https://dx.doi.org/10.17850/njg97-4-01
GEOLOGICAL SOCIETY OF NORWAY

Foraminifera from the carbonate cobbles and pebbles of Early Jurassic conglomerates of Franz Joseph Land as direct evidence of the existence of a Late Palaeozoic carbonate succession in the northeastern Barents Sea

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Here we present the first description and images of foraminiferal fauna from the carbonate cobbles and pebbles of Early Jurassic polymictic conglomerates from Graham Bell Island, in the easternmost part of the Franz Joseph Land archipelago. The composition of the conglomerates suggests a proximal provenance area. The identified foraminiferal genera and species suggest a Serpukhovian–Late Carboniferous age for the primary carbonates from which the conglomerate clasts were derived, and which can be correlated with coeval carbonate strata of Svalbard, the Volga–Urals and the Pechora region. Combined with previous studies, our new data lead us to assert that a shallow-marine carbonate platform occupied the entire Barents shelf, including its northeasternmost part, during Carboniferous–Early(?) Permian time. This study improves our understanding of the composition and age of pre-Mesozoic successions of Franz Joseph Land and surrounding parts of the Barents Sea.

Keywords: Foraminifera; Arctic; Barents Sea; Franz Joseph Land archipelago; Carboniferous; Palaeozoic

Received 19. May 2017 / Accepted 4. September 2017 / Published online 3. November 2017

Introduction

The Barents Sea sedimentary basin is one of the principle targets of oil and gas companies exploring in the Arctic region due to its potentially significant, undiscovered, hydrocarbon resources. However, whilst the Norwegian portion of the Barents Sea is covered by a dense network of seismic lines and penetrated by numerous wells, the Russian portion is comparatively poorly studied. The sedimentary succession there to date has been reconstructed from only a few wells drilled in the southern part of the basin, 4 wells drilled onshore across the Franz Joseph Land (FJL) archipelago, and onshore outcrop exposures across the FJL and Novaya Zemlya archipelagoes. However, the deeper pre-Mesozoic succession in the northeastern part of the Barents Sea has been constrained mainly by seismic data (Makariev, 2006, 2011; Basov et al., 2009; Henriksen et al., 2011) and only penetrated by the Nagurskaya well drilled on the westernmost part of FJL. Here, we present new data on the age of the pre-Mesozoic succession of FJL and the surrounding parts of the Barents Sea based on foraminiferal faunas from carbonate pebbles and cobbles collected from the Lower Jurassic conglomerates of Graham Bell Island.

Ershova, V., Leven, E. & Prokopiev, A. 2017: Foraminifera from the carbonate cobbles and pebbles of Early Jurassic conglomerates of Franz Joseph Land as direct evidence of the existence of a Late Palaeozoic carbonate succession in the northeastern Barents Sea. *Norwegian Journal of Geology 97*, 255–261. https://dx.doi.org/10.17850/njg97-4-01.

Previous data on the Palaeozoic succession of FJL

The Palaeozoic stratigraphic succession of FJL is based solely on the stratigraphy penetrated by the Nagurskaya well on Zemlya Aleksandra Island, in the westernmost part of the archipelago (Gramberg et al., 1985; Dibner, 1998; Makariev, 2006). The Palaeozoic was penetrated between 1657 and 1895 m depth and described as horizontally bedded Lower–Upper Carboniferous clastic-carbonate rocks, overlying deformed and metamorphosed basement rocks, presumed to be of Neoproterozoic age, with an angular unconformity (Gramberg et al., 1985; Makariev, 2006).

Based on the succession penetrated by the Nagurskaya well, along with carbonate xenoliths described from a number of other localities, Makariev (2006) defined three Palaeozoic formations deposited across FJL.

The **Dezhnevskaya Formation** is described from the Nagurskaya well within the depth interval 1740–1895 m, attaining a total thickness 102 m, excluding younger basaltic intrusions. It is composed of alternating light-coloured quartz sandstones and dark-coloured clayey siltstones and mudstones, with layers of coal. A characteristic feature is the presence of coalified plant detritus and lenses of graphitised coals, with the formation containing a characteristic, Early to early-Late Carboniferous, fossilised floral assemblage.

