KECK GEOLOGY CONSORTIUM

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

April 2009
Franklin & Marshall College, Lancaster PA.

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2008-2009 PROJECTS

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Faculty: *WILLIAM H. PECK*, *BRUCE W. SELLECK* and *MARTIN S. WONG*: Colgate University
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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

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GEOLOGY OF THE HÖH SERH RANGE, MONGOLIAN ALTAI
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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

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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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INTRODUCTION

A variety of eruptive morphologies, including pillowed, massive, and hyaloclastite flows occur in the submarine volcanic rocks of the Blake River Group in Rouyn-Noranda, Quebec. Among all these styles of eruption, differing styles of vesiculation can be observed. This study examines the vesicle distributions in individual pillow basalts and massive flows within this suite of rocks from three relatively small sites. The three sites examined here cross a syncline (see Tekverk, this volume) – with the Snoopy site on the western limb (with an average 095 strike and S facing-direction), the Air Liquide site on the eastern limb (with an average 078 strike and N facing-direction), and the John Deere site on the eastern limb, but nearer the hinge surface of the fold than the Air Liquide site (with a highly variable strike and N to NE facing-direction).

Eighteen 1-4 m^2 areas of pillows at the Air Liquide, John Deere, and Snoopy sites were examined in detail, with vesicle sizes and densities measured in 3 to 17 1 cm^2 regions on each individual pillow. Twenty thin-sections were taken from various sites (11 from the Air Liquide locality and 9 from the John Deere locality); although three of the thin-sections were prepared from samples taken from unmapped areas, most (9) of the thin-sections were prepared from samples taken just beneath specific points where vesicles were measure in the field. Some thin-sections can, therefore, be well correlated to some field observations.

Vesicle size, distribution, and orientation were determined to investigate patterns of deformation and vesicle formation within pillow basalts. Previous studies done by Sahagian (1985) and Sahagian et al. (2002) of massive flows, compared with this study, help to document the differences of vesiculation between massive and pillowed flows. Patterns of vesicularity might also act as facing indicators (structures in the rock that show a distinct, original up-direction), as they do in massive flows, by showing an increase in average vesicularity towards either the top or the bottom of the pillow basalt (Sahagian, 1985). A secondary goal of this project was to compare field and thin-section observations to see the effects of weathering on the pillow basalts, and determine if weathering significantly increases the apparent amount of vesicularity (as opposed to the original amount of vesicularity) shown in the field or not.

FIELD OBSERVATIONS

Rectangular areas of 1-4 m^2 of pillow basalts were mapped in detail (see Fig. 1 for example). Measurements of both pillows and the surface vesicles therein, which appear in the field as open porosity, consist of horizontal (H) and vertical (V) lengths (H was measured along paleohorizontal; V was measured perpendicular to H). Vesicles were sorted into size classes on the basis of the horizontal length (<0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-1.0, or >1.0 mm).

Pillow basalts, hyaloclastites, and massive flows are present at all three sites. Occasional hydrothermal zones, areas of increased alteration due to apparent primary or secondary hydrothermal flow, can be observed. Spherical to ellipsoidal open pores interpreted to be vesicles are present on the surface of each of these basalt morphologies, with vesicles at the Air Liquide site distinctly more abundant and

