Validation of a New Sand Tracking Technique: Pb isotopes in detrital plagioclase

Blowick, A[1]., Tyrrell, S.[1], Haughton, P.D.W.[2]

[1]Earth and Ocean Sciences, National University of Ireland, Galway [2] School of Earth Sciences, University College Dublin, Ireland

aoife.blowick@icrag-centre.org

1 Background

Plagioclase is a common mineral in both felsic and mafic rocks and can therefore offer a much needed way of fingerprinting mafic source inputs which are typically underrepresented by more felsic sourced provenance tracers such as zircon and K-feldspar (Table 1). However, its potential as a sand tracking tool has yet to be thoroughly explored.

To date, the small number of detrital plagioclase grains analysed demonstrate similar Pb isotopic compositions as detrital K-feldspar (Figure 1), highlighting the potential for the Pb isotopic composition of detrital plagioclase to be used as a source fingerprint.

This project therefore aims to characterise the Pb isotopic and geochemical composition of plagioclase grains in order to assess its utility as a provenance indicator. If validated, Pb isotopes in detrital plagioclase will provide a powerful fingerprinting tool for sand tracking, particularly within basins along active margins.

	Probability of being recycled	Relative fertility in felsic basement	Relative fertility in mafic basement	Relative persistence in sedimentary environment	Relative abundance in sedimentary rocks	Relative ease of adequate source characterisation	Probability of modification prior to/after deposition	Validated
U-Pb Zircon	high	high	low	high	low	low	low	✓
U-Pb Apatite	low	high	high	average	high	low	average	✓
Pb-in K-feldspar	low	high	low	average	high	high	high	✓
Pb-in Plagioclase	low	average	high	low	high	high	high	✗

Table 1. *Comparison of some potential provenance tracers. Plagioclase has yet to be validated as a sand tracking technique.*

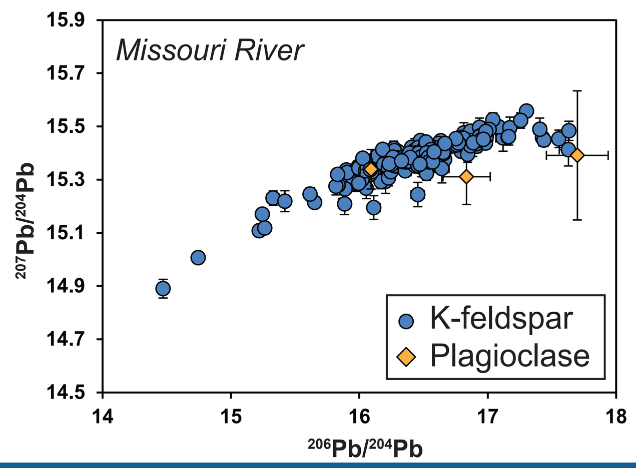


Figure 1. (Right) *Plagioclase grains within the Missouri River have comparable Pb isotopic compositions with detrital K-feldspar grains, albeit with larger analytical errors.*

2 Key Questions

(1) Does the Pb isotopic composition of plagioclase reflect the initial Pb isotopic composition of its source or has *in situ* radiogenic ingrowth occurred?

(2) Does the Pb isotopic composition of detrital plagioclase remain unchanged through weathering, transport, burial and diagenesis?

(3) Is plagioclase zoned with respect to Pb isotopes? If so, is the variation between zones greater than the natural spread in composition observed in putative source rocks? Can these discrete zones be used as diagnostic provenance signals?

(4) What is the optimal analytical procedure to analyse low Pb contents in plagioclase?

