A Stratigraphy-Based Method for Reconstructing Ice Core Orientation

J. Westhoff, N. Stoll, S. Franke, I. Weikusat, P. Bons, J. Kerch, D. Jansen & D. Dahl-Jensen

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Abstract

Ever since the first deep ice cores were drilled, it has been a challenge to determine their original, in-situ orientation.

In general, the orientation of an ice core is lost as the drill is free to rotate during transport to the surface.

For shallow ice cores, it is usually possible to match the adjacent core breaks, which preserves the orientation of the ice column.

However, this method fails for deep ice cores, such as the EastGRIP ice core in Northeast Greenland.

We provide a method to reconstruct ice core orientation using visual stratigraphy and borehole geometry.

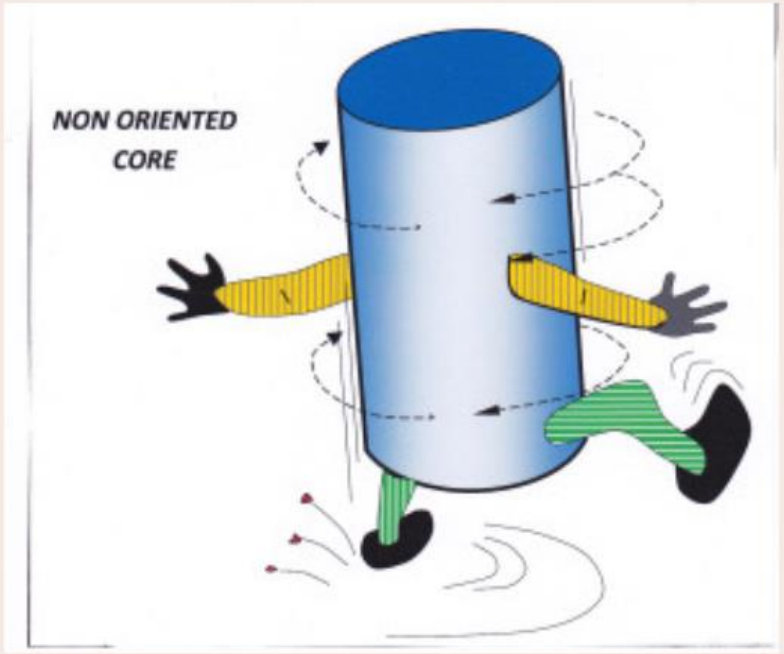
As the EastGRIP ice core is drilled through the Northeast Greenland Ice Stream, we use information about the directional structures to perform a full geographical re-orientation.

We compared the core orientation with logging data from core break matching and the pattern of the stereographic projections of the crystals' c-axis orientations.

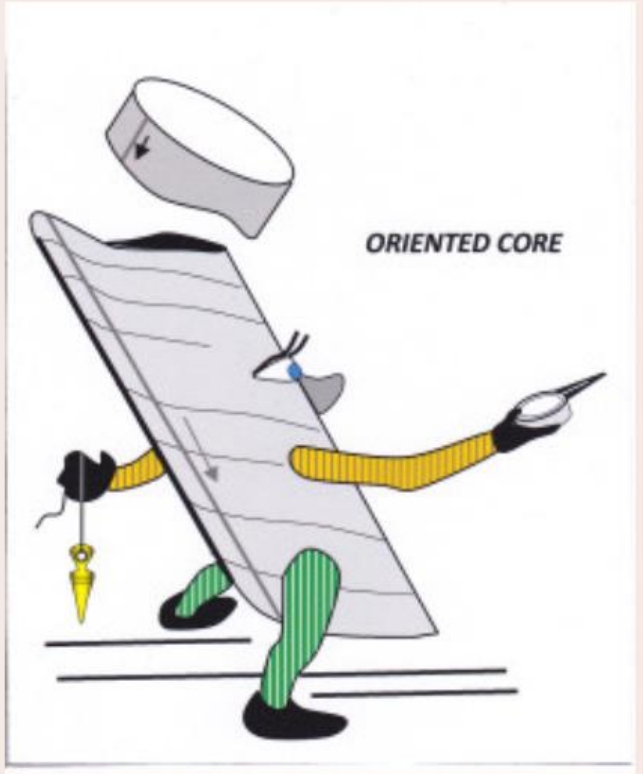
Both comparisons agree very well with the proposed orientation method.

The method works well for 441 out of 451 samples from a depth of 1375–2120m in the EastGRIP ice core.

It can also be applied to other ice cores, providing a better foundation for interpreting physical properties and understanding the flow of ice.

