KECK GEOLOGY CONSORTIUM

PROCEEDINGS OF THE TWENTY-SECOND ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

April 2009
Franklin & Marshall College, Lancaster PA.

Dr. Andrew P. de Wet, Editor
Keck Geology Consortium Director
Franklin & Marshall College

Dr. Stan Mertzman
Symposium Convenor
Franklin & Marshall College

Kelly Erb
Keck Consortium Administrative Assistant

Diane Kadyk
Academic Department Coordinator
Department of Earth & Environment
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster PA 17604-3003
717 291-4132 keckgeology.org

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2008-2009 PROJECTS

THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS (GRENVILLE PROVINCE, NEW YORK)

Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University
Students*: JOE CATALANO*: Union College; *ISIS FUKAI*: Oberlin College*; STEVEN HOCHMAN*: Pomona College; *JOSHUA T. MAURER*: Mt Union College*; ROBERT NOWAK*: The College of Wooster*; SEAN REGAN*: St. Lawrence University*; ASHLEY RUSSELL*: University of North Dakota; *ANDREW G. STOCKER*: Claremont McKenna College; *CELINA N. WILL*: Mount Holyoke College

PALEOECOLOGY & PALEOENVIRONMENT OF EARLY TERTIARY ALASKAN FORESTS, MATANUSKA VALLEY, AL.

Faculty: *DAVID SUNDERLIN*: Lafayette College, *CHRISTOPHER J. WILLIAMS*: Franklin & Marshall College
Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

SEAFLOOR VOLCANIC AND HYDROTHERMAL PROCESSES PRESERVED IN THE ABITIBI GREENSTONE BELT OF ONTARIO AND QUEBEC, CANADA

Faculty: *LISA A. GILBERT,* Williams College and Williams-Mystic and NEIL R. BANERJEE, U. of Western Ontario
Students: *LAUREN D. ANDERSON*: Lehigh University; *STEFANIE GUGOLZ*: Beloit College; *HENRY E. KERNAN*: Williams College; *ADRIENNE LOVE*: Trinity University; *LISA SMITH:* Amherst College; *KAREN TEKVERK*: Haverford College

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, CO

Faculty: *DAVID P. DETHIER*: Williams College and *MATTHIAS LEOPOLD*: Technical University of Munich
Students: *EVEY GANNAWAY*: The U. of the South; *KENNETH NELSON*: Macalester College; *MIGUEL RODRIGUEZ*: Colgate University

GEOARCHAEOLOGY OF THE PODERE FUNGHI, MUGELLO VALLEY ARCHAEOLOGICAL PROJECT, ITALY

Faculty: *ROB STERNBERG*: Franklin & Marshall College and *SARA BON-HARPER*: Monticello Department of Archaeology
Students: *AVERY R. COTA*: Minnesota State University Moorhead; *JANE DIDALEUSKY*: Smith College; *ROWAN HILL*: Colorado College; *ANNA PENDLEY*: Washington and Lee University; *MAIJA SIPOLA*: Carleton College; *STACEY SOSENKO*: Franklin and Marshall College

GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI

Faculty: *NICHOLAS E. BADER and ROBERT J. CARSON*: Whitman College; *A. BAYASGALAN*: Mongolian University of Science and Technology; *KURT L. FRANKEL*: Georgia Institute of Technology; *KARL W. WEGMANN*: North Carolina State University
Students: *ELIZABETH BROWN*: Occidental College; *GIA MATZINGER, ANDREA SEYMOUR, RYAN J. LEARY*, *KELLY DUNDON* and *CHELSEA C. DURFEY*: Whitman College; *BRITTANY GAUDETTE*: Mount Holyoke College; *KATHRYN LADIG*: Gustavus Adolphus College; *GREG MORTKA*: Lehigh U.; *JODI SPRAJCAR*: The College of Wooster; *KRISTIN E. SWEENEY*: Carleton College.

BLOCK ISLAND, RI: A MICROCOSM FOR THE STUDY OF ANTHROPOGENIC & NATURAL ENVIRONMENTAL CHANGE

Faculty: *JOHAN C. VAREKAMP*: Wesleyan University and *ELLEN THOMAS*: Yale University & Wesleyan University
Students: *ALANA BARTOLAI*: Macalester College; *EMMA KRAVET and CONOR VEENEMAN*: Wesleyan University; *RACHEL NEURATH*: Smith College; *JESSICA SCHEICK*: Bryn Mawr College; *DAVID JAKIM*: SUNY.

