Late Ordovician–early Silurian conodonts and their colour alteration index values from carbonate xenoliths in kimberlite CH-06 on Hall Peninsula, Baffin Island, Nunavut

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Abstract

Hall Peninsula, located on southeastern Baffin Island, Nunavut, hosts the Chidliak kimberlite province. Precambrian rocks currently crop out at surface, but these were covered by Ordovician and Silurian sedimentary rocks during the Late Jurassic–Early Cretaceous. The carbonate xenoliths, and the numerous conodont microfossils within them, that were recovered from kimberlite drillcores have proved that all these sedimentary rocks were present at the time of kimberlite emplacement (157.0–139.1 Ma) and have been subsequently removed by erosion. This study is a continuation of the work carried out since 2013 on conodonts recovered from Hall Peninsula kimberlites and their colour alteration index. The results from 5 drillholes in kimberlite CH-06 are summarized in this paper. Of the 17 collected samples, 10 contain conodonts, from which about 230 identifiable conodont specimens, with conodont colour alteration index values ranging between 6 and 7, have been recovered. These provide additional data to help in understanding the kimberlite emplacement processes and cooling history. More importantly, four early Silurian conodont species were previously unknown from Hall Peninsula, two of which are Aeronian and Telychian in age; this provides new evidence for younger strata being present in the region.

Résumé

La péninsule Hall, située dans la partie sud-ouest de l’île de Baffin, abrite la province de kimberlites de Chidliak. Des roches précambriennes s’y trouvent aujourd’hui exposées en surface mais ces dernières étaient recouvertes de roches sédimentaires au cours de l’époque s’étendant de la fin du Jurassique au début du Crétacé. Les xénoîlites de calcaire récupérés de sondages forés dans les unités de kimberlite, ainsi que les nombreux microfossiles de conodontes qu’ils renferment, ont permis d’établir que ces roches sédimentaires étaient présentes au moment de la mise en place de unités de kimberlite (de 157.0 à 139.1 Ma) mais qu’elles ont depuis disparu, enlevées par l’érosion. La présente étude s’inscrit dans le cadre de travaux en cours depuis 2013 axés sur les conodontes provenant des kimberlites de la péninsule Hall et leurs indices d’altération de la couleur. Dans cet article, un résumé des résultats acquis de 5 forages exécutés dans l’unité de kimberlite CH-06 est présenté. Parmi les 17 échantillons recueillis, dont 10 contenaient des conodontes, quelque 230 spécimens de conodontes identifiables ont pu être récupérés; l’indice d’altération de la couleur de ces derniers variait entre 6 et 7. Les données additionnelles que ces conodontes apportent permettent d’améliorer le niveau de connaissance au sujet de la mise en place des kimberlites et de l’histoire de leur refroidissement. Fait plus important encore, quatre espèces de conodontes...
datant du début du Silurien n’avaient pas été identifiées dans la péninsule Hall auparavant, dont deux appartenant aux étages de l’Aéronien et du Télychien. Il s’agit-là de nouvelles preuves de la présence de strates plus jeunes dans la région.

Introduction

The Chidliak kimberlite province, located on Hall Peninsula, southern Baffin Island, covers an area measuring approximately 40 by 70 km (Figure 1). Precambrian rocks crop out at surface on Hall Peninsula, but during the time of kimberlite emplacement in the Late Jurassic and Early Cretaceous (156.7–139.1 Ma; Heaman et al., 2012), these older rocks were covered by Upper Ordovician and lower Silurian sedimentary rocks, which have been subsequently removed by erosion. The lost geological record has been reconstructed by studying numerous conodont microfossils preserved in carbonate xenoliths recovered from kimberlite drillcores (Zhang and Pell, 2013, 2014, 2016). The kimberlite emplacement temperature has been estimated by employing the conodont colour alteration index (CAI; Pell et al., 2015, 2018).

This paper presents new conodont data collected from five 2017 drillholes in the CH-06 kimberlite, in addition to those reported by Zhang and Pell (2013, 2014, 2016), and focus on new evidence of younger strata being present in

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Figure 1: Simplified geology of the Foxe Basin and vicinity (modified from Wheeler et al., 1997), showing the location of the Chidliak project area (red polygon).
the region than those previously confirmed by Zhang and Pell (2013, 2014, 2016).

**Geological setting**

Hall Peninsula is divided into three major crustal tectonic entities (from west to east): Cumberland Batholith, a belt of Paleoproterozoic metasedimentary rocks and a gneissic terrane named the ‘Hall Peninsula block’ (Figure 2; Scott, 1996, 1999; St-Onge et al., 2006; Whalen et al., 2010).