The **Kropotkinskaya Formation** is described from the Nagurskaya well within the depth interval 1657–1740 m, and comprises bioclastic coarse-grained limestones which disconformably overlie terrigenous deposits of the Dezhnevskaya Formation. The Kropotkinskaya Formation has reportedly been dated as Late Carboniferous–Early Permian based on its brachiopod and foraminiferal assemblage (Makariev, 2006); however, there are no published descriptions or images of these findings.

The **Knipovischevskaya Formation** has been defined from the discovery of fragments of dolomites and dolomitised limestones along the coast of Victoria Island, with a Bashkirian fusulinid fauna including *Profusulinella prisca* and *P.* cf. *gorskyi*. Makariev (2006) suggested that these fragments were either xenoliths weathered out from younger Mesozoic intrusions, reworked pebbles within Jurassic conglomerates, or they represent erosion of a portion of the Palaeozoic strata, buried beneath younger Mesozoic deposits onshore across the island. Based on the age of the carbonates, coeval strata are either missing or represented by a portion of the Kropotkinskaya Formation in the Nagurskaya well, with a facies transition between the two locations. Bashkirian, Moscovian and Sakmarian foraminifera have also been discovered in carbonate pebbles from Quaternary deposits on a number of islands across the FJL archipelago (Davydov, 1997). However, it is uncertain whether they were reworked from a local provenance on the archipelago or transported over greater distances by glacial ice from a more distal provenance.

Geological background of the studied samples

The Mesozoic succession of Graham Bell Island has been studied on Cape Kolzat in the northeast (Fig. 1). The lower part of the succession is represented by two units. The first unit comprises 2 m-thick silts and clays and 12 m-thick medium-grained sandstones, overlain by the second unit comprising a 57 m-thick, coarse-grained, sandstone package. A 30 m-thick bed of matrix-supported conglomerates occurs at the base of this coarse-grained second unit, with pebbles and cobbles ranging in size from 2 to 10 cm. The clasts are of diverse compositions including granites, felsic volcanics, quartzites, argillites, metasandstones, shales, schists, vein quartz, cherts and limestones. Units 1 and 2 have been dated as Early Jurassic based on rare palynological data (Kosteva, 2005). Unit 3 comprises 5 m-thick, fine- to medium-grained sandstones and has been dated as Late Oxfordian based on its ammonite fauna (Kosteva, 2005; Makariev, 2011). Unit 4 comprises grey to black argillites with subordinate beds of siltstone, containing an ammonite and bivalve fauna diagnostic of a Kimmeridgian age. The uppermost Unit 5 consists of 8 m-thick, fine- to coarse-grained sandstones of Tithonian age (Fig. 1C) (Makariev, 2011).

This study focuses on the carbonate cobbles and pebbles collected from the matrix-supported conglomerates of Unit 2 (Fig. 1C–E), which include limestones eroded from underlying Palaeozoic strata, offering the only insight into the underlying stratigraphy which is not exposed anywhere on Graham Bell Island.

Petrography of carbonate pebbles

Forty thin-sections from the carbonate pebbles and cobbles were cut for further analysis. Many of the studied carbonates are partly to fully recrystallised and have commonly been affected by secondary silicification, which hampers the identification of initial fabrics, textures and composition. Thin veins of recrystallised calcite occur in places, as well as networks of opaque veins.