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Keck Geology Consortium: Projects 2008-2009
Short Contributions – CANADA

SEAFLOOR VOLCANIC AND HYDROTHERMAL PROCESSES PRESERVED IN THE ABITIBI GREENSTONE BELT OF ONTARIO AND QUEBEC, CANADA

Project Director: ***LISA A. GILBERT*,** Williams College and Williams-Mystic
Project Faculty: ***NEIL R. BANERJEE***, University of Western Ontario

GEOCHEMICAL INVESTIGATION OF HYDROTHERMALLY ALTERED MAFIC VOLCANIC FLOWS FROM THE 2.7 GA ABITIBI GREENSTONE BELT, ONTARIO AND QUÉBEC, CANADA

***LAUREN D. ANDERSON*:** Lehigh University
Research Advisor: Gray E. Bebout

INTERPILLOW HYALOCLASTITES, PILLOW RIM ALTERATION, AND FLUID FLOW IN MAFIC VOLCANICS OF THE BLAKE RIVER GROUP, ROUYN-NORANDA, QUÉBEC

***STEFANIE GUGOLZ*: Beloit College**
Research Advisor: Jim Rougvie

FLUID INDUCED MINERALOGY IN A SERIES OF MAFIC EXTRUSIVES OF THE ABITIBI GREENSTONE BELT, ROUYN-NORANDA, QUEBEC

HENRY E. KERNAN: Williams College
Research Advisors: Reinhard A. Wobus and Lisa A. Gilbert

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***ADRIENNE LOVE*:** Trinity University
Research Advisors: Benjamin Surpless and Lara Heister

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***LISA M. SMITH*:** Amherst College
Research Advisors: Peter D. Crowley: Amherst College and Lisa A. Gilbert: Maritime Studies Program of Williams College and Mystic Seaport

MINERALOGY AND METASOMATISM OF THE ROUYN-NORANDA HYALOCLASTITES IN THE ABITIBI GREENSTONE BELT

KAREN TEKVERK: Haverford College
Research Advisor: Chris Oze, Bryn Mawr College

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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STEFANIE GUGOLZ: Beloit College
Research Advisor: Jim Rougvie

INTRODUCTION

Understanding hydrothermal fluid flow and alteration in pillow basalts is important in understanding such diverse subjects as ore deposits and early biological life in hydrothermal systems. In this study a number of methods are employed in order to describe and characterize hydrothermal alteration and fluid flow through the pillow and interpillow zones of Archean mafic volcanics of the Blake River Group (BRG) of the Abitibi Greenstone Belt (AGB), specifically within the town of Rouyn-Noranda, Quebec. The AGB and Rouyn-Noranda, in particular, are host to economically important volcanogenic massive sulfide deposits (e.g., Hannington et al., 2002), and recently microbial trace fossils have been found in samples from the BRG (Bridge at al., 2007). In order to further understand these environments, the alteration history and porosity of these rocks must be studied.

Pillowed lava flows have several components. Pillows are mantled by a glassy rind (from quenching of the pillow during extrusion) that may act differently as a fluid pathway from the coarser pillow core. The space between pillows is called the interpillow hyaloclastite zone (IPH) and is made up of broken off bits of glassy pillow rinds and other volcanic detritus. Pillow rinds and IPH are likely the primary fluid pathways, rather than through the less permeable pillows (Gillis and Sapp, 1997).

Pillow morphology, characterized by pillow size and shape (aspect ratio), and interpillow hyaloclastite (IPH) amount and distribution, may have an impact on the way hydrothermal fluids move through pillowed flows and may also influence patterns of alteration. This paper seeks to describe pillow morphology, constrain initial intrapillow porosity, and characterize the alteration effects on the different components of the pillowed flows in the BRG.