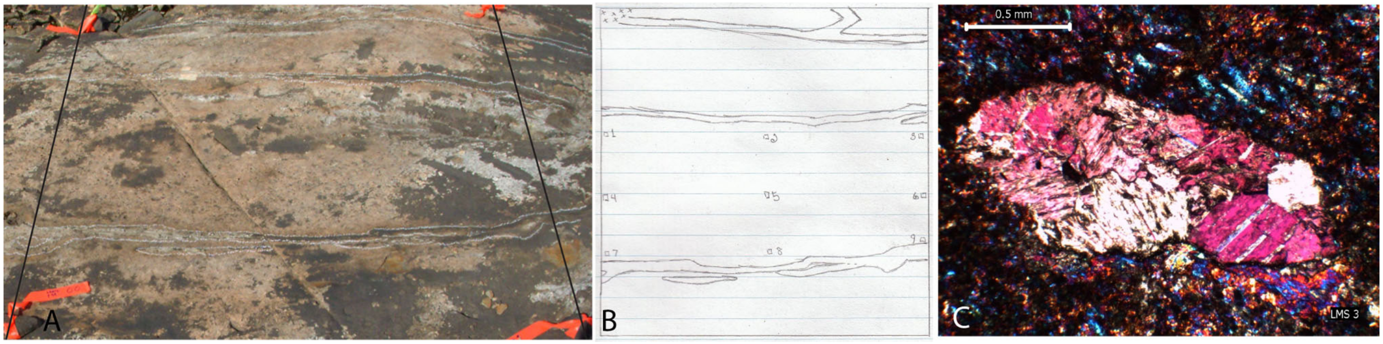

Figure 1. 1A: A photograph of a 1 m^2 section of an Air Liquide site in the field. White lines drawn with chalk can be seen identifying the rim of one pillow as well as an interior drainback feature. The photograph is oriented so that up is both North and facing-direction for the pillow basalts. 1B: The same outcrop as mapped in field notes. 1C: A photomicrograph of a calcite-filled vesicle with slightly rounded edges within a matrix of mafic minerals under cross-polarized light and the gypsum plate, oriented so that up is North. The gypsum plate was used for all vesicle identification in thin-section, because it allows the vesicles to be seen more clearly.

larger than those at either the John Deere or the Snoopy sites. Pillow basalts at John Deere have 2.1% vesicles by area compared to 9.4 % at Air Liquide. Mapped vesicles at John Deere are up to 6.0 mm in diameter with vesicles >12.0 mm observed at the Air Liquide site.

Flows tend to dip steeply (on average, 85S at Air Liquide, 51NE at John Deere, and 67S at Snoopy). Pillows are visibly flattened N-S with the flattening more apparent at the Air Liquide site than at the John Deere site. The average aspect ratio (H/V) for individual pillows in this study is 3.8 for Air Liquide and 1.4 at John Deere. That is, pillows are more horizontally elongate at Air Liquide (also see Gugolz, this volume). Deformation affected vesicle shape as well, transforming the vesicles into ellipsoids that are commonly elongate subparallel to paleohorizontal. This is particularly true at the Air Liquide site. Vesicles at the John Deere site commonly appeared undeformed. Vesicle orientation at the Snoopy site, on the opposite limb of the fold, is more chaotic with vesicles elongated at many angles to paleohorizontal; pillows at this site also showed complex deformation. Most vesicles are elongate parallel to paleohorizontal; vesicles that are elongate at a high angle to paleohorizontal occur more often at Snoopy than at either John Deere or Air Liquide. When these types of vesicles do occur at John Deere or Air Liquide, they are most abundant in zones near the brecciated tops of pillowed flows, where overlain by massive flows.

Vesicle density varies across individual pillows. Field observations show that many pillows exhibit a characteristic vesicle pattern with a near radial symmetry and a high density of vesicles in the center of the pillow. This is surrounded by a region of decreased vesicle density, which is surrounded by a ring ~10 cm away from the pillow rim of high vesicle density and a vesicle-poor chill margin. Figure 2 shows a drawing of the idealized form of a pillow according to these patterns found in the field. There are higher concentrations of vesicles (in decreasing order of how often these densities were exemplified by vesicle counts) found in the middle of a pillow, around the outside edges (beginning ~10 cm away from the outer rim), around drainback features (especially above and below), at buds, in pinched corners of highly strained pillows, and at the bases of pillows. Although most pillow shapes in the field are highly variable and not likely to resemble the "ideal" pillow, the vesicle density patterns in the pillow are likely to do so (see Fig. 2). These observations are shown in Figure 2 in contrast with a graph taken from Sahagian (1985) of his findings on the vesicle density patterns within massive flows.

