# Testing Deformation-Enhanced Element Mobility in Plagioclase

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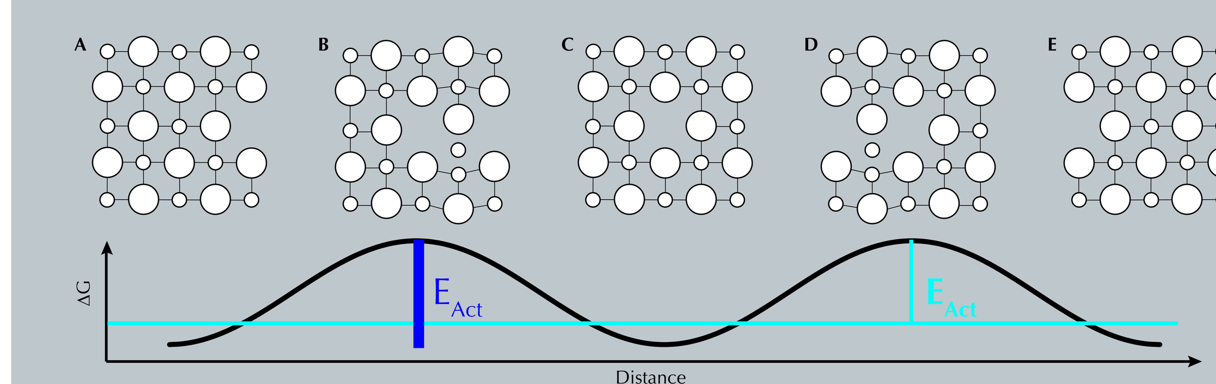
## Why do we care?

If deformation enhances element mobility in minerals:

- Geochronometers, thermometers, and barometers based on static diffusion models cannot be applied to deformed rocks.
- Deformation can be directly linked to a time-dependent process as a basis for a strain speedometer.

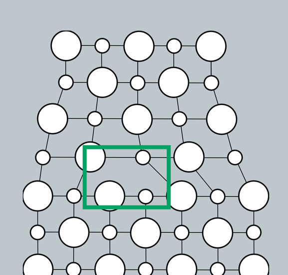
## How can deformation enhance element mobility?

### Point Defects



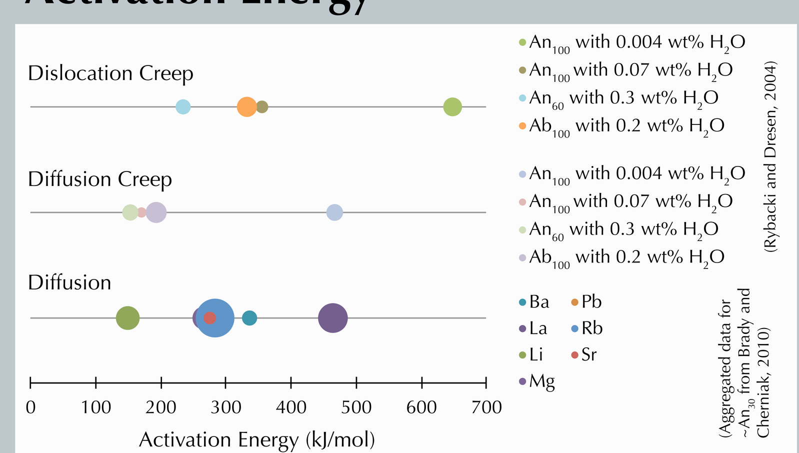

Vacancy and atomic migration amount to lattice deformation. (Figure after Porter and Easterling[1], Fig. 2.6.)

