Study of sedimentary rock xenoliths from kimberlites on Hall Peninsula, Baffin Island, Nunavut

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Abstract

This study is part of the Canada-Nunavut Geoscience Office’s Hall Peninsula Integrated Geoscience Program, a multiyear bedrock and surficial geology mapping program with associated thematic studies. Hall Peninsula, located on southeastern Baffin Island, Nunavut, hosts the newly discovered Chidliak kimberlite province. Presently, this area lacks Phanerozoic sedimentary cover; however, Late Ordovician and Early Silurian microfossils (conodonts) have been recovered from carbonate xenoliths preserved in the Upper Jurassic–Lower Cretaceous kimberlites. The well-preserved conodont faunas provide reliable evidence for estimating 1) the thickness of Lower Paleozoic sedimentary cover prior to the intrusion of the kimberlites; and 2) the variations in temperature recorded by conodonts preserved in sedimentary rock xenoliths within the same kimberlite, and among the different kimberlites.

The project activities include 1) collecting sedimentary rock xenoliths from the drillholes intersecting kimberlites in the Chidliak-Qilaq area; 2) processing the carbonate xenoliths for conodonts; 3) estimating the total thickness of Lower Paleozoic sedimentary cover and the degree to which the xenoliths were heated by the kimberlites, using the conodonts’ age and colours; and 4) obtaining information about the Paleozoic petroleum system in the nearby Baffin Bay area by studying sedimentary rock types and collecting Rock-Eval 6 data.

Résumé

Cette étude fait partie du Programme géoscientifique intégré de la péninsule Hall, du Bureau géoscientifique Canada-Nunavut, un programme pluriannuel de cartographie du substratum rocheux et de la géologie de surface accompagnée d’études thématiques connexes. La péninsule Hall, située dans le sud-est de l’île de Baffin (Nunavut) renferme la nouvelle province kimberlitique de Chidliak, récemment découverte. À l’heure actuelle, cette région n’a pas de couverture sédimentaire du Phanérozoïque, mais des microfossiles (conodontes) de l’Ordovicien tardif et du Silurien précoce ont été récupérés de xénolites carbonatés préservés dans les kimberlites du Jurassique supérieur et du Crétacé inférieur. Les faunes de conodontes bien conservées fournissent des preuves fiables pour estimer 1) l’épaisseur de la couverture sédimentaire du Paléozoïque inférieur avant l’intrusion des kimberlites et 2) les variations de température enregistrées par les conodontes préservés dans les xénolites des roches sédimentaires au sein de ces mêmes kimberlites et dans des kimberlites différentes.

Les activités du projet comprennent : 1) la collecte de xénolites de roches sédimentaires dans les forages recoupant les kimberlites dans la région de Chidliak–Qilaq; 2) le traitement des xénolites carbonatés pour déceler la présence de conodontes; 3) l’estimation de l’épaisseur totale de la couverture sédimentaire du Paléozoïque inférieur et l’évaluation, en fonction de l’âge et de la couleur des conodontes, de la mesure dans laquelle les xénolites ont été chauffés par les kimberlites; et 4) l’obtention d’information sur le système d’hydrocarbures du Paléozoïque dans la région environnante de la baie de Baffin grâce à l’étude des types de roches sédimentaires et à la collecte de données Rock-Eval 6.

Introduction

The Hall Peninsula Integrated Geoscience Program (HPIGP) is being led by the Canada-Nunavut Geoscience Office in collaboration with the Government of Nunavut, Aboriginal Affairs and Northern Development Canada, Dalhousie University, University of Alberta, Université Laval, University of Manitoba, University of Ottawa, University of Saskatchewan, Nunavut Arctic College and the Geological Survey of Canada. It is supported logistically by several local, Inuit-owned businesses. The study area comprises all or parts of six 1:250 000 scale National Topographic System...
(NTS) map areas north and east of Iqaluit (NTS 025J, O, P, 026A, B).

In the summer of 2012, fieldwork was conducted in the southern half of the peninsula (NTS 025 I, J, O, P) between June 22 and August 8. Fieldwork was supported by a 20–25 person camp located approximately 130 km southeast of Iqaluit. The focus was on bedrock mapping at a scale of 1:250 000 and surficial-sediment mapping at a scale of 1:100 000. A range of thematic studies was also supported. This included Archean and Paleoproterozoic tectonics, geochronology, landscape uplift and exhumation, detailed mapping in mineralized areas, microdiamonds, sedimentary rock xenoliths and permafrost. Summaries and preliminary observations for all of these studies can be found in this volume.