The Hall Peninsula block (Figure 2) comprises largely 2.92–2.80 Ga Archean orthogneissic and supracrustal rocks. It hosts more than seventy kimberlites discovered since 2008, which are referred to as the Chidliak kimberlite province. A majority of the kimberlites are pipes and have been dated as Late Jurassic–Early Cretaceous (156.7–139.1 Ma; Heaman et al., 2012); some steeply dipping, sheet-like bodies are also present (Pell et al., 2013). The pipes commonly contain sedimentary xenoliths derived from the paleosurface and incorporated into an open vent structure.

At present, there is no Phanerozoic sedimentary cover on Hall Peninsula, except for unconsolidated glacial deposits. Regionally, the Paleozoic rocks are exposed west of the Cumberland Batholith (Sanford and Grant, 2000; Zhang, 2012), farther to the northwest on Brodeur Peninsula (Nentwich and Jones, 1989), on northern Baffin Island (Trettin, 1975; Zhang, 2018), on northeastern Melville Peninsula (Sanford, 1977; Sanford and Grant, 2000; Zhang, 2013) and on several small islands in the northeastern and central Foxe Basin (Figure 1). A nearly complete Paleozoic stratigraphic record was recovered by the drilling on Rowley Island in the northern Foxe Basin (Trettin, 1975). These Paleozoic rocks were deposited in the Foxe Basin and were present on Hall Peninsula before the Late Jurassic–Early Cretaceous when the kimberlites were emplaced, as was proved by the conodonts discovered from the carbonate xenoliths preserved in the kimberlites on Hall Peninsula (Zhang and Pell, 2013, 2014, 2016).

**Kimberlite CH-06: new carbonate xenolith samples and conodonts**

All conodonts reported herein were recovered from the carbonate xenoliths preserved in kimberlite CH-06, which is a pipe, 1 ha in surface area, dominated by apparent coherent kimberlite (ACK), with lesser pyroclastic kimberlite (PK) and coherent kimberlite (CK; Pell et al., 2013).

Zhang and Pell (2016, Table 2) reported a total of 21 conodont specimens discovered in 16 carbonate xenolith samples recovered from four drillholes in kimberlite CH-06. These conodont specimens represent two Late Ordovician species, *Aphelognathus cf. A. divergens* Sweet and *Panderodus unicostatus* (Branson and Mehl), and two Late Permian–Early Triassic species, *Neogondolella* sp. and

![Figure 2: Simplified regional geology of southern Baffin Island (after St-Onge et al., 2006; Whalen et al., 2010), showing the location of the Chidliak kimberlite province (green diamond).](image-url)
Neospathodus sp.; the latter two were considered the result of cross-contamination in the lab. All of these conodonts have CAI values ranging between 4 and 8.

Following Zhang and Pell (2016), an additional 17 carbonate xenolith samples were collected from five drillholes (CHI-050-17-DD36, -DD38, -DD39, -DD43 and -DD44) in kimberlite CH-06. Of 17 samples collected and processed, ten were productive for conodonts. These ten samples, which were from three (DD36, DD43 and DD44) of the five drillholes, yielded a total of 239 recognizable conodont specimens (Table 1). Most of the samples in drillholes DD36 and DD44 are from continuous cores through intervals of side-wall collapse (or talus) deposits containing numerous large carbonate blocks measuring up to approximately 5 m in core length, and interlayered intervals of kimberlite plus small carbonate xenoliths. For example, six out of seven samples are from interval 49.6–68.83 m in drillhole DD36, and five out of six samples are from interval 88.7–93.8 m in drillhole DD44; these two intervals contained at least seven and three large blocks, respectively (Figure 3a), plus numerous small ones. All samples from these intervals are white brecciated marble (Figure 3b), which most likely was brecciated limestone before being captured by the kimberlite. A few samples are buff-coloured, layered, recrystallized limestone (Figure 3c).

Table 1: Conodont elements recovered from three out of five drillholes in kimberlite CH-06 and their CAI values.

