# Dynamic development of mineral layering and crystal alignments by pulsed magmatic flow in crystal mush of an upper-crustal diabase sill

LeeAnn Srogi[1], Nikolas Watson[1], and Timothy Lutz[1]

[1]West Chester University

November 24, 2022

**Abstract**

Magmatic structures are well-preserved in a 201.5 Ma diabase sill (PA, USA, equivalent to the Palisades sill) formed as part of the Central Atlantic Magmatic Province during rifting of Pangea. The sill was emplaced at ˜6 km depth and tilted ˜20° NNW by post-magmatic fault movement. Detailed mush structures are exposed in a dimension stone quarry with walls cut parallel and perpendicular to the strike of the sill. Light gray, plagioclase-rich layers (PLR) a few mm thick contain up to 75% modal plag and are underlain by more pyroxene-rich layers with larger orthopyx antecrysts up to 1 mm length. PLR are sub-parallel to sill margins, have dm-m lateral dimensions, and spaced 0.33 m apart on average. Magma replenishments $< 1$m thick cross-cut plag-pyx layers at low angles and have basal load-cast-like structures. Since mafic replenishments have PLR at their tops and similar thickness to PLR spacing, we interpret all PLR as having formed by emplacement of small-volume magma pulses bearing ˜30% larger pyx and smaller plag antecrysts. This model is similar to Petford and Mirhadizadeh (R Soc Open Sci, 2017) for the Basement sill, Antarctica. Upward migration of mafic melts in pipe-like channels (cm to dm wide) disrupted plag-pyx layers to form dm-scale graben-like and slump-like structures that resemble sediment liquefaction. Channelized flow late in sill development may have been enhanced by seismicity (Davis et al., JVGR, 2007). Diabase micro-structures are similar to published experimental results and numerical simulations of flow and shear-thinning in particle-rich slurries (e.g., Cimarelli et al., G3, 2011; Ishibashi, JVGR, 2009; Deubelbeiss et al., G3, 2011). These include layers such as the plag-pyx couplets and orientations of euhedral plag around pyx phenocrysts. Plag long-axis orientations and tiling indicators in the PLR have strike-parallel and strike-normal components in vertical and plan views consistent with flow alignment in the plane perpendicular to the stress gradient. Plag chemical zoning patterns, limited deformation, and long-axis orientations parallel to inclined layer margins also indicate magmatic flow rather than compaction. Mineral x-ray maps are used to derive initial crystal fraction and aspect ratios for modeling relative viscosity and explore compositional aspects of layer development.

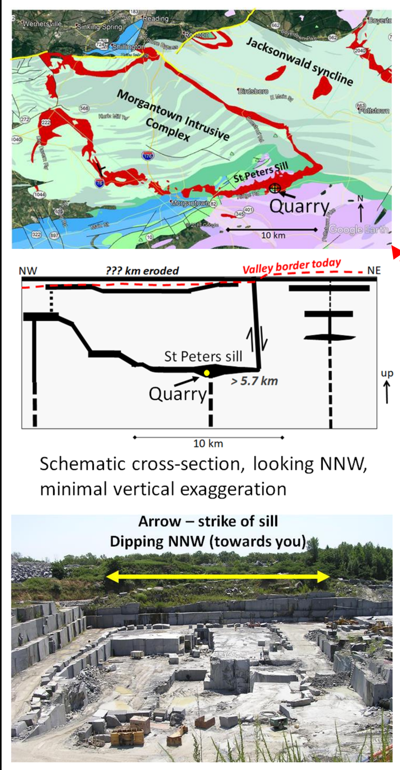
V51H-0151

# Dynamic development of mineral layering and crystal alignments by pulsed magmatic flow in crystal mush of an upper-crustal diabase sill


**LeeAnn Srogi (lsrogi@wcupa.edu), Nikolas Watson, and Tim Lutz**

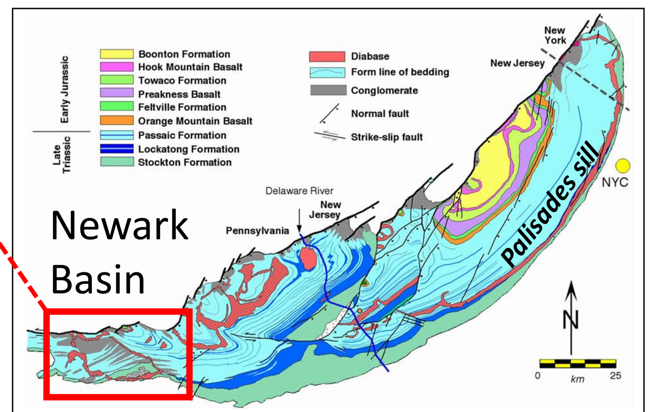
Department of Earth and Space Sciences, West Chester University of Pennsylvania