3 Approach

Validation

In order to validate that the Pb isotopic composition of plagioclase reflects the initial composition of its source the Pb isotopic and U, Th and Pb concentrations of both felsic and mafic crystalline basement-arkose pairs will be characterised. An example of a felsic pair is shown below:

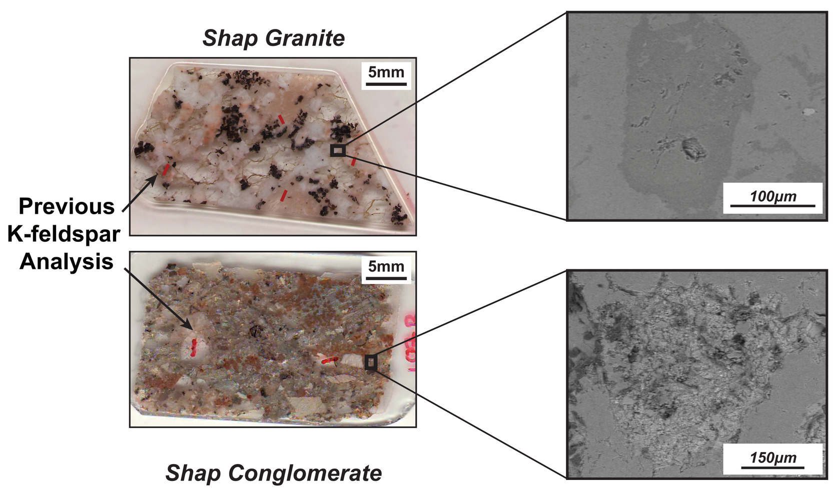


Figure 2. *Backscatter electron images of plagioclase grains in the Shap Granite and Shap Conglomerate.*

Modern Settings

Plagioclase in systems with simple dispersal pathways and limited burial will be analysed in order test whether detrital plagioclase retains the Pb isotopic compositon of its source rock despite weathering, erosion and deposition. Volcanic crystals will also be tested for Pb isotopic zoning.

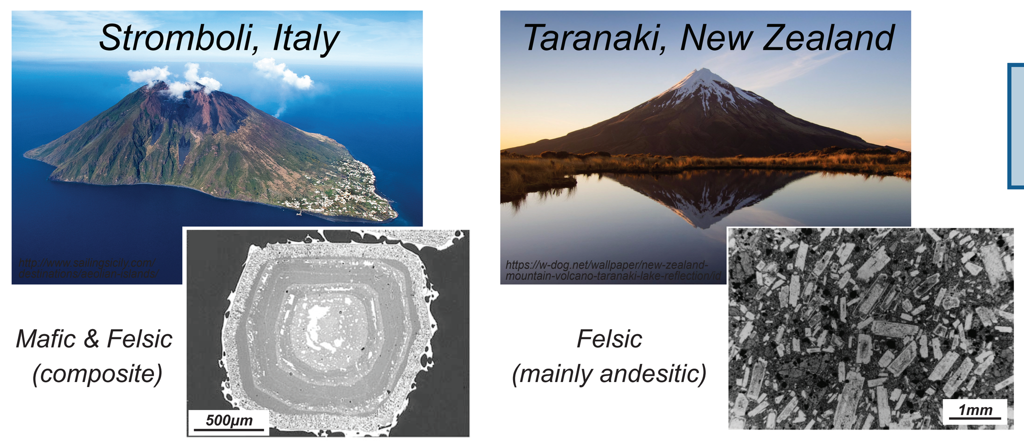
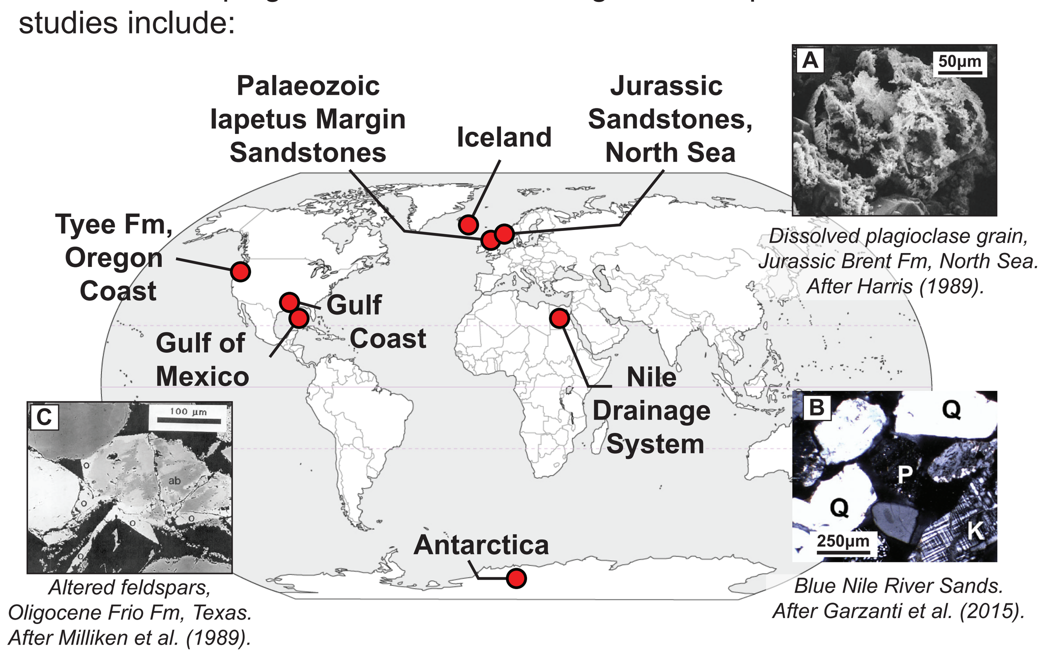