<table>
<thead>
<tr>
<th>Drillhole</th>
<th>Sample no.</th>
<th>Undissolved sample mass (g)</th>
<th>Depth (m)</th>
<th>Species</th>
<th>CAI</th>
</tr>
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<tbody>
<tr>
<td>CHI-050-17-DD36</td>
<td>228</td>
<td>49.6-50.3</td>
<td>2683</td>
<td>Aulocognathus bullatus</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>457</td>
<td>50.75-51.5</td>
<td>2683</td>
<td>Distomodus staurognathoides</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>2461</td>
<td>53.53-55.9</td>
<td>2683</td>
<td>Kokkelella? manitoulinensis</td>
<td>6.5-7</td>
</tr>
<tr>
<td></td>
<td>1055</td>
<td>57.92-58.3</td>
<td>418</td>
<td>Ozarkodina cf. O. hassi</td>
<td>7</td>
</tr>
<tr>
<td>CHI-050-17-DD38</td>
<td>485</td>
<td>58.3-59.0</td>
<td>473</td>
<td>Belodina confinis</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>2447</td>
<td>58.8-59.1</td>
<td>1233</td>
<td>Culumobdina penna</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>2447</td>
<td>58.1-58.1</td>
<td>1233</td>
<td>Drepanoistodus suberectus</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1483</td>
<td>59.3-59.1</td>
<td>1233</td>
<td>Panderodus brevisculus</td>
<td>6.5-7</td>
</tr>
<tr>
<td></td>
<td>2091</td>
<td>58.1-58.1</td>
<td>1233</td>
<td>Phragmodus undatus</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1816</td>
<td>58.1-58.1</td>
<td>1233</td>
<td>Walliserodus curvatus</td>
<td>6.5</td>
</tr>
<tr>
<td>CHI-050-17-DD40</td>
<td>17</td>
<td>88.7-89.3</td>
<td>692</td>
<td>Oulodus sp.</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>2484</td>
<td>89.3-90.3</td>
<td>692</td>
<td>Panderodus iratus</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>2484</td>
<td>89.3-90.3</td>
<td>692</td>
<td>Panderodus unicosatus</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>363</td>
<td>91.6-92.3</td>
<td>692</td>
<td>Pseudoonotoctodus beckmanni</td>
<td>7</td>
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<tr>
<td></td>
<td>2000</td>
<td>93.25-93.8</td>
<td>692</td>
<td>broken ramiform</td>
<td>6</td>
</tr>
<tr>
<td>CHI-050-17-DD44</td>
<td>117</td>
<td>108.8-109.3</td>
<td>692</td>
<td>Total</td>
<td>2</td>
</tr>
</tbody>
</table>

Notes: 1) total number of specimens is 239; 2) samples with * and grey shade are barren of conodonts.
Conodonts from kimberlite CH-06 and new insight into reconstruction of Paleozoic stratigraphy on Hall Peninsula

Zhang and Pell (2014) reported more than 1300 conodont specimens representing 32 species of Late Ordovician–early Silurian (Llandovery) ages from carbonate xenoliths preserved in kimberlites on Hall Peninsula. Based on these conodonts, the lower Paleozoic stratigraphic units, including the Upper Ordovician Frobisher Bay, Amadjuak, Akpatok and Foster Bay formations, and the lower Silurian Severn River Formation, were reconstructed on the Paleozoic-barren Hall Peninsula (Figure 4).

The lower Silurian (Llandovery) is divided into Rhuddanian, Aeronian, and Telychian. Several early Silurian conodonts recovered from the carbonate xenoliths in Chidliak kimberlites on Hall Peninsula are from the Severn River Formation, with an age of Rhuddanian and possibly Aeronian (Zhang and Pell, 2014). This conclusion was based on conodonts *Ozarkodina elibata* (Pollock, Rexroad and Nicoll), *O. hassi* (Pollock, Rexroad and Nicoll), *Oulodus jeanneae* Schönlaub, *O. panaurensis* (Bischoff) and *Pterospathodus? originalis* Zhang and Barnes, as well as two indeterminate species of *Distomodus* Branson and Branson. Almost all these species were recovered from drillhole CHI-050-11-DD16 in kimberlite CH-06 (Zhang and Pell, 2014).

Most of conodonts among the 239 recovered specimens are Late Ordovician species (Table 1), which were reported from the previous studies (Zhang and Pell, 2013, 2014, 2016). Only 16 specimens are recognized as early Silurian conodont species (Table 1): *Aulacognathus bullatus* (Nicoll and Rexroad; Figure 5b), *Distomodus stauagnostoides* (Walliser; Figure 5a), *Kockelella? manitoulinensis* (Pollock, Rexroad and Nicoll; Figure 5c) and *Ozarkodina cf. O. hassi* (Pollock, Rexroad and Nicoll; Figure 5e–g) were not reported from the earlier studies (Zhang and Pell, 2013, 2014, 2016). All these species were recovered from sample SZ17-050-02 from drillhole CHI-050-17-DD36 and sample SZ17-050-14 from drillhole CHI-050-17-DD44 (Table 1). Among these species,

- *Distomodus stauagnostoides* is a nominate species of *D. stauagnostoides* Zone across the boundary between upper Aeronian and lower Telychian (Figure 4), but it can extend upward into the *Pterospathodus a. amorphagnostoides* Zone at the top of the Telychian (Barrick and Klapper, 1976; Clark et al., 1981) and even into the lowermost Wenlock (Sweet, 1988; Bancroft et al., 2015).