However, there are a number of samples with distinguishable structures and negligible recrystallisation

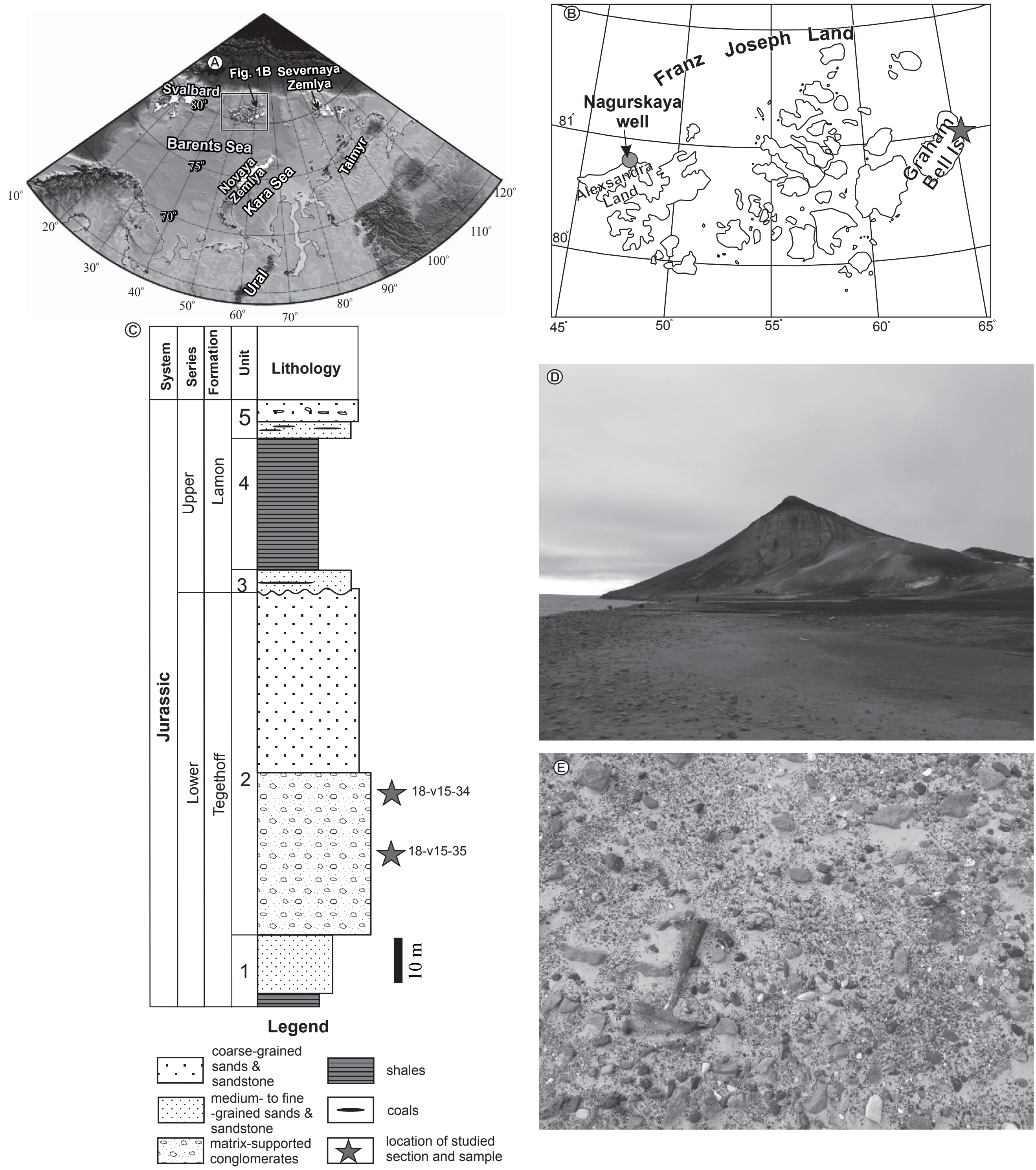

Figure 1. (A, B) Location of the studied region and sample sites; (C) Mesozoic succession of Kolzalt mountain (Graham-Bell Island); (D) General view of outcrop; (E) Polymictic Lower Jurassic conglomerates.

which have been used for age discrimination based on foraminifera (Fig. 2).