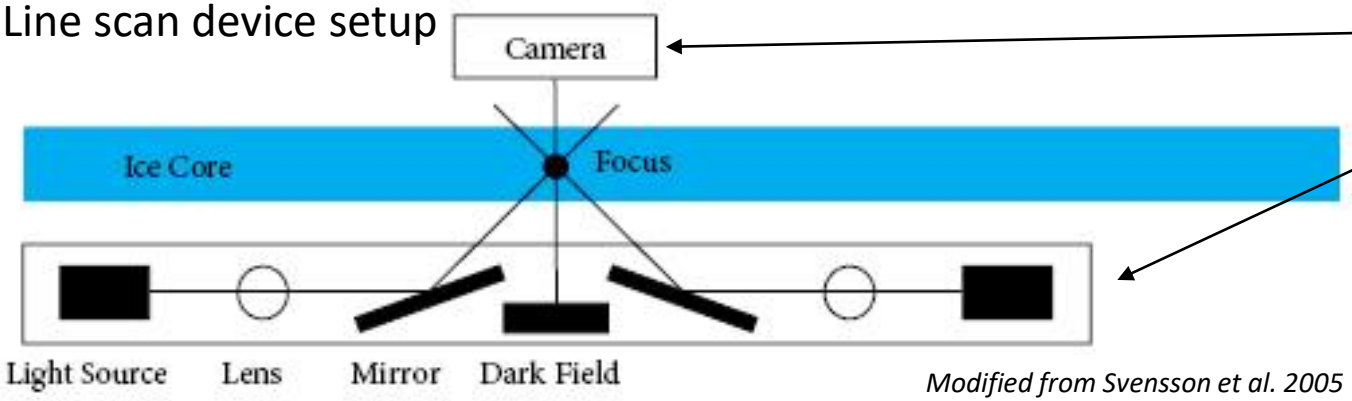


http://rogermarjoribanks.info

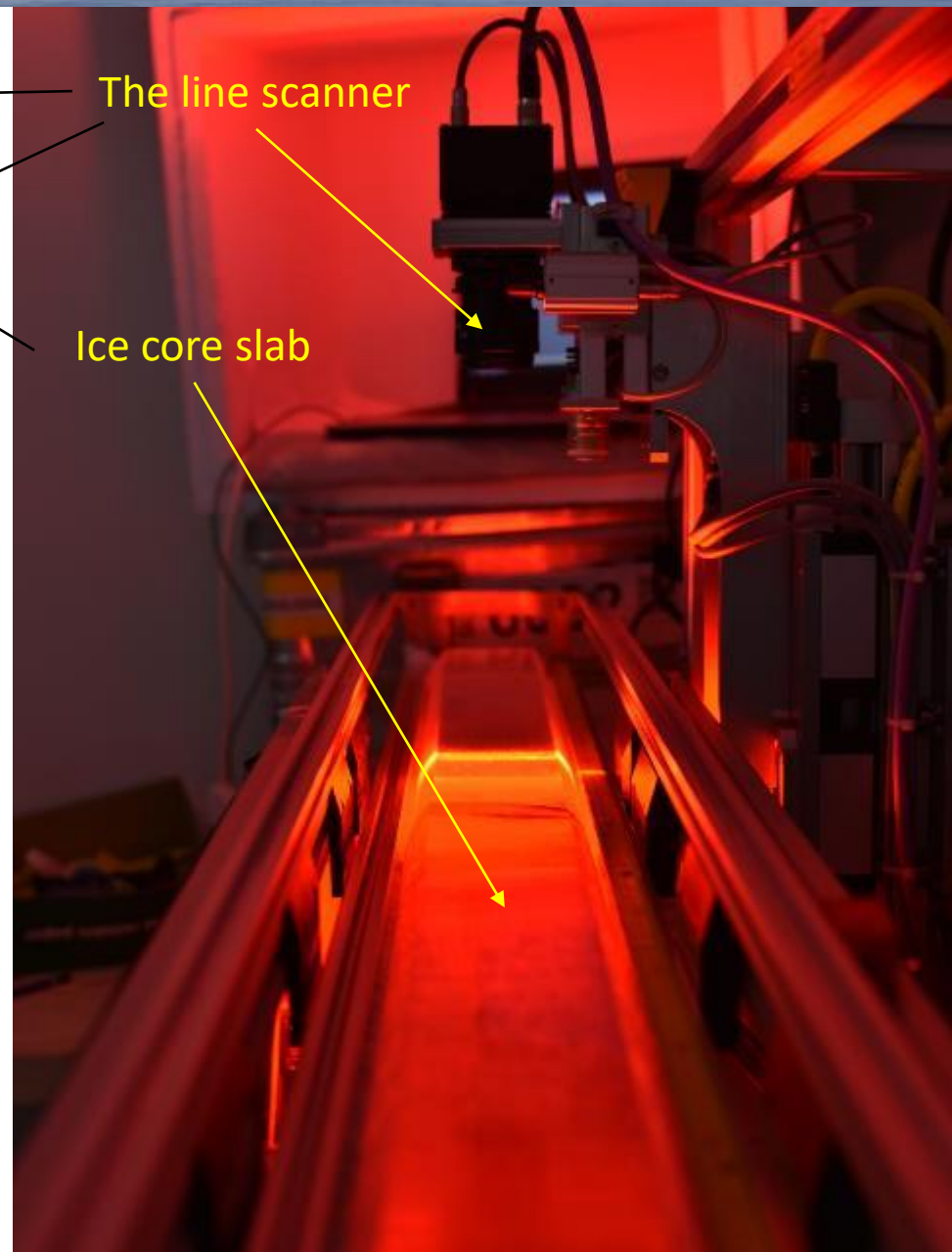


Visual Stratigraphy

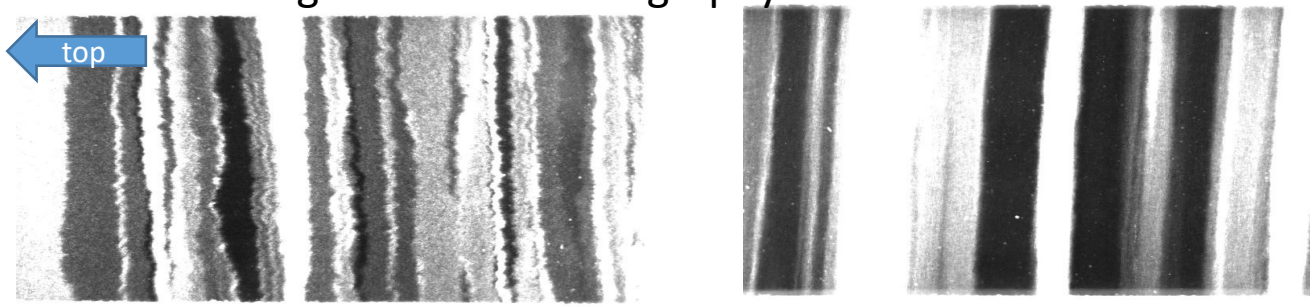
Line scan device setup



Modified from Svensson et al. 2005



Line scan images or visual stratigraphy

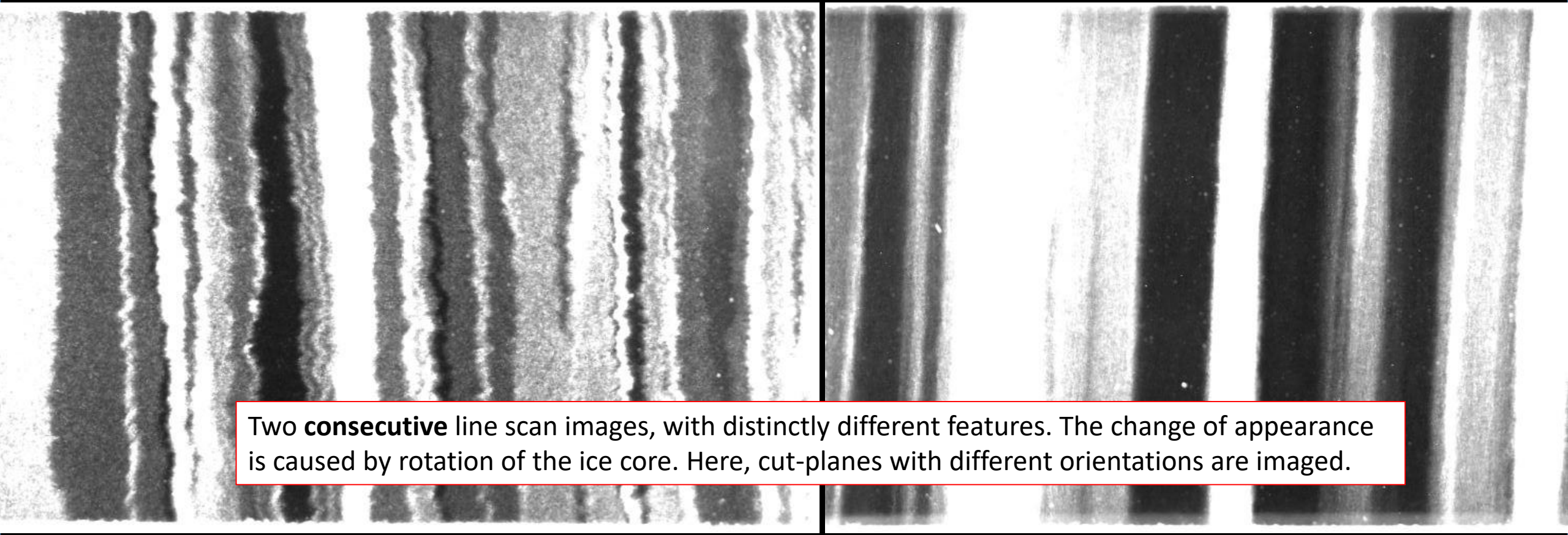


Bright sections: reflection/scatter of light from trapped air, fractures, dust, or others

Dark sections: no reflection/scattered due to “clean” ice

Visual Stratigraphy

| 1633.95m | 1634.00m | 1634.05m | 1634.10m | 1634.15m |



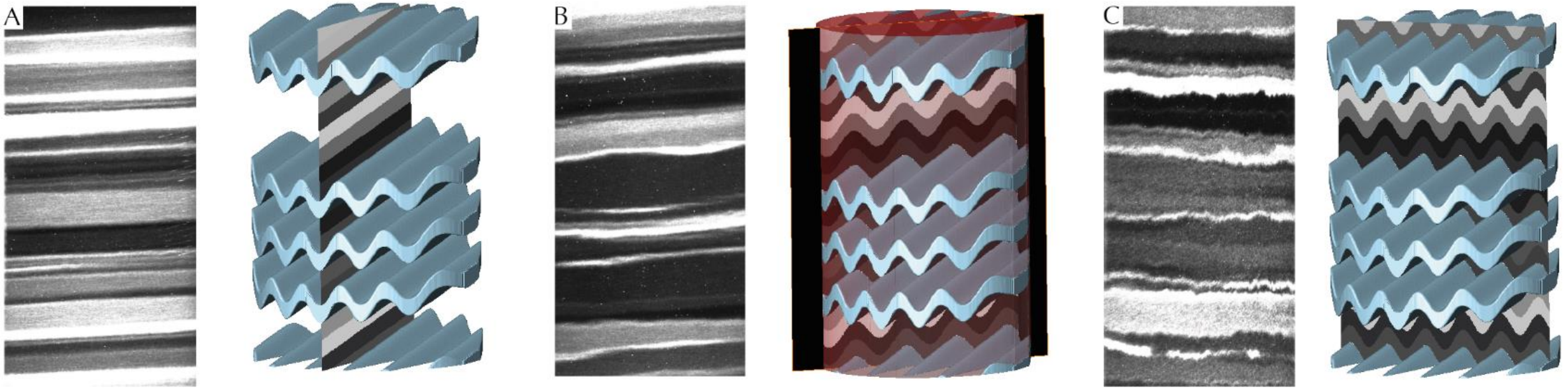
Two **consecutive** line scan images, with distinctly different features. The change of appearance is caused by rotation of the ice core. Here, cut-planes with different orientations are imaged.

