Supplemental Information for

**Instruments and Methods: A case study of ice-core bubbles as strain indicators**

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Figures S1 – S10

**INTRODUCTION**

Included in this supporting/supplemental information are 10 additional figures related to this work (all references in the main text). In addition, results from statistical testing related to the data plotted Fig. 7 are included, as well as the link to the complete data set referenced in the main text and figures therein.

**DATA POLICY**

The complete set of data used in this manuscript and supporting information is available via download from USAP-DC (<https://doi.org/10.15784/601087>; Fegyveresi, 2018) or through request of the corresponding author.

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| FigB-2.pdf |
| **Figure**S1: Thick-section of ice sample *VHS-580*, shown here thinned to ~1.5 mm, and imaged as a bubble section. Overall section measures approximately 10 cm by 6 cm. Stratigraphic up-core is to the left as indicated. |

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| FigB-3b.pdf |
| **Figure**S2: A series of elongated “bubble features” artificially generated to test and verify moment angle and chord measurements. Bubbles are colored in (A) based on their moment angle () with the maximum straight chord lines also drawn. Panel (B) shows each bubble labeled with numerical moment angle. Angles are only expressed from 0° to 180° as shown by axis and colorbar. Numerical moment angles closely agree with marked chords, however only numerical moment angle values were used in pertinent image processing calculations. Panel (C) shows one of many calculations used to determine an overall average moment angle measurement error. In this panel, a bubble of equivalent radius size 0.11 mm and aspect ratio of 1.4 from the *VHS-580* sample was rotated at 5° increments from 0° to 90°. The labeled value indicates measured moment angle (). The average error for this one typical bubble was 0.85° ± 0.4°. |

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| FigB-4.pdf |
| **Figure**S3: Thin-section of ice sample *VHS-580*, shown here thinned to ~0.5 mm, and imaged as a grain-analysis section (see also Fitzpatrick and others, 2014). Section was digitally imaged under cross-polarized transmitted light in order to more easily delineate grain boundaries. Resultant grain-boundary tracing is shown as an orange skeletonized mesh between the grains. Stratigraphic up-core is to the left as indicated. |

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| FigB-5.pdf |
| **Figure**S4: Hybrid grain-bubble mesh map of all identified *intra-grain* bubbles from sample *VHS-580*. This map combines the grain-boundary mesh (orange), with the all of the identified bubbles (purple) that are contained entirely within grains, and clear of any grain boundary. Stratigraphic up-core is to the left as indicated. |

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| FigB-6.pdf |
| **Figure**S5: Hybrid grain-bubble mesh map of all identified *inter-grain* bubbles from sample *VHS-580*. This map combines the grain-boundary mesh (orange), with the all of the identified bubbles (purple) that are either on, or touching any of the grain boundaries. Stratigraphic up-core is to the left as indicated. |

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| Fig3-6.jpg |
| **Figure S6:** Stereonet illustration of fabric conventions used. The plane of the sample is the plane of the page, and thus the circumference of the stereonet, with stratigraphic up-core to the left as indicated. The theta angle ( represents how far out of the plane of the sample the c-axis of the grain is pointing. A theta value of 90° indicates a c-axis that lies on the plane of the thin-section, while a theta value of 0° indicates a c-axis that lies perpendicular to the plane of the sample. The phi angle (represents the angle at which the c-axis lies around the horizontal plane of the section, measured from 0 to 180 degrees. In this case, a phi value of 0° indicates a c-axis pointing stratigraphic down-core, with a phi value of 180° indicating a c-axis pointing stratigraphic up-core. Stratigraphic up-core is to the left as indicated. See also Fig. S7 for 3-dimensional representation of fabric conventions. Figure adapted from Fitzpatrick and others (2014). |

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| FigB-7.pdf |
| **Figure**S7: 3-dimensional representation of fabric conventions used with plane of sample shown in dark grey. The c-axis theta () and phi () angles are indicated. An example c-axis projection is shown as a red dot, combining both angles for reference. Stratigraphic up-core is to the lower-left ( = 180°) as indicated. See also Fig. S6 for stereonet representation of fabric conventions. |