### Line Defects



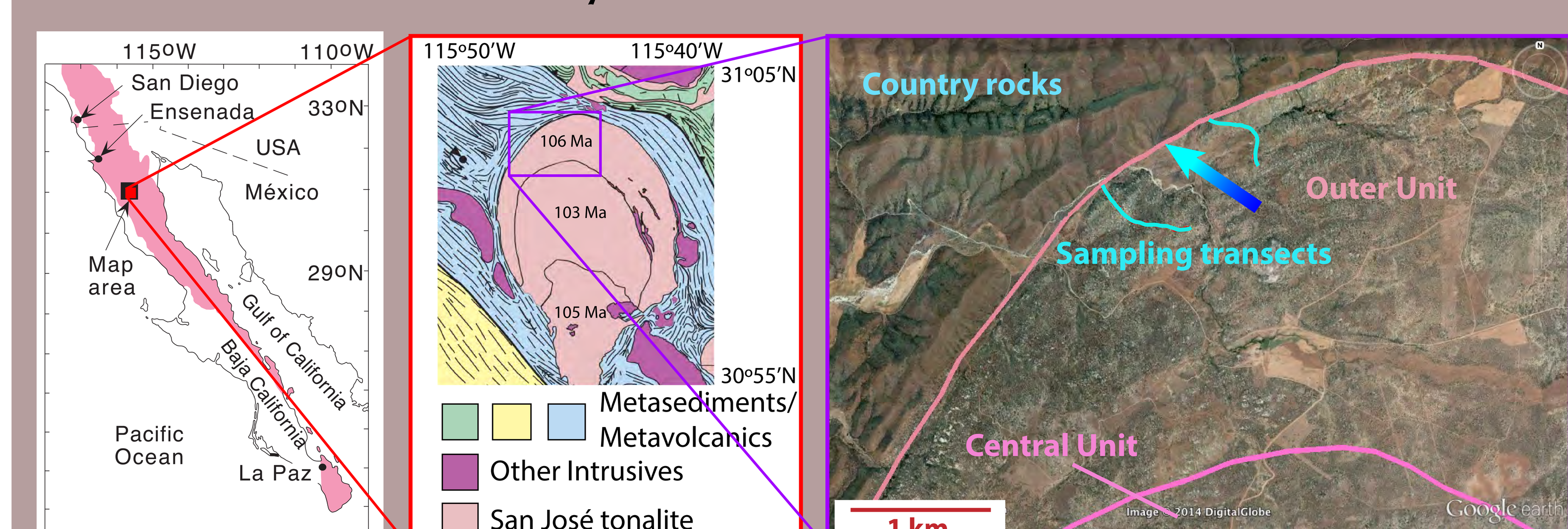
Dislocations provide efficient travel paths that mobilize during deformation.

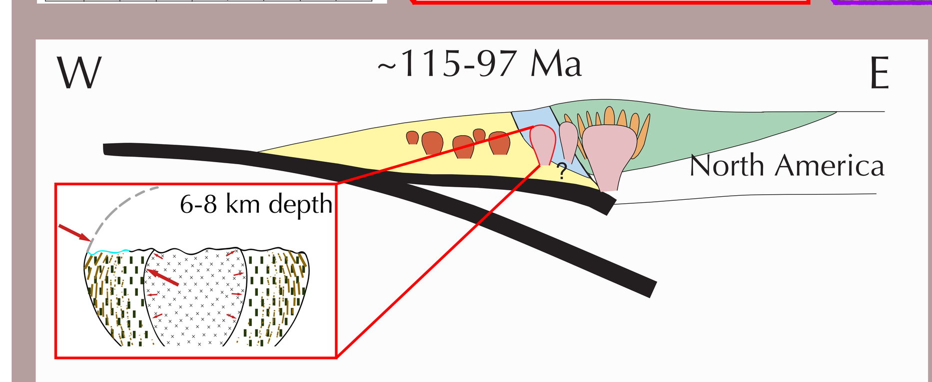
### Activation Energy




Strain adds energy to the lattice, making the atomic jumps easier (cyan line on graph above). Activation energies for diffusion and deformation are similar, for example in plagioclase[2,3].

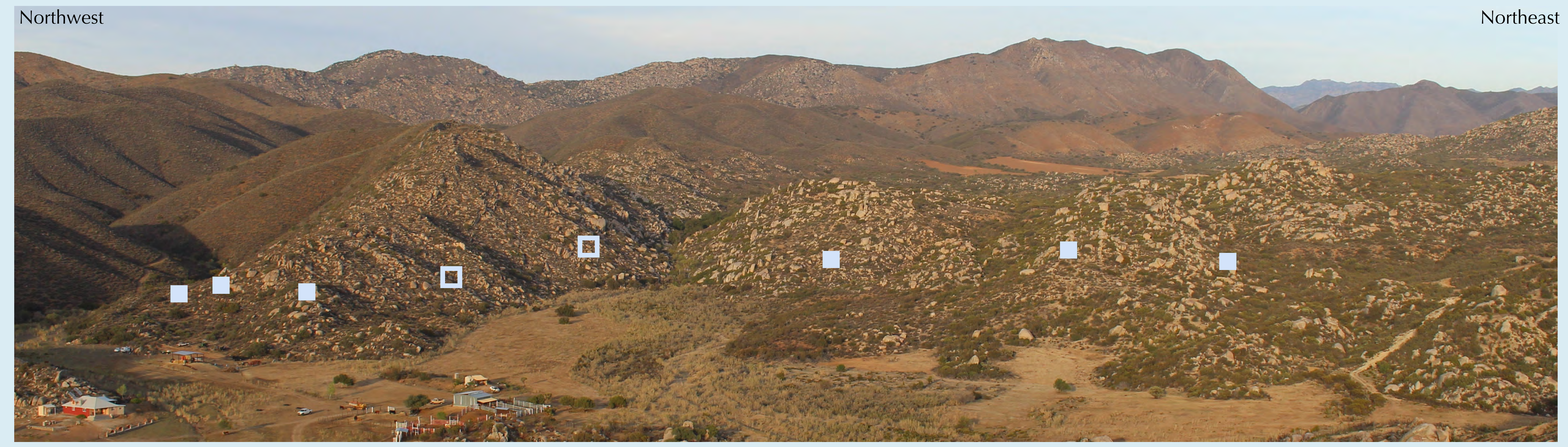
## Where can we study this?