bag 2971

bag 2972

Visual Stratigraphy

Sketch of the 3D structures

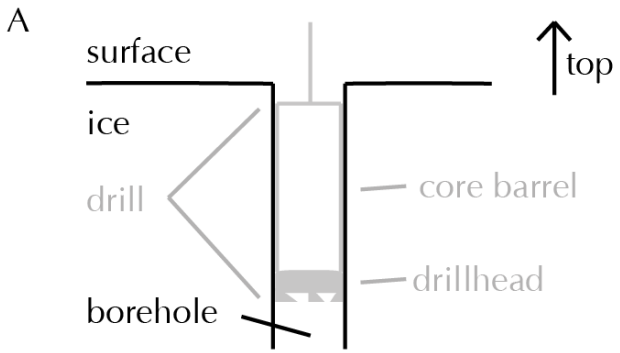


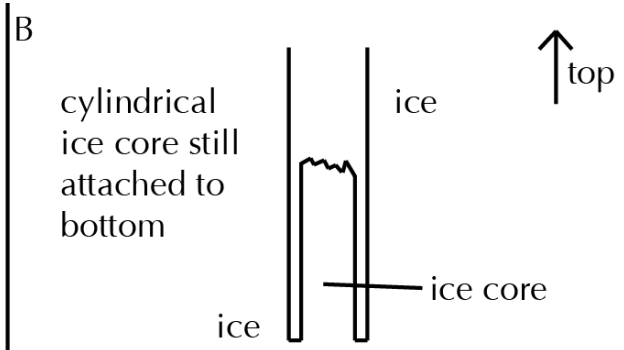
Imaged plane is:
- parallel to folds,

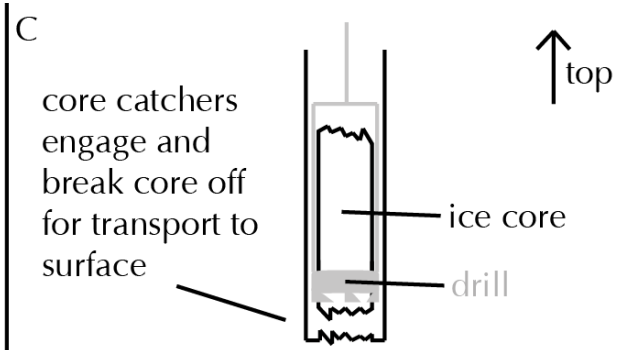
- at an angle to folds, and

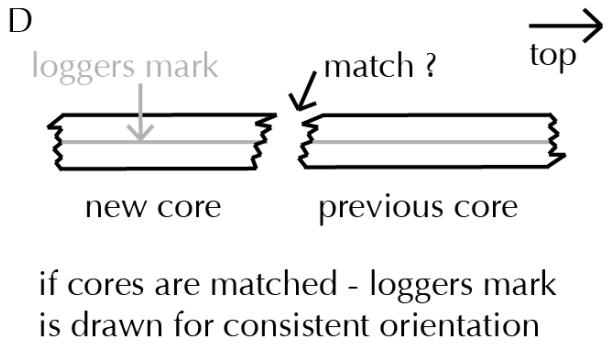
- perpendicular to folds.

