Canadian Journal of Earth Sciences
Revue canadienne des sciences de la Terre

Upper Ordovician conodont biostratigraphy and revised lithostratigraphy and geological map, Akpatok Island, Ungava Bay, Nunavut

Journal:	<i>Canadian Journal of Earth Sciences</i>
Manuscript ID	cjes-2017-0145.R1
Manuscript Type:	Article
Date Submitted by the Author:	08-Sep-2017
Complete List of Authors:	Zhang, Shunxin; Canada-Nunavut Geoscience Office,
Is the invited manuscript for consideration in a Special Issue? :	N/A
Keyword:	Upper Ordovician, conodont biostratigraphy, geological map, Akpatok Island, Ungava Bay

SCHOLARONE™
Manuscripts

**Upper Ordovician conodont biostratigraphy and revised lithostratigraphy
and geological map, Akpatok Island, Ungava Bay, Nunavut**

Shunxin Zhang

Canada - Nunavut Geoscience Office, PO Box 2319, 1106 Inuksugait IV, 1st floor, Iqaluit,
Nunavut X0A 0H0, Canada; shunxin.zhang@canada.ca

Correspondence author:
Shunxin Zhang

PO Box 2319, 1106 Inuksugait IV, 1st floor, Iqaluit, Nunavut X0A 0H0, Canada;
Phone: (867) 975-4579
Fax: (867) 979-0708
Email: shunxin.zhang@canada.ca

ESS contribution number: 20160440

Upper Ordovician conodont biostratigraphy and revised lithostratigraphy and geological map, Akpatok Island, Ungava Bay, Nunavut

Shunxin Zhang

Abstract

Stratigraphic units exposed on Akpatok Island, Ungava Bay, Nunavut, were previously recognized as Boas River and Akpatok formations; their biostratigraphic ages and correlations, in particular the stratigraphic position and age of the organic rich “Boas River” Formation, were largely based on limited data. New detailed field observations have recognized three stratigraphic units, namely the Amadjuak, Akpatok and Foster Bay formations, in which extensive microfossil sampling recovered over 22 000 conodont elements from 66 productive samples from both outcrops and rubble at over 20 localities in four areas. Four Upper Ordovician conodont zones and one unzoned interval are established for the three redefined formations: *Belodina confluens* and *Oulodus velicuspis* Interval zones are confined to the exposed Amadjuak Formation and correlated to Edenian and Maysvillian; *Amorphognathus ordovicicus*-*Plegagnathus dartoni* Concurrent-range Zone occurs with the Akpatok Formation and correlated to lower Richmondian; and *Rhipidognathus symmetricus* Taxon-range Zone is retained in the Foster Bay Formation and correlated to upper Richmondian; and an “Unzoned Interval” is defined between that last two zones in the lower Foster Bay Formation. The conodont *Amorphognathus ordovicicus* occurs in both Akpatok and lower Foster Bay formations, and it is also recovered from the bituminous, argillaceous limestone rubble, based on which the stratigraphic position of the previously named “Boas River” Formation is most likely positioned within the lower Foster Bay Formation. The biostratigraphy and lithostratigraphy are combined

50 with geographic information systems (GIS) to establish the thicknesses of the three formations
51 and revise the geologic map of the island.

52

Draft

Introduction

Akpatok Island is one of the uninhabited Canadian Arctic islands in the Baffin Region of Nunavut, Canada (Fig. 1A). It is the largest island in Ungava Bay, off the northern coast of Quebec where meeting Hudson Strait. With an area of 903 km², it is predominantly formed by limestone, ringed with steep cliffs that rise 150 to 200 m above sea level (Fig. 1B). The cliffs are broken in some places by deep ravines allowing access to the flat plateau. The plateau is about 23 km wide and 45 km long with the highest elevation about 280 m in its central area (Fig. 1B). Geologically, Akpatok Island is one of many Ordovician outliers on the Canadian Shield. It is the only location where the Paleozoic rocks are exposed in Ungava Bay and Hudson Strait; therefore, it plays a key role in understanding the petroleum potential in these offshore areas. However, given the remoteness and isolated location of the island, the logistical challenges have resulted in only limited geological studies to date.

The previous knowledge of the Ordovician stratigraphy of the island resulted from visits by Geological Survey of Canada in 1897 (Bell 1899; Whiteaves 1899), the Oxford University Hudson Strait Expedition in 1931 (Cox 1933a, 1933b, 1933c), and a test hole (Premium Homestead Akpatok F-26 at 60°25'40"N, 68°20'30"W) drilled for hydrocarbons on Akpatok Island in 1969 and the surface survey near the test hole (Workum et al. 1976). Based on these limited data and the previous authors' interpretation, a stratigraphic framework of Akpatok Island and adjacent offshore region, including the Middle Ordovician Ungava Bay and Frobisher Bay formations and the Upper Ordovician Amadjuak, "Boas River" and Akpatok formations, was established, and a geological map of the region was also compiled, without sufficient measured sections and precise age assignments (Sanford and Grant 2000) (Fig. 2A). Although not much of information from the conodont microfossils and outcrop studies supports this

stratigraphic division and the compiled geological map, these stratigraphic interpretations were used by a recent report (McCracken 2017) on 11 Ordovician conodont samples from Akpatok Island collected by James Gray (University of Montreal) in 1989.

Given these limited earlier studies with uncertain stratigraphic division and age assignments, and stratigraphic relationships between Ungava Bay, Hudson Strait, Hudson Bay and Foxe basins, as well as the implications for hydrocarbon potential, the objectives of this present study are to 1) measure many stratigraphic sections in detail along the deep ravines; 2) sample extensively for conodont microfossils, and document the conodont distribution and establish the conodont zonation; 3) establish more refined Ordovician stratigraphic units and define their thickness to aid regional correlations; 4) determine the correct stratigraphic position of the organic-rich unit; and 5) revise the geological map of Akpatok Island. This present study, therefore, examined over 20 localities in four areas (area I: west of D'Aeth Point; area II: lower reach of Gregson Creek; area III: unnamed creek south of Singer Point; area IV: Cox Ridges) on Akpatok Island (Figs. 1B, 2B, 3A–3D) during two field seasons in 2014 and 2015, and focused on stratigraphic measurements and sampling for conodonts mainly from outcrops, with a few from frost-shattered rubble.

Ordovician stratigraphy of Akpatok Island: the issues, sections, and conodont samples

Ungava Bay Formation

To replace the Ship Point Formation that was used by Workum et al. (1976), an informal name Ungava Bay Formation was proposed and then elevated to formal status by Sanford and Grant (1990, 2000) to identify the Ordovician sandstones and minor carbonate and shales that lie

directly on the Precambrian basement beneath Ungava Bay and eastern Hudson Strait (Fig. 2A). The formation was completely penetrated by the Premium Homestead Akpatok F-26 borehole, and defined at a depth ranging from 172 to 354 m from the surface, taking the borehole as a type section (Sanford and Grant 2000). However, based on the lithological details from this borehole provided by Workum et al. (1976, fig. 3, appendix), this unit obviously ranges from 146 m to 335 m from the surface.

Within the over 180 m thick Ungava Bay Formation, the only fossil record is a total of 197 conodont specimens representing seven species and one indeterminate element recovered from the carbonate rocks at a depth between -264 m (867 ft) and -298 m (979 ft) (Workum et al. 1976). This conodont fauna contains *Histiodella altifrons* Harris represented by two specimens, based on which the Ungava Bay Formation was interpreted as an early Middle Ordovician (middle Whiterockian) age. Except for *Oistodus multicorrugatus* Harris and *Drepanoistodus basiovalis* (Sergeeva), this conodont fauna does not show a great similarity to that recovered from Ship Point Formation on the Melville Peninsula, which is referred to as the upper Lower Ordovician by Zhang (2013). Based on the limited conodont data from Akpatok Island, it is uncertain whether 1) the Ungava Bay Formation is younger than the Ship Point Formation on Melville Peninsula, 2) the entire Ungava Bay Formation belongs to early Middle Ordovician, and 3) the Ungava Bay Formation spans the Lower–Middle Ordovician boundary. However, considering the latest Early Ordovician age of the Ship Point Formation, this present study temporarily correlates the Ungava Bay Formation to the upper Lower Ordovician and lower Middle Ordovician (Fig. 4). The formation is nowhere exposed onshore; therefore, it was not observed and sampled during this study.

123 **Frobisher Bay Formation**

124 The Frobisher Bay Formation was informally proposed by Sanford and Grant (1990) to
125 identify some 15 m of strata overlying the Ship Point Formation on Melville Peninsula, and then
126 given formal status and correlated to the Middle Ordovician by Sanford and Grant (2000). Based
127 on the conodont fauna recovered from the Frobisher Bay Formation on southern Baffin Island
128 (McCracken 2000) and Melville Peninsula (Zhang 2013), it can be assigned an age of
129 Chatfieldian, Late Ordovician.

130 The Frobisher Bay Formation is nowhere exposed in the Ungava Bay, Hudson Strait and
131 Foxe Channel, but it is identified in the Premium Homestead Akpatok L-26 borehole at 172 m to
132 146 m below the surface by Sanford and Grant (2000). It does not have fossils to prove whether
133 it correlates to the Frobisher Bay Formation exposed on southern Baffin Island and Melville
134 Peninsula. Without other offshore wells, it is uncertain whether the formation's distribution is the
135 same as that mapped by Sanford and Grant (2000) (Fig. 2A). In the absence of outcrops and
136 conodont data, this study correlates the Frobisher Bay Formation to the early Late Ordovician
137 (Fig. 4) following that on Melville Peninsula (Zhang 2013).

138

139 **Amadjuak Formation**

140 The Amadjuak Formation was informally established by Sanford and Grant (1990) for
141 the limestones, shaly limestones and shales that disconformably succeed the Frobisher Bay
142 Formation in the Foxe Basin and adjacent areas of Ungava Bay, Hudson Strait and Foxe Channel.
143 It was raised to formal status by Sanford and Grant (2000).

144 Sanford and Grant (2000) interpreted that the Amadjuak Formation forms the bedrock
145 surface on the west shore of Akpatok Island, and the formation can be also determined from

cuttings in the Premium Homestead Akpatok L-26 well at depths of 22.9 to 146 m from the surface.

During a one-day reconnaissance survey in 2014, Zhang and Mate (2015) found the gastropod *Maclurites* sp., one of the distinctive *Fisherites-Maclurites* fauna in the Amadjuak Formation on southern Baffin Island (Bolton 2000), and other gastropods and cephalopods from outcrops at an elevation of about 75 m (locality 6A in Fig. 3B). Therefore, the presence of the Amadjuak Formation on the Akpatok Island is not only at the surface on west coast as Sanford and Grant (2000) interpreted, but also up to a height about 75 m on the western part of the island.