## 1.Tectonic Context: *Triassic Rifting of Pangaea, Basaltic Magmatism*




Dimension stone Quarry in sill (5-6 km paleo-depth) Walls are cut along strike (ESE-WSW) and across strike (NNW-SSE)

Prominent plag-rich layers identify tops of intra-sill sills or magma "flow lobes," <1m thick on average




Source: Roy Schlische, Rutgers University; http://www-rci.rutgers.edu/~schlisch/

**Central Atlantic Magmatic Province (CAMP)**

**Newark Basin, Pennsylvania-New Jersey-New York, U.S.A.**

High-Ti Quartz-normative **basalts and diabase (dolerite) intrusions**

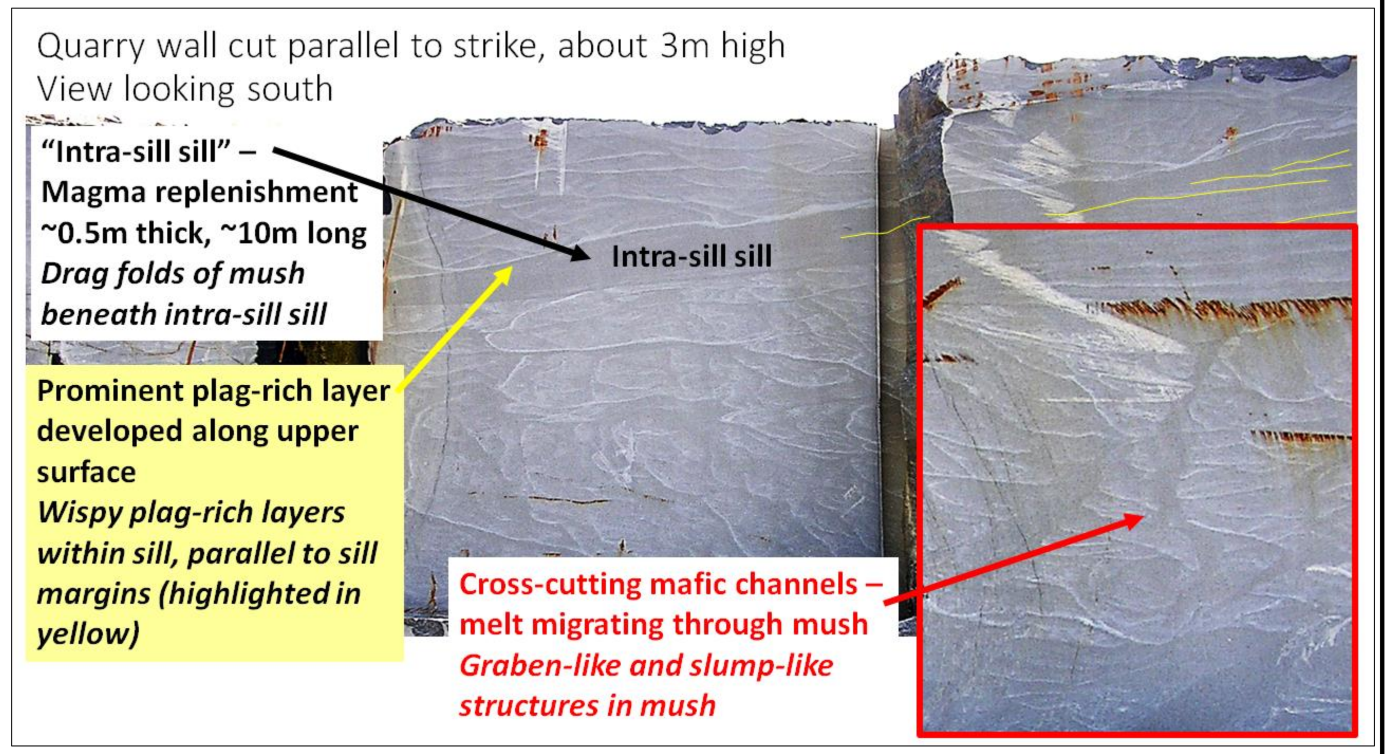
*Age:* 201.520 ± 0.034 Ma; *Duration: ~ 100,000 yrs.; Area: ~ 2-3 million km²*

Blackburn, et al., 2013, Science, v. 340, p. 941-945.