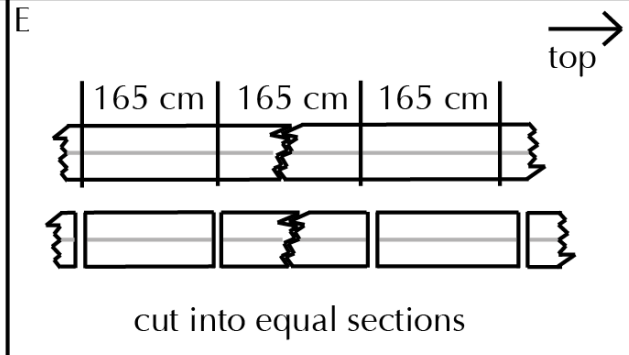
An Ice Core's Journey

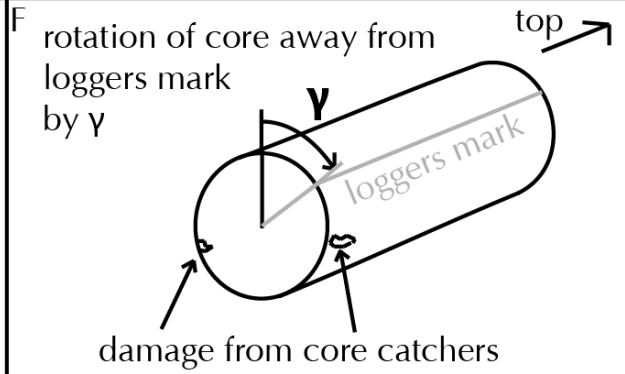


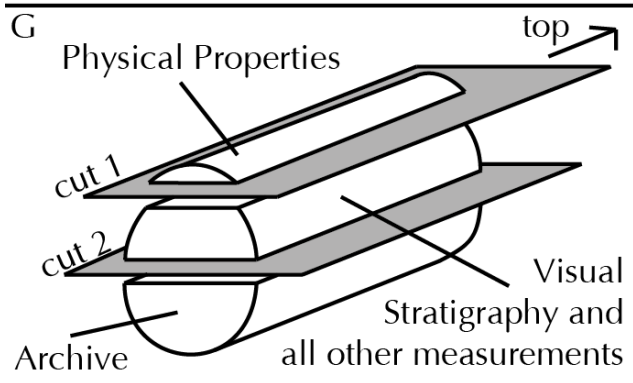


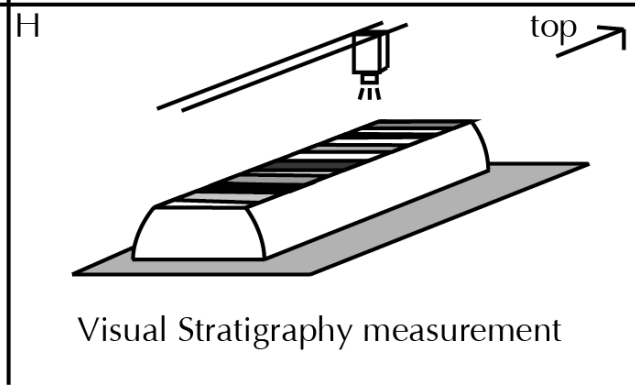


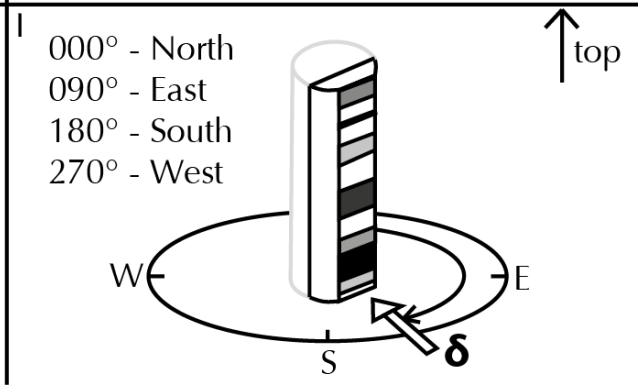












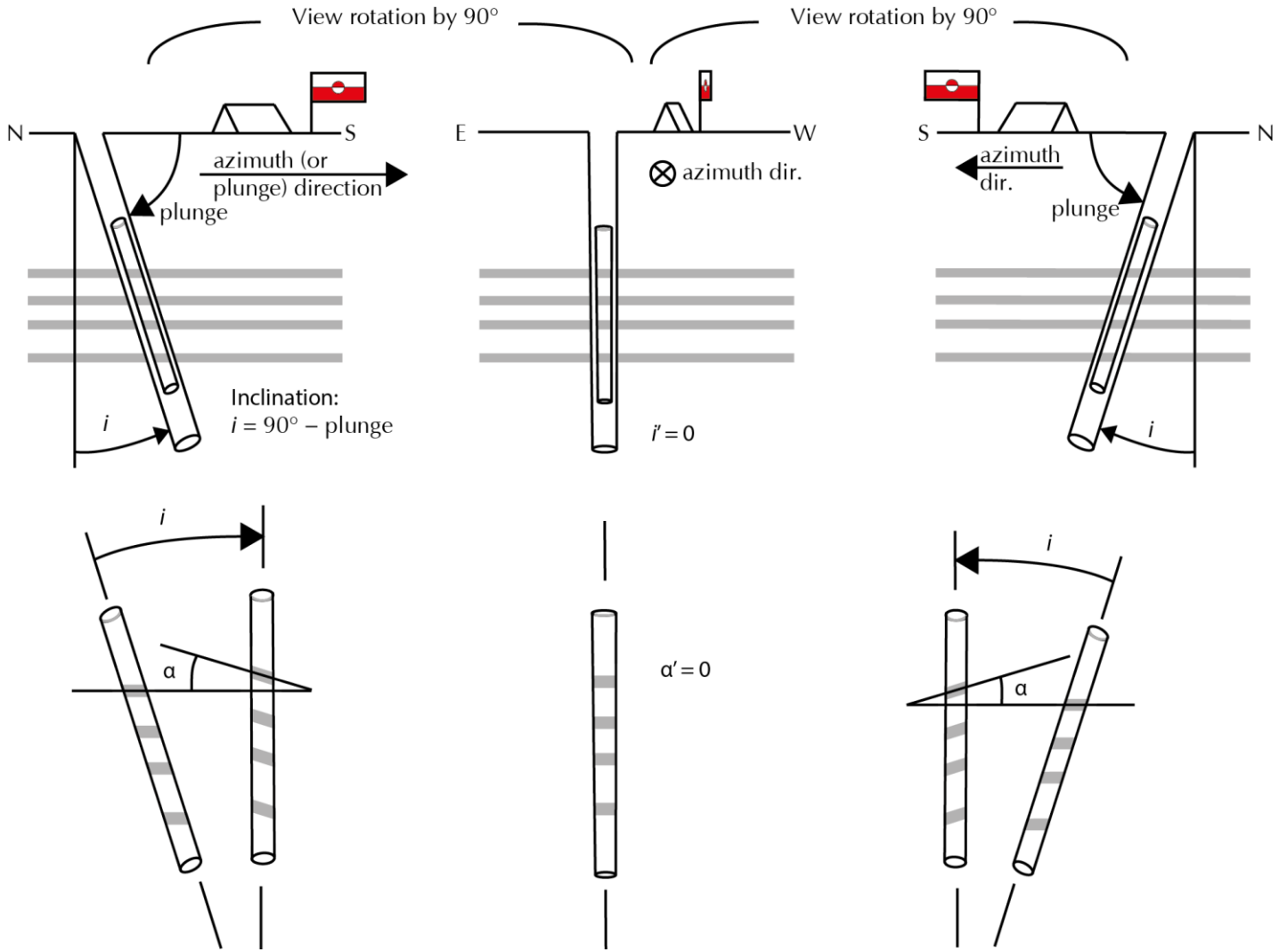
An ice core's journey – from the bottom of the ice sheet to the measurement table

C) Orientation of ice core is lost, as drill is free to rotate during transport to the surface.

D) relative orientation is restored.
(relative to previous run)

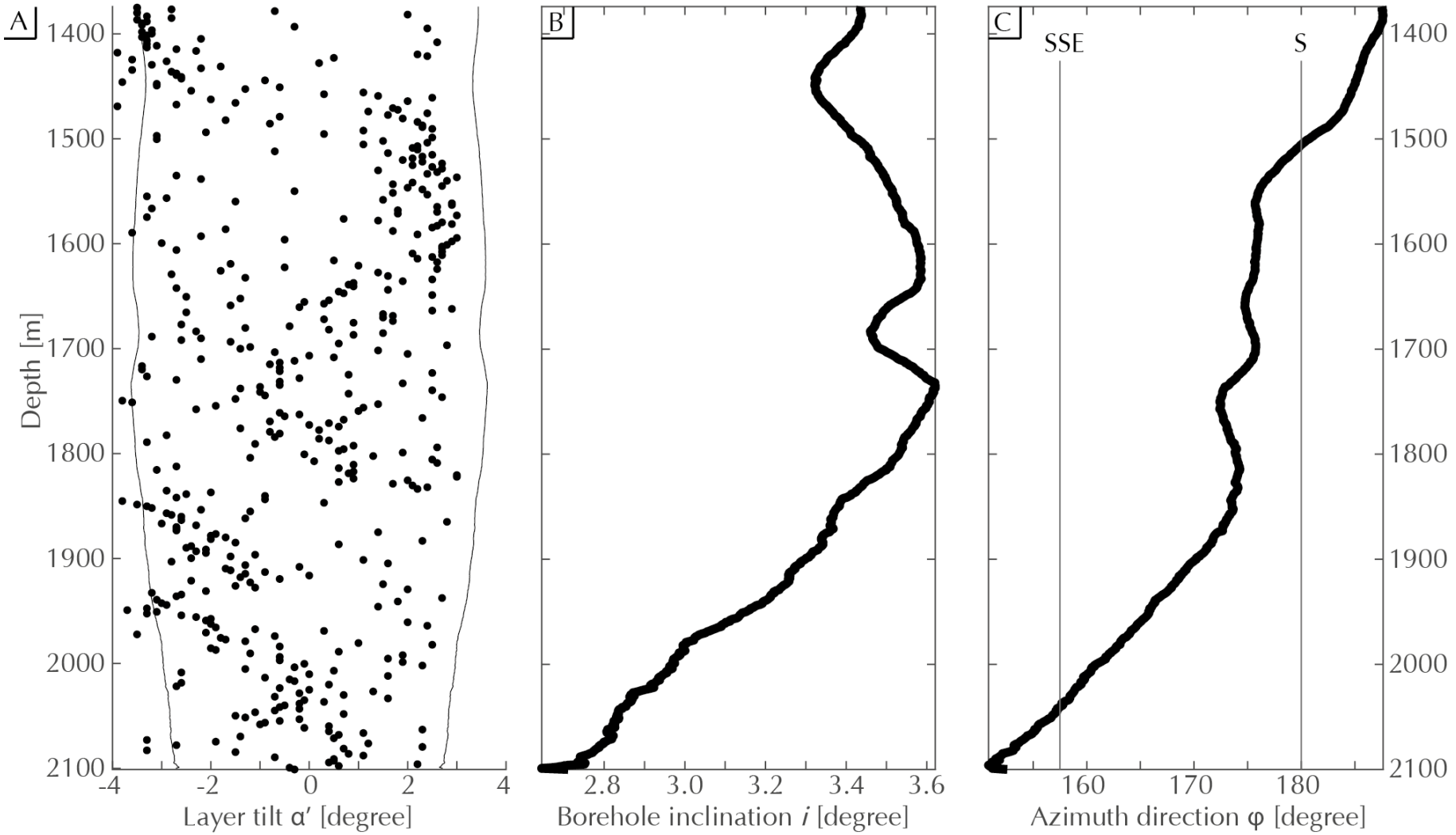
I) reconstruction of ice core orientation.

The Idea



The inclination of horizontal layers changes, when the bore hole is inclined and then viewed from different angles.

Input data for our Method



A) measured tilts of layers in the EastGRIP ice core.

B) borehole inclination

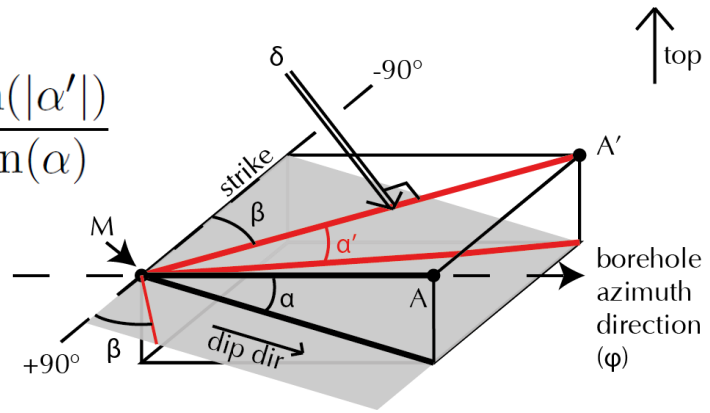
C) azimuth direction.

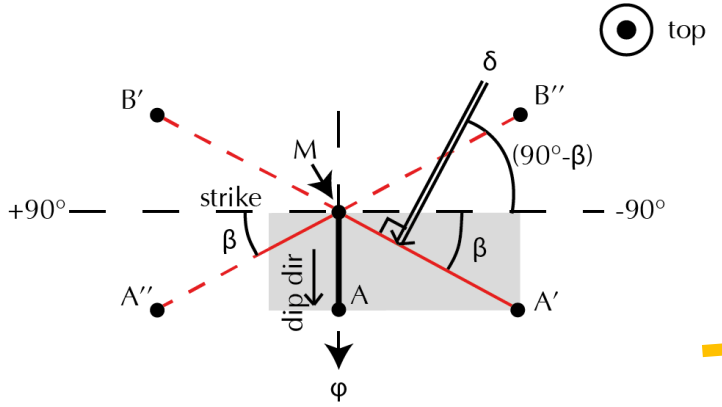
If we know the tilt/inclination of each layer and the borehole geometry, then we can reconstruct the ice core orientation.