Figure 3. *Backscatter electron images of plagioclase crystals from Stromboli pumice (left) and andesitic lava from the Egmont (Taranaki) summit (right) showing zoning. After Landi et al. (2004) and Higgins (1996) respectively.*

Ancient Settings

Analysis of plagioclase in ancient systems, at a range of stratigraphic depths, will help to constrain any potential diagenetic biases, in particular albitisation of plagioclase with increasing burial depth. Potential case studies include:



4 Principles

If plagioclase crystals contain neglibile quantities of U and Th, and thus negligible radiogenic ingrowth has occurred over time, the Pb isotopic composition of individual crystals represent the unchanged (i.e. initial) Pb isotopic composition of their source rock. Alternatively, it may be possible to correct for the radiogenic ingrowth using the Pb isotopic composition of K-feldspar.

If it can be shown that this Pb isotopic fingerprint is retained through weathering, transport, burial and diagenesis, then it can be matched to the Pb isotopic signatures of crystalline basement rocks (Figure 4). In addition, if detrital plagioclase grains are isotopically zoned it may be possible to use sucessive zonal Pb isotopic compositions as high resolution provenance indicators. However, this remains to be tested.

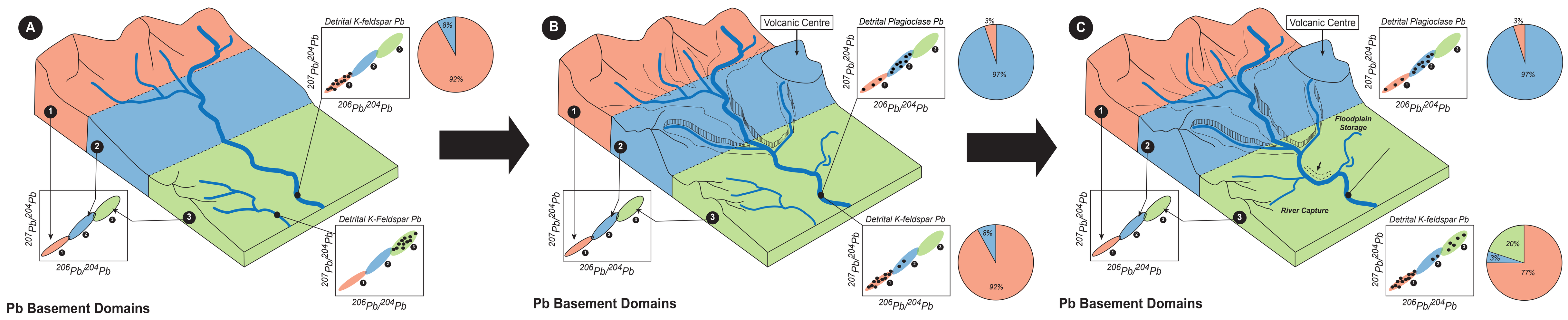