- *Aulacognathus bullatus* is not a zonal species, but it has a narrower stratigraphic distribution than that of *D. stauagnostoides*. It is only restricted in the *Pterospathodus amorphagnostoides angulatus* Zone in the Baltic (Männik, 2007) and Arctic (Zhang et al., 2017) areas but extends lower in the *Pterospathodus eopennatus* Zone in the state of Iowa (Waid and Cramer, 2017) and in the *Pt. celloni–Pt. eopennatus* Zone in both the Severn River and Ekwan River formations in the Hudson Bay area (Zhang and Barnes, 2007). Therefore, the total known stratigraphic distribution of the species covers both *Pt. eopennatus* and *Pt. a. angulatus* zones in the Telychian.

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**Figure 3:** a) Large block of white brecciated marble from interval 53–56 m in drillhole CHI-050-17-DD36. b) Close-up of white brecciated marble from interval 57.92–58.30 m in drillhole DD36. c) Buff-coloured, layered, recrystallized limestone from interval 137.34–138.28 m in drillhole CHI-050-17-DD43.
Figure 4: Upper Ordovician and lower Silurian stratigraphy reconstructed based on the Late Ordovician and early Silurian conodonts from the carbonate xenoliths preserved in the kimberlites on the Hall Peninsula, and its correlation within the Late Ordovician and early Silurian chronostratigraphic framework. The shaded interval is reconstructed based on the new conodont data in this paper, and the remainder is based on Zhang and Pell (2014). For the Late Ordovician part, Geological Time Scale (GTS; second column from left) is after Cooper and Sadler (2012); British (third column from left) and North American series and stages (fourth and fifth columns from left) are adopted from Webby et al. (2004). For the Llandovery, GTS is after Melchin et al. (2012). The Late Ordovician and Llandovery conodont zones are from Cooper and Sadler (2012) and Melchin et al. (2012), respectively. Abbreviations: Fm., Formation; HI, Hirnantian; PEN., Peninsula; W, Wenlock. Unit for the numbers on the left is Ma.

Figure 5: a) Distomodus staurognathoides (Walliser); upper view of Pa element; NUFV 2154; from sample 14 in drillhole DD44. b) Aulocagnosthus bullatus (Nicoll and Rexroad); upper view of Pa element; NUFV 2155; from sample 14 in drillhole DD44. c) Kockelella? manitoulinensis (Pollock, Rexroad and Nicoll); c and c’, outer lateral and under views of Pa element, respectively; NUFV 2156, from sample 02 in drillhole DD36. d) Oulodus sp.; posterior view of M element; NUFV 2157; from sample 13 in drillhole DD44. e–g) Ozarkodina cf. O. hassi (Pollock, Rexroad and Nicoll); e) lateral view of Pb element, NUFV 2158; f) inner lateral view of Sc element, NUFV 2159; g) lateral view of Pa element, NUFV 2160, from sample 14 in drillhole DD44. h) Panderodus liratus Nowlan and Barnes; inner lateral view of asymmetric graciliform element; NUFV 2161. i) Panderodus unicostatus (Branson and Mehl); outer lateral view of compressiform element; NUFV 2162. j) Phragmodus undatus Branson and Mehl; outer lateral view of P element; NUFV2163. k) Panderodus breviusculus Barnes; outer lateral view of compressiform element; NUFV 2164. l) Drepanoistodus suberectus (Branson and Mehl); inner lateral view of homocurvatiform element; NUFV 2165. m–n) Belodina confluens Sweet; m) outer lateral view of eobelodiniform element, NUFV 2166; n) outer lateral view of grandiform element, NUFV 2167. o–p) Culumbodina penna Sweet; o) and o’) inner and outer lateral views of subtriangular element; NUFV 2168; p) and p’) inner and outer lateral views of L-shaped element; NUFV 2169. Conodont elements in parts h–p) are from sample 17 in drillhole DD44. Conodont elements in parts a–g and h–p have CAI values 6–6.5 and 7, respectively. All sample numbers have a prefix SZ17-050; all drillholes have a prefix CHI-050-17. Scale bars: 0.25 mm. All illustrated specimens are curated in the Canadian Museum of Nature.
These two newly discovered conodont species suggest that Silurian strata on the Hall Peninsula were deposited until at least the Telychian of Llandovery (Figure 4), and possibly the earliest Wenlock. This is the first time that Aeronian and Telychian conodonts have been discovered in the Foxe Basin area, thus proving that Silurian strata in Foxe Basin area were deposited not only during the Rhuddanian (documented by Zhang and Pell, 2014) but also during the Aeronian and Telychian. Considering that they occur in both the Severn River and Ekwan River formations in the Hudson Bay area (Zhang and Barnes, 2007), the Silurian strata probably include not only the Severn River Formation but also the Ekwan River Formation in the Foxe Basin area (Figure 4).