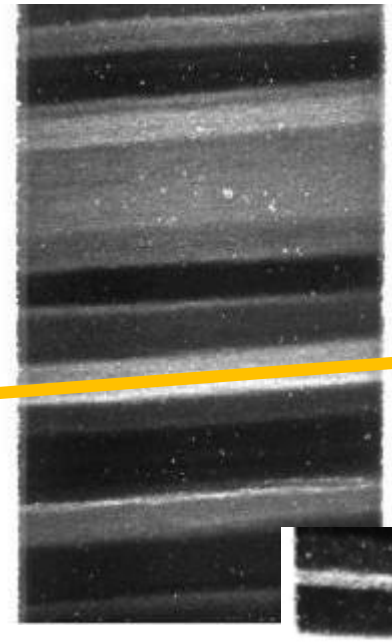
See next slide.

The Method

$$\sin(\beta) = \frac{\tan(|\alpha'|)}{\tan(\alpha)}$$



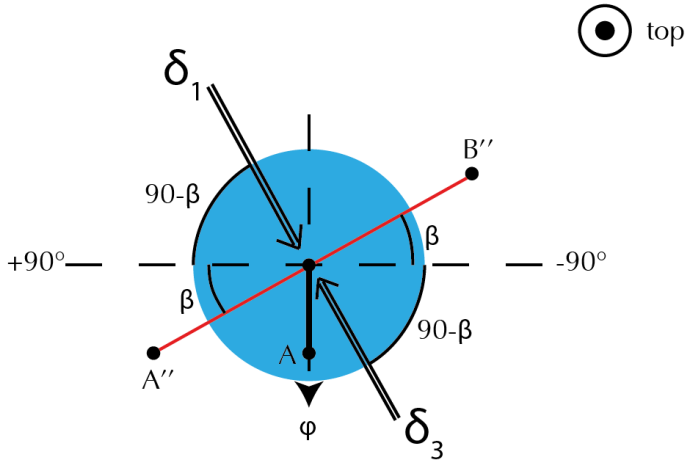


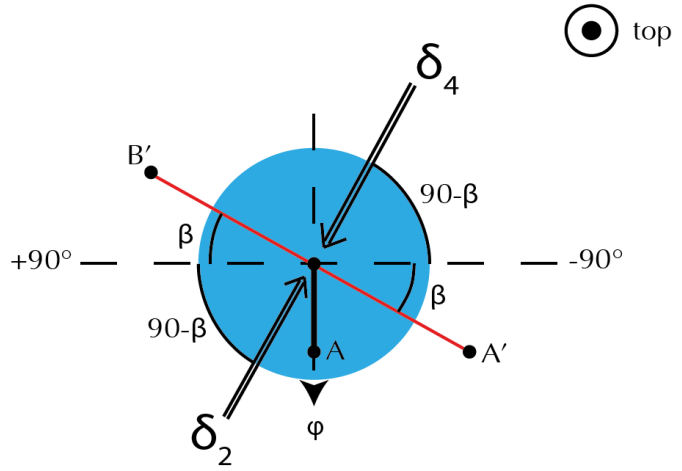


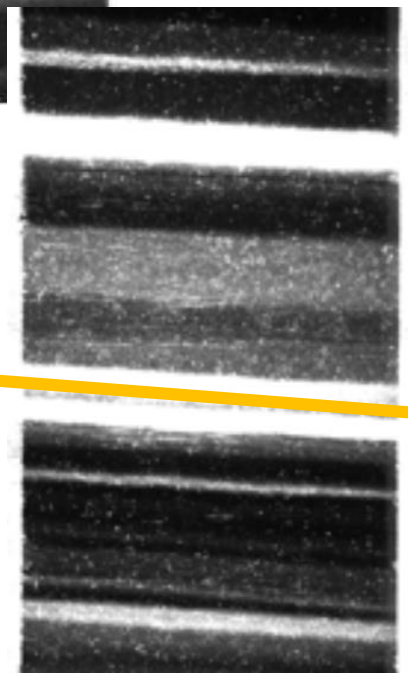
negative tilt

$\delta_{(1,2)}$

B







positive tilt

$\delta_{(3,4)}$

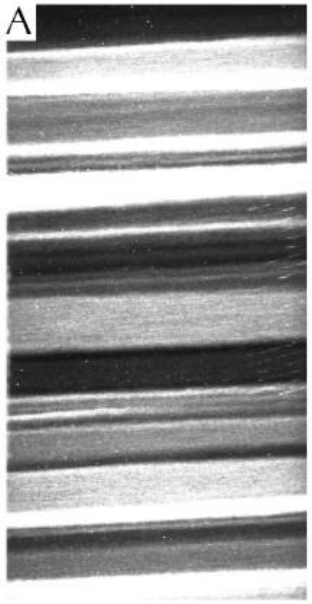
$$\delta_{(1,2)} = \varphi + 90 \pm (90 - \beta)$$

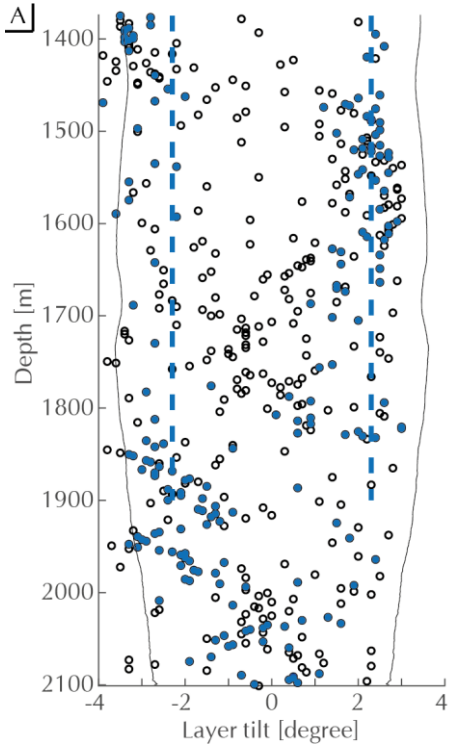
$$\delta_{(3,4)} = \varphi - 90 \pm (90 - \beta)$$

Geometrical reconstruction of the viewing direction of tilted layers, thus the ice core orientation.