*Western Newark Basin:* Srogi, et al., 2017, Geol. Assn. NJ, Ann. Mtg. guidebook, p. 30-48.

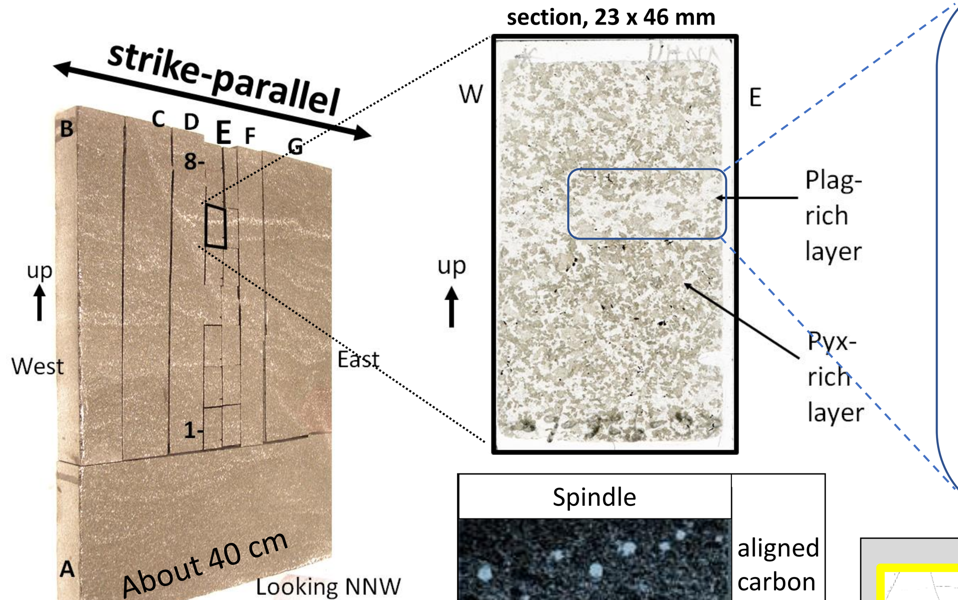

Wall cut perpendicular to strike of sill, looking WSW, about 3m high. Modal layering dips about 20° NNW, tilted after solidification due to rift-basin border fault.

Quarry wall cut parallel to strike, about 3m high
View looking south




## 2. Mush in Basal Sill: *Opx-Plag Antecryst Layering Preserves Incremental Emplacement of Thin "Flow Lobes" Within Sill – Short Timescale Pulses?*

## 3. Fabrics in Modal Layers: *Separation of Pyroxene and Plagioclase Antecrysts and Alignment of Tabular Plagioclase are Consistent with Flow and Shear Thinning*