Study area of fully-exposed strain gradient in tonalite with compositionally zoned plagioclase phenocrysts which serve as physical and chemical strain markers. Maps modified from Johnson *et al.*[4] and sattelite image from Digital Globe/GoogleEarth 2014.

## What changes along the map-scale strain gradient?

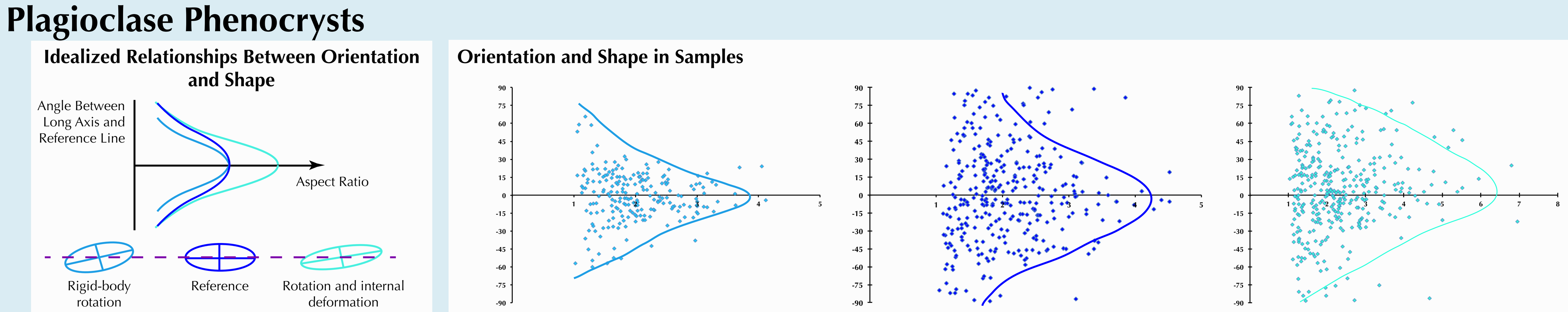



Strain gradient sample locations, with ranch for scale.

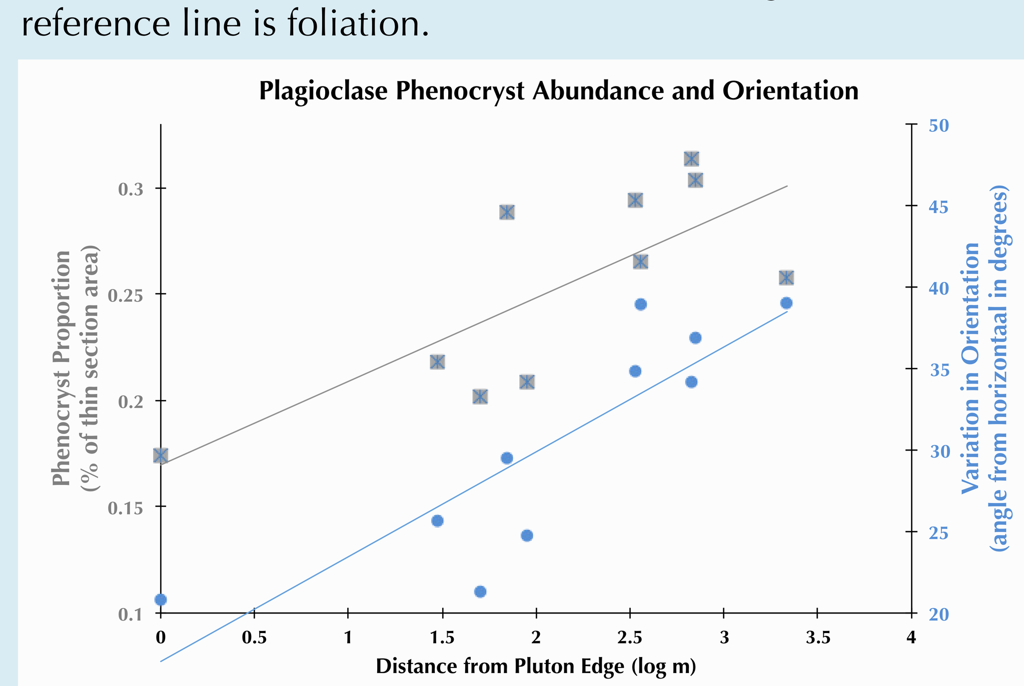
### Deformation at Meter to Micrometer Scales