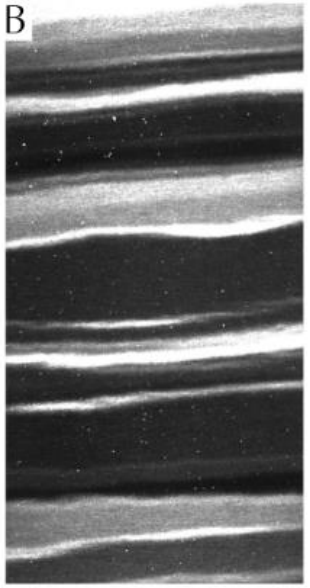
The Method

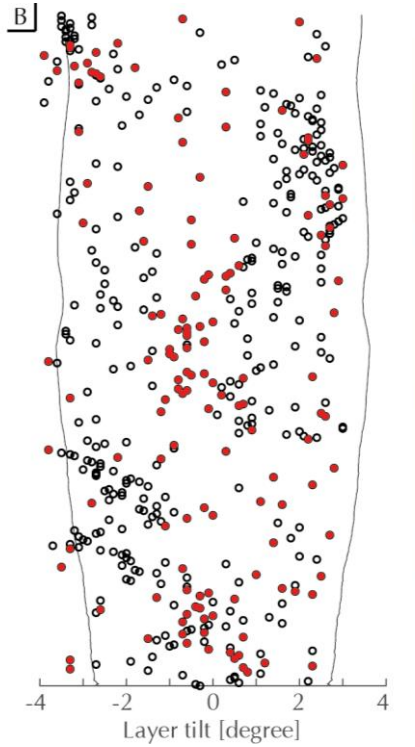
No features or flat layers



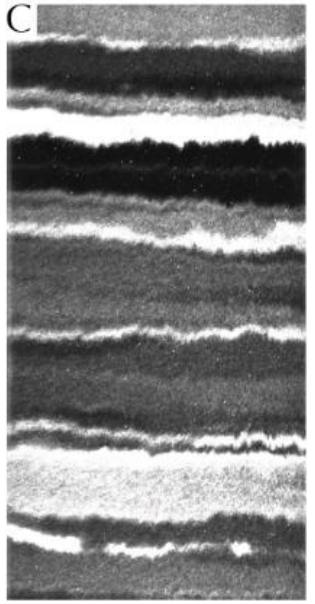


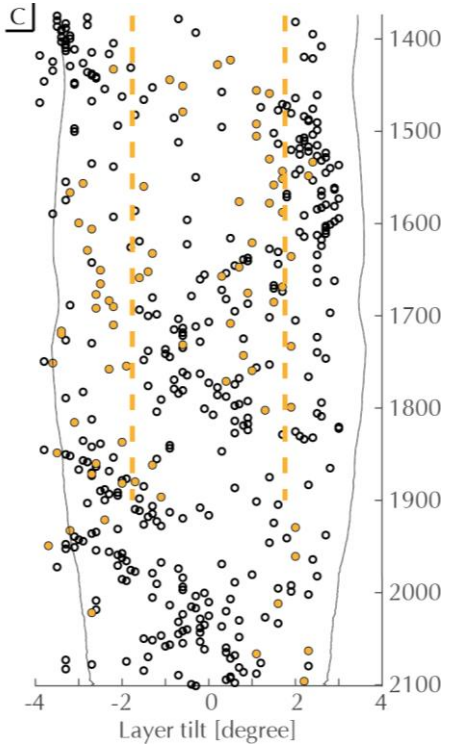
Undulations in layering





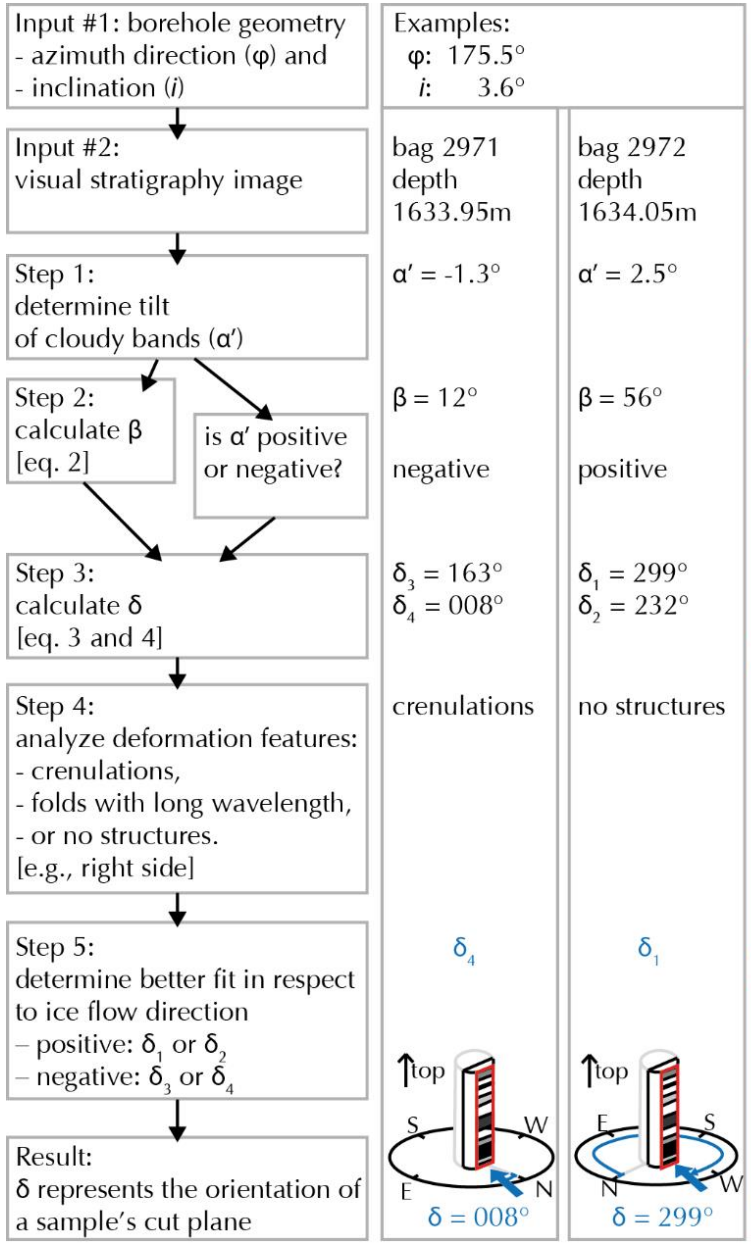
Crenulations (short upright folds)

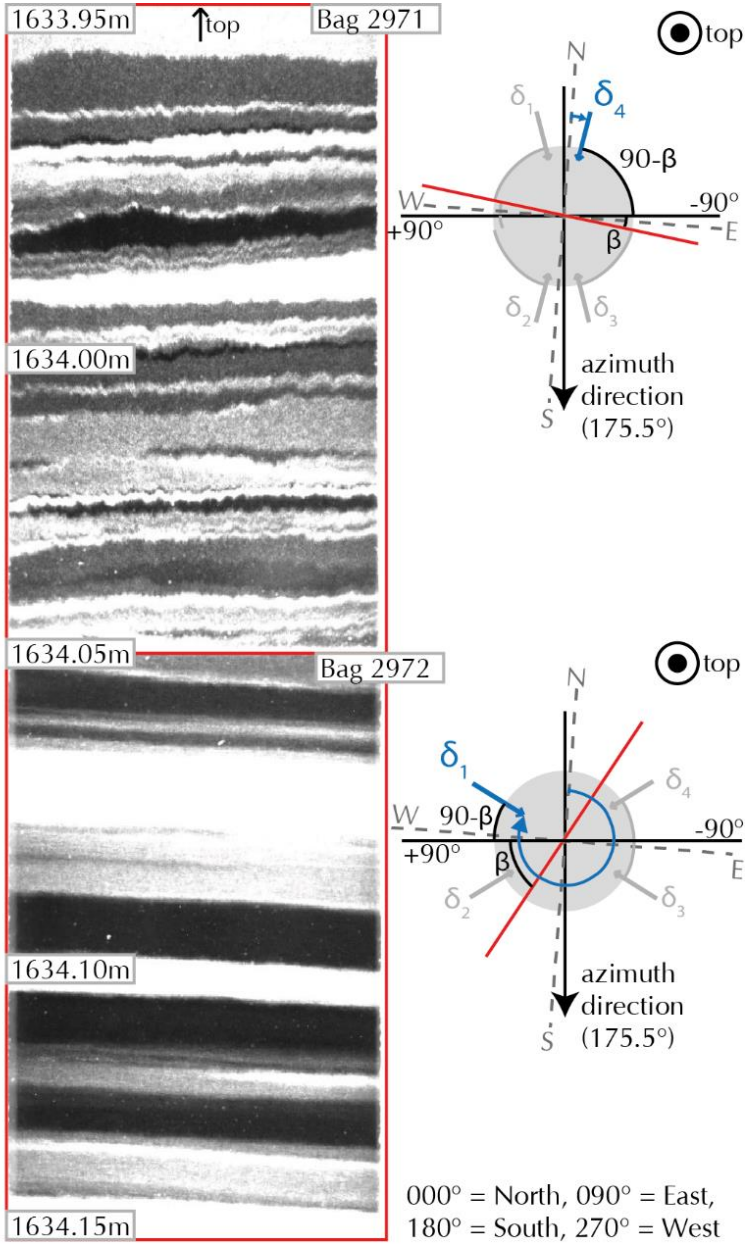




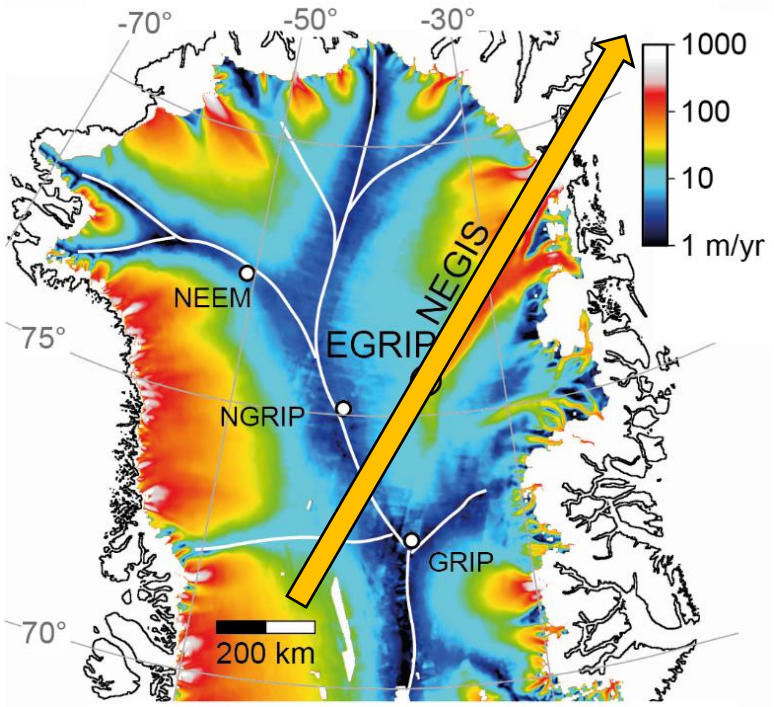
Layers with features as in the image indicated as a colored point in the layer tilt overview. Dashed lines represent mean of positive and negative values.

