The lack of radiolarians from the Turonian-late Santonian interval in the Western Interior Basin is most likely the result of low productivity or low preservation of siliceous microorganisms within the basin due to adverse physicochemical conditions in the water column or the water-sediment interface. These conditions did not affect calcareous microfossils as they have been recovered from the same stratigraphic interval in the whole Western Interior Basin (e.g. McNeil and Caldwell, 1981; Nielsen et al., 2003; Diaz and Velez, in press; Da Gama et al., 2014; Lowery et al., 2016). The distribution of foraminiferal assemblages throughout the basin is closely linked to the surface circulation of the seaway during the Late Cretaceous (Caldwell et al., 1978). According to Slingerland et al. (1996), this circulation consisted of a basin-scale counterclockwise gyre which brought a major influx of cold water from the polar sea to the westernmost part of the Western Interior Basin. In contrast, surface waters in the east were controlled by warm waters from the Tethys Ocean (McNeil and Caldwell, 1981, Schröder-Adams, 2014).
model explains why the number of planktic foraminifera decreases from south to north and from east to west and may also indicate a direct relationship between the temperature of surface waters and the presence of radiolarians within the basin.

As mentioned before, the deposition of volcanic ash in the lower part of the Niobrara Formation is consistent with the appearance of radiolarians and the reduction of foraminifera. In the middle part of the bentonitic interval at well 14-26-015-27W3 (core depth 605.70-603.25), where the ratio of bentonite to mudstone is higher, foraminifera disappear entirely and radiolarians reach their utmost abundance and diversity values. This indicates that foraminifera were probably more susceptible than radiolarians to the disturbed marine conditions resulting after the ash-fall. The negative effects of volcanic ash on the distribution and diversity of foraminifera have been previously reported in modern and ancient analogues (Hess and Kuhnt, 1996; Galeotti et al., 2002, respectively). The fact that radiolarians were recovered only from a stratigraphic interval dominated by bentonites may indicate that enhanced preservation of these siliceous microfossils could have been caused by the increased silica into the water column (De Wever et al., 2002; Wall, 1975; Pugh et al. 2014).

After the volcanic event both benthic and planktic foraminiferal species of the Marsonella oxycona Subzone gradually recolonized the western portion of the Canadian Western Interior Basin (Diaz, 2017). This subzone contains similar species to those recovered from the Gavelinella kansasensis Subzone, but with a gradual increase of calcareous-cemented agglutinated species (e.g. Marsonella oxycona, Dorothisa bulleta and Spiroplectinella sp.). Similarities in the foraminiferal assemblages from these two intervals indicate that the
dysoxic and stressed conditions that took place at the end of the transgressive Greenhorn Cycle (Turonian) prevailed within the earliest stage of the Niobrara transgressive Cycle.

Conclusions

Eleven species of well-preserved radiolarians have been recovered from a bentonitic interval in the lowermost part of the Niobrara Formation (Govenlock Member) at well 14-26-015-27W3, southwestern Saskatchewan. This discovery represents the first report of a Coniacian radiolarian assemblage in the entire Western Interior Basin and also one of the few reports of Late Cretaceous radiolarians in North America. This assemblage contains similar species to those recovered from the *Dictyomitra multicostata* partial range zone proposed by Pugh et al. (2014) for the Sverdrup Basin. Correlation of this radiolarian fauna with molluscan and foraminiferal zones (e.g. Jeletzky, 1971; Diaz, 2017) indicates a lower-middle Coniacian age. This coincides with the Coniacian age suggested by Pugh et al. (2014) for their *Dictyomitra multicostata* partial range zone. A more detailed analysis of radiolarian assemblages in North America is needed to draw a parallel between Tethyan and Polar faunas, as well as to define circulation patterns of the Western Interior Seaway during the Late Cretaceous.

List of species

The list of the eleven species found is presented in alphabetical order and includes the original and additional references of each species. A full taxonomic description of each species is not undertaken in this study. However, additional observations and remarks are made to some species.
1. *Dictyomitra multicostata* ZITTEL, Figure 5-1

2. - 1876 *Dictyomitra multicostata* ZITTEL: Zittel, p. 81, pl. 2, figs. 2-4.