The southern half of Baffin Island, Nunavut, including Hall Peninsula, was targeted for greenfields diamond exploration by BHP Billiton and Peregrine Diamonds Ltd. in 2005. Since that time, focused exploration for primary diamond sources on Hall Peninsula has resulted in the discovery of 61 kimberlites on the Chidliak project and three more kimberlites on the adjacent Qilaq project. Together, these 64 bodies form the completely new Chidliak kimberlite province, which covers a 40 × 70 km area (Figure 1; Pell et al., 2012). These Late Jurassic–Early Cretaceous (139.1–156.7 Ma) kimberlites (Heaman et al., 2012) intruded dominantly 2.92–2.80 Ga orthogneiss of the Hall Peninsula Block (Figure 2; Whalen et al., 2010).

At present, the Chidliak-Qilaq area lacks Phanerozoic sedimentary cover, except for unconsolidated glacial deposits. However, the Lower Paleozoic carbonate xenoliths that have been recovered from the kimberlites prove that this part of the Hall Peninsula was overlain by Lower Paleozoic sedimentary rocks before and during the Late Jurassic and Early Cretaceous (i.e., the time of kimberlite emplacement).

This study reports the preliminary results on the conodonts that were recovered from carbonate xenoliths preserved in the kimberlite pipes, and estimates the total thickness of Lower Paleozoic sedimentary cover and the degree to which the xenoliths were heated by the kimberlites, using the conodonts’ age and Colour Alteration Index (CAI). In addition to the carbonate xenoliths, a black-shale xenolith was also found in one of the pipes in the Chidliak kimberlite province; this research is ongoing.

**Conodonts and materials**

Conodonts are common marine microfossils; they first appeared in the Cambrian and became extinct by the end of the Triassic. The fossils themselves are believed to be the

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![Figure 1. Simplified geology of southern Baffin Island, showing major tectonostratigraphic assemblages, bounding crustal structures (adapted from Pell et al., 2012) and the Chidliak/Qilaq project area (greenish-blue polygon).](image)
skeletal elements of conodont animals’ feeding apparatus. Conodonts are normally preserved in carbonate rocks; dissolving the carbonates in 10–12% acetic acid is the common method of isolating the fossil conodonts.

Conodonts have many important characteristics that are useful in different geological applications. The following characteristics are employed in this study:

- Most of the conodont species have shorter temporal ranges than most other fossil groups; therefore, they are commonly the first choice for dating Paleozoic and Triassic marine sedimentary rocks. The biostratigraphic information derived from conodonts can be used to estimate the thickness of Paleozoic cover that has been lost to erosion from the Chidliak kimberlite province.

- Conodont colour changes with increasing temperature under burial conditions. Unweathered and unheated conodonts are pale yellow; with increasing temperature, their colour alters to light to dark brown, black, grey, opaque white or crystal clear. A well-established method, the Conodont Colour Alteration Index (CAI) that relates these colour changes to temperature, was developed by Epstein et al. (1977) and Rejebian et al. (1987). The CAI scale of 1–8 covers a temperature range from less than 50°C to more than 600°C. This scale is employed in this study to estimate the variations in temperature recorded by the conodonts preserved in carbonate xenoliths within the kimberlites.

In total, 109 carbonate-xenolith samples were collected from 19 drillholes in the Chidliak-Qilaq kimberlites (Table 1). Because of the random sizes of the xenoliths, the sample sizes range between 0.5 kg and 5 kg. Of the 109 samples, 95 samples from 16 drillholes have been processed (14 samples from CH1-554-11-DD01, CH1-192-11-DD01 and CH1-400-11-DD01 are still being processed); 69 of these were productive, with a total of 1022 identifiable conodont specimens with numerous fragments being recovered.

Age of conodonts and inferred thickness of Paleozoic strata eroded from the Chidliak kimberlite province

Among the 1022 conodont specimens, 33 species were recognized, with ages ranging from Late Ordovician to Early Silurian. This confirms that, during the Late Ordovician and Early Silurian, the Chidliak-Qilaq area was covered by a shallow tropical sea.