Results

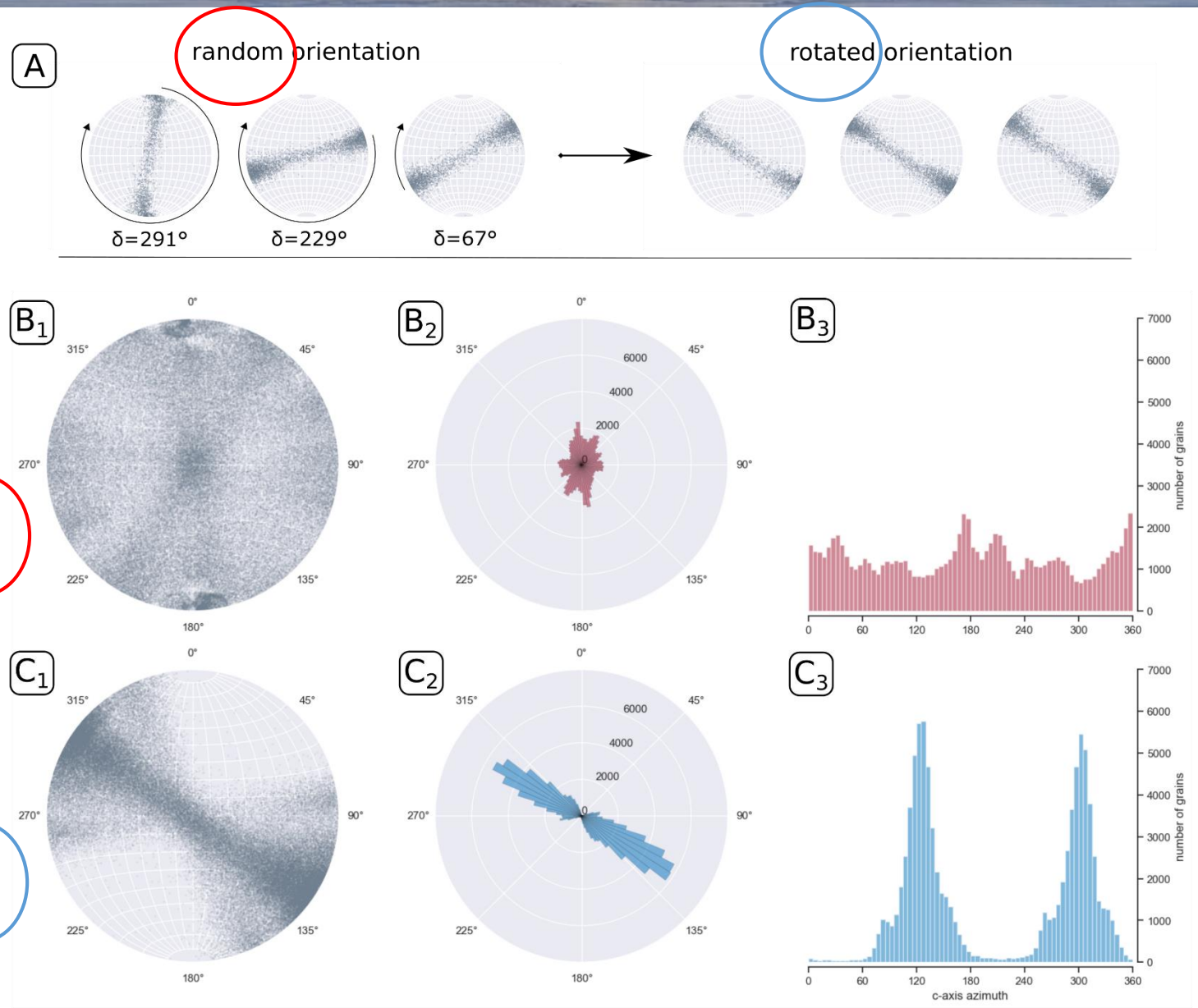




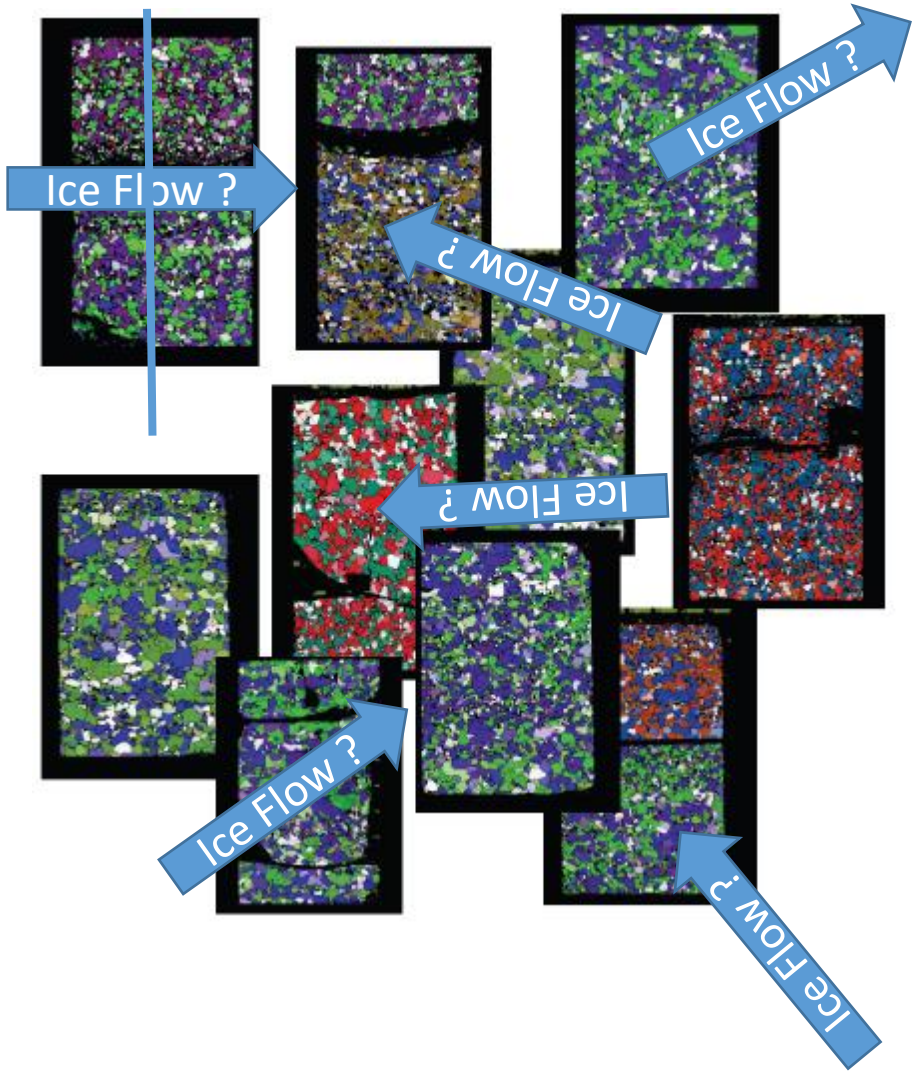
Flow chart for reconstructing ice core orientation (for details see paper). Ice flow direction, here NEGIS, is necessary for the reconstruction.