Foraminifera have been found in two types of carbonate pebbles. The first type consists of poorly sorted foraminiferal packstone and is dominated by foraminifera bioclasts with rare fragments of bryozoans, algae, brachiopods and indeterminable bioclasts, with a micrite matrix which is either partly dissolved or recrystallised to sparite. A few samples display a secondary ferruginous overgrowth around bioclasts or a ferruginous impregnation of the matrix (Fig. 2A–D). The

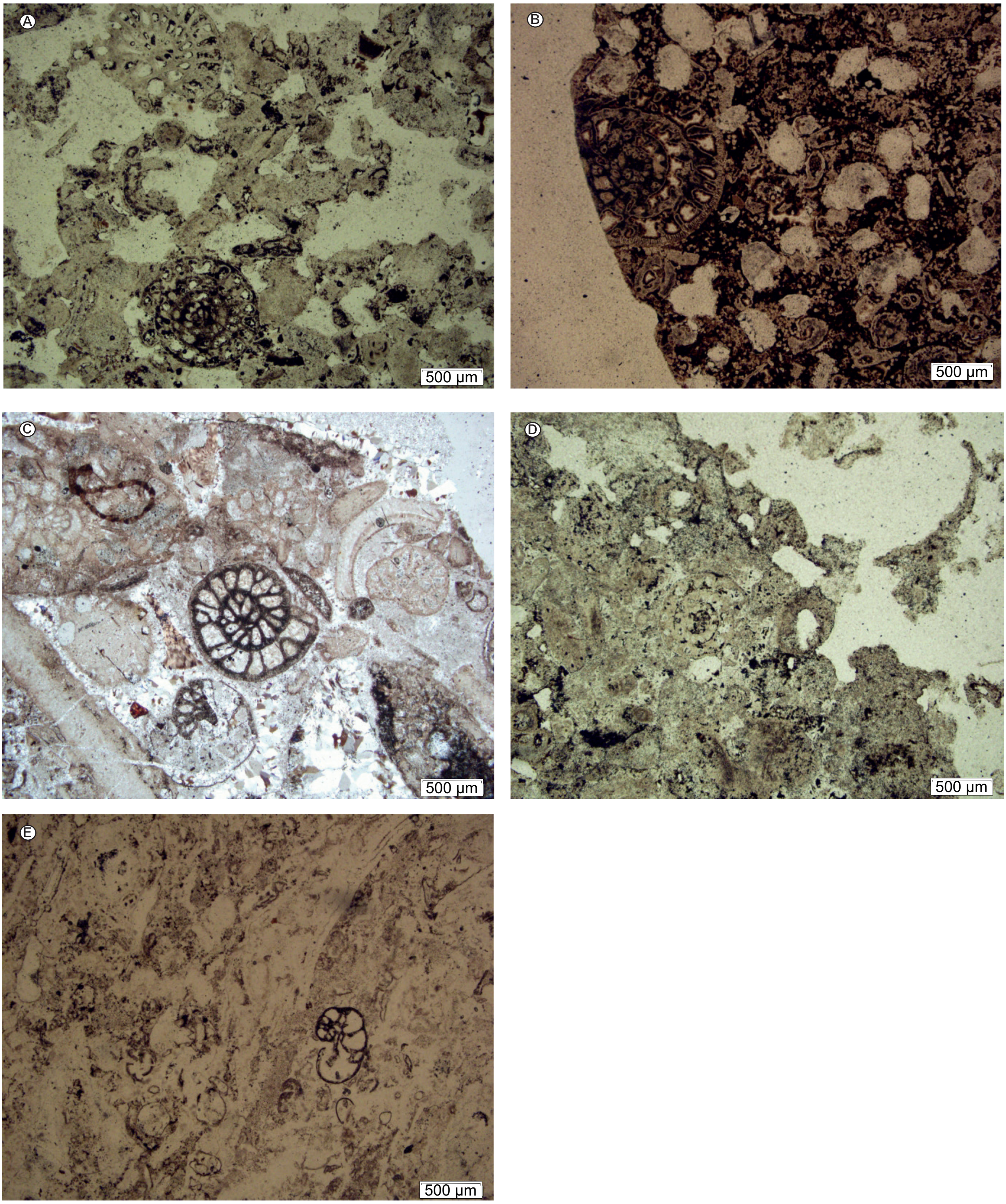

Figure 2. Photomicrographs of thin-sections of studied carbonate cobbles and pebbles from the Lower Jurassic conglomerates. (A) Partly ferruginous foraminiferal packstone; (B) Strongly ferruginous foraminiferal packstone; (B) Foraminiferal packstone; (D) Heavily recrystallised foraminiferal packstone; (E) Bioclastic wackestone.