Ordovician carbonate rocks presently crop out on southwestern Baffin Island, some 150–280 km west of Chidliak-Qilaq area. There, the exposed rock units include the Frobisher Bay, Amadjuak and lower Akpatok formations, with a total thickness about 100 m (Zhang, 2012). Conodonts recovered from the sedimentary xenoliths within the kimberlites, such as Appalachignathus delicatulus (Figure 3A), Belodina confluens (Figure 3C), Oulodus velicuspis (Figure 3E) and many other species, are also known from the Frobisher Bay, Amadjuak and lower Akpatok formations on southwestern Baffin Island (McCracken, 2000). In turn, this suggests that these formations must also have been present in the Chidliak-Qilaq area prior to kimberlite emplacement but were erosionally removed from the study area sometime between the Early Cretaceous and the present.

Other conodont species, such as the late Late Ordovician Rhipidognathus symmetricus (Figure 3D), Early Silurian Ozarkodina elibata (Figure 3B) and many others of the same age, have not been reported from southwestern Baffin Island (McCracken, 2000) but occur in strata in Hudson Bay and on Southampton Island (Zhang and Barnes, 2007; Zhang, 2011). The former species is from the Upper Ordovician Red Head Rapids Formation that is 26–98 m thick in Hudson Bay (Zhang and Barnes, 2007) and about 40 m thick on Southampton Island (Zhang, 2011); the latter is from the Lower Silurian Severn River Formation that is 223–252 m thick in Hudson Bay (Zhang and Barnes, 2007), but the O. elibata Zone is restricted to the lower 40–100 m of the Severn River Formation. The discovery of these conodonts suggests that at least another 66–198 m of strata younger than the Frobisher Bay, Amadjuak and lower Akpatok formations must have been present in the Chidliak-Qilaq area when the kimberlites were emplaced, and that these younger strata were also likely present on southwestern Baffin Island, where the Ordovician sedimentary cover remains preserved. Therefore, it is estimated that a total of about 165–300 m of Upper Ordovician and Lower Silurian strata have been lost to erosion in the Chidliak-Qilaq area.

The above interpretation regarding the age of the xenoliths and the inferred thickness of Paleozoic strata is based on the 95 processed samples. Owing to the 14 unfinished samples from drillholes CH1-554-11-DD01, CH1-192-11-DD01 and CH1-400-11-DD01, any conodonts additional to the 33 recognized species would change the inferred thickness of Paleozoic strata lost to erosion in the Chidliak-Qilaq area.

Conodont CAI and temperature variation among the kimberlites in the Chidliak kimberlite province

As noted earlier, 1022 identifiable conodont elements have been recovered from 69 productive samples from 16 drillholes intersecting kimberlite in the Chidliak-Qilaq area. Although some of the conodont species have a relatively long stratigraphic range and are not useful in dating the xenoliths, each element has its specific colour and provides a reliable CAI value. The conodont elements in the kimberlites from the Chidliak kimberlite province have a
wide CAI range, from 1.5 to 8. The CAI data can be used to determine the temperatures to which the sedimentary xenoliths were heated, which provides an independent estimate for the minimum temperature of emplacement of the various types of pipe infill found within the Chidliak-Qilaq kimberlites. The temperatures recorded within these xenoliths range from 50°C to more than 600°C. The sedimentary xenoliths occur in kimberlites that have either pyroclastic or apparently coherent kimberlite infill (Pell et al., in press); work is ongoing to relate the temperatures these xenoliths attained to pipe-infill types.

Xenoliths of black shale, and dolostone or dolomitic-limestone breccia from the Chidliak kimberlite province

A 10 cm long black-shale xenolith was collected from a drillhole (CH1-482-10-DD01) into kimberlite. The following work has been completed on it:

- Three samples from this black-shale xenolith were sent for Rock-Eval 6 analysis. The analysis provided some reasonably reliable values of total organic carbon (TOC) and T_max (a parameter of thermal maturation for petroleum source rock), which could be an indication of potential petroleum source rocks in the Baffin Bay area, if the age of the sample was known.
- Two samples from this black-shale xenolith were sent for palynology and chitinozoan processing to obtain biostratigraphic data. Residue of abundant, blackish-brown, degraded organic debris was found, but no identifiable palynomorphs were observed (Sweet, 2011) and no chitinozoans were found (E. Asselin, pers. comm., 2011); therefore, the age of this xenolith remains unknown.
- In a further attempt to get an age for this black-shale xenolith, the sample has been sent to Tracer Isotope Lab at the University of Alberta for isotope dating. The results are pending.