Fabric Orientation

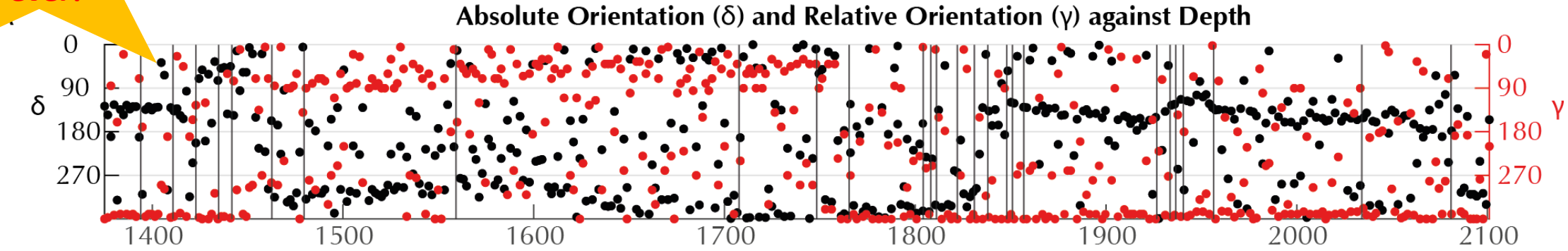


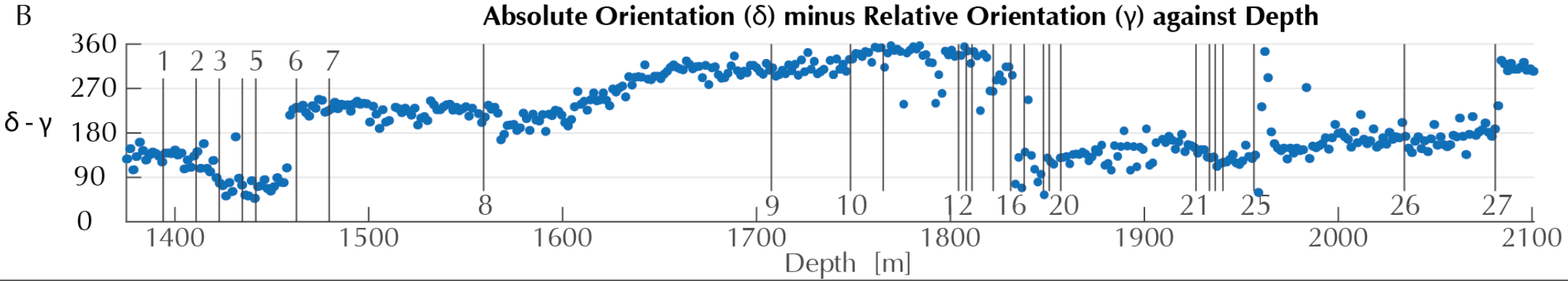
Now orientation reconstruction of fabric data is possible.



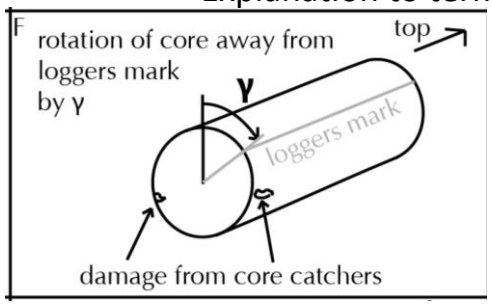
Core Break Matching

First time ever! → **We are now able to quantify how well core break matching in the field works! For details, see paper.**

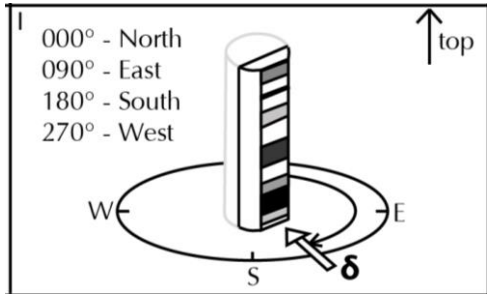




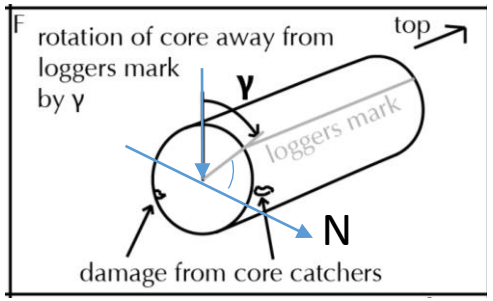
Explanation to terms in figure:



gamma: relative orientation



delta: absolute orientation



delta minus gamma: angle of loggers mark from North

Summary

We have: - oriented the glacial section of the EastGRIP ice core
- shown that the structures below are an effect of core orientation, not change of deformation regime
- shown that the method works using the fabric orientation and core break matching as references
- paved the way for a detailed inspection of deformation structures in the ice core

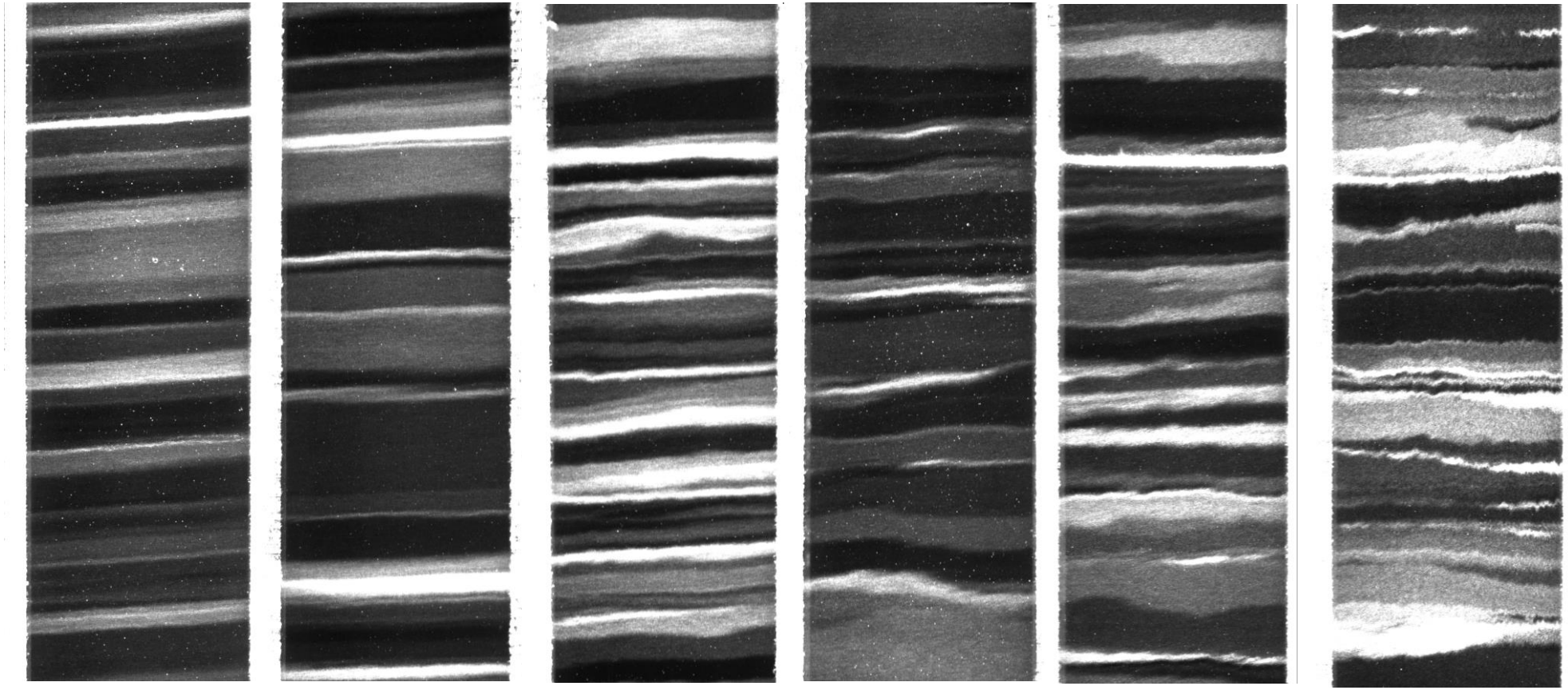


image width: 7cm

Bag	2503	2518	2555	2509	2534	2599
Layer Tilt	-3.5	-3.3	-2.2	-0.7	-0.3	0.2