The Amadjuak Formation on southern Baffin Island and Melville Peninsula was assigned a Late Ordovician Edenian to mid-Maysvillian age (Sanford and Grant 2000; Zhang 2013) based on the typical *Fisherites* and *Maclurites* macrofossils (Bolton 2000) and conodont microfossils (McCracken 2000; Zhang 2013). However, there is no fossil record from the Amadjuak Formation (at depths of -22.9 m to -146 m, the Premium Homestead Akpatok L-26 well) determined by Sanford and Grant (2000) to support whether this interval equates to the Amadjuak Formation or part of the Amadjuak Formation on the southern Baffin Island and northeastern Melville Peninsula.

The field observations performed by the present author confirm the presence of the Amadjuak Formation from sea level up to an elevation about 80 m and 50 m on the west and east sides of the island, respectively. The sections were measured from the lowest tide level west of the Premium Homestead Akpatok L-26 well up to the lower reach of Gregson Creek southeast of the wellsite (area II in Figs. 1B and 2B), and a total of 13 samples were collected from localities 20, 5A, 2A and 6A (Figs. 3B and 5; Tables S1 and S2). In addition, two samples were collected from locality 8A (Figs. 3C and 5; Table S2) on the cliff-top in an unnamed creek south of Singer

Point (area III in Figs. 1B and 2B), and another four from localities 9A and 14 (Fig. 3A and 6; Tables S1 and S2) near the foot of the cliffs west of D’Aeth Point (area I in Figs. 1B and 2B), respectively.

The exposed Amadjuak Formation is composed of hard, light to dark brown, micritic limestone, interbedded with thin layers of chert or chert nodules (Fig. 7A).

“Boas River” Formation

The “Boas River Shale” was originally named for an “oil shale” unit on Southampton Island, northern Hudson Bay, and its stratigraphic position was placed between the Bad Cache Rapids and Churchill River groups by Heywood and Sanford (1976). It was formally named Boas River Formation by Sanford and Grant (2000). Much more detailed stratigraphic and biostratigraphic studies by Zhang (2008, 2011) proved that the “Boas River Shale” is the lower one of the three oil shale intervals in the lower Red Head Rapids Formation on Southampton Island.

Workum et al. (1976) documented a 4.5 m thick bituminous, brown argillaceous limestone in a stream-cut section along Gregson Creek immediately east of the Premium Homestead Akpatok L-26 wellsite on Akpatok Island, and correlated it to the “Boas River Shale” on Southampton Island. McCracken and Nowlan (1989) reported several Late Ordovician conodont species from two samples from the brown argillaceous limestone collected by G. Macauley and N.J. McMillan in 1986, but could not be certain of their stratigraphic position. This bituminous, argillaceous limestone was assigned to the Boas River Formation, its stratigraphic position was placed between the Amadjuak and Akpatok formations, and its

geographic distribution was illustrated along the east shore of the Akpatok Island (Sanford and Grant 2000, fig. 12) (Fig. 2A).

During a geological reconnaissance on Akpatok Island (Zhang and Mate 2015), the bituminous, argillaceous limestone with abundant graptolites (Figs. 7C–7F), yielding average and maximum total organic carbon (TOC) values of 3.11 and 4.19%, was found at two localities (localities 2A and 3A in area II; Fig. 3B) along lower reach of Gregson Creek, the same creek as section II reported by Workum et al. (1976); however, they were considered as local rubble, rather than outcrops (Zhang and Mate 2015). In addition, much bituminous limestone rubble was also observed around the wellsite (Zhang and Mate 2015; locality 4A in Fig. 3B) which is about 10–20 m higher than localities 2A and 3A. Based on 1) the macluritid gastropod, the characteristic fossil of the Amadjuak Formation found at an elevation about 75–80 m; and 2) the rubble of the brown bituminous, argillaceous limestone found at elevations between 20 and 30 m (locality 4A in Fig. 3B), an estimation was made that the organic-rich interval may occur in the lower Amadjuak Formation on Akpatok Island (Zhang and Mate 2015), rather than between Amadjuak and Akpatok formations as Sanford and Grant (1990, 2000) concluded.

However, Cox (1933b) described a graptolitic bed at an elevation between 143 and 144 m (470 and 473 ft) in a gully in the southern end of the island (most likely in Umiak Cove area), which is a chocolate-coloured limestone with the graptolite *Climacograptus inuiti* Cox (Cox 1933c), a species to be considered as a synonym of *Amplexograptus latus* (Elles and Wood) by Riva (1988) and others. This species was also found from talus at an elevation of 131 m (430 ft) in section III along Langley Creek by Workum et al. (1976), which may be at the same stratigraphic level as other graptolite species found at an elevation about 10 m (30 ft) in section II along Gregson Creek of Workum et al. (1976). The conodont and graptolite fauna collected by

the present author from the bituminous, argillaceous limestone rubble (Figs. 7C–7F) at locality 3A along Gregson Creek in area II (Fig. 3B), the same Creek as section II reported by Workum et al. (1976) confirms that the bituminous, argillaceous limestone rubble most likely came from the same elevation as the chocolate-coloured limestone described by Cox (1933b), and the bituminous, argillaceous limestone is both topographically and stratigraphically higher than that interpreted by Sanford and Grant (2000) and estimated by Zhang and Mate (2015). However, where is it exactly? Determining the stratigraphic position of the bituminous, argillaceous limestone is critical for its stratigraphic correlation with the organic rich interval in the Hudson Bay and Foxe basins. The conodont and graptolite fauna recovered from the bituminous limestone rubble at locality 3A (Fig. 3B) provides the determination that the term “Boas River” Formation is not deemed appropriate to use on Akpatok Island where the bituminous, argillaceous limestone represents a thin unit, most likely in the lower Foster Bay Formation. This is discussed later in the section on the Upper Ordovician conodont biostratigraphy of Akpatok Island.

Akpatok Formation

The Akpatok Formation was informally proposed and then raised to formal status for over 240 m of thin, uniformly bedded limestone exposed in the cliff sections succeeding the Boas River Formation on Akpatok Island by Sanford and Grant (1990, 2000). It was interpreted to underlie much of eastern Hudson Strait and was compared to the Churchill River Group in the Hudson Bay Basin (Sanford and Grant 1990). The highest elevation of Akpatok Island is 281 m in Cox Ridges area (Figs. 1B and 2B); based on Sanford and Grant (1990, 2000), the island is almost entirely underlain by the Akpatok Formation. However, based on the trilobites and

graptolites discovered by Cox (1933b, 1933c), graptolites by Workum et al. (1976), and gastropods by Zhang and Mate (2015), the lower part of the island belongs to the Amadjuak Formation, but it is unclear where the exact boundary between these two formations is, and whether the Akpatok Formation is the youngest strata on the island.

An almost complete section of the Akpatok Formation was found in a creek west of D'Aeth Point (area I in Figs. 1B and 2B) at an elevation between 50 and 120 m. The section was measured and a total of 27 conodont samples were collected along localities 15 and 16 (Figs. 3A and 6; Table S1). The upper part of the formation is also exposed in the uppermost reach of an unnamed creek south of Singer Point (area III in Figs. 1B and 2B) at an elevation between 130 and 140 m, where 11 samples were collected from localities 7A and 21 (Figs. 3C and 5; Tables S1 and S2).

The lithological expression of the Akpatok Formation is noticeably different from that of underlying Amadjuak Formation; it is formed by grey to dark brownish grey, thin-medium layered limestone, interbedded with thin layered argillaceous limestone (Fig. 7B).

Foster Bay Formation

The Foster Bay Formation was informally introduced by Sanford and Grant (1990) for the succession of limestones and dolomitic limestones and associated reefs conformably overlying the Akpatok Formation, representing the youngest Ordovician strata, and succeeded by the lower Silurian Severn River Formation in central Foxe Basin. Later on, it was raised to formal status by Sanford and Grant (2000). However, the Foster Bay Formation was not recognized on Akpatok Island and the adjacent offshore region by Sanford and Grant (2000, fig.

12; Fig. 2A). The field observations and conodont study by the present author confirmed the presence of the Foster Bay Formation on Akpatok Island.

In the Foxe Basin area, the Foster Bay Formation is not preserved on southern Baffin Island (Zhang 2012), and incompletely exposed on northeastern Melville Peninsula (Zhang 2013). Therefore, it is difficult to compare the Foster Bay Formation to that unit in the Foxe Basin area. Lithostratigraphically, the Foster Bay Formation was correlated to the Red Head Rapids Formation in the Hudson Bay Basin (Sanford and Grant 2000). The Red Head Rapids Formation is well exposed on Southampton Island (Haywood and Sanford 1976; Zhang 2008, 2011) and divided into four units: unit 1 - thin-layered and laminated argillaceous limestone interbedded with oil shale, unit 2 - massive breccia limestone, unit 3 - thick, massive biostromal dolostone and limestone, and unit 4 - thin-bedded limestone with bioherms (Zhang 2008).

In area I, west of D'Aeth Point (Fig. 3A), the rocks exposed on the hill at locality 17 at an elevation between 120 and 150 m are thin bedded calcareous dolostone (Fig. 7G), where 10 conodont samples were collected (Fig. 6; Table S1); and those at localities 18, 13, 12 and 11 at an elevation between 150 and 220 m along a creek are thin-medium bedded dolomitic limestone interbedded with massive breccia dolomitic limestone (Fig. 7H), where 17 samples were collected (Fig. 6; Table S1). These rocks are lithologically similar to units 1 and 2, Red Head Rapids Formation on Southampton Island. No outcrops were found at an elevation between 220 m and the highest point (281 m) on the Akpatok Island. However, the conodonts collected from three out of five dolostone rubble samples at an elevation between 260 and 281 m (Fig. 3D; Table S1) confirmed that this interval is part of the Foster Bay Formation (Fig. 6) (see discussion below).

The Upper Ordovician conodont biostratigraphy of Akpatok Island

The earliest study on the Late Ordovician conodonts on Akpatok Island was Workum et al. (1976) who reported a total of 61 conodont elements collected from four small outcrop samples (totalling less than 1000 g) at their sections I and II (along Gregson Creek and Langley Creek). Most of the conodonts were long-ranged simple cone elements, except for one specimen of *Belodina dispansa* (Glenister) of Late Ordovician age. Several Late Ordovician conodont species from two samples in the “Boas River shale” were reported by McCracken and Nowlan (1989) with uncertain stratigraphic relationship. Most recently, 38 Late Ordovician conodont species, two elements indeterminate and five species of incertae sedis from 11 samples within an interval (mostly Amadjuak Formation in light of this study) between elevations -5 m and 100 m along Gregson, Langley and Umiak creeks collected by James Gray (University of Montreal) in 1989 were reported by McCracken (2017). In this report, the stratigraphic framework of Sanford and Grant (2000) was followed, and all samples above sea level were located within their Akpatok Formation without support from diagnostic species.