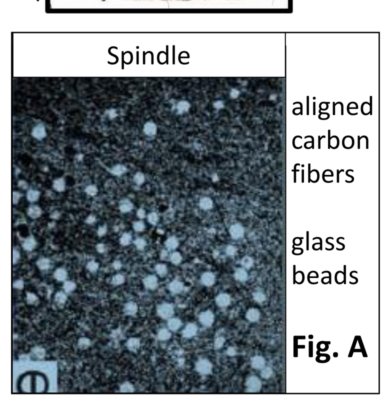
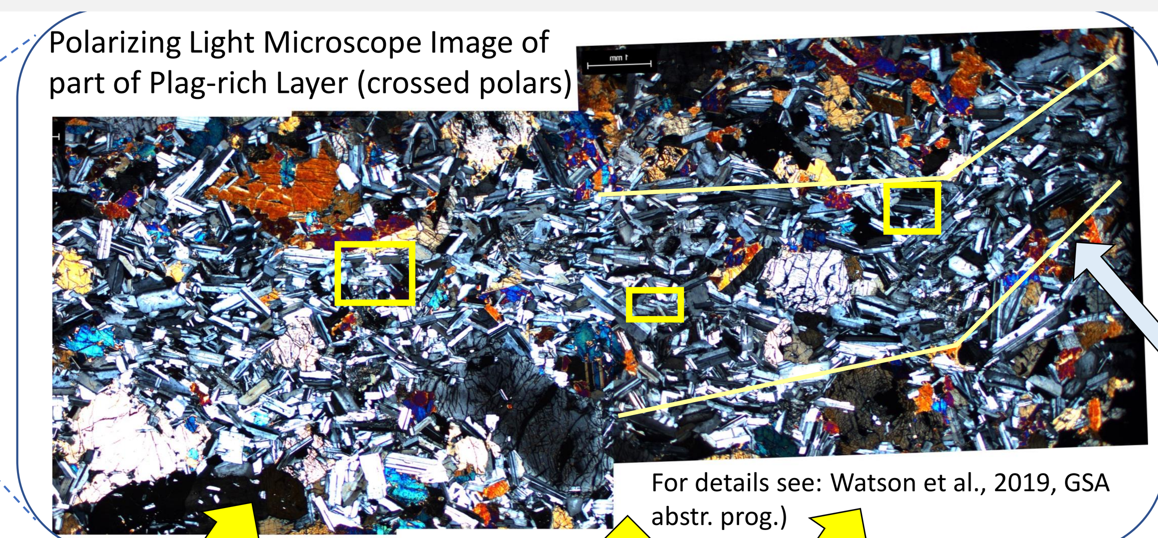




**Fig. A.** Shear thinning separates particles by shape, rotational viscometer experiments (Cimarelli et al., 2011, G³, Fig. 6e.)




For details see: Watson et al., 2019, GSA abstr. prog.)

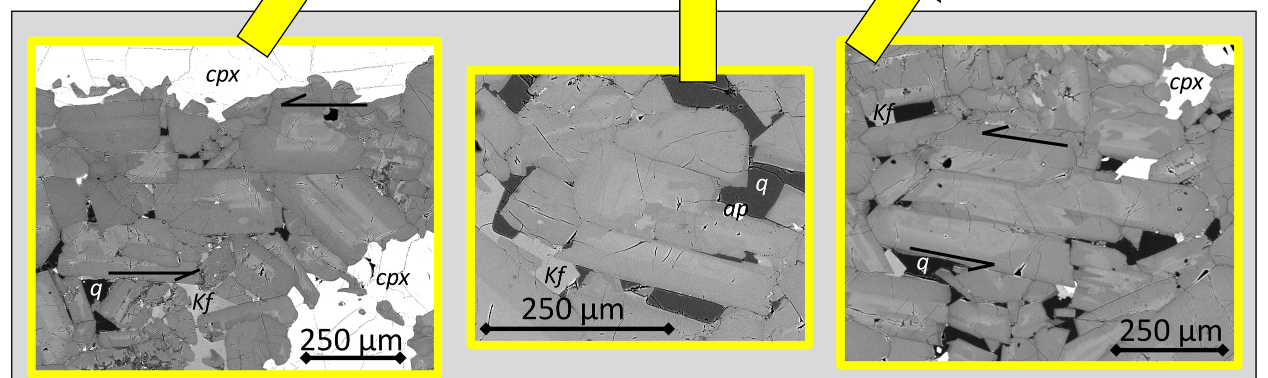
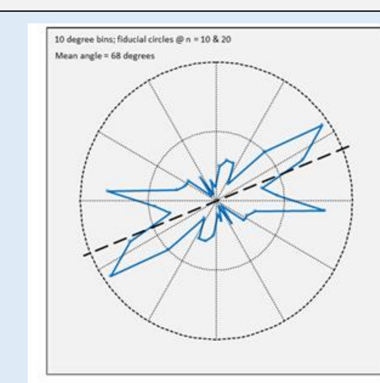
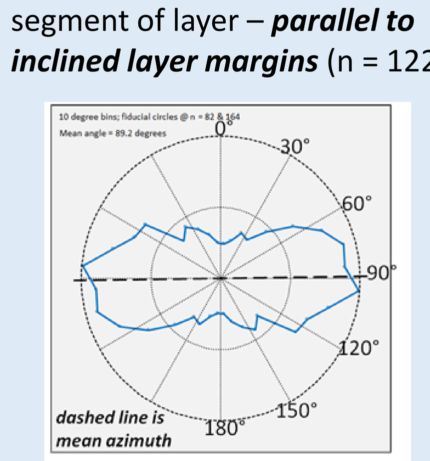



**Fig. D.** Back-scattered Electron (BSE) images: 3 examples of tiled plagioclase grains (out of 12 in plag-rich layer). Images made on FEI Quanta SEM.