The density of vesicles is often higher near the base of a pillow than near the top. Vesicles also are smaller at the tops of pillows and/or pillowed flows than at the bottoms (see Fig. 3). The vesicle density

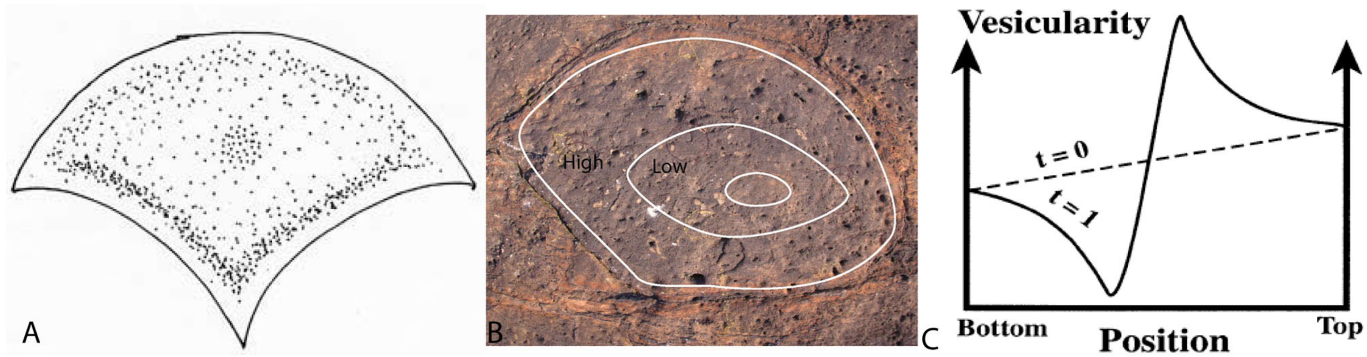

Figure 2. 2A: A drawing of the idealized version of a regular pillow (without a drainback feature or budding) following the patterns found by this study. Density of dots represents density of vesicles. 2B: A photograph of a pillow (from Air Liquide study site 18W-21N) with vesicle density zones marked. 2C: A graph taken from Sahagian, 1985: the typical vesicularity profile from the bottom to the top of a 3-m flow, which shows a vertical change in vesicularity as opposed to a concentric one (as occurs in the pillow basalts of this study). The vertical changes show a high vesicle density at the bottom, an area of decreased vesicle density, a spike in vesicularity and then a slow decrease from that point to the top of the flow.

and area are directly related; for example, the top of one pillowed flow at site 0E-93N has 0.5% vesicles, the vesicles have a cross-sectional area of 0.005 mm^2, and the pillows have an average area of 0.15 m^2, while the bottom of the same flow at site 18W-21N has 11% vesicles, the vesicles have an area of 0.1 mm^2, and the pillows have an average area of 0.45 m^2.

These field observations may be skewed towards larger pillows (H>0.5 m), because measurements were only made where pillows can be easily seen.

THIN-SECTION OBSERVATIONS

Thin-sections were cut from twenty samples chosen to cover a range of different locations in pillow forms (the center, ~10 cm from edge, just above