GEOLOGIC SETTING

As summarized in Mueller et al. (2007), the 2.7 Ga AGB is generally divided into two subdivisions: a lower tholeiitic sequence, and the BRG upper sequence of tholeiitic and calc-alkaline rocks, that is the focus of this study. The BRG, which lies in the southern section of the belt, is a 10 km thick mega-nested caldera complex comprised of three calderas. It is the youngest volcano-pluton group of the Abitibi (Mueller et al., 2007).

The New Senator Caldera, in the middle of the BRG, was formed between 2703 and 2700 Ma (Pearson, 2005). In the caldera is a succession of mafic and lesser felsic volcanics. Hydrothermal fluids, driven by a multitude of intrusive events, have altered tens of kilometers of rock in the area (Cathles, 1993). The boundaries and faults between the New Senator Caldera and the later Noranda Caldera provided the primary fluid flow pathways. The rocks contain greenschist facies mineral assemblages, and spilitization (albite-chlorite alteration), chloritization, epidote-quartz alteration, and silicification are the most abundant types of alteration found (Hannington et al., 2002). Volcanic massive sulfide (VMS) deposits are mined extensively throughout the BRG.

This study focuses on two localities in Rouyn-Noranda, just south of the Horne Creek Fault in the New Senator Caldera, Air Liquide (AL) and John Deere (JD) (see map, Gilbert and Banerjee, this volume). AL is an area of outcrops in town. The

JD locality is approximately 360 m northwest and is stratigraphically higher. The stratigraphy is a succession of mafic massive, pillowed, and hyaloclastite flows. At both localities, flows are tilted vertically with N up directions; JD is on the lower limb of an open z-shaped fold.

METHODS

Field

Six different pillow areas from AL were mapped and analyzed. At JD, three areas were studied along a 23 m transect across a pillowed flow, parallel to paleovertical. The areas chosen were at 2 m, 6 m, and 22 m along the transect. Paleohorizontal (H) and paleovertical (V) dimensions of pillows were measured based upon the strike of amygdules. At 15 cm intervals, the thickness of the IPH, the glassy rind, and an orange differential weathering halo were measured, perpendicular to the edge of the pillow, to find the average of each (Fig. 1b). The weathering halos are thought to be related to grain size.

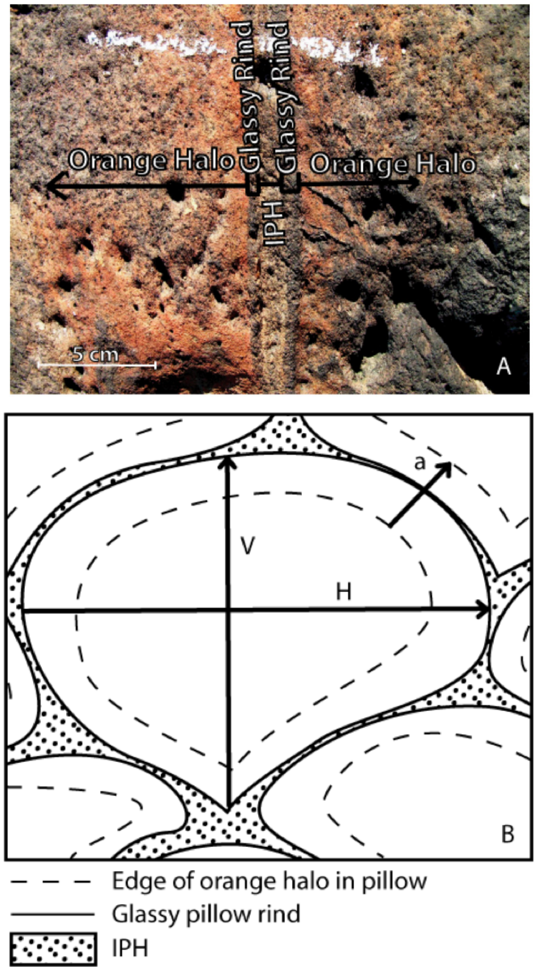

Figure 1: a) Photograph of pillow rim with glassy rind, IPH and orange halo. b) Pictorial representation of measurements of pillows. The thickness of the halo, the IPH, and the rind were measured. The arrow marked "a" represents where these were measured in 15 cm intervals. The size and shape of the pillows are determined with horizontal (H) and vertical (V) measurements.