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| FigB-8.pdf |
| **Figure**S8: Schmidt plot of c-axis data from final 148 measured sample subset (*HS*) of grains in sample *VHS-580*. Plot (a) shows the data plotted raw using the fabric convention shown in Fig. 4 with stratigraphic up-core to the left (red dot). Plot (b) shows the data rotated and converted to represent a view down-core. Here, stratigraphic up-core is coming out of the page. In this view, nascent grain rotation is apparent as there minor clustering about the center, combined with a faint outline of a weak girdle pattern. No grains were measured along the horizontal plane of the core also confirming that crystals have undergone rotation. |

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| FigB-9.pdf |
| **Figure**S9: Plot of raw bubble-orientation angle () vs. c-axis horizontal rotation angle () for sample *VHS-580*. Data points indicate all 2377 individual bubbles measured without ±90° offset. This figure is shows the unadjusted data set from Fig. 6. Here the linear regression (solid black line) again yields an R2 of ~0.95 and true basal planes (±90° from ) are indicated by red dotted lines. The data clearly cluster on or near the ±90° lines, indicating elongation on or near the basal planes. Histogram inset (bin width = 2°) shows left-skewed distribution of the (- offset angles for each bubble (shown as absolute values), which confirms that over 75% of all bubbles are elongated within 20° of the basal plane (90°). Effects of pixelization and cut bubbles were ignored here.    **Figure S10:** Comparison between the overall bubble aspect ratio distributions and those of the sample planar bubble sub-set (*HS\_PLANAR*), shown as bin percentages (bin width 0.1). While the percentages vary only slightly, the planar sub-set (*HS\_PLANAR*) does show slightly higher average elongations than the overall bubble set as expected based upon full elongations being more observable in their entirety for bubbles oriented in the plane of the sample. |

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**Statistics for elongation data plotted in Figure 7 – Calculated in MATLAB**

**FIGURE-7a Stats**

**FITLM Results:**

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| --- | --- | --- | --- | --- |
|  | Estimate | SE | tStat | pValue |
| (Intercept) | 1.4924 | 0.017947 | 83.154 | 0 |
| X1 | 0.94798 | 0.3169 | 2.9914 | 0.0028328 |

Number of observations: 1225, Error degrees of freedom: 1223, RMS Error: 0.321

R-squared: 0.00726, Adjusted R-Squared 0.00645

F-statistic vs. constant model: 8.95, **p-value = 0.00283**

**TTEST Results:**

TTEST = 1. The result is 1 if the test rejects the null hypothesis at the 5% significance level

**REGSTATS Results:**

R^2 = 0.00726360989541963

Pval = 0.00283276043581012

**FIGURE-7c Stats**

**FITLM Results:**

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| --- | --- | --- | --- | --- |
|  | Estimate | SE | tStat | pValue |
| (Intercept) | 1.4379 | 0.019438 | 73.971 | 0 |
| X1 | 0.33316 | 0.055898 | 5.8554 | 6.1077e-09 |

Number of observations: 1225, Error degrees of freedom: 1223, RMS Error: 0.317

R-squared: 0.0273, Adjusted R-Squared 0.0265

F-statistic vs. constant model: 34.3, **p-value = 6.11e-09**

**TTEST Results:**

TTEST = 1. The result is 1 if the test rejects the null hypothesis at the 5% significance level

**REGSTATS Results:**

R^2 = 0.0272695784812710

Pval = 6.10765274210828e-09

**FIGURE-7d Stats**

**FITLM Results:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Estimate | SE | tStat | pValue |
| (Intercept) | 1.4799 | 0.017832 | 82.993 | 0 |
| X1 | 0.1697 | 0.044311 | 3.8298 | 0.00013473 |

Number of observations: 1225, Error degrees of freedom: 1223, RMS Error: 0.32

R-squared: 0.0119, Adjusted R-Squared 0.011

F-statistic vs. constant model: 14.7, **p-value = 0.000135**

**TTEST Results:**

TTEST = 1. The result is 1 if the test rejects the null hypothesis at the 5% significance level

**REGSTATS Results:**

R^2 = 0.0118510842841301

Pval = 0.000134726051764585