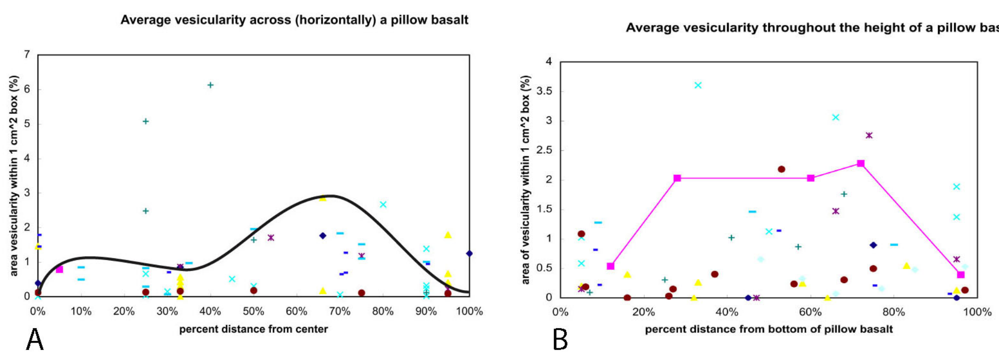

Figure 3. 3A: Vesicle density varies horizontally through pillow basalts in this study (graph shows variations starting from the center of a pillow basalt – 0% represents no distance from center – and moving outwards – 100% is the full distance away from the center), starting from a slightly high vesicularity just outside of the center of the pillow basalt, a decrease in vesicularity, and then a strong increase nearer to the edges, with a vesicle poor chill margin. 3B: Vesicle density also varies vertically through pillow basalts in this study (graph shows variations starting from the base of the pillow – 0% – and moving up – 100% represents the top of the pillow). Pillows show slightly variable patterns. One specific set of measurements from a single pillow was outlined. This pattern shows an increase in vesicularity just above the chill margin at the base of the pillow, a continued (or decreased, in the case of other pillows) amount of vesicularity, and then a secondary increase just below the chill margin on the top of the pillow. Some pillows also show a slight increase in vesicularity towards the middle of the pillow and a slight decrease just above and below. In both graphs, all anomalously large vesicle density counts (>10%) were omitted for clarity. Also, both graphs take only a select number of vesicle counts into account, so although these graphs are relatively representative of the vesicle densities throughout pillow basalts in this study, they are not entirely representative. For instance, the graph on the right does not show a higher vesicularity at the bottom of the pillow than the top, which is a pattern observed when all vesicle measurements are taken into account.

drainback feature, etc.) as well as sections along entire pillowed flows (a "pillowed flow" defined here as a section of pillow basalts bounded by massive and/or hyaloclastite flows both above and below). Vesicle size was measured optically, and vesicle density was calculated for each thin-section. Individual measurements were made for each vesicle instead of the size ranges created for field work.

Although now composed of a greenschist facies chlorite-actinolite-clinozoisite assemblage, pseudomorphs after both plagioclase and pyroxene are common. Vesicles, 0.01 to 15.0 mm in diameter, are commonly filled with calcite (and occasionally unfilled and shown as open porosity). See Figure 1 for a photomicrograph of a calcite-filled vesicle. Occasional depositional zoning of calcite can be observed within the vesicles. Weiershauser & Spooner (2005) note that this shows a primary original porosity of the vesicles.

The calcite has a distinctly different texture than the surrounding mineral matrix. Numerous separate calcite crystals can be observed in each vesicle. They occur in distinct clusters of crystals (the clusters of calcite crystals are much larger than any other groups of minerals which might also be referred to as "clusters" in these thin-sections). The vesicle walls occasionally have a curvature as might befit a relict of a bubble, but are also often composed of quasi-planar surfaces defined by either mineral shapes outside of the vesicle or calcite grains inside of the vesicle (curvature is often simply a matter of resolution – what looks curved in hand sample or even at four times magnification no longer looks curved at ten times magnification). Vesicles in the Ben Nevis region to the west of this study (Weiershauser & Spooner, 2005) are filled with silica and, in contrast to the vesicles in this study, which commonly show very complex shapes, have either rounded or simple rectangular shapes.

In three of the twenty thin-sections, some vesicles occur as open pores. One of these occurrences is in a hydrothermal zone, and another is at the brecciated top of a pillowed flow. All three samples that preserve open porosity were collected from regions of low vesicular density in the field. Figure 4 shows the average densities of vesicles in field observations and in thin-section counts at John Deere and at Air Liquide as well as overall vesicle counts, comparing field observations to thin-section counts.