Six one-meter by two-meter boxes were mapped around these pillows. These were photographed and printed, and the IPH zones were traced onto transparencies and digitized. Leica LAS and ImageJ software was used to calculate the percentage of IPH and glassy rind per box to provide a measure of the porosity of each pillow outcrop (e.g., Gillis and Sapp, 1997). Drill samples of pillow rims and cores were taken from the mapped areas.

Lab

In the Williams-Mystic Marine Geosciences lab physical properties measurements for specific gravity, velocity, density, and porosity were performed on all samples. Compressional wave velocity was measured at ambient pressure on 1" and 2" leveled cores using a 200 MHz GCTS velocity meter. Volume was measured with a Quantichrome Helium penta pycnometer, and mass and specific gravity were determined using a Denver Instruments M-220D balance. Thin sections were studied petrographically and with Scanning Electron Microscopy (SEM). Modal compositions of representative samples were determined through point counting (n > 200 points) with SEM.

RESULTS

Pillow Morphology

Horizontal and vertical dimensions of pillows varied dramatically (Fig. 2a) with the horizontal ranging from 3 to 370 cm (mean = 71 cm) and the vertical from 3 to 125 cm (mean = 31 cm). Aspect ratios also varied greatly (0.14 to 2.9 cm, mean = 0.67), where 1 is "spherical", aspect ratios < 1 are horizontally elongate, and aspect ratios > 1 are vertically elongate (Fig. 2b). Pillows at AL almost always had aspect ratios < 1, but at JD, about half the pillows

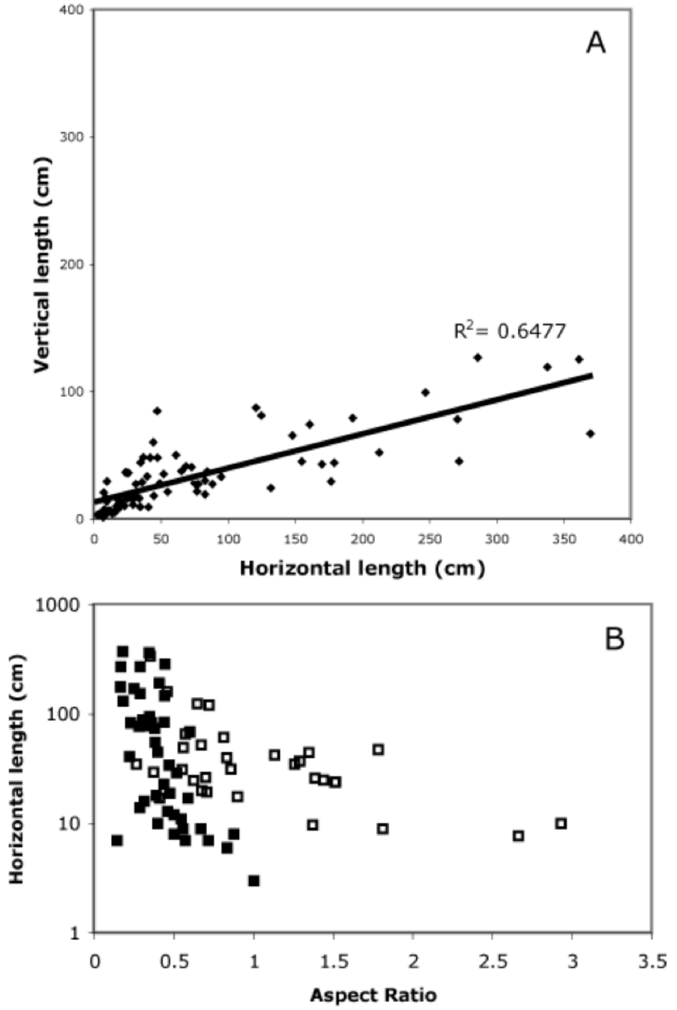

Figure 2: a) Plot of pillows' vertical versus horizontal dimensions. b) Plot of pillow aspect ratio versus horizontal dimension. The solid symbols are AL and open symbols are JD.

had aspect ratios > 1, with no noticeable trend along the transect.