Plag orientations in inclined segment of layer – ***parallel to inclined layer margins*** (n = 122)




All plag orientations in layer (n = 1609)

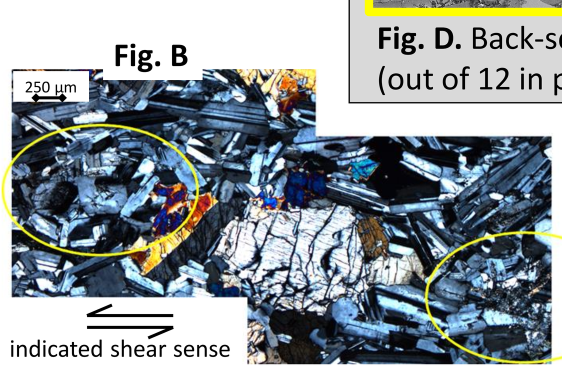
**Long-axis orientations of tabular plagioclase** – shape-preferred orientation (SPO) aligned parallel to layer margins – ***orientations not by compaction alone***

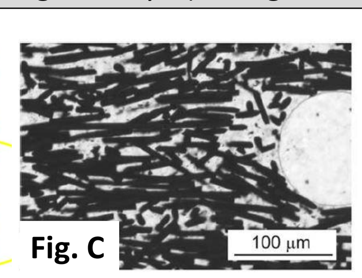
**Evidence for Shear Flow:**

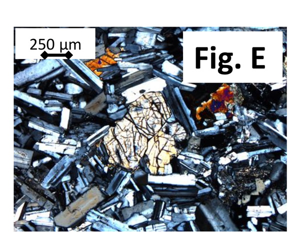
**Fig. B:** Areas of less aligned plag (**yellow circles**) resemble "pressure shadows," and