This present report is based on a study of conodonts from 66 conodont-bearing samples out of 90 (each about 3000 g) collected at different elevations from the lowest tide level up to the highest point (281 m) on Akpatok Island, which are confined to the four areas with the best outcrop and rubble potential as shown in Figures 1B, 2B and 3. All the conodonts have excellent preservation with a Colour Alteration Index (CAI) value of 1, indicating minimal thermal alteration in the region (less than 50°C–80°C) (Epstein et al. 1977). The numerical conodont distribution data are presented in Tables S1 and S2, and the conodont stratigraphic distribution on the western and eastern parts of the island are shown in Figures 5 and 6, respectively. In total, over 22 000 identifiable conodont specimens plus numerous broken elements are recovered, with

37 species representing 22 genera identified, and seven elements indeterminate (Tables S1 and S2). Type and figured specimens are illustrated in Figures 8–10, which are deposited in the National Type Collection of Invertebrate and Plant Fossils, the Geological Survey of Canada (GSC), Ottawa, with assigned curation numbers GSC139109–GSC139212.

Based on the new data, four conodont zones are recognized; namely the *Belodina confluens* and *Oulodus velicuspis* Interval zones, *Amorphognathus ordovicicus*-*Plegagnathus dartoni* Concurrent-range Zone, and *Rhipidognathus symmetricus* Taxon-range Zone, with an “Unzoned Interval” between the last two zones. The age of the newly identified and revised lithostratigraphic units on Akpatok Island are redefined based on the conodont zones (Fig. 4).

***Belodina confluens* Interval Zone**

The lower boundary of the *Belodina confluens* Interval Zone is marked by the lowest occurrence of *Belodina confluens* Sweet (Figs. 8.17–8.19) in the sample 20-06 (Fig. 5) at locality 20 near the mouth of Gregson Creek in area II during the lowest tide (Fig. 3B). This lowest occurrence most likely does not represent the first appearance of the species in older strata offshore. The zone is only exposed in about 10 m strata in the western part of the island at the lowest tide level.

The dominant conodonts in the *B. confluens* Interval Zone are *Drepanoistodus suberectus* (Branson and Mehl) (Figs. 8.20–8.23), *Periodon grandis* (Ethington) (Figs. 8.16–8.20), *Protopanderodus liripipus* Kennedy, Barnes and Uyeno (Figs. 10.25–10.26), and species of *Panderodus* (Table S1).

In the North American Midcontinent Province (NAMP) (Barnes et al. 1973; Sweet and Bergström 1974, 1984), *Belodina confluens* ranges from the base of the *B. confluens* Zone to the middle of the *Oulodus robustus* Zone (Sweet 1988), and the base of the zone is correlated to the

middle Chatfieldian, Late Ordovician (Fig. 4). In Foxe Basin, the lowest occurrence of this species is close to the base of Frobisher Bay Formation that contains the *Appalachignathus delicatulus*-*Polyplacognathus ramosus* conodont fauna (McCracken 2000; Zhang 2013). Without finding this latter fauna on Akpatok Island, the occurrence of *B. confluens* at locality 20 confirms the presence of *B. confluens* Zone, but it is uncertain whether the lower zonal boundary falls within Chatfieldian, or Edenian, or at the boundary of these two stages (Fig. 4).

The strata exposed during the lowest tide on the eastern part of the island were not sampled, but the *Belodina confluens* Interval Zone may not be exposed there, because the slight eastward dip of the strata results in a slightly higher stratigraphic level outcropping on the east coast. However, it is most likely that this zone occurs just below sea level around most of the island.

***Oulodus velicuspis* Interval Zone**

The lower boundary of the *Oulodus velicuspis* Interval Zone is marked by the lowest occurrence of *Oulodus velicuspis* (Pulse and Sweet) (Figs. 10.27–10.32) in the sample 05A-01C (Fig. 5) at locality 05A in the lower reach of Gregson Creek in area II (Fig. 3B), and referenced in sample 9A-01C (Fig. 6) at locality 9A near the mouth of a creek in area I, west of D'Aeth Point (Fig. 3A).

Most of the conodont species from the underlying *Belodina confluens* Interval Zone extended into the *Ou. velicuspis* Interval Zone, but quite a few new representatives of the NAMPA fauna are found in the *Ou. velicuspis* Interval Zone. Besides the zonal species, it is characterized by several panderodonts with rastrate-element apparatuses, including a belodiniiform element Nowlan and McCracken (Fig. 9.16), *Culumbodina occidentalis* Sweet (Figs. 9.2–9.3), *C. penna*

Sweet (Figs. 9.13–9.15), *Plegagnathus nelsoni* Ethington and Furnish (Figs. 9.11–9.12), *Pseudobelodina torta* Sweet (Figs. 9.28–9.33) and *Ps. v. vulgaris* Sweet (Figs. 9.18–9.23). The overall feature of the fauna is similar to that in the *Ou. velicuspis* Zone in the NAMP (Sweet 1988; chart 1), which affirms the correlation between the base of *Ou. velicuspis* Interval Zone on Akpatok Island and the base of the *Ou. velicuspis* Zone in the NAMP (Fig. 4). However, these two zones do not span the same stratigraphic intervals; the *Ou. velicuspis* Interval Zone on Akpatok Island can be correlated to the *Ou. velicuspis*, *Ou. robustus* and lower *Aphelognathus grandis* zones in the NAMP (Fig. 4). This zone is recognized from the outcrops on both sides of the island (Figs. 5 and 6) in the upper Amadjuak Formation.

***Amorphognathus ordovicicus* - *Plegagnathus dartoni* Concurrent-range Zone**

Amorphognathus ordovicicus Branson and Mehl (Figs. 10.1–10.5) is a critical species for global correlation of the Richmondian Stage. Its earliest appearance either marks the base of Richmondian Stage (e.g., Harris et al. 1995) or is slightly higher than the base (Webby et al. 2004; Bergström et al. 2009). This present study accepts the latter (Fig. 4). This species is present in the Churchill River Group in Hudson Bay Basin (Zhang and Barnes 2007; Zhang 2011) and the Akpatok Formation in Foxe Basin (McCracken 2000; Zhang 2013), which are correlated to lower Richmondian.

On Akpatok Island, the lowest occurrence of *Am. ordovicicus* is observed in sample 15-01 at the base of Akpatok Formation (Fig. 6) in area I, west of D'Aeth Point (Fig. 3A), which is taken as the base of *Am. ordovicicus*-*Plegagnathus dartoni* Concurrent-range Zone. Almost all conodont species that dominated the NAMP fauna in the underlying *Oulodus velicuspis* Interval Zone survived within this zone. The prominent change in the *Am. ordovicicus*-*Pl. dartoni*

Concurrent-range Zone is that *Am. ordovicicus*, a representative of North Atlantic Province (NAP) fauna (Sweet and Bergström 1974, 1984), invaded the region, indicating a change in environment or climate. Additionally, *Plegagnathus dartoni* (Stone and Furnish) (Fig. 9.17), a rastrate-element panderodont, is a newcomer, first occurring slightly later than *Am. ordovicicus*.

Plegagnathus dartoni was also used as another indicator of the lower Richmondian *Am. ordovicicus* Zone in the Hudson Bay area (Zhang 2011). The lowest and the highest occurrences of *Pl. dartoni* (samples 15-03 and 16-19) are close to the lower and upper boundary of the Akpatok Formation at localities 15 and 16 in area I, west of D'Aeth Point, respectively (Figs. 3A and 6). Given the co-occurrence of *Am. ordovicicus* and *Pl. dartoni* in the Akpatok Formation, this study establishes the *Am. ordovicicus*-*Pl. dartoni* Concurrent-range Zone, and correlates it to the lower *Am. ordovicicus* Zone in the lower Richmondian in the NAP (Fig. 4). The conodont fauna recovered from the samples within an interval between elevations 10 m and 78 m in Gregson Creek were assigned to the Akpatok Formation by McCracken (2017), which apparently lacks the support from the *Am. ordovicicus* and *Pl. dartoni* fauna.

Normally the two species of *Plegagnathus*, *Pl. dartoni* and *Pl. nelsoni* Ethington and Furnish (Figs. 9.11–9.12) have a similar stratigraphic distribution; therefore, some studies have recognized *Pl. dartoni* as the plegagnathiform element of *Pl. nelsoni* (e.g. McCracken 2000). The *Am. ordovicicus*-*Plegagnathus* Assemblage in the Akpatok Formation on Melville Peninsula was recognized by Zhang (2013), but is not adopted by this study, because 1) the conodont samples in the Akpatok Formation were collected from rubble and the real stratigraphic distribution of *Pl. dartoni* and *Pl. nelsoni* was unclear on Melville Peninsula (Zhang 2013); and 2) *Pl. dartoni* and *Pl. nelsoni* on Akpatok Island have a different lowest occurrence: the former in the lower Akpatok Formation and the latter in the upper Amadjuak Formation, respectively (Fig. 6).

Unzoned Interval

The Unzoned Interval is defined for an interval between the highest occurrence of *Plegagnathus dartoni* and the lowest occurrence of *Rhipidognathus symmetricus* Branson, Mehl and Branson at locality 17 through lower part of locality 18 in area I, west of D'Aeth Point (Figs. 6 and 3A), which is in the lower Foster Bay Formation, and possibly includes the uppermost Akpatok Formation that is covered (Fig. 6). The lower Foster Bay Formation is formed by thin bedded calcareous dolostone and massive breccia dolostone, in which the conodont fauna exhibits a dramatic change. Several lineages disappeared including several rastrate-element apparatuses of the Panderodontidae (*Belodina*, *Culumbodina*, *Plegagnathus* and *Pseudobelodina*), simple cone apparatuses of Protopanderodontidae (*Pseudooneotodus* and *Staufferella*), and Belodellida (*Walliserodus*), as well as ramiform apparatuses of *Oulodus* and *Plectodina*. Only a small number of specimens belonging to *Amorphognathus ordovicianus*, *Drepanoistodus suberectus*, *Panderodus unicostatus* (Branson and Mehl), and *Paroistodus? nowlani* Zhen, Webby and Barnes are found in the upper part of this interval, but there are almost no conodonts in rest of the interval (Fig. 6; Table S1).