Numerous xenoliths of dolostone or dolomitic-limestone breccia (Figure 4) were collected from four drillholes (CH1-258-11-DD07, CH1-258-11-DD08, CH1-050-11-DD16, CH1-050-11-DD19) into kimberlite. This rock type does not outcrop on southwestern Baffin Island (McCraeken, 2000; Zhang, 2012). This kind of dolostone and dolomitic limestone breccia was first reported from the Upper Ordovician Red Head Rapids Formation on Southampton Island (Zhang, 2008) and was interpreted as hydrothermal dolomite, which can be a significant conventional reservoir for oil and gas (Lavoie et al., 2011).

The petroleum system in the nearby Baffin Bay area is poorly understood. The xenoliths of black shale, and dolostone or dolomitic-limestone breccia discovered in the Chidliak kimberlite province are valuable in understanding the Paleozoic source rock and reservoir rock in the area.

Table 1. Summary of sedimentary xenolith samples from Chidliak-Qilaq kimberlites, Hall Peninsula, southern Baffin Island.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (m)</th>
<th>No. of samples</th>
<th>Basic lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH1-050-11-DD16</td>
<td>80.1-88.6</td>
<td>3</td>
<td>Black shale</td>
</tr>
<tr>
<td>CH1-050-11-DD19</td>
<td>79.25-80.12</td>
<td>1</td>
<td>Carbonate rocks</td>
</tr>
<tr>
<td>CH1-101-11-DD02</td>
<td>13.5-68.07</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>CH1-101-11-DD03</td>
<td>32.38-37.03</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>CH1-101-11-DD04</td>
<td>35-52.47</td>
<td>4</td>
<td></td>
</tr>
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<td>CH1-166-11-DD02</td>
<td>68.5-68.9</td>
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<td></td>
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<td>CH1-192-11-DD01</td>
<td>102.2-165</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>CH1-251-10-DD05</td>
<td>120.66-120.86</td>
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<td></td>
</tr>
<tr>
<td>CH1-251-11-DD08</td>
<td>146.75-148.2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CH1-251-11-DD14</td>
<td>38.4-219</td>
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<td></td>
</tr>
<tr>
<td>CH1-258-11-DD05</td>
<td>58.1-104.9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>CH1-258-11-DD06</td>
<td>63.9-118.1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>CH1-258-11-DD07</td>
<td>11.2-41</td>
<td>2</td>
<td></td>
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<tr>
<td>CH1-258-11-DD08</td>
<td>11-94.3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>CH1-400-11-DD01</td>
<td>39.8-144.4</td>
<td>4</td>
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</tr>
<tr>
<td>CH1-452-10-DD01</td>
<td>13.84-407</td>
<td>46</td>
<td></td>
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<tr>
<td>CH1-488-11-DD02</td>
<td>128.95-151.05</td>
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<td></td>
</tr>
<tr>
<td>CH1-554-11-DD01</td>
<td>84.2-152.35</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>CH1-557-11-DD02</td>
<td>77.8-181.4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>CH1-482-10-DD01</td>
<td>295.5-305.5</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Economic or applied considerations

The Paleozoic xenoliths in the Chidliak kimberlite pipes provide evidence that will help in understanding these kimberlites and their emplacement processes. The estimate of the thickness of eroded strata (165–300 m) is a minimum estimate of the postemplacement erosion in the area, which is consistent with having the uppermost parts of the craters removed but does not suggest that the pipes were deeply eroded. The presence of large kimberlites in this area is therefore possible. The conodonts recovered from xenoliths in the kimberlites have a wide CAI range of 1.5 to 8, which corresponds to temperatures ranging from 50°C to more than 600°C. Understanding the temperatures to which the sedimentary xenoliths were heated provides an independent estimate for the minimum temperature of emplacement of the various types of pipe infill, which will further the understanding of emplacement processes.

In addition to the significance of Paleozoic xenoliths and microfossil conodonts in the Chidliak kimberlite study, the xenoliths of black shale, and dolostone or dolomitic-limestone breccia discovered in the kimberlite pipes provide rare information that will help in understanding the potential Paleozoic petroleum source rock and reservoir rocks in the nearby Baffin Bay area.

Acknowledgments

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Natural Resources Canada, Earth Science Sector contribution 20120335

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Zhang, S. 2011: Late Ordovician conodont biostratigraphy and re-definition of the age of oil shale intervals on Southampton Island; Canadian Journal of Earth Sciences, v. 48, p. 619–643. doi:10.1139/E10-089


Figure 4: A) and B) Xenoliths of dolostone or dolomite-limestone breccia from drillholes Ch1-050-11-DD16 and CH1-258-11-DD08, respectively. C) Enlargement of red rectangle in (A).