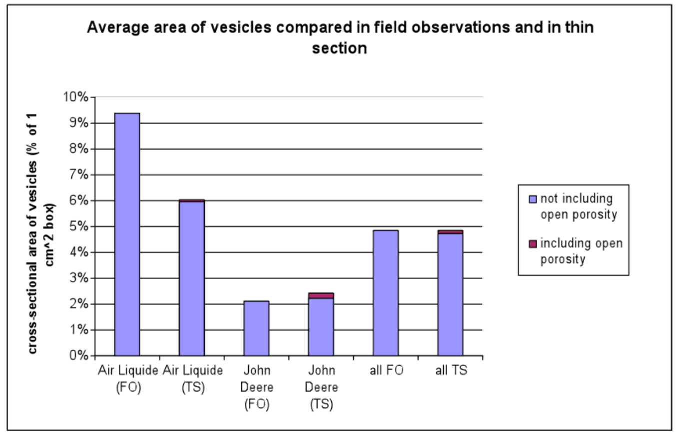

Figure 4. The overall vesicle measurements were not drastically different in most places when compared between field observations and thin-section measurements. (FO=field observations; TS=thin-sections; OP=open porosity)

The measurement of vesicle density in thin-section show that thin-sections from the John Deere locality have 2.4% vesicles, of which 0.2% is open porosity. Thin-sections from the Air Liquide locality have 6.0% vesicles with less than 0.1% open porosity. The average cross-sectional area of vesicles in these samples is 0.14 mm^2 at John Deere and 1.22 mm^2 at Air Liquide. This calculation of average size of vesicles was only done for thin-sections.

DISCUSSION

Vesicle density

Vesicle density determined by both methods – field counting and thin-section measurements – is surprisingly similar. At John Deere, both methods yielded about 2% vesicle porosity; at Air Liquide, thin-section measurements were slightly lower: 6% compared to 9% measured in the field, but this variability may be explained by slightly different locations of measurements. The overall average density of vesiculation from thin-section measurements is 4.8% (0.1% by area of which occurs as open porosity), which is the same as overall average field observations show. Although what was seen as vesicularity was shown in the field as open porosity on the weathered rock surfaces and in thin-section as filled porosity from fresher surfaces, these observations show that the surface expression of open vesicles represents a similar area as filled vesicles in thin-section, which suggests that the distribution of porosity determined in the field probably entirely represents vesicle distribution rather than marks of weathering.

Vesicle distribution and coalescence

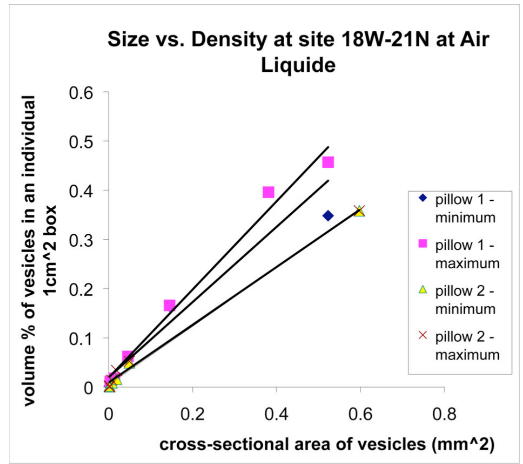

Figure 5. The average cross-sectional area of vesicles (in mm^2) increases as the percent by area of vesicles increases. Two separate pillows from a specific study area at the Air Liquide site are shown (since field observations were made with ranges of sizes, the minimum and maximum calculations for each pillow are shown here).

Figure 5 shows a correlation between average size and density of vesicles – as average vesicle size increases, so does average vesicle density. The average vesicle sizes vary by about an order of magnitude (0.14 mm^2 at John Deere and 1.22 mm^2 at Air Liquide) and the vesicle densities at Air Liquide are about three times greater than John Deere. Since John Deere is upsection of Air Liquide, and since a lower hydrostatic pressure is usually correlated to a larger amount of vesiculation, it is most probable that the basalts at John Deere were erupted at a time of higher water level stand than the basalts at Air Liquide. If this is the case, water level must have risen drastically between the times of eruption. Other possibilities include Air Liquide lavas simply having a higher volatile content or being more highly hydrothermally altered than John Deere lavas (since this study shows hydrothermally altered areas as having larger and more profuse vesicles).