Conodont CAI values and their implications

The conodont CAI is a tool used in estimating the maximum temperature reached by a sedimentary rock using thermal alteration of conodont fossils. When temperature increases from 50–80°C to more than 800°C, the conodont colour can change from amber to brown, black, grey, white and finally transparent, with the colours indexed as 1–8 (Epstein et al., 1977; Harris, 1981). All conodonts from kimberlite CH-06 reported herein have grey and white colours, corresponding with CAI values of 6–7 (Table 1; Figure 5), which are within the range previously reported for CH-06 (from 6 to 7–8; Pell et al., 2018). These CAI values were obtained not only from depths as great as 391.3 m (SZ17-050-17) but also from a depth of only 50.75 m (SZ17-050-02); therefore, the CAI values are not depth dependent in this case.

The carbonate xenoliths in pipes dominated by apparent coherent kimberlite (ACK), such as CH-06, have a distinct CAI mode of 6–6.5, similar to the pyroclastic-dominated pipes. However, some xenoliths from ACKs record the highest CAI values observed at Chidliak, up to 7–8 (Zhang and Pell, 2016); these CAI values indicate that the xenoliths were heated to temperatures of 780°C to >960°C, which is hotter than seen in the majority of pyroclastic (PK) deposits. The ACKs are interpreted as welded or agglutinated deposits, so the CAI values recorded by the entrained xenoliths constrain the minimum temperatures required for welding within kimberlite pipe deposits. Material deposited at temperatures less than ~700°C apparently does not weld, whereas deposition at temperatures in excess of 700°C facilitates welding and formation of clastogenic kimberlite deposits (Pell et al., 2015, 2018).

Economic considerations

The CH-06 kimberlite contains an NI 43-101 Inferred Mineral Resource of 17.96 million carats of diamonds in 7.46 million tonnes of ore, at an average grade of 2.41 carats per tonne to a depth of 525 m below surface (Fitzgerald et al., 2018). Additional to the discoveries of Zhang and Pell (2013, 2014, 2016), conodonts recovered from carbonate xenoliths in kimberlite CH-06 provide new insight into the Paleozoic depositional history of the Foxe Basin, providing direct evidence for the Ordovician and Silurian strata that existed on Hall Peninsula at the time of kimberlite emplacement (Zhang and Pell, 2013, 2014, 2016). This allows for a reliable and economic way to reconstruct the Paleozoic stratigraphy and the amount of kimberlite and other rock cover that was subsequently lost to the erosion. The new CAI data further the understanding of the kimberlites’ emplacement and postemplacement history, and allow estimates of the minimum temperature of emplacement (Pell et al., 2015, 2018), which furthers the understanding of this mineral deposit.

Conclusions

A total of 239 conodont specimens were recovered from 10 productive carbonate xenolith samples out of the 17 samples collected and processed from five drillholes in kimberlite CH-06. All of these conodonts have CAI values of 6–7. Among them, four Silurian species had not previously been found in this area, thus providing new evidence that

- strata with an age of Aeronian and Telychian, younger than the Late Ordovician and Rhuddanian of early Silurian ages, occurred on Hall Peninsula prior to the kimberlites’ emplacement;
- the strata of early Silurian age had been deposited in Foxe Basin during the entire early Silurian (i.e., Rhuddanian, Aeronian and Telychian), including the Severn River Formation and possibly the Ekwan River Formation; if any strata younger than these existed in Foxe Basin, no evidence has been found so far; and
- the conodont CAI values of 6–7 are within the range previously reported for CH-06; CAI values of 7 are higher than observed in PK deposits at Chidliak and provide some constraints on the minimum temperature required for welding (i.e., deposition at temperatures in excess of 700°C facilitates welding and formation of clastogenic kimberlite deposits).

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References


Zhang, S. 2013: Ordovician conodont biostratigraphy and redefinition of the age of lithostratigraphic units on northeastern Melville Peninsula, Nunavut; Canadian Journal of Earth Sciences, v. 50, p. 808–825.