The stratigraphic distribution of *Am. ordovicianus* and *R. symmetricus* overlaps in the lower Red Head Rapids Formation on Southampton Island, which is assigned to the lower *R. symmetricus* Zone (Zhang 2011). Although *Amorphognathus ordovicianus* extends into the lower Foster Bay Formation on Akpatok Island, *R. symmetricus* is not found in this interval (Fig. 6). Without *R. symmetricus*, this part of the stratigraphy is assigned as an Unzoned Interval, but it probably correlates to the lower *R. symmetricus* Taxon-range Zone (see discussion below) based on lithology.

***Rhipidognathus symmetricus* Taxon-range Zone**

The lower boundary of *Rhipidognathus symmetricus* Taxon-range Zone is marked by the lowest occurrence of *R. symmetricus* (Figs. 10.21–10.24) in sample 18-08 (Fig. 6) at locality 18 in area I, west of D'Aeth point (Fig. 3A). The highest occurrence of this species is almost at the highest point (281 m) of the island, which is the rubble sample 19-02 at locality 19 in area VI, close to Cox Ridges (Fig. 3D). Therefore, this highest occurrence may mark the upper boundary of the *R. symmetricus* Taxon-range Zone, but it is equally possible that the upper part of the zone has been eroded off. Between the lowest and highest occurrence of the zonal species, only four out of 15 samples produce conodont elements, all with low abundance and diversity (Table S1). Only three species, namely *R. symmetricus*, *Belodina confluens* and *Panderodus unicostatus*, are present. Given the rarity of *R. symmetricus* in the region, it is possible that this zone extends down to the underlying Unzoned Interval.

It has been documented that *R. symmetricus* has a relatively wide stratigraphic range from Edenian to late Richmondian in the NAMP (Sweet 1984, 1988). However, this species is restricted in a much narrower stratigraphic interval in the Hudson Bay Basin (Zhang and Barnes 2007; Zhang 2011), Foxe Basin (Zhang 2013) and southern Ontario (Zhang et al. 2011) than elsewhere in the NAMP. *R. symmetricus* is limited within the Red Head Rapids Formation in the Hudson Bay Basin (Zhang and Barnes 2007; Zhang 2011), the Foster Bay Formation in the Foxe Basin (Zhang 2011), and the upper Georgina Bay Formation in southern Ontario (Zhang et al. 2011). These rock units have a common feature that they are composed of thin bedded calcareous dolostone or thin bedded dolomitic limestone and massive breccia dolostone or bioherms; additionally they are also as unproductive of conodonts as the Foster Bay Formation

on Akpatok Island. This is an indication of the shallowest and restricted environment (Sweet 1988).

Given the co-occurrence of *Aphelognathus* cf. *A. divergens* Sweet and *Rhipidognathus symmetricus*, the *R. symmetricus* Zone in the Red Head Rapids Formation on Southampton Island and *R. symmetricus*-*A. cf. A. divergens* Assemblage in the Foster Bay Formation on Melville Peninsula were correlated to the *A. divergens* Zone in the upper Richmondian of NAMP (Zhang 2011, 2013). This correlation is followed in this present study (Fig. 4).

The stratigraphic position and the age of organic-rich bituminous, argillaceous limestone

As noted earlier, the present author did not find a 4.5 m thick bituminous, brown argillaceous limestone in a stream-cut section immediately east of the Premium Homestead Akpatok L-26 wellsite on Akpatok Island as reported by Workum et al. (1967), but the lithology was seen as rubble at localities 2A and 3A in the lower reach of Gregson Creek in area II (Fig. 3B), the same creek as that of Workum et al. (1976). One bituminous, argillaceous limestone rubble sample (SZ15-22-01; Table S1) was processed for conodonts and yielded (number of specimens in brackets) *Amorphognathus ordovicicus* (10), *Belodina confluens* (6), *Coelocerodontus trigonius* Ethington (35) *Drepanoistodus suberectus* (Branson and Mehl) (74), *Panderodus feulneri* (Glenister) (253), *Paroistodus? nowlani* (134), *Plectodina tenuis* (Branson and Mehl) (5), *Pseudooneotodus beckmanni* (Bischoff & Sannemann) (3), and *Scabbardella* sp. (55).

Most species in this fauna are relatively long-ranging, except for *Amorphognathus ordovicicus* and *Belodina confluens*. *B. confluens* occurs in almost all samples from the Amadjuak and Akpatok formations, and its highest occurrence is on the top of the Foster Bay

Formation on Akpatok Island (Figs. 5 and 6). *Am. ordovicicus* has a relatively shorter stratigraphic range in the Akpatok and lower Foster Bay formations. Therefore, the bituminous, argillaceous limestone rubble sample yielding *Am. ordovicicus* may be from either the upper Akpatok Formation or lower Foster Bay Formation. Considering the oil shale intervals in the lower Red Head Rapids Formation on Southampton Island that contain both *Am. ordovicicus* and *R. symmetricus* (Zhang 2011), the bituminous, argillaceous limestone rubble on Akpatok Island is most likely from the lower Foster Bay Formation.

Additionally, the graptolites discovered from the bituminous, argillaceous limestone rubble confirm this correlation. A “chocolate-coloured limestone” band yielding the graptolite *Amplexograptus latus* (Elles and Wood) (= *Climacograptus inuiti* Cox described by Cox (1933c) occurs at an elevation between 143 and 144 m (470 and 473 ft) in a creek (most likely Umiak Creek) at the southern end of the island (Cox 1933b). This species was not found in the bituminous, argillaceous limestone rubble that yields graptolites *Anticosti? decipiens* (Riva) and *Rectograptus socialis* (Lapworth) (identified by Riva 2017; author’s collection). On Anticosti Island, the former is associated with *A. latus* in the graptolite *Paraorthograptus prominens* Zone (Riva 1988), and the latter’s highest occurrence is in the lower part of the zone (McLaughlin et al. 2016). Therefore, the bituminous, argillaceous limestone rubble discovered by this study can be correlated with the “chocolate-coloured limestone” band of Cox (1933b), which is within the stratigraphic level of lower Foster Bay Formation recognized by this study (Fig. 6).

Thus, the stratigraphic position of the organic-rich bituminous, argillaceous limestone on Akpatok Island is in the lower Foster Bay Formation, and probably within the Unzoned Interval, rather than between the Amadjuak and Akpatok formations as inferred by Sanford and Grant (2000) (Fig. 4). Regionally, taking graptolites into account, the organic-rich bituminous,

argillaceous limestone on Akpatok Island may be related to the lower oil shale interval of the three, yielding the graptolite *Amplexograptus latus* (identified by Riva 2017; the author's collection), of the Red Head Rapids Formation on Southampton Island (Zhang 2008); and it has an age of late Richmondian, Late Ordovician based on the conodonts and graptolites. Therefore, the present study does not consider "Boas River" Formation as an appropriate stratigraphic unit on Akpatok Island.

Topographically, the organic-rich bituminous, argillaceous limestone is distributed at an elevation about 140 m, instead of at the foot of the cliff along east coast as illustrated by Sanford and Grant (2000) (Fig 2A). Additionally, the 4.5 m thick bituminous, brown argillaceous limestone documented by Workum et al. (1967) is most likely a pile of rubble by the stream (locality 3A in Fig. 3B) where the bituminous, argillaceous limestone rubble sample described herein was collected.

Combining conodont data with GIS technology to revise the geological map

ArcGIS Map provides contour lines at 10 m intervals for Akpatok Island (Fig. 3). The Ordovician rocks on Akpatok Island only slightly dip eastward; therefore, the contour lines and elevations provided by GIS can be used to define the thickness of stratigraphic units, and revise the existing geological map by combining with paleontologic and stratigraphic data. The prerequisite of this approach is that the known localities have reliable coordinate data, zonal fossils, and (or) exposed stratigraphic boundaries between different units (Zhang 2013).

Defining the thickness of different stratigraphic units

As noted earlier, the rocks rising abruptly from the sea to form Akpatok Island were assigned to mostly one unit, the Akpatok Formation, by Sanford and Grant (2000); the present

detailed field observations and conodont study have identified three formations within this sequence. The rocks on Akpatok Island are either very well exposed on the inaccessible vertical cliffs surrounding the island, or scattered along streams inland, which make it difficult to measure the exact thickness of different stratigraphic units. However, the contour lines and elevation data on ArcGIS map provide an ideal tool to accomplish this task.

Amadjuak Formation: The lower boundary of Amadjuak Formation is under the low tide level; the upper boundary can be recognized by either the appearance of thin bedded argillaceous limestone, the typical lithology of the overlying Akpatok Formation, or the lowest occurrence of *Amorphognathus ordovicicus*, the characteristic species present throughout the Akpatok Formation, which is close to the 50 m contour line at locality 15, area I, west of D'Aeth Point (Figs. 3 and 6). In the western part, the highest elevation where samples lack *Am. ordovicicus* is between the 70 m and 80 m contour lines. Therefore, the exposed Amadjuak Formation is about 70–80 m on western side and 50 m on the eastern side, respectively, because of the eastward dipping strata.

Akpatok Formation: The lower boundary of the Akpatok Formation equates to the upper boundary of the Amadjuak Formation (50 m contour line) at locality 15, area I, west of D'Aeth Point (Figs. 3 and 6). The boundary between the Akpatok Formation and the overlying Foster Bay Formation is not exposed in the studied areas, but most likely occurs between the 100 m and 120 m contour lines in area I, west of D'Aeth Point (Fig. 6). In this area, the typical thin bedded dolostone appears near the 120 m contour line; therefore, the thickness of the Akpatok Formation is between 50 m and 70 m on the eastern part of the island. In area III, along an unnamed creek south of Singer Point, the highest occurrence of *Plegagnathus dartoni* is between the 130 m and 140 m contour lines, and the highest sample lacking *Amorphognathus ordovicicus* is between 70

m and 80 m contour lines; therefore, the thickness of the formation is about 60 m in this area. Thus, the estimations made in both areas I and III are close to 60 m for the thickness of the Akpatok Formation.

Foster Bay Formation: All the rocks above the Akpatok Formation belong to the Foster Bay Formation. Its thickness can be either above the 140 m contour line based on the estimation in area III, or above the 120 m contour line based on the estimation in area I. However, the highest point, 281 m, in area IV close to Cox Ridges is in the central island, where the lower boundary of the Foster Bay Formation is most likely at an average contour value between area I and III. Thus, the thickness of the Foster Bay Formation is about 150 m.