Air Liquide pillows in general had thicker weathering halos, ranging from 1 to 4 cm (mean = 2), whereas John Deere had little to no visible halos ranging from 0 to 2 cm, (mean = 0.6). However, halos that did occur at JD grew wider and more abundant towards the top of the transect, the stratigraphic top of the flow.

The percentage of IPH in each mapped box section was variable from 0.3% to 17%. JD areas had more IPH than the AL (compare AL mean = 5% and JD mean = 12%). Percent glassy rind in each section varied from 2%-4% (mean = 3%). There is no systematic change in percent IPH or rind along the JD transect. There is a weak correlation between glassy rind thickness and the size of the pillow (2D area calculated as an ellipse, using the H and V dimensions).

On average, rim samples had a lower lab-measured bulk density and more porosity than core samples. Rim bulk density ranged from 2.56 – 3.31 g/cc (mean = 2.81), while the range for cores was 2.57– 2.66 g/cc (mean = 2.61). Porosity of rims ranged from 0.2% - 2.7% (mean = 0.7%), and rims ranged from 0.2% - 0.4% (mean = 0.3%). There is no systematic difference between these values from AL and JD.

Petrography

Pillow cores and rims are both extremely fine-grained. The most abundant minerals are epidote, albite, chlorite, quartz, and locally calcite. Pillow rims have recognizable mineralogical and textural differences from their respective cores. A few samples (both from rims and cores) contain large aggregates of anhedral calcite crystals (up to 1.5 mm). They appear to be filling vesicles or replacing igneous phenocrysts. Rim samples contain more sulfides (mostly pyrite) than cores. Rim samples often contain coarse-grained quartz, calcite, and chlorite veinlets. Locally quartz and chlorite veinlets cut epidote. In the JD samples, the matrix is composed of anhedral albite and quartz with multitudes of tiny (≤ 10 μm long), euhedral chlorite crystals.

In a comparison of glassy rind, the adjacent crystalline pillow rim, and the core of a pillow from AL, there is a decrease in abundance of epidote and chlorite from rind to crystalline rim to core (Fig. 3). Titanite is most abundant in the rind, but is not enriched in the crystalline rim with respect to the pillow core. Albite abundance increases from rind to rim to core. The core contains a substantial amount of muscovite (16%), whereas the rind and pillow rim do not. These trends are typical of AL samples (Fig. 4). All AL cores contain > 4% muscovite, whereas the rims contain none, and all samples contain > 10% quartz. Minor pyrite, zircon, and apatite are

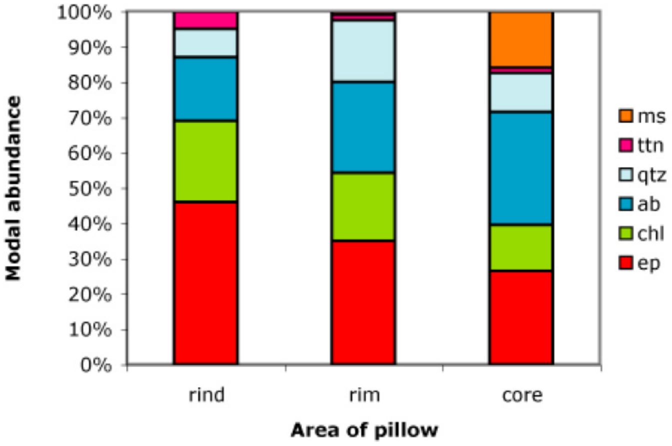

Figure 3: Modal compositions of a glassy rind, outer crystalline rim (next to the glassy rind), and inner crystalline core from AL. "Rim" refers to the crystalline outer rim of the pillow just inside the glassy rim. In the legend, ep = epidote, chl = chlorite, ab = albite, qtz = quartz, ttn = titanite, ms = muscovite.

present. JD samples contain markedly less epidote and it is found only in pillow cores. There is also a greater abundance of calcite and zeolite in the JD samples (Fig 4).