4. - 2005 Dictyomitra multicostata ZITTEL. Packer and Hart, p. 157, text-fig. 6 (O and P).

5. *Dictyocephalus cf. cayeuxi* SQUINABOL, Figures 5-2a-b

6. - 1903 *Dictyocephalus cf. D. cayeuxi* SQUINABOL: Squinabol, p. 132, pl. 8, fig. 28

7. - 1966 *Dictyocephalus (?) lepidosus* KOSLOVA. Koslova & Gorbovets, 1966, p. 102, pl. 5, fig. 3


Remarks: *Dictyocephalus cf. D. cayeuxi* is the most abundant species recovered from the samples analyzed. We opted to include these specimens within the genus *Dictyocephalus* following the original description by Squinabol (1903). This specimens may belong to the genus *Diacanthocapsa* (e.g. Pugh et al., 2014), however, the complete absence of the abdomen hinders a distinction between the two genera.

6. *Dactyliodiscus cf. lenticulatus* (JUD), Figure 5-3


8. -1994 *Dactyliodiscus lenticulatus* (JUD). O’Dogherty, p. 331, pl. 61, figs. 12-15

Remarks: The specimens of *Dactyliodiscus cf. lenticulatus* recovered in this study are similar to those described by O’Dogherty (1994), but they lack the peripheral spines.
Dactyliodiscus differs from Dactyliosphaera by possessing numerous small tubercles on the surfaces of the test and by lacking the raised central cavity (O’Dogherty, 1994).

Cryptamphorella conara (FOREMAN), Figures 5-4, 5

- 1968. Hemicryptocapsa conara FOREMAN: Foreman, p. 35, pl. 4, figs. 11a-b.
- 1970. Cryptamphorella conara (FOREMAN). Dumitrica, p. 36, pl. 11, figs. 66a-c.
- 2004. Cryptamphorella conara (FOREMAN). Goric & Smuc, pl. 2, figs. 7a-b, 9, 10.

Xitus sp., Figures 5-6, 7

- 2014. Eostichomitra sp. B. Pugh et al., pl. 2, figs. 9, 10

Remarks: Xitus sp. is characterized by the presence of a small perforated cephalis with a horn, large aperture and tubular termination of the postabdominal chamber (Interrad, 2016). Some individuals of this species are densely ornamented (Figure 5-6) which makes the classification at species level more challenging.

Pessagnobrachia cf. fabianii (SQUINABOL), Figure 5-8.

- 1914 Rhopalastrum Fabianii SQUINABOL: Squinabol, p. 274, pl. 21 (2), fig. 4.
- 1992 Patulibracchium cf. P. teslaensis PESSAGNO. - Marcucci & Gardin, text-fig. 4 j.
- 1994 Pessagnobrachia cf. P. fabianii SQUINABOL. O’Dogherty, p. 359, pl. 67, figs. 17-25

Crucella cf. messinae PESSAGNO, Figure 5-9

- 1971 Crucella messinae PESSAGNO: Pessagno, p. 56, pl. 6, figs. 1-3.
- 1976 Crucella messinae PESSAGNO. Pessagno, p. 32, pl. I, fig. 4.
- 1994 *Crucella messinae* PESSAGNO. O’Dogherty, p. 368, pl. 70, figs. 21-24; pl. 71, figs. 1-6.

**Paronaella sp.,** Figure 5-10

Remarks: Classified as *Paronaella* following the description of O’Dogherty (1994). The specimens described in this study possesses sub-circular to nearly squared short rays similar than those observed in *P. californicaensis* Pessagno (O’Dogherty, 1994). The main features of this species include the presence of a prominent spine at central ray tip, irregular arrangement of pores and short rays equal in length.

**Orbiculiforma? sp.,** Figure 5-11

Remarks: *Orbiculiforma?* sp. is circular in outline and possesses relatively short peripheral spines as defined by Pessagno (1973) in the original description of the genus *Orbiculiforma*. However, the central cavity that is characteristic of this genus was not observed in any of the specimens recovered. Since this feature is not observable, the name of the genus is questionable.