Revising the geological map of Akpatok Island

The lower and upper boundaries of the Akpatok Formation are important in modifying the geological map of Sanford and Grant (2000) (Fig. 2A). Based on the discussion earlier, these boundaries are close to the 50 m and 120 m contour lines on the eastern side of the Island (Figs. 3A and 6), and 70 m and 140 m on the western part of the island (Figs. 3C and 5). Using these contour lines as the boundaries between the Amadjuak and Akpatok formations and between the Akpatok and Foster Bay formations, a new geological map of Akpatok Island is completed (Fig. 2B). Thus, most of surface area on Akpatok Island is covered by the Foster Bay Formation (Fig. 2B), rather than the Akpatok Formation as mapped by Sanford and Grant (2000) (Fig. 2A). A cross section from A through A' to A'' shown in Figure 2B is illustrated in Fig. 2C, which clearly shows that both Amadjuak and Akpatok formations are exposed in the high cliffs that surround the island.

Summary

- The strata exposed on Akpatok Island are recognized as Upper Ordovician upper Amadjuak, Akpatok and Foster Bay formations.
- Thirty-seven conodont species representing 22 genera, with seven elements indeterminate, are identified among 22 000 identifiable conodont specimens from 66 conodont-bearing samples at over 20 localities in four areas on Akpatok Island, which stratigraphically covers the newly recognized three formations.
- Four Upper Ordovician conodont zones, namely *Belodina confluens* and *Oulodus velicuspis* Interval zones, *Amorphognathus ordovicianus*-*Plegagnathus dartoni* Concurrent-range Zone, and *Rhipidognathus symmetricus* Taxon-range Zone are newly established, and an “Unzoned Interval” is defined between that last two zones within the exposed Upper Ordovician sequence. The *B. confluens* and *Ou. velicuspis* Interval zones are confined to the exposed Amadjuak Formation and correlated to the upper *B. confluens*, *Ou. velicuspis* and *Ou. robustus* zones throughout an interval of Edenian and Maysvillian; the *Am. ordovicianus*-*Pl. dartoni* Concurrent-range Zone occurs in the Akpatok Formation and is correlated to the lower *Am. ordovicianus* Zone, lower Richmondian; the “Unzoned Interval” and *R. symmetricus* Taxon-range Zone are present in the Foster Bay Formation and related to the *Aphelognathus divergens* Zone, upper Richmondian. Except for the fauna in the *Am. ordovicianus*-*Pl. dartoni* Concurrent-range Zone partially having a relationship to the North Atlantic Province (NAP) fauna, those in the other zones are mostly related to the North American Midcontinent Province (NAMP) faunas.
- The occurrence of conodont *Amorphognathus ordovicianus* in the outcrops of both the Akpatok and lower Foster Bay formations and in the bituminous, argillaceous limestone

582 rubble, as well as graptolite *Anticotia? decipiens* and *Rectograptus socialis*, indicate that the
583 stratigraphic position of the thin bituminous, argillaceous limestone unit is most likely in the
584 lower Foster Bay Formation, rather than between the Amadjuak and Akpatok formations, and
585 its topographic position is about 140 m above sea level, instead of on the shore.

- 586 • The field observation, paleontological data and stratigraphic analysis on Akpatok Island
587 combined with GIS technology enable accurate calculations of the thickness of different
588 lithostratigraphic units and substantially revising the geological map of Akpatok Island.

590 Acknowledgements

591 This study is part of the Hudson-Ungava Project under Natural Resource Canada
592 (NRCan), Earth Science Sector's (ESS) Geo-mapping for Energy and Mineral Program 2 (GEM-
593 2), and it is financially supported by both GEM-2 and the Canada-Nunavut Geoscience Office
594 (CNGO). Logistic support in the field was provided by the Polar Continental Shelf Project. Many
595 thanks are extended to D. Lavoie (Geological Survey of Canada (GSC) Quebec) for his
596 organization of the project and participation in the fieldwork and to J. Riva (GSC Quebec) for his
597 identification of graptolite fossils. Sincere thanks go to the Inuit from Kuujjuaq, northern Quebec
598 for their field assistance, to H. Taylor and L. Tingley for their hard work in processing samples at
599 the conodont labs at GSC Vancouver and GSC Calgary, respectively, and to P. Hunt (GSC
600 Ottawa) for her assistance in taking scanning electron microscopy images. Particular thanks go to
601 C.R. Barnes (University of Victoria) for his comments on the first draft of the manuscript, to M.
602 Orchard (GSC Vancouver) for acting as ESS internal scientific reviewer, to A.D. McCracken
603 (GSC Calgary) and G.L. Albanesi (Universidad Nacional de Córdoba) for acting as external
604 scientific reviewers, and to A. Polat, B. Pratt and D. Regier for their editorial assistance from the
605 journal.

References

- Albanesi, G.L., and Ortega G. 2016: Conodont and graptolite biostratigraphy of the Ordovician System of Argentina. *Stratigraphy and Timescales*, **1**: 61–121.
- Barnes, C.R., Rexroad, C.B., and Miller, J.F. 1973: Lower Paleozoic conodont provincialism. *In* Symposium on Conodont Paleozoology. *Edited by* F.H.T. Rhodes. The Geological Society of America, Special Paper 141, pp.156–190.
- Barrass, R. 1954: Graptolites from Anticosti Island. *Quarterly Journal of the Geological Society of London*, **110**: 55–74.
- Bell, R. 1899: Contribution to Paleontology. Geological Survey of Canada Annual Report, New Series 10, pp. 75A–83A.
- Bergström, S.M., Chen, X., Gutiérrez-Marco, J.C., and Dronov, A. 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to $\delta^{13}\text{C}$ chemostratigraphy. *Lethaia*, **42**(1): 97–107.
- Bolton, T.E. 2000. Ordovician megafauna, southern Baffin Island, Nunavut. *In* geology and paleontology of the southeast Arctic Platform and southern Baffin Island, Nunavut. *Edited by* A.D. McCracken and T.E. Bolton. Geological Survey of Canada Bulletin 557, pp. 39–157.
- Cooper, R.A., and Sadler, P.M. 2012. Chapter 20. The Ordovician Period. *In* The Geological Time Scale 2012. *Edited by* F.M. Gradstein, J.G. Ogg, M.D. Schmitz, and G.M. Ogg. Elsevier, Amsterdam (ebook). pp. 489–523.
- Cox, I. 1933a: Rejuvenation on Akpatok Island: Topographical Unconformity in North-Eastern Canada. *Geological Magazine*, **70**: 67–83.
- Cox, I. 1933b. Richmondian trilobites from Akpatok Island. *Geological Magazine*, **70**: 359–373.

- 630 Cox, I. 1933c. On *Climacograptus inuiti* sp. nov. and its Development. Geological Magazine, **70**:
631 1–19.
- 632 Epstein, A.G., Epstein, J.B. and Harris, L.D. 1977. Conodont color alteration—An index to
633 organic metamorphism. U.S. Geological Survey Professional Paper 995, 27 pp.
- 634 Harris, A.G., Dumoulin, J.A., Repetski, J.E., and Carter, C. 1995. Correlation of Ordovician
635 rocks of Northern Alaska. In *Ordovician odyssey. Edited by J.D. Cooper*. Society for
636 Sedimentary Geology, Pacific Section. pp. 21–26.
- 637 Heywood, W.W., and Sanford, B.V. 1976. Geology of Southampton, Coats and Mansel Islands,
638 District of Keewatin, Northwest Territories. Geological Survey of Canada, Memoir 382,
639 35 p.
- 640 McCracken, A.D. 2000. Middle and Late Ordovician conodonts from the Foxe Lowland of
641 southern Baffin Island, Nunavut. Geological Survey of Canada Bulletin 557, pp. 159–216.
- 642 McCracken, A.D. 2017. Report on 11 Ordovician conodont samples from Akpatok Island,
643 Nunavut collected by James Gray (University of Montreal) in 1989, NTS 25B/5 and
644 25C/8. Geological Survey of Canada Paleontological Report 1-ADM-2017, 26 pp.
- 645 McCracken, A.D., and Nowlan, G.S. 1989. Conodont paleontology and biostratigraphy of
646 Ordovician carbonates and petroliferous carbonates on Southampton, Baffin, and
647 Akpatok islands in the eastern Canadian Arctic. Canadian Journal of Earth Sciences,
648 **26**(10): 1880–1903.
- 649 McLaughlin, P.I., Emsbo, P., Desrochers, A., Bancroft, A., Brett, C.E., Riva, J.F., Premo, W.,
650 Neymark, L., Achab, A., Asselin, E., and Emmons, M.M. 2016: Refining 2 km of
651 Ordovician chronostratigraphy beneath Anticosti Island utilizing integrated
652 chemostratigraphy. Canadian Journal of Earth Sciences, **53**(8): 865–874.

- 653 Riva, J. 1988: Graptolites at and below the Ordovician-Silurian boundary on Anticosti Island,
654 Canada. *Bulletin of the British Museum (Natural History), Geology*, **43**: 221–237.
- 655 Sanford, B.V., and Grant, A.C. 1990: New findings relating to the stratigraphy and structure of
656 the Hudson Platform. *Geological Survey of Canada Current Research, Part D, Paper 90-*
657 *1D*, pp. 17–30.
- 658 Sanford, B.V., and Grant, A.C. 2000: Geological framework of the Ordovician system in the
659 southeast Arctic Platform, Nunavut. *In geology and paleontology of the southeast Arctic*
660 *Platform and southern Baffin Island, Nunavut. Edited by A.D. McCracken and T.E.*
661 *Bolton. Geological Survey of Canada Bulletin 557*, pp. 13–38.
- 662 Sweet, W.C. 1984. Graphic correlation of upper Middle and Upper Ordovician rocks, North
663 American Midcontinent Province, U.S.A. *Palaeontological Contribution from the*
664 *University of Oslo*, No. 295, pp. 23–35.
- 665 Sweet, W.C. 1988. The Conodonta – morphology, taxonomy, paleoecology, and evolutionary
666 history of a long-extinct animal phylum. *Oxford Monographs on Geology and*
667 *Geophysics* No. 10, 212 p.
- 668 Sweet, W.C. and Bergström, S.M. 1974. Provincialism exhibited to Ordovician conodont fauna.
669 *Society of Economic Paleontologists and Mineralogists Special Publication 21*, pp. 189–
670 202.
- 671 Sweet, W.C. and Bergström, S.M. 1984. Conodont provinces and biofacies of the Late
672 Ordovician. *Geological Society of America Special Paper 196*, pp. 69–87.
- 673 Webby, B.D., Cooper, R.A., Bergström, S.M., and Paris, F. 2004. Stratigraphic framework and
674 time slices. *In The great Ordovician Biodiversification Event. Edited by B.D. Webby, F.*
675 *Paris, M.L. Droser, and I.G. Percival. Columbia University Press, New York.* pp. 41–47.