Solid-state, Bt foliation, Plg phenocrysts rare — Connected Bt, fewer Plg phenocrysts, smaller Hbl — Bt flattening, increasing Plg alignment — Magmatic alignments, Hbl dominates mafic phases

### Plagioclase Phenocrysts

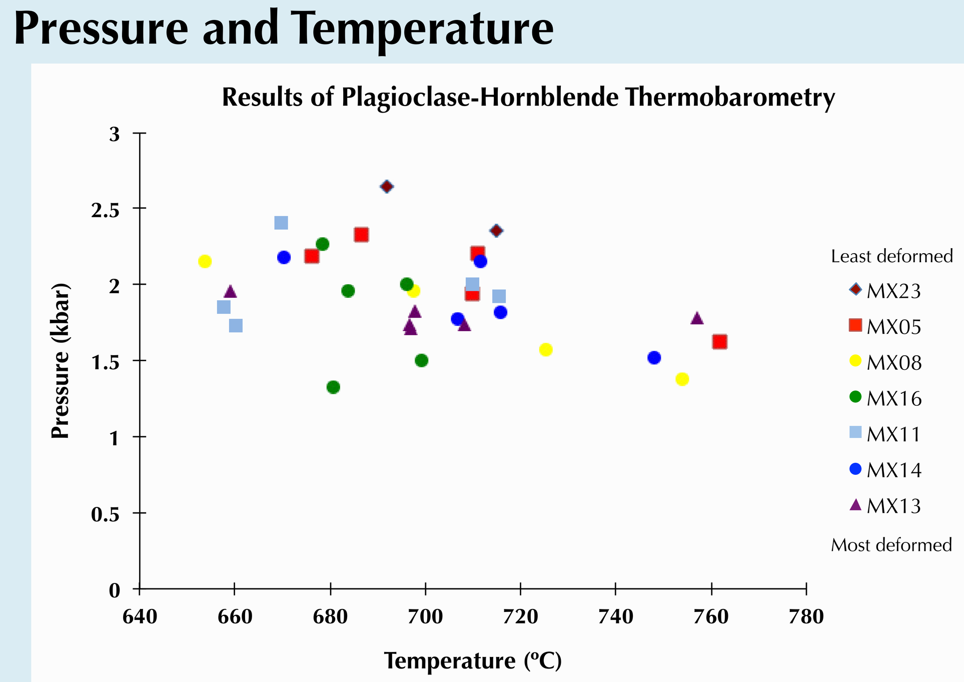



Ellipses fit to Plg phenocrysts circled in thin sections show rotation with little internal deformation. Here the reference line is foliation. — Strongly deformed, phenocrysts rare, strong alignment in foliation — Undeformed, little to no magmatic alignment — Very low strain, strong magmatic alignment, long phenocrysts




Phenocrysts decrease in abundance and size with increasing strain toward the edge of the pluton. Decreasing variation of phenocryst long axes shows increasing preferrent alignment.

### Pressure and Temperature

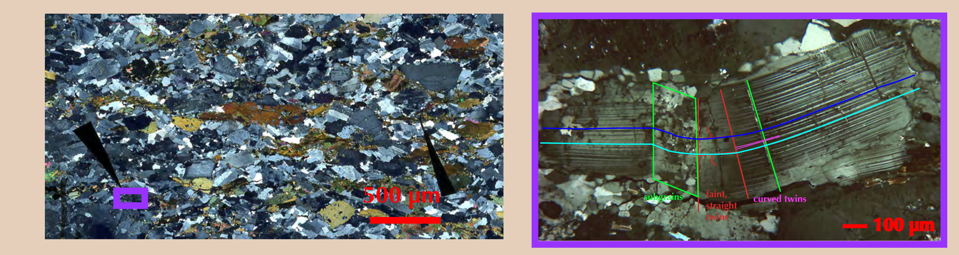



Pressures and temperatures measured in plagioclase and hornblende[5] do not vary with strain indicating no systematic fluid overprint nor divergent thermal history.