One consistent vesicle distribution pattern shown in both field observations and in thin-section is the increase in vesicularity towards the edges of pillows (see Fig. 3, which shows an increase towards the edges of pillow basalts). Shin et al. (2005) state that the rim/crust of an erupting body of lava loses gas before it solidifies. The top of the pillow might therefore show a lower vesicularity, because much of the gas in the area has been lost to the surrounding medium (in this case, to seawater). Field observations and thin-sections from the tops of pillowed flows (which are usually at least mildly brecciated) show that these areas have high numbers of vesicles, but very low densities (as shown by an above example in Field Observations), meaning that the vesicles nucleated, but did not coalesce much if at all. This probably implies that the volcanic rocks in areas where this anomaly of high vesiculation at areas of brecciation is seen were erupted and cooled rather quickly so as not to allow bubbles to coalesce. Another possibility might be that the bubbles were too few and far between to come near enough to one another to coalesce.

Sahagian et al. (2002) address post-emplacement inflation in lava flows. The drainback features seen in this study are features in the rocks which might represent a "draining back" of lava, but which also might represent a point of inflation. If they are the latter, the process of inflation might explain the higher vesicularity found near the drain-back features since inflation would allow for a fresh influx of lava with a fresh influx of gases causing the formation of more vesicles.

The concentric pattern found here in pillow basalts is in stark contrast to the patterns of vesicularity shown in massive flows, which show a more linear vesiculation pattern with vesicles increasing up (Sahagian, 1985 and Sahagian et al., 2002).

VESICLES AS INDICATORS OF DEFORMATION

Although on the eastern limb of the fold, the Air Liquide site, the ellipticity of vesicles mirrors the aspect ratio of the flattened pillows to record deformation, vesicles at the Snoopy site on the opposite limb of the fold do not show the same distinct pattern. They are instead more chaotic: 43% of deformed vesicles have H>V, while the other 57% have V>H. In addition, the fact that vesicles are not, necessarily, originally round (as noted by Shin et al., 2005) might affect how deformation is shown by vesicle shapes. Vesicles shapes, therefore, may or may not illustrate deformation; data from this study are too incomplete to prove this one way or the other.

SUMMARY

Agreement between results from the two methods of measuring vesicle size and shape – field observations and thin-section measurements – suggest that weathering has not greatly affected the surface expression of vesicles in pillow basalts and massive flows throughout this area. Brecciated tops of pillowed flows, where they directly underlie massive flows, do not show the same reliable vesicle patterns as other portions of pillowed flows. The brecciated areas do not show any constancy in aspect ratios of vesicles, nor do they show the same vesicle density patterns usually seen in pillow basalts (and shown in Figure 2).

This study shows that distinct vesicle distribution patterns can be found within individual pillow basalts: a near radial symmetry and a high density of vesicles in the center of the pillow. This high density area is surrounded by a region of decreased vesicle density, a ring ~10 cm away from the pillow rim of high vesicle density and a vesicle-poor chill margin. Higher concentrations of vesicles occur in the middle of a pillow, around the outside edges (beginning ~10 cm away from the outer rim), around drainback features (especially above and below), at buds, in pinched corners of deformed pillows, and at the bottoms. It is the common assumption (Sahagian, 1985) that vesicularity increases towards the tops of pillow basalts and lava flows of all sorts. Vesicle density patterns are shown by this study to be different in pillow basalts. The concentric pattern in pillow basalts, if applicable to all pillow basalts, could serve to help workers identify whether a vesiculated area is pillowed or massive when contacts are difficult to see. Also, the variability in vesicle densities found here, compared to the assumed models, at least tempers the assumptions of vesicle density patterns.

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