**Fig. C:** flow of carbon fibers around glass beads (Cimarelli et al., 2011, Fig. 7a).

**Fig. D:** Tiling and imbrication of tabular plagioclase (half-arrows show indicated shear sense).



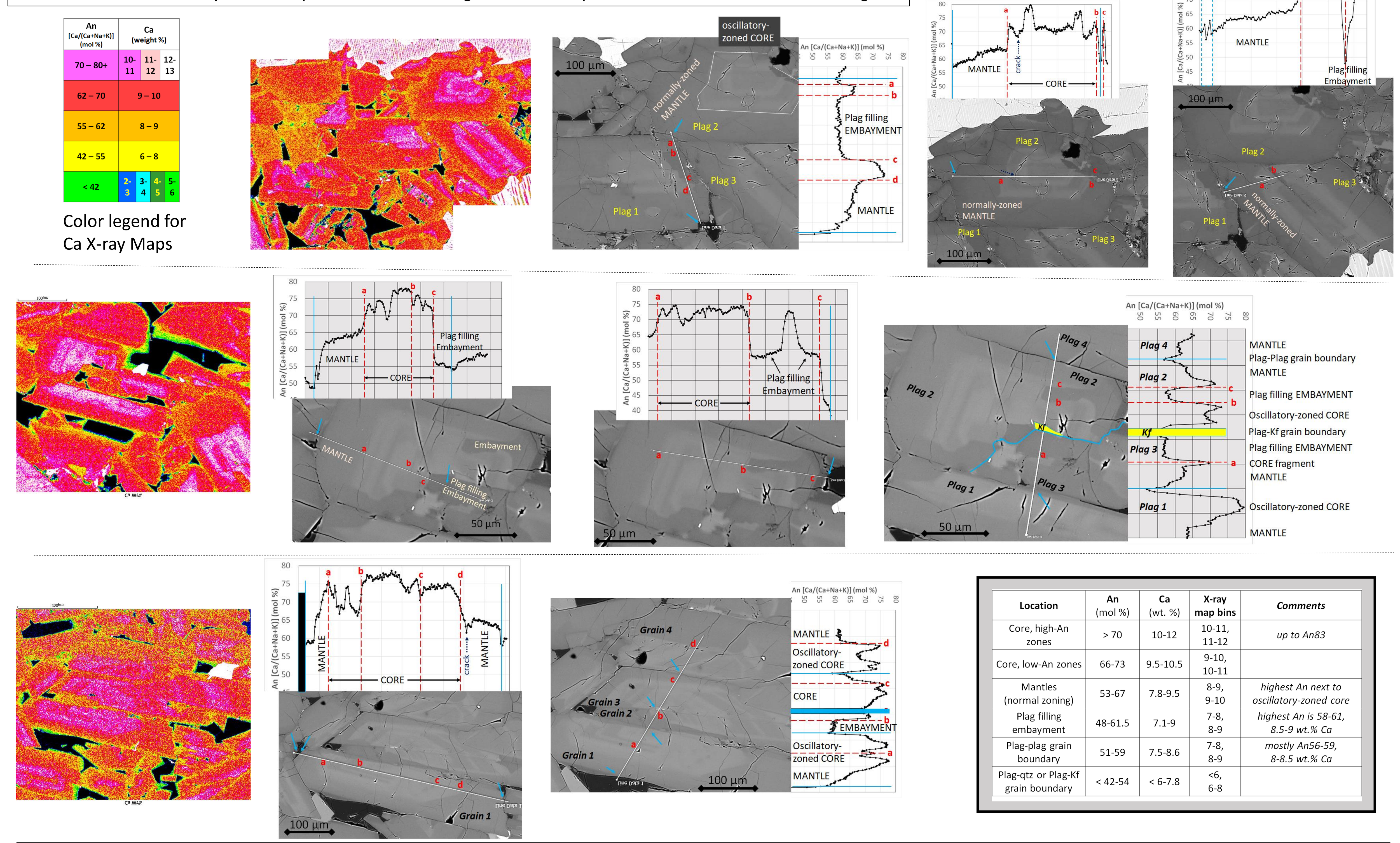




**Evidence for Flow:**

**Fig. E:** Tabular plagioclase wraps larger pyroxene phenocryst (similar to analog experiment, Fig. C).

## 4. Compositions of Tiled Plagioclase Clusters: *Stages of Crystal Alignment and "Cementation" Revealed by Thresholding Ca X-ray Maps and Checked by EDS Linescan Data*

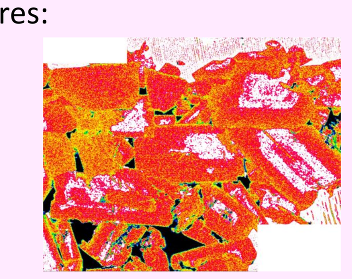
Ca X-ray maps, BSE images, and Linescan analyses obtained using FEI Quanta SEM and Oxford Aztec EDS with Silicon-Drift Detector. X-ray Quant maps are binned for weight % Ca and equivalent An values shown in color legend.




| Location | An (mol %) | Ca (wt. %) | X-ray map bins | *Comments* |
|---|---|---|---|---|
| Core, high-An zones | > 70 | 10-12 | 10-11, 11-12 | *up to An83* |
| Core, low-An zones | 66-73 | 9.5-10.5 | 9-10, 10-11 | |
| Mantles (normal zoning) | 53-67 | 7.8-9.5 | 8-9, 9-10 | *highest An next to oscillatory-zoned core* |
| Plag filling embayment | 48-61.5 | 7.1-9 | 7-8, 8-9 | *highest An is 58-61, 8.5-9 wt.% Ca* |
| Plag-plag grain boundary | 51-59 | 7.5-8.6 | 7-8, 8-9 | *mostly An56-59, 8-8.5 wt.% Ca* |
| Plag-qtz or Plag-Kf grain boundary | < 42-54 | < 6-7.8 | <6, 6-8 | |