**Praeconocaryomma sp. (medullary shell),** Figure 5-12


Remarks: Only one medullary shell of *Praeconocaryomma* was recovered in this study. It resembles the medullary shells of *P. californicaensis* illustrated by Pessagno (1976).

**Spongodiscus? multus** KOSLOVA, Figure 5-13

- 1966 *Spongodiscus? multus* KOSLOVA. Koslova & Gorbovets, 1966, p. 88, pl. 4, fig. 10.
Acknowledgments

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Figures captions

Figure 1. Reports of Cretaceous radiolarians in North America. In the Canadian portion of the Western Interior Basin, most radiolarian species have been recovered from the
Campanian Pierre Shale Formation. Coniacian species have been recovered mainly in the Sverdrup Basin (e.g. Pugh et al. 2014)

Figure 2. Location of well 14-26-015-27W3 (red star), southwestern Saskatchewan. A few radiolarian specimens were also recovered at well 05-08-018-28W3 (blue star), but in smaller amounts.

Figure 3. Lithostratigraphy and foraminiferal zonations of the Carlile and Niobrara formations in southwestern Saskatchewan. The bentonitic interval belongs to the *Marsonella oxycona* Subzone (*Trochammina* sp. Zone) (Diaz and Velez, in press).

Figure 4. Bentonitic interval at the base of the Niobrara Formation, well 14-26-015-27W3, southwestern Saskatchewan. A detailed micropaleontological analysis was performed in 21 rock samples (S1-S21). Samples S1, S2 S3 and S21 are out of the range of this figure. Red stars represent samples that hold radiolarian tests.

Figure 5. Stratigraphic ranges of radiolarian (pink rectangle) and foraminiferal species in the lower part of the Niobrara Formation (Govenlock Member) at well 14-26-015-27W3. Vertical grey bars represent intervals barren of microfossils.


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<tr>
<td>Niobrara Formation</td>
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<td>Upper Carlile</td>
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</tbody>
</table>

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Bentonite interval
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**LEGEND**
- Bentonite
- Mudstones
- Calcareous mudstones/ siltstones
- Sand lenses
- Pyrite
- Fish remains
- Shell fragments
- Ammonite
- Coccoliths
- Sparse bioturbation
- Moderate bioturbation
- Undefined burrows

**APACHE 141 HATTON**
14-26-015-27W3
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Sample #</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
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<td>603.5</td>
<td>A2</td>
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<tr>
<td>604.5</td>
<td>A3</td>
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<td>605</td>
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<td>A6</td>
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<td>608</td>
<td>A9</td>
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</table>

Apache 141 Hatton (14-26-015-27W3), southwestern Saskatchewan

**Foraminiferal Zone**

**Unit**

**Trochammina sp. Zone**

**Subzone**

**Marsonella oxycona**

- Haplophragmoides spp.
- Haplophragmoides collyra
- Saccammina alexanderi
- Bolivina sp.
- Neobulimina sp.
- Pseudobolivina rollaensis
- Dorothia smokakensis
- Bathysiphon vitta
- Dorothia glabrata
- Reophax sp.
- Reophax spp.
- Marsonella oxycona
- Reophax deckeri

**Barren**

- Dictyomitra multicostata
- Dictyocephalus cf. cayeuxi
- Dactyliodiscus cf. lenticulatus
- Cryptamphorella conara
- Xitus sp.
- Pessagnobrachia cf. fabianii
- Crucella cf. messinae
- Paronaella sp.
- Orbiculiforma sp.
- Praeconocaryomma sp. (medullary shell)
- Spongodiscus? multus
- Gyroidina sp.
- Fursenkoina tegulata
- Gavelinella kansasensis
- Haplophragmoides kirkii
- Reophax clavulina
- Muricoheadbergella planispira
- Neobulimina albertensis
- Planoheterohelix globulosa
- Haplophragmoides linki

**Radialarians**

**Radiolarian**

**Rare** (<50 individuals)

**Common** (51-300 individuals)

**Abundant** (> 300 individuals)