Figure 4. *Schematic illustrating the main principle behind the Pb-in-feldspar technique. Plagioclase grains which retain the Pb isotopic signal of their source rock can be matched to discrete basement domains, each with a diagnostic Pb isotopic range. Plagioclase can be particularly useful to trace inputs from mafic sources which are otherwise underrepresented by felsic grains such as K-feldspar (plot B).The 2D plots show where feldspars in each sample would plot in Pb-Pb plots while pie charts show the relative proportion of each source population in each sample. Modified from Tyrrell et al. (2006).*

5 Methods

Petrography

Petrography will be used to characterise all grains including the presence of inclusions, twinning and/or zoning. In buried sandstones, diagenetically altered grains will be targeted.

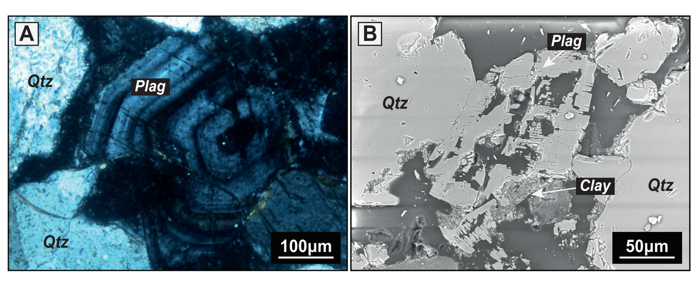


Figure 5. (A) *A zoned plagioclase grain in the Rio Grande River, characteristic of a volcanic source (Pettijohn et al., 1987).* ***(B)*** *Dissolved plagioclase grain and associated clay formation.*

LA-ICPMS Elemental Mapping

Plagioclase grains will be mapped using high resolution LA-ICPMS mapping, scanning electron microscopy and EDX spectral analysis in order to determine elemental distributions and compositions.

Adapted after xser.carleton.edu/details/images/8598.html.

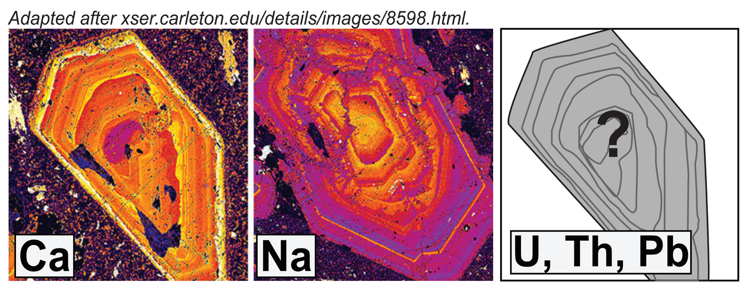


Figure 6. *Element maps of a typical plagioclase crystal with an anorthite rich core and an albite rich rim.*

LA-MC-ICPMS

Plagioclase grains will be analysed *in situ* using Laser Ablation ICPMS. High resolution analysis (<30μm) will help to overcome problems associated with areas of low Pb and/or small grain sizes.

