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U/Pb–^{40}Ar/^{39}Ar Coupling Approach for the Reconstruction of Paleo-River Systems: A Case Study of the Siluro-Devonian Old Red Sandstone

Nicholas Christie-Blick
Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York

We report on progress over the past two years to characterize the ^{40}Ar/^{39}Ar geochronological signature of muscovite from the Silurian-Carboniferous Old Red Sandstone (ORS) and potential source terranes within the Caledonide orogen of Scotland, Norway, and Greenland. It was determined early in the project to focus on ^{40}Ar/^{39}Ar dating because detrital zircons yield consistently one-billion-year 'Grenville' ages that we judged to be less useful in discriminating sediment sources.

The hypothesis that we set out to test was that the source of the ORS was for the most part distant from what is now the Scottish Highlands because pebbles and larger fragments (clasts) in conglomerates are composed largely of felsic to intermediate igneous rocks rather than metamorphic rocks that are characteristic of the Southern Highland terrane. It was recognized that local clasts make an appearance within the upper part of the ORS, but not in sufficient quantities to account for the bulk of the sediment. This was taken as evidence for paleogeographic separation between the Southern Highland and Midland Valley (ORS) terranes until deposition of the uppermost part of the ORS in early Carboniferous time. Unusually large sandstone bars (in excess of 10 m thick) were interpreted to imply the existence of a large river system, sourced perhaps as far away as Scandinavia.

Our main conclusion is that clast assemblages alone cannot be used in this way to discriminate between distal and proximal sources. Indeed, it is not possible to exclude the idea that Scottish 'terranes' developed in more or less their contemporary arrangement. Among evidence leading to this revised view, detrital age spectra for the uppermost ORS – the section containing the widely cited metamorphic fragments from the Southern Highlands – are indistinguishable from those asserted to have been distally sourced. Detrital muscovite ages from the ORS cluster between 480 and 420 Ma. Ages as young as 370 Ma reported last year turn out with additional measurements to be less abundant that initially thought.

Muscovite ages from potential source rocks in Scotland are primarily between 490 and 400 Ma. Published ages from Scandinavian source rocks cluster between 500 and 390 Ma, making it very difficult to determine the origin of the ORS from aggregate data. A difference nonetheless exists between the ORS of Scotland and comparable sedimentary rocks in Scandinavia. In Scotland, detrital ages do not vary much with stratigraphic position, consistent with modest rates of exhumation associated with the erosion of a compressional orogen. In Scandinavia, rocks were rapidly exhumed tectonically from depths as great as 100 km, a circumstance in which age spectra should include detrital ages close to contemporaneous with the time of deposition. In a Columbia PhD study completed in 2015, John A. Templeton observed that age spectra in Scandinavia vary systematically with stratigraphic position, consistent with that expectation. It seems likely on these grounds that Scottish ORS sandstones were sourced primarily from Scotland. We note that at several Scottish localities at which a depositional age can be independently established on the basis of biostratigraphy, the youngest detrital ages are as much as 5-15 million years older than the time of deposition. The paleo-river system that led to the

deposition of the ORS is consistent in scale with the unroofing of a major mountain belt. Our data nonetheless suggest that the ultimate source for sediment may not have been as far afield as Scandinavia, a result that changes decades of thinking about Scottish geology.

A broader conclusion to emerge from the research concerns the value of considering the stratigraphic context of detrital muscovite ages, and how the perception of source terranes is influenced by how rapidly exhumation took place. The $^{40}Ar/^{39}Ar$ system thus provides a materially different way of thinking about provenance compared with more widely employed U/Pb detrital zircon geochronology. Zircon data integrate all of the sources of sediment, some or much of which may be recycled from older sedimentary rocks and ultimately, deep crustal rocks.

Further work is indicated on unresolved issues: 1) to employ step-heating experiments on ORS muscovite to test for post-depositional resetting of ages; 2) to obtain better constraints on stratigraphic ages for comparison with detrital data through dating of volcanic flows; 3) to re-evaluate the varied relationships between volcanic rocks and conglomerate in the Midland Valley terrane; 4) to place additional constraints on the source of the igneous clasts in ORS conglomerates; and 5) to reconsider the signficance of the Highland Boundary fault between the Midland Valley (ORS) and South Highland terranes. Michael DeLuca plans to continue working on these issues insofar as we are able to obtain follow-up funding. The project has contributed to his goal of becoming a well rounded geologist with diverse geochronological and geochemical skills. We are most grateful to ACS-PRF for getting us this far.

A comprehensive manuscript is close to submission for publication. It was determined, before finalizing the text, to test our stratigraphic model with the dating of selected volcanic flows, and to undertake several step-heating experiments to firm up our interpretation of detrital muscovite ages as provenance indicators.