- 676 Whiteaves, J.F. 1899: Recent discovery of rocks of the age of the Trenton formation at Akpatok
677 Island, Ungava Bay, Ungava. *American Journal of Science*, **7** (42), 433–434.
- 678 Workum, R.H., Bolton, T.E., and Barnes, C.R. 1976. Ordovician geology of Akpatok Island,
679 Ungava Bay, District of Franklin. *Canadian Journal of Earth Sciences*, **13**: 157–178.
- 680 Zhang, S. 2008: New insights into Ordovician oil shales in Hudson Bay Basin: their number,
681 stratigraphic position, and petroleum potential. *Bulletin of Canadian Petroleum Geology*,
682 **56** (4): 300–324.
- 683 Zhang, S. 2011: Late Ordovician conodont biostratigraphy and redefinition of the age of oil shale
684 intervals on Southampton Island. *Canadian Journal of Earth Sciences*, **48**: 619–643.
- 685 Zhang, S. 2012. Ordovician stratigraphy and oil shale, southern Baffin Island, Nunavut –
686 preliminary field and post-field data. Geological Survey of Canada, Open File 7199, 26 p.
- 687 Zhang, S. 2013. Ordovician conodont biostratigraphy and redefinition of the age of
688 lithostratigraphic units on northeastern Melville Peninsula, Nunavut. *Canadian Journal of*
689 *Earth Sciences*, **50** (8): 808–825.
- 690 Zhang, S., and Barnes, C.R. 2007. Late Ordovician – Early Silurian conodont biostratigraphy and
691 thermal maturity, Hudson Bay Basin. *Bulletin of Canadian Petroleum Geology*, **55** (3):
692 179–216.
- 693 Zhang, S., and Mate, D.J. 2015. Geological reconnaissance for Ordovician stratigraphy and
694 petroleum potential, Akpatok Island, Nunavut. *In* Summary of Activities 2014, Canada-
695 Nunavut Geoscience Office, pp. 79–88.
- 696 Zhang, S., Tarrant, G.A., and Barnes, C.R. 2011. Upper Ordovician conodont biostratigraphy
697 and the age of the Collingwood Member, southern Ontario, Canada. *Canadian Journal of*
698 *Earth Sciences*, **48**: 1497–1522.

699

Draft

Figure Captions

Figure 1. A: Location of Akpatok Island in Ungava Bay; B: elevation map of Akpatok Island, showing the studied areas (red rectangles) and locality numbers.

Figure 2. Geological maps of Akpatok Island. A: modified from Sanford and Grant (2000); B: new map by this study based on the paleontological and stratigraphical data combined with GIS data, showing the studied areas (red rectangles) and locality numbers; C: stratigraphic cross section from A through A' to A'' in map B.

Figure 3. Detailed geological maps in four selected studied areas on Akpatok Island with sampling localities. A: area I, west of D'Aeth Point; B: area II, lower reach of Gregson Creek; C: area III, unnamed creek south of Singer Point; D: area IV, Cox Ridges. See Figures 1 and 2 their locations.

Figure 4. Ordovician stratigraphy on Akpatok Island and its correlation with the Ordovician chronostratigraphic and biostratigraphic framework adopted from Cooper and Sadler (2012) (* in North Atlantic conodont zonation is base on Albanesi and Ortega (2016)). Shaded area represents the stratigraphy exposed on Akpatok Island and conodont zones lithostratigraphic units recognized herein.

Figure 5. Conodont distribution at different elevations in areas II and III on the western side of Akpatok Island. The numbers before and after hyphen are locality and sample numbers, respectively.

Figure 6. Conodont distribution at different elevations in areas I and IV on the eastern side and central of Akpatok Island. The numbers before and after hyphen are locality and sample numbers, respectively.

Figure 7. Typical lithology of Upper Ordovician units on Akpatok Island. A: Amadjuak Formation brown micritic limestone, interbedded with thin layers of chert and chert nodules that are circled with white at locality 14, area I; B: Akpatok Formation grey to dark brownish grey, thin-medium bedded limestone, interbedded with thin bedded argillaceous limestone at locality 21, area III; C–F: brown argillaceous, bituminous limestone rubble at locality 2 and 3, area II; E: an enlargement of a spot marked by a hammer on the left corner in D; F: enlargement marked by a hammer on the right in D and where the graptolites are found; G and H: Foster Bay Formation thin bedded dolomitic limestone (G) and thin-medium bedded dolomitic limestone interbedded with massive breccia dolomitic limestone (H) at localities 17 and 18, area I.

Figure 8. Late Ordovician conodonts and incertae sedis

1. *Milaculum ethinclarki* Müller (non-conodont) ($\times 60$) from SZ15-16-11, Akpatok Formation; upper view, GSC139109.
2. *Milaculum* sp. (non-conodont) ($\times 60$) from SZ15-16-12, Akpatok Formation; upper view, GSC139110.
- 3–7. *Walliserodus curvatus* (Branson and Branson) ($\times 70$) from SZ14-05-01C, Amadjuak Formation; 3, inner lateral view of unicostatiform element, GSC139111; 4, inner lateral view of curvatiform element, GSC139112; 5 and 6, lateral and lateral-posterior view of dyscritiform element, GSC139113; 7, inner lateral view of multicostatiform element, GSC139114.
- 8–11. *Panderodus breviusculus* Barnes ($\times 35$) from SZ15-16-18, Akpatok Formation; 8 and 9, inner and outer lateral views of asymmetric graciliform element, GSC139115; 10 and 11, inner and outer lateral views of subsymmetric graciliform element, GSC139116.

745 **12–16.** *Panderodus feulneri* (Glenister) ($\times 85$) from SZ15-22-01 (bituminous, argillaceous
 746 limestone rubble), Foster Bay Formation (?); 12, inner lateral view of truncatiform element,
 747 GSC139117; 13, inner lateral view of compressiform element, GSC139118; 14, inner lateral
 748 view of tortiform element, GSC139119; 15, inner lateral view of arcuatiform element,
 749 GSC139120; 16, inner lateral view of asymmetric graciliform element, GSC139121.

750 **17–19.** *Belodina confluens* Sweet ($\times 55$) from SZ-15-04, Akpatok Formation; 17, outer lateral
 751 view of compressiform element, GSC139122; 18, outer lateral view of grandiform element,
 752 GSC139123; 19, inner lateral view of eobelodiniiform element, GSC139124.

753 **20–23.** *Drepanoistodus suberectus* (Branson and Mehl) ($\times 35$) from SZ15-15-06, Akpatok
 754 Formation; 20, inner lateral view of curvatiform element, GSC139125; 21, inner lateral view of
 755 homocurvatiform element, GSC139126; 22, lateral view of suberectiform element, GSC139127;
 756 23, inner lateral view of oistodiform element, GSC139128.

757 **24–25.** *Staufferella lindstroemi* (Ethington and Schumacher) from SZ14-02A-02C, Amadjuak
 758 Formation; 24 ($\times 60$), inner lateral view of asymmetricform element, GSC139129; 25 ($\times 50$),
 759 posterior view of symmetricform element, GSC139130.

760 **26.** *Pseudooneotodus mitratus* (Moskalenko) ($\times 90$) from SZ15-16-01, Akpatok Formation; upper
 761 view, GSC139131.

762 **27.** *Pseudooneotodus beckmanni* (Bischoff and Sannemann) ($\times 65$) from SZ15-16-01, Akpatok
 763 Formation; upper view, GSC139132.

764 **28–29.** N. Gen. A n. sp. A McCracken ($\times 70$) from SZ15-21-07, Akpatok Formation; lateral and
 765 posterior views, GSC139133.

766 **30–34.** *Panderodus liratus* Nowlan and Barnes ($\times 45$) from SZ15-15-03, Akpatok Formation; 30,
 767 inner lateral view of arcuatiform element, GSC139134; 31, outer lateral view of truncatiform

768 element, GSC139135; 32, inner lateral view of asymmetrical graciliform element, GSC139136;
 769 33, outer lateral view of compressiform element, GSC139137; 34, inner lateral view of
 770 subsymmetric graciliform element, GSC139138.
 771 **35–36.** *Coelocerodontus trigonius* Ethington ($\times 67$) from SZ15-22-01, Akpatok Formation; 35,
 772 posterior view of symmetric triangular element, GSC139139; 36, posterior view of asymmetric
 773 triangular element, GSC139140.
 774 **37–40.** *Zanclodus* sp. ($\times 50$) from SZ15-16-04, Akpatok Formation; 37 and 38, inner and outer
 775 lateral views of low-based element, GSC139141; 39 and 40, inner and outer lateral views of
 776 high-based element, GSC139142.
 777 **41–42.** *Staufferella* n. sp. A McCracken ($\times 75$); 41 from SZ15-16-04, Akpatok Formation,
 778 posterior view of symmetric element, GSC139143; 42 from SZ15-16-01, Akpatok Formation,
 779 posterior view of asymmetric element, GSC139144.
 780 **43–49.** *Panderodus unicostatus* (Branson and Mehl) ($\times 53$); from SZ15-21-02, Amadjuak
 781 Formation; 43, inner lateral view of arcuatiform element, GSC139145; 44, inner lateral view of
 782 tortiform element, GSC139146; 45, lateral view of aequitiform element, GSC139147; 46, inner
 783 lateral view of compressiform element, GSC139148; 47, outer lateral view of subsymmetric
 784 graciliform element, GSC139149; 48, inner lateral view of truncatiform element, GSC139150;
 785 49, inner lateral view of asymmetrical graciliform element, GSC139151.
 786
 787 **Figure 9.** Late Ordovician conodonts (Sg^2 , Sg^1 , Sc^1 and Sc^0 represent grandiform with costa on
 788 two sides, grandiform with costa on one side, compressiform with costa on one side, and
 789 compressiform without costa in the *Pseudobelodina* apparatus, respectively).