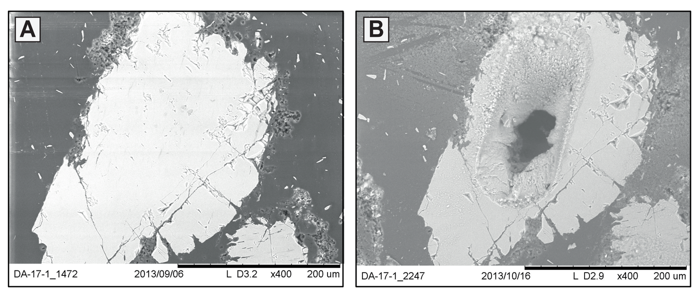


Figure 7. *Backscatter electron micrographs showing a detrital K-feldspar* ***(A)*** *before and* ***(B)*** *after in situ laser ablation. Pre-screening of grains allows intragrain heterogenities to be avoided.*

Weathering Experiments

Both field and lab based experiments will run alongside the validation study in order to better understand what impact, if any, weathering has on the Pb isotopic composition of feldspar grains.

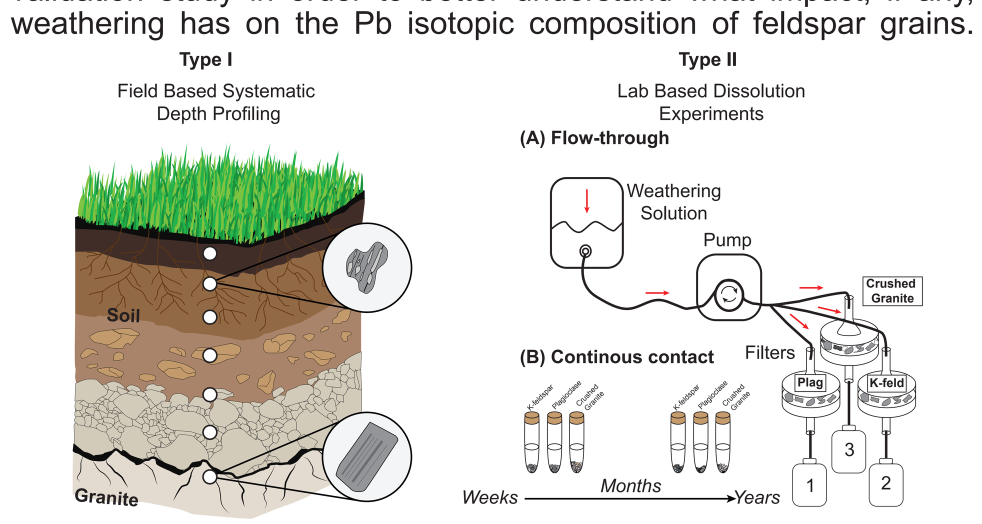


Figure 8. *Feldspar grains in soil profiles will be characterised at systematic intervals. Lab based experiments will include flow-through and continuous submergence set-ups to mimic natural weathering conditions.*

6 Potential Complications & Solutions

(1) Zoning

K-feldspar grains have been previously shown to exhibit Pb isotopic zoning (Gagnevin *et al.,* 2005, Tyrrell *et al.,* 2006). High resolution laser mapping combined with multi-track isotope analysis will be used to constrain if plagioclase grains are isotopically zoned.