## What should change at the grain scale?

We measured diffusion profiles and strain in zoned plagioclase phenocrysts with complete internal strain gradients. This way, we control for variables such as starting concentrations, magmatic history, and crystallographic orientation effects. We present results from the grain with highest strain, nicknamed "MTL".

### Strain

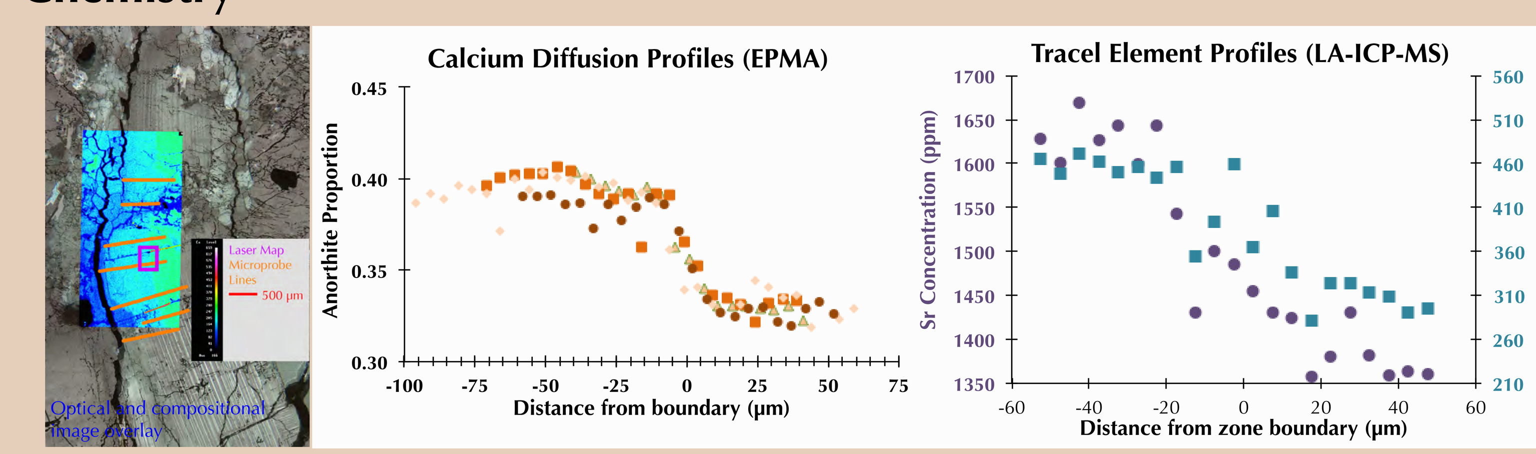


Thin section scan, xpl — Photomicrograph, xpl

- Total integrated elongation: 1.5±.5% at the composition zone boundary (cyan line)
- Localized strain in the hinge of the bend: total elongation of 11±2%.

Three intragrain regions accommodate extension with different deformation mechanisms. The shortening direction is approximately vertical to this grain, consistent with the elongation direction (measured in oriented thin section) and flattening of the pluton carapace.

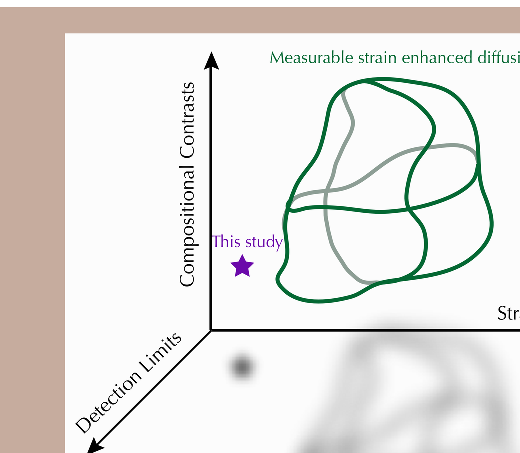
### Chemistry




We anticipated that diffusion profiles would be more smooth with increasing strain for the same elements (here Ca) and that more slowly diffusing species (Ba) would show more sharp steps than more rapid diffusers (Sr). Rather, we see perfect, consistent major element profiles. Trace element profiles have variation which cannot be accounted for.

## What does this boil down to?

For this small strain, deformation-enhanced element mobility cannot be measured in plagioclase with present methods. However, previous work[6,7] in silicates indicates it can be measured in natural samples. Future work should explore variables such as compositional contrasts, strain, time, temperature, pressure, thermal history, and analytical methods to constrain the realm of deformation enhanced diffusion.




## Where did the information come from?

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## Who helped us?

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