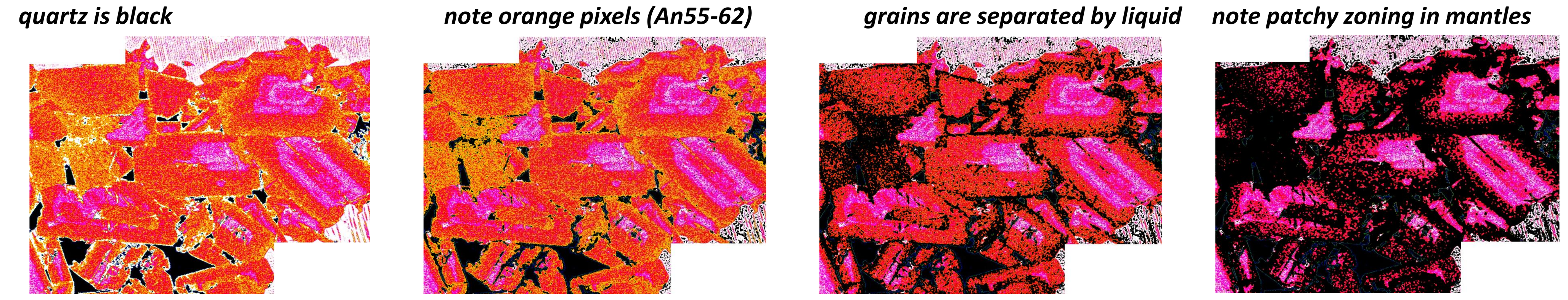
Tiled plagioclase have similar compositions in comparable zones, as summarized in the Table above. Note compositions overlap between most zones. Linescan data help refine bins for X-ray maps and thresholding to explore stages of crystallization (below).

**Color Threshold Ca X-ray Maps in ImageJ (Fiji) to highlight compositional zones.** Turn high-An zones (magenta and pink pixels) to white to see sharp, euhedral Ca-rich zones in cores:



RIMS to CORES: Use Color Threshold in ImageJ (Fiji) to sequentially color pixels in compositional zones.

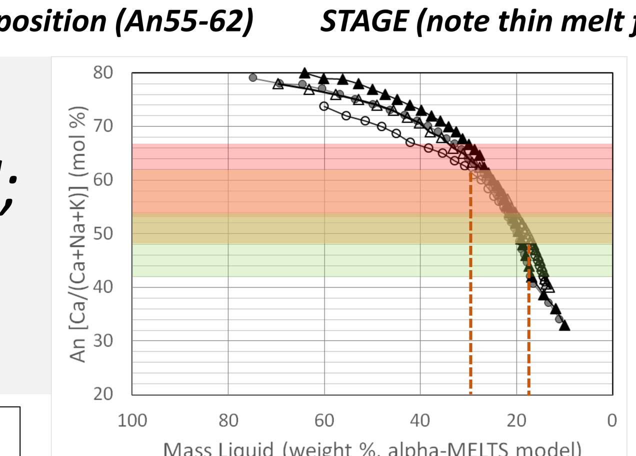
*1. An <42-54, outer rims are white; quartz is black* — *2. An <42-54, outer rims are black; note orange pixels (An55-62)* — *3. up to An62 is black (liquid); grains are separated by liquid* — *4. up to An66 is black (liquid) note patchy zoning in mantles*



Interpret Stages of Crystallization:

*4. outer rims are thin and occur next to quartz (and K-feldspar)* — *3. CEMENTATION STAGE; orange pixels are cementing composition (An55-62)* — *2. ALIGNMENT AND IMBRICATION STAGE (note thin melt films)* — *1. ANTECRYST STAGE - patchy zoning – ascent? resorption?*

## 5. MELTS models of Crystallization Stages: *Alignment and Impingement at 50-30% Liquid; Cementation at 30-20% Liquid (orange, right) Flow in Crystal-Rich Slurries*




**WHITE:** Oscillatory-zoned Cores
*Na-rich zones overlap with Mantles*

**RED:** Mantles around Cores

**ORANGE:** Outer Mantles, Plag filling Embayments, and Plag-Plag Boundaries

**GREEN:** Thin rims along Plag-Qtz and Plag-Kf Grain Boundaries

*Black symbols: bulk rock composition*
*Gray symbols: average lava/chill comp.*
*Closed: 0.5 and Open: 1.0 wt.% H2O*


*Acknowledgements: WCU; NASA Space Grant for Ugrad Research; Meagan Pollock, College of Wooster; Samantha Shumlas, WCU CMIRT Director; Bobby James and Rock of Ages, Inc. for quarry access*