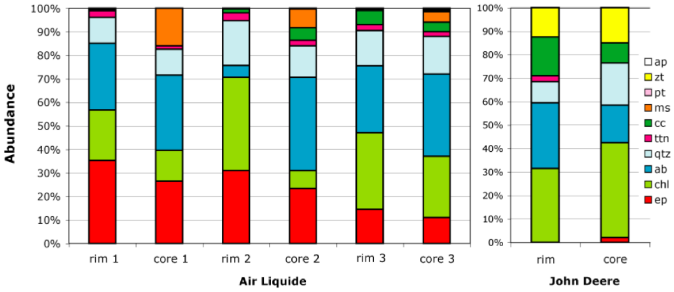

Figure 4: Modal compositions of rim and core samples of pillows. Each pair is from one pillow: a rim sample and then a core sample. In the legend, ep = epidote, chl = chlorite, ab = albite, qtz = quartz, ttn = titanite, ms = muscovite, cc = calcite, pt = pyrite, zt = zeolite, and ap = apatite.

Geochemistry

Whole rock major and trace element analyses (Kernan, this volume) from AL document differences between hyaloclastite, pillow rims and pillow cores. SiO_2, K_2O, and Na_2O decreases from pillow center to pillow rim to hyaloclastite, and FeO increases from pillow center (7%) to pillow rim (9%) to hyaloclastite (13%). CaO also increases from core to rim. MgO is locally enriched in rims compared to cores. Among trace elements Ba and Rb decrease from core to rim to Hyaloclastite. Rims are also enriched in trace elements Ni, Cu, and V.

DISCUSSION AND CONCLUSION

This study characterizes porosity, pillow morphology and alteration features. The percentage of IPH in each mapped box section was variable from 0.3% to 17% (JD sections were higher). This range is comparable to what Gillis and Sapp (1997) found in the Troodos Ophiolite. They also estimated that initial porosity within the IPH was 22 to 55 %. Based on % IPH and glassy rind from this study, IPH porosities from Gillis and Sapp (1997), vesicle porosity of average 5% (Smith, this volume), total initial macroporosity of a pillowed flow will be comparable to those determined for the Troodos Ophiolite (6 to 17 %; Gillis and Sapp, 1997). This does not include fracture porosity, which is present but has not been quantified.

This study documents alteration of hyaloclastite and pillow rims at AL and JD based on mineralogy, geochemistry and physical properties. Hydrothermal alteration is most intense in IPH zones, and decreases as it moves into the less porous parts of pillows, from the glassy rind inwards. The pillows at AL have experienced chlorite and epidote enrichment and albite depletion at the rim, consistent with the findings of Baragar et al. (1979) who compared in great detail the mineralogy of an altered Archean pillow to a modern one. Many of the rim samples are over 30% epidote (Fig. 4) which implies alteration by Ca-rich seawater (Hannington et al., 2002). In the BRG, titanite and local calcite are products of low temperature alteration (Hannington et al., 2002). Unless JD pillows initially contained compositional differences from AL, the two have experienced significant differences in alteration despite the fact that they are less than 400 meters apart, suggesting that hydrothermal fluids can vary greatly across relatively short distances.

When pillows are extruded they mostly form shapes between horizontally elongate and spherical (aspect ratio ≤1). Deformation of the ocean crust is usually responsible for vertically elongate (aspect ratio >1) pillows (Walker, 1991). The dimensions found at AL and JD are comparable to those of Walker who studied 19 pillow lavas from a variety of settings. Figure 1b shows variation of aspect ratio and pillow size for the pillows of AL and JD. Since so many of the JD pillows have aspect ratios higher than 1, it can be surmised that the JD pillows have experienced more deformation than the AL pillows. The present morphology of JD pillows may not be representative of morphologies when fluid flow was active. JD pillows also have complex rather than typical pillow shapes (ie. Fig. 1b), which commonly indicates deformation.

There is a correlation between pillow size and the thickness of the orange weathering halo inside the pillow. Presumably this is because larger pillows take a longer time to cool and therefore the grain size gets larger more gradually towards the inside of the pillow than in small pillows. Rim samples are finer-grained than core samples. Although pillow rims are more altered than cores, it is unknown whether the width of the orange halo corresponds to any alteration front. No samples were taken at the inside edge of the halo where it met the grey part of the pillow.

Glass in hyaloclastite and pillow lava rinds are where microbial trace fossils have been found in the Abitibi (Bridge et al., 2007; Anderson, this volume). Pillowed flows provide a significant amount of glass in which microbes may live, making them prime spots to look for such trace fossils.

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