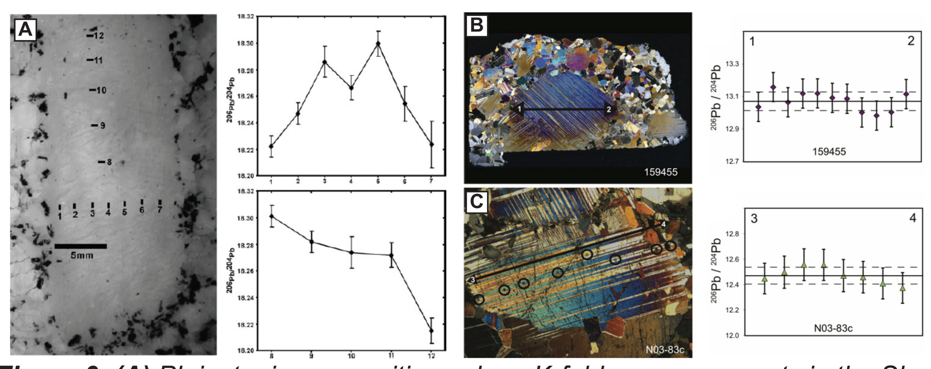


Figure 9. (A) *Pb isotopic compositions along K-feldspar megacrysts in the Shap Granite have been shown to exhibit systematic zoning (Tyrrell et al., 2006).* ***(B-C)*** *Example of plagioclase grains showing no clear Pb isotopic zoning after Souders et al. (2013).*

(2) Low Pb and/or Small Grain Sizes

Plagioclase grains typically contain <10ppm of Pb, significantly less than K-feldspar grains (Figure 10 below). Low Pb contents will require analysis using ion counters and/or highly efficient laser transmission pathways.

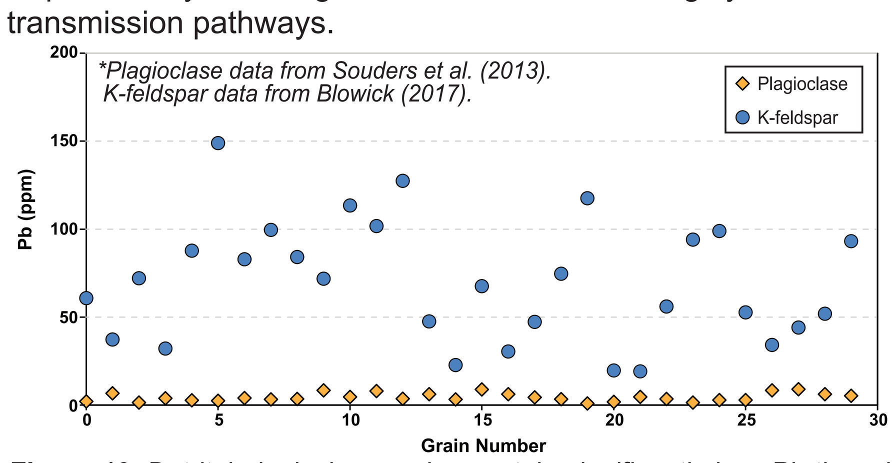


Figure 10. *Detrital plagioclase grains contain significantly less Pb than detrital K-feldspar, and may therefore require an alternative analytical approach.*

(3) Albitisation and Inclusions

Inclusions and altered zones, which may perturb the initial Pb isotopic signal, are avoided by screening samples using optical and scanning electron microscopy prior to ablation. However, albitised plagioclase grains will be targeted in buried sandstones and carefully characterised in order to assess if Pb isotopic signals are retained at depth.

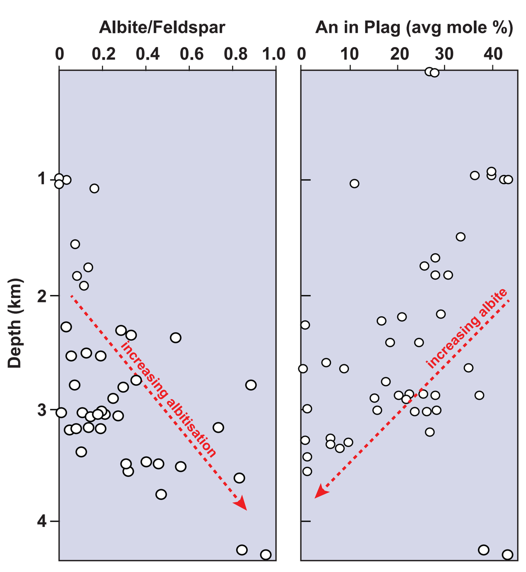


Figure 11. *Example of progressive albitisation of feldspar with depth from the Oligocene Frio Formation, Texas. Modified after Milliken et al. (1989).*

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