second type is composed of recrystallised wackestones. Bioclasts are dominated by bryozoans, algae, brachiopod needles, as well as a few very small foraminifera shells (Fig. 2E). Most bioclasts have been replaced by sparry calcite, but some retain a foliated microstructure. The matrix is dominated by micrite; however, significant sparry calcite is also present.

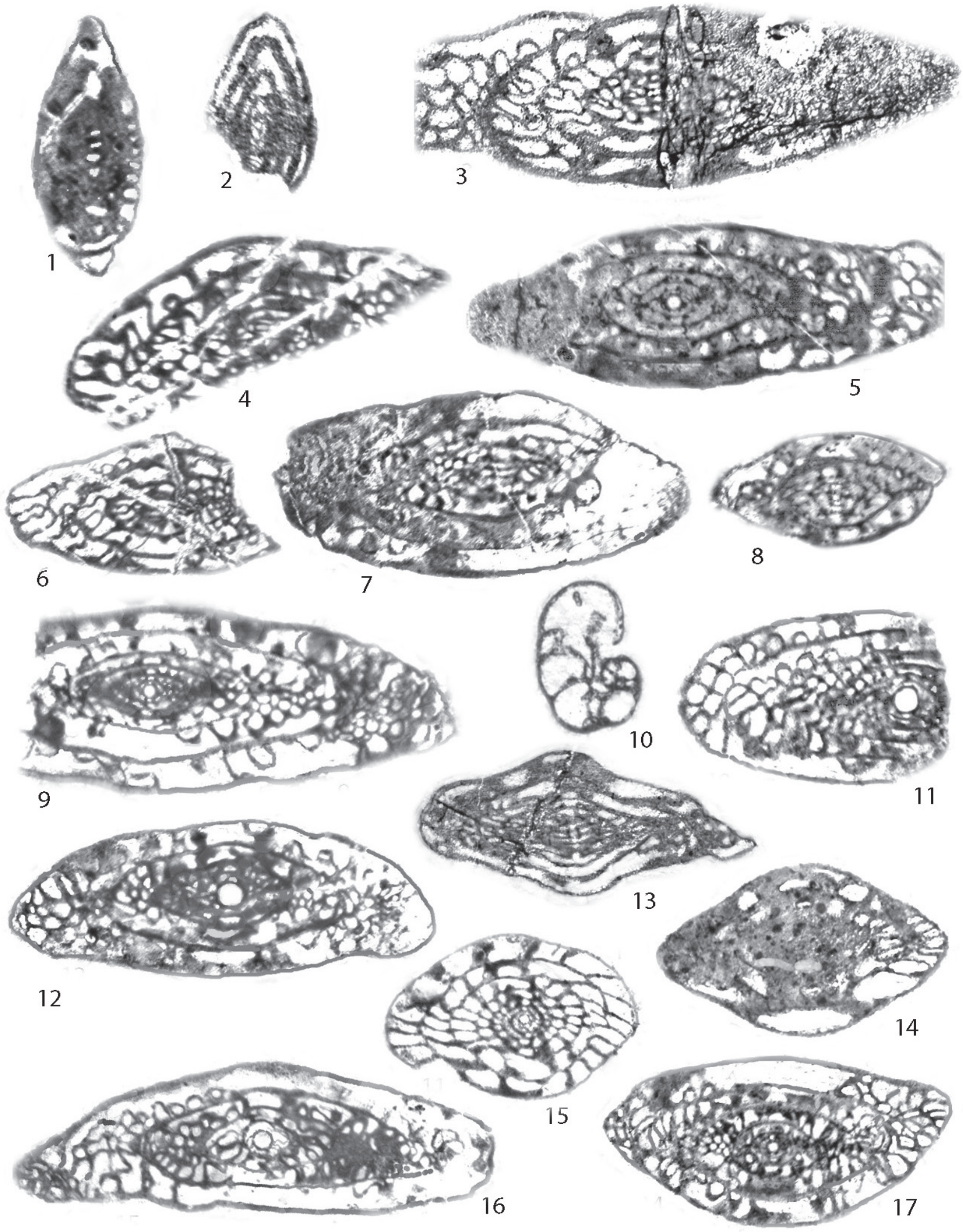

Figure 3. Carboniferous fusulinids from the carbonate pebbles and cobbles of the Lower Jurassic conglomerates, Graham Bell Island, Franz Joseph Land. Photos 3–9, 11–13, 15–17 magnification 15; Photo 10 magnification 30; Photo 14 magnification 35; Photos 1 & 2 magnification 45. 1 – Ozawainella *sp., subaxial section; 2 –* Ozawainella *cf.* mosquensis *Rauser, subaxial section; 3 –* Rauserites *cf.* variabilis *Rosovskaya, subaxial section; 4 –* Rauserites *cf.* petchoricus brevis *(Rauser et Beljaev), subaxial section; 5 –* Rauserites *ex gr.* paraarcticus *(Rauser), axial section; 6 & 7 –* Rauserites *cf.* atelicus *(Rauser), oblique tangential sections; 8 –* Rauserites *cf.* bashkiricus *Rosovskaya, subaxial section; 9 –* Rauserites *ex gr.* postarctisus *(Rauser), axial section; 10 –* Biseriella minima *(Reitlinger); 11 –* Rauserites *aff.* irregularis *(Grozdilova), oblique section; 12 –* Rauserites stuckenbergi *(Rauser), axial section; 13 –* Kanmeraia *cf.* condensa *Solovieva, subaxial section; 14 –* Profusulinella *sp., subaxial section; 15 –* Pulchrella*? sp., oblique section; 16 –* Rauserites*? sp., subaxial section; 17 –* Rauserites perlevis *(Grozdilova), axial section.*

Foraminiferal fauna

Foraminifera have been found in 25 thin-sections made from the limestone pebbles and cobbles described above.

1. Within the recrystallised wackestones, foraminifera are mostly poorly preserved and difficult to identify to species level. With varying degrees of reliability, genera of small foraminifera *Dainella*, *Chernyshinella*, *Pseudoglomospira*, *Eolasiodiscus ?*, *Eblanasia ?* and *Archaediscidae* have been determined. The above foraminiferal genera are typical of the Early Carboniferous, although based on the finding of a single specimen of *Biseriella minima* (Reitlinger) we can potentially narrow the age range to latest Serpukhovian–early Bashkirian.

2. The strongly altered ferruginous packstone is characterised by the presence of numerous fusulinid shells, most of which are likely to belong to the genus *Pseudostaffella,* although it is difficult to identify to species level due to poor preservation of the foraminifera. In addition to *Pseudostaffella*, we found a single shell which can be attributed to the genus *Profusulinella* (Fig.3). Based on these identifications, we can tentatively date the ferruginous packstone as Late Bashkirian in age.