- 790 **1.** *Culumbodina* cf. *C. n.* sp. X McCracken ($\times 60$); from SZ15-16-04, Amadjuak Formation; inner
 791 lateral view of adenticulate triangular element, GSC139152.
- 792 **2–3.** *Culumbodina occidentalis* Sweet from SZ15-15-03, Akpatok Formation; 2 ($\times 55$), inner
 793 lateral views of bifid-cusp element, GSC139153; 3 ($\times 42$), inner lateral view of adenticulate
 794 element, GSC139154.
- 795 **4–6.** *Pseudobelodina adentata* Sweet ($\times 80$); from SZ14-09-02C, Amadjuak Formation; 4, inner
 796 lateral view of Sg^2 element, GSC139155; 5 and 6, inner and outer lateral views of Sc^1 element,
 797 GSC139156.
- 798 **7–10.** *Pseudobelodina? dispansa* (Glenister) ($\times 55$) from SZ15-16-04, Akpatok Formation; 7 and
 799 8, outer and inner lateral views of Sc^0 element, GSC139157; 9 and 10, outer and inner lateral
 800 views of Sg^2 element, GSC139158.
- 801 **11–12.** *Plegagnathus nelsoni* Ethington and Furnish ($\times 60$) from SZ15-15-03, Akpatok Formation;
 802 11, inner lateral view of nelsoniform element, GSC139159; 12, outer lateral view of
 803 plegagnathiform element, GSC139160.
- 804 **13–15.** *Culumbodina penna* Sweet ($\times 73$) from SZ15-15-06, Akpatok Formation; 13, outer lateral
 805 view of L-shape element, GSC139161; 14, inner lateral view of L-shape element, GSC139162;
 806 15, inner lateral view of subtriangular element, GSC139163.
- 807 **16.** Belodiniiform element of Nowlan and McCracken (in Nowlan et al. 1988) ($\times 60$) from SZ15-
 808 15-03, Akpatok Formation; inner lateral view, GSC139164.
- 809 **17.** *Plegagnathus dartoni* (Stone and Furnish) ($\times 65$) from SZ15-16-01, Akpatok Formation;
 810 inner lateral view of plegagnathiform element, GSC139165.
- 811 **18–23.** *Pseudobelodina v. vulgaris* Sweet ($\times 80$); 18 and 19 from SZ15-15-01, Akpatok
 812 Formation, inner and outer lateral views of Sg^2 element, GSC139166; 20 and 21 from SZ14-07-

813 01C, Akpatok Formation, inner and outer lateral views of Sg^1 element, GSC139167; 22 and 23
814 from SZ15-14-01, Amadjuak Formation, inner and outer lateral views of Sc^1 element,
815 GSC139168.

816 **24–27.** *Pseudobelodina quadrata* Sweet ($\times 65$); 24 and 25 from SZ15-15-01, Akpatok Formation,
817 inner and outer lateral views of Sc^0 element, GSC139169; 26 and 27 from SZ15-14-01,
818 Amadjuak Formation, outer and inner lateral views of Sg^1 element, GSC139170.

819 **28–33.** *Pseudobelodina torta* Sweet ($\times 65$) from AZ15-16-05, Akpatok Formation; 28 and 29,
820 inner and outer lateral views of Sc^2 element, GSC139171; 30 and 31, outer and inner lateral
821 views of Sg^1 element, GSC139172; 32 and 33, outer and inner lateral views of Sg^2 element,
822 GSC139173.

823 **34–37.** *Paroistodus? nowlani* Zhen, Webby and Barnes ($\times 63$) from SZ15-22-01, Akpatok
824 Formation; 34 and 35, inner lateral views of Sb-c element, GSC139174, GSC139175; 36, lateral
825 view of Sa element, GSC139176; 37, inner lateral view of M element, GSC139177.

826 **38–42.** *Scabbardella* sp. ($\times 57$) from SZ15-22-01, Akpatok Formation; 38, inner lateral view of
827 asymmetric element, GSC139178; 39 and 40, outer and lateral views of subsymmetric element,
828 GSC139179; 41 and 42, outer and inner lateral views of symmetric element, GSC139180.

829

830 **Figure 10.** Late Ordovician conodonts

831 **1–5.** *Amorphognathus ordovicicus* Branson and Mehl ($\times 75$, except for 1×50) from SZ15-16-04,
832 Akpatok Formation; 1, upper view of Pa element, GSC139181; 2, lateral view of Sa element,
833 GSC139182; 3, outer lateral view of Pb element, GSC139183; 4, outer-posterior view of M
834 element, GSC139184; 5, inner lateral views of Sb–Sc element, GSC139185.

835 **6–9.** *Phragmodus undatus* Branson and Mehl ($\times 85$) from SZ14-05A-02C, Amadjuak

836 Formation; 6, outer lateral view of Pa element, GSC139186; 7, lateral view of S element,
837 GSC139187; 8, outer lateral view of Pb element, GSC139188; 9. 24. inner lateral view of M
838 element, GSC139189.

839 **10–15.** *Plectodina tenuis* (Branson and Mehl) ($\times 60$) from SSZ14-09A-02C, Amadjuak
840 Formation; 10, inner lateral view of Pa element, GSC139190; 11, inner lateral view of Sc
841 element, GSC139191; 12, inner-posterior view of M element, GSC139192; 13, posterior view of
842 Sb element, GSC139193; 14, posterior view of Sa element; GSC139194; 15, inner lateral view
843 of Pb element, GSC139195.

844 **16–20.** *Periodon grandis* (Ethington) ($\times 85$) from SZ14-02-02C, Amadjuak Formation; 16, inner
845 lateral views of Sc element, GSC139196; 17, inner lateral view of M element, GSC139197; 18,
846 inner lateral views of Sb element, GSC139198; 19, inner lateral view of P element, GSC139199;
847 20, lateral view of Sa element, GSC139200.

848 **21–24.** *Rhipidognathus symmetricus* Branson, Mehl and Branson ($\times 70$) from SZ15-13-01 except
849 for 23 from SZ15-18-08, Foster Bay Formation; 21, inner lateral view of Pa element,
850 GSC319201; 22 and 23, posterior view of Sa element, GSC139202 and GSC139203; 24 inner
851 lateral view of Pb element, GSC139204.

852 **25–26.** *Protopanderodus liripipus* Kennedy, Barnes and Uyeno ($\times 40$) from SZ14-02A-02C,
853 Amadjuak Formation; 25, lateral view of scandodontiform element, GSC139205; 26, lateral view
854 of acontiodontiform element, GSC139206.

855 **27–32.** *Oulodus velicuspis* (Pulse and Sweet) ($\times 55$) from SZ15-14-02, Amadjuak Formation; 27,
856 posterior-lateral view of Pa element, GSC139207; 28, posterior view of Sb element, GSC139208;
857 29, posterior view of Sa element, GSC139209; 30, posterior-lateral view of Pb element,

858 GSC139210; 31, inner lateral view of Sc element, GSC139211; 32, posterior-lateral view of M
859 element, GSC139212.

860

Draft

Figure 1

172x121mm (300 x 300 DPI)

Figure 2

162x181mm (300 x 300 DPI)

Figure 3

175x216mm (300 x 300 DPI)

Age (Ma)	Epoch/Age (Stage)	Stage Slices	British Columbia	North America	Conodont zonation		Sanford & Grant (2000) Stratigraphy	This study																						
					North Atlantic	N. American Midcontinent		Conodont zones	Stratigraphy																					
445	443.8 Silurian			Medinan																										
	Hirnantian 445.2	Hi2	Ashgill	Gamachian		<i>Aphelognathus shatzeri</i>	Akpatok Fm	<i>Rhipidognathus symmetricus</i> Taxon-range Zone Unzoned Interval	Foster Bay Fm																					
		Hi1			<i>Amorphognathus ordovicianus</i>	<i>Aphelognathus divergens</i>		<i>Amorphognathus ordovicianus</i> - <i>Plegagnathus dartoni</i> Concurrent-range	Akpatok Fm																					
		Katian		Ka4	Richmondian			<i>Aphelognathus grandis</i>																						
				Ka3				<i>Oulodus robustus</i>	<i>Oulodus velicuspis</i> Interval Zone	Amadjuak Fm																				
				Ka2				<i>Amorphognathus superbus</i>	<i>Ou. velicuspis</i>	<i>Belodina confluens</i> Interval Zone																				
	Edenian	Ka1			<i>Belodina confluens</i>																									
		Chatfieldian																												
			Turinian																											
				Sa2																										
					Sa1																									
455	453.0 Sandbian																													
	Sa2	Caradoc				Mohawkian	Turinian	<i>Amorphognathus tvaerensis</i>	<i>Plectodina tenuis</i>	Amadjuak Fm																				
			<i>Baltoniodus alobatus</i>					<i>Phragmodus undatus</i>																						
			<i>Baltoniodus gerdæ</i>	<i>Belodina compressa</i>																										
			<i>Amorphognathus tvaerensis</i>	<i>Erismodus quadridactylus</i>																										
			<i>Baltoniodus variabilis</i>	<i>Plectodina aculeata</i>																										
	Sa1	Whiterockian	Llanvirn	Rangerian	<i>R. inequalis</i>	<i>Cahabagnathus sweeti</i>																								
					<i>Pygodus aserius</i>	<i>Cahabagnathus frendsvillensis</i>																								
					<i>Pygodus serra</i>	<i>Phragmodus polonicus</i>																								
					<i>Eoplacognathus suecicus</i>	<i>Histiodella holodetata</i>																								
					<i>*E. pseudoplanus</i>	<i>Histiodella sinuosa</i>																								
460	458.4 Darrivillian																													
	Dw3	Dw2	Dw1	Dp3	Dp2	Dp1	F13	F12	F11																					
										Dapingian	Dp3	Dp2	Dp1	F13	F12	F11														
																	Dapingian	Dp3	Dp2	Dp1	F13	F12	F11							
																								Dapingian	Dp3	Dp2	Dp1	F13	F12	F11
	Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																							
								Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																
															Dapingian	Dp3	Dp2	Dp1	F13	F12	F11									
																						Dapingian	Dp3	Dp2	Dp1	F13	F12	F11		
																													Dapingian	Dp3
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2
Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																								
							Dapingian	Dp3	Dp2	Dp1	F13	F12	F11																	
														Dapingian	Dp3	Dp2	Dp1	F13	F12	F11										
																					Dapingian	Dp3	Dp2	Dp1	F13	F12	F11			
																												Dapingian	Dp3	Dp2

Figure 4

150x196mm (300 x 300 DPI)

Figure 5

142x146mm (300 x 300 DPI)

Figure 6

181x221mm (300 x 300 DPI)

Figure 7

174x229mm (300 x 300 DPI)

Figure 8

171x221mm (300 x 300 DPI)

Figure 9

171x220mm (300 x 300 DPI)

Figure 10

171x221mm (300 x 300 DPI)

Table S1. Conodont numerical data for the samples collected in 2015

Samples	SZ15-22-01	SZ15-20-06	SZ15-20-05	SZ15-20-04	SZ15-20-03	SZ15-20-02	SZ15-20-01	SZ15-21-01	SZ15-21-02	SZ15-21-03	SZ15-21-04	SZ15-21-05	SZ15-21-06	SZ15-21-07	SZ15-21-08	SZ15-21-09	SZ15-14-01
Areas (in Figures 1, 2 and 3)	II							III									
Elevation (m)	10-20	0-10							130-140								10-
Mass (g)	2002	2005	2002	2005	2023	2009	2003	2001	2013	2002	2026	1995	2007	2005	2013	2023	2753
% Dissolution	71.3	78.1	68.7	80.6	83	84.8	86.3	84.5	76.8	88.9	80.6	78	78.7	80	85.3	89.7	99.7
<i>Amorphognathus ordovicicus</i>	10							17	29	18	15				3	11	
<i>Belodina confluens</i>	6	4	12	4	6	1	20	4	5	4	2						9
belodiniform el. Nowlan & McCracken																	1
<i>Coelocerodontus trigonius</i>	35		4		3		1										
<i>Cullumbodina occidentalis</i>																	
<i>Culumbodina penna</i>																	
<i>Culumbodina</i> cf. <i>C. sp. n.</i> X MacCracken																	
<i>Drepanoistodus suberectus</i>	74	8	9	4	8	1	12	7	8	5	1	3	4	1	1	5	54
<i>Milaculum ethinclarki</i>										1							10
<i>Milaculum</i> sp. n.																	
<i>Oulodus velicuspis</i>																	10
<i>Panderodus breviusculus</i>																	
<i>Panderodus feulneri</i>	253																
<i>Panderodus liratus</i>		6	4		11	1	8	7	9	7	7		8		2	3	6
<i>Panderodus unicostatus</i>		59	112	49	52	18	81	163	239	148	91	25	72	15	14	51	415
<i>Paroistodus? nowlani</i>	134																
<i>Periodon grandis</i>			2		3		3										
<i>Phosphannulus universalis</i>			1		1												6
<i>Phragmodus undatus</i>			2		4												12
<i>Plectodina tenuis</i>	5		4		4				6				1				126
<i>Plegagnathus dartoni</i>												1					
<i>Plegagnathus nelsoni</i>											1		1				2
<i>Protopanderodus liripipus</i>		1	2	6	4		5										
<i>Pseudobelodina adentata</i>																	
<i>Pseudobelodina? dispensa</i>			3		2			4	5		2		1		1	1	
<i>Pseudobelodina torta</i>									1	7							4
<i>Pseudobelodina quatrata</i>																	3
<i>Pseudobelodina v. vulgaris</i>																	1
<i>Pseudooneotodus beckmanni</i>	3							2	3								
<i>Pseudooneotodus mitratus</i>																	
<i>Rhipidognathus symmetricus</i>																	
<i>Scabbardella</i> sp.	55																
<i>Staufferella lindstroemi</i>					1?				1		1						
<i>Staufferella</i> n. sp. A of McCracken																	
<i>Walliserodus curvatus</i>		2	4	1	3		2	1	1		3		3				2
<i>Zanclodus</i> sp.									3	3						2	
N. Gen. A n. sp. A MacCracken														1			

NOTE: Sample numbers in grey-colored cells represent barren samples; sample numbers with red font represent rubble samples.

SZ15-14-02
SZ15-15-01
SZ15-15-02
SZ15-15-03
SZ15-15-04
SZ15-15-05
SZ15-15-06
SZ15-15-07
SZ15-16-01
SZ15-16-02
SZ15-16-03
SZ15-16-04
SZ15-16-05
SZ15-16-06
SZ15-16-07
SZ15-16-08
SZ15-16-09
SZ15-16-10
SZ15-16-11
SZ15-16-12
SZ15-16-13
SZ15-16-14
SZ15-16-15
SZ15-16-16
SZ15-16-17
SZ15-16-18

-20	50-60							70-100																	
2599	2585	2666	2565	2575	2721	2568	2778	2588	2871	2796	2553	2548	2625	2560	2551	2523	2573	2691	2502	2556	2465	2524	2677	2583	2566
99.4	99	100	99.5	100	100	98.6	99	99.1	99.5	99.9	96.6	99.5	95.3	92.7	99.1	98.7	98.7	97.8	99.6	98.4	97.8	99	99.4	99.2	99.7
	3	6	202	47	44	52	80	79	76	185	158	162	57	44	135	96	165	39	61	22	10	6	2	4	7
7	8	3	41	7	9	14	3	18	6	20	39	10	17	1	18	12	15	12	7	2					
1			1																						
			2	3				2			1	1				5	1								
1			4		1	1	1	1							1										
	1		8		1	6		5		1								1?		1?					
											1														
37	50	67	84	26	46	34	7	70	39	121	5	51	7	4	12	5	4	16	13	10	1	5		2	6
14	40	32	7		4	1	1										5	33	24			1	1		
		4	13	5	3	1	1	2	4	4	10	3	4			3			13	1	3				1
13	5	6						22	27	84		36	2	12	11										
3	2	2	74	8	4	9				9			8	5	16		5	5							1
	3	2	54	11	4	15	5	17	13	6	12	5	6	13	26	12	6	23	7	7		4		4	6
257	367	116	836	327	168	205	147	305	203	541	594	267	81	64	478	237	466	220	237	132	52	107	58	30	41
			3	2	2		8	1	2		91	1	14			1	2	7	13	9	2	2	2		1
3	2	1	6	4		2	2	6	2		9	18	2		1	3	2	2	3	1					
	20	10																							
51	125	130	16	3	8	12	4												2	1					
			3		2		3	5	3	7		4		1	6		2	2	1	2			1		
1			5	4	3	4		1		1		1		2		1	1	3							
1	2	8																							
5	4	2	32	14	1	6	1	14	2	15	23	6	5	3	9	3	14	8	5	4	1	1			
2			1		5			2		2	3	6			2		2								
	1							1?																	
2	1		3	1		1	6			4	1	1	2			1	3	3		1				1	
	6	6	5	7	5	7	5	16	8	10	6	3	6	1	4	1		1	4					1	
		1	4	3	3	3	1	7		3		2	1		2	1		1	1						
			1																						
								1	3	10	1	2			1										
9	5	4	5	3	2	2	3	3			12		3			1	2	2	2	6	2	1	1		
		1	4	1	1		1		1	2	12	5	2		8	6	14		1	1					
				1			1																		

SZ15-13-05	SZ15-13-04	SZ15-13-03	SZ15-13-02	SZ15-13-01	SZ15-18-09	SZ15-18-08	SZ15-18-07	SZ15-18-06	SZ15-18-05	SZ15-18-04	SZ15-18-03	SZ15-18-02	SZ15-18-01	SZ15-17-10	SZ15-17-09	SZ15-17-08	SZ15-17-07	SZ15-17-06	SZ15-17-05	SZ15-17-04	SZ15-17-03	SZ15-17-02	SZ15-17-01	SZ15-16-20	SZ15-16-19
------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------	------------

I

		120-150										150-180								190-200					
2570	2530	2594	2489	1997	2014	2005	1996	1995	1997	2035	2003	1998	2001	2002	2006	2007	2021	2000	1996	1998	2573	2745	2680	2581	2592
88.8	100	99.6	99	9.2.8	84.9	88.4	88.5	91	86.5	90	86	87.8	84	83.7	80.8	84.8	82	87.8	95	85.2	100	99.2	100	98.7	100
17															4										
6															3										
86		1													13	28	6								
1															1										
2																									
1																									
									</																

Table S2. Conodont numerical data for the samples collected in 2014

Samples	SZ14-05A-01C	SZ14-05A-02C	SZ14-02A-01C	SZ14-02A-02C	SZ14-06A-01C	SZ14-06A-02C	SZ14-06A-03C	SZ14-08A-01C	SZ14-08A-02C	SZ14-07A-01C	SZ14-07A-02C	SZ14-09A-01C	SZ14-09A-02C
Areas (in Figures 1, 2 and 3)	II							III				I	
Elevation (m)	10-20		10-20		70-80			60-70		130-140		10-20	
Mass (g)	2707	2552	2647	2583	2620	2757	2744	2665	2577	2454	2479	2601	2657
% Dissolution	93.9	95	97.6	97.1	97.5	94.7	95.1	96.8	98.9	99.5	99.2	98.3	96.8
<i>Amorphognathus ordovicicus</i>										35	14		
<i>Belodina confluens</i>	57	46	86	23	1	20	27	37	12	4	6	8	4
belodiniform el. Nowlan & McCracken	1			1		2	1						
<i>Coelocerodontus trigonius</i>	18	1	11	31		3	11	16					
<i>Cullumbodina occidentalis</i>				2			1					2	
<i>Culumbodina penna</i>				1									1
<i>Decoriconus</i> sp.				5									
<i>Drepanoistodus suberectus</i>	34	36	36	51	1	25	33	37	7	5	3	62	110
<i>Milaculum ethinclarki</i>	3		4			23	11	23	21	21	24	2	2
<i>Oulodus velicuspis</i>	1			2				7				12	36
<i>Panderodus breviusculus</i>	9		16	3								1	
<i>Panderodus feulneri</i>												4	
<i>Panderodus liratus</i>	39	21	13	13	1	2	5	19	3	16	7	4	4
<i>Panderodus unicostatus</i>	662	365	568	423	53	214	461	542	131	194	171	293	166
<i>Paroistodus? nowlani</i>	22	4	11	19	2	7	12	19	4	26	10		
<i>Periodon grandis</i>	26	463	4	373		58	54	73	14				
<i>Phosphannulus universalis</i>	6	33	5	11		2	4	5	2	4		2	
<i>Phragmodus undatus</i>	9	19	9					3					
<i>Plectodina tenuis</i>	2	1				5		11				95	167
<i>Plegagnathus dartoni</i>											1		
<i>Plegagnathus nelsoni</i>											5		
<i>Protopanderodus liripipus</i>	51	129	46	45		1							
<i>Pseudobelodina adentata</i>								2				5	6
<i>Pseudobelodina? dispensa</i>	6		2	4		4	2		2	8	7		
<i>Pseudobelodina torta</i>												3	6
<i>Pseudobelodina quatrata</i>													
<i>Pseudobelodina v. vulgaris</i>							1	1		6			3
<i>Pseudooneotodus beckmanni</i>	1					1				3	1		
<i>Rhipidognathus symmetricus</i>													
<i>Staufferella lindstroemi</i>			2	2									
<i>Staufferella</i> n. sp. A of McCracken													
<i>Walliserodus curvatus</i>	54	23	53	12		8	10	11	1	5	4		
<i>Zanclodus</i> sp.	2	12	7	7	2		1	8		3	3		