3. The foraminiferal packstone is characterised by a diverse foraminiferal fauna with a reasonable quality of shell preservation. The following taxa were identified: *Eostaffella* sp., *Ozawainella* cf. *mosquensis* Rauser, *Schubertella* sp., *Quasifusulina* sp., *Pulchrella?* sp., *Kanmeraia* cf. *condensa* Solovieva, *Rauserites* ex gr. *postarcticus* (Rauser), *R.* aff. *parairregularis* (Grozdilova), *R. stuckenbergi* (Rauser), *R. perlevis* (Grozdilova), *R.* cf. *variabilis* Rosovskaya, *R.* cf. *petschoricus brevis* (Rauser et Beljaev), *R.* cf *paraarcticus* (Rauser), *R.* cf. *atelicus* (Rauser), *R.* cf. *bashkiricus* Rosovskaya, *Rauserites* sp. (Fig.3). The *Rauserites* species are dominant within the described foraminiferal fauna and are diagnostic of the upper Kasimovian and lower Gzhelian stages of the Upper Carboniferous of the Volga–Ural region (Rozovskaya, 1950, 1958; Rauzer-Chernousova, 1958). Two of the representatives of this genus, *parairregularis* and *perlevis*, have been described from Gzhelian deposits of northern Timan (Grozdilova, 1966). The genus *Kanmeraia* is known from deposits of Kasimovian, Gzhelian and Asselian ages, with *K. condensa* described by Solov'eva (1984) from the lower part of the Kasimovian stage of the Ugor Peninsula (Pai-Khoi region), where it is accompanied by numerous *Pulchrella*. The genus *Ozawainella* appeared in the Bashkirian stage and ranged up into the Early Permian. The species *O. mosquensis* is diagnostic of the Moscovian stage, but can also occur at younger stratigraphic levels. The genus *Quasifusulina* appeared in the Kasimovian stage and extended up to the end of the Early Permian, whilst the genera *Eostaffella* and *Schubertella* have a wide stratigraphic distribution from Serpukhovian and Early Bashkirian to Early Permian, respectively. Based on the above definitions, we can date the foraminiferal packstones as Late Kasimovian to Early Gzhelian.

Conclusions

The studied polymictic Lower Jurassic conglomerates are quite immature, inferring a proximal provenance area. In addition, the studied carbonate pebbles and cobbles are a good indicator of proximity to a source of clastics. Here, we present the first systematic descriptions of the Late Palaeozoic foraminiferal fauna from the northeastern part of the Barents Sea region. The foraminiferal fauna determined from the carbonate pebbles and cobbles of the Lower Jurassic conglomerates allows us to date the source of the cobbles as Serpukhovian–Late Carboniferous. The taxonomic composition of fusulinids described from the studied carbonates is comparable to those described from coeval Carboniferous–Lower Permian strata of Svalbard, the Volga–Urals and the Pechora region (Rauser-Chernousov, 1958; Rozovskaya 1958; Grozdilova, 1966; Solov'eva, 1984; Davydov & Nilsson, 1999).

Carboniferous deposits have been previously described from the Nagurskaya well (Gramberg et al., 1985; Makariev, 2006) in the westernmost part of the FJL archipelago, along with Lower Permian fusulinids in limestone fragments within Quaternary sediments across a number of the islands in the same archipelago (Davydov, 1997). Combined with our new foraminiferal fauna data from Graham Bell Island presented here, we propose that the FJL archipelago and adjacent northeastern part of the Barents Shelf were occupied by a shallow-marine carbonate platform from at least the end of the Early Carboniferous to the beginning of the Permian. Our conclusions are in good agreement with the well-studied Carboniferous–Lower Permian sedimentary succession of Svalbard (Stemmerik & Worsley, 2000; Larssen et al., 2002; Ahlborn & Stemmerik, 2015 and references therein), which comprises predominantly carbonates, with compositionally similar, coeval, foraminiferal packstones described from central Svalbard (Ahlborn & Stemmerik, 2015). Furthermore, the data presented here has allowed us to assess the existing paleogeographic reconstruction for Carboniferous–Permian time in the Barents Sea region. Thus, according to Worsley (2008) during most of the Carboniferous and Permian the FJL was an area of erosion/non-deposition with locally developed shallow-marine environments along the southern margin of archipelago. Our study therefore provides additional evidence that a shallow-marine carbonate platform extended across the entire Barents Sea shelf during Carboniferous–Early Permian time, deposits of which are now deeply buried beneath a thick Meso–Cenozoic succession across its northeastern part, and which until now has made such an inference difficult.

Acknowledgements. Journal reviewers Benoit Beauchamp and Natalia Kosteva provided critical and constructive comments that helped improve the paper. This research was supported by RFBR grant 16-55-20012 and the Research Council of Norway grant 254962/H30.

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