Post Acadian Sediment Recycling in the Devonian Old Red Sandstone of Southern Ireland

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Introduction

The Late Palaeozoic tectonostratigraphic history in southern Ireland is dominated by three distinct orogenic phases corresponding to the end-Silurian Caledonian, the mid-Devonian Acadian and end-Carboniferous Variscan orogenies, with two intervening periods of net crustal extension and associated basin development.The first of these phases of extension resulted in the development of the Upper Silurian-Lower Devonian Dingle Basin with a Lower Old Red Sandstone (LORS) fill. The second phase is associated with the Upper Devonian-Carboniferous Munster Basin which contains Upper Old Red Sandstone (UORS) units. The UORS fill of the Munster Basin has traditionally been seen as a post-orogenic mollase deposit sourced from the Caledonide belt to the north[1], which was deformed by the subsequent Variscan event *c.* 320 Ma[2]. However this represents an oversimplification of both the tectonic and sedimentary histories of southern Ireland since it ignores the impact of the mid-Devonian Acadian orogeny.

This study uses a multidisciplinary approach to establish a genetic relationship, by similar provenance, between the LORS and UORS sequences of southern Ireland. A combination of petrographic and microprobe analysis in conjunction with $^{40}Ar/^{39}Ar$ detrital mica dating suggest a shared common provenance between the two units[3].

This new data requires a revised model for the provenance of the UORS deposits in southern Ireland and Britain by highlighting the significance of the Acadian event as a driver for sediment recycling. In addition the $^{40}Ar/^{39}Ar$ data underlines the importance of the onset of a Late Devonian thermal event resulting in the reset of the Ar signature in the detrital mica populations in both the LORS and UORS units in southern Ireland.

Sedimentary Analysis

Lithology (see Fig.2 top)

The Dingle Basin sandstones plot in the sublitharenite field of the QFL diagram, the sandstone formations are chemically and texturally immature, there is a crude increase in maturity moving up sequence into the Smerwick Group.

The Munster Basin samples plot in the quartz arenite field of the QFL diagram and are super mature quartz dominant sandstone units.

Provenance (see Fig.2 bottom)

The Dingle Basin samples plot within the recycled orogen to crayon interior fields, the contain high proportions of polycrystalline quartz, feldspar and abundant volcanic lithic fragments. This combination suggests the sandstones have a local source - most likely the Silurian volcanic hinterland.

The Munster Basin UORS sandstone plots int he craton interior field and are dominated by mono crystalline quartz (>95%), this basin wide sandstone maturity strongly suggests that they represent at a minimum second cycle deposits.

The Munster Basin as a mature second cycle deposit cannot have been sourced directly from the Caledonides to the north, the LORS of the Dingle Basin is much closer in composition to the traditional mollase deposits typical of ORS basins as in the Midland Valley - a basin which is believed to have been the source material for the UORS deposits in the area[4].

Electron Probe Micro-Analysis (EPMA)

Plots of the mica geochemistry highlight the almost indistinguishable trend in composition in both ORS sequences in southern Ireland (Fig. 3). This level of similarity in mica chemistry suggests either a common source for the detritus in both basins or the recycling of material from the LORS Dingle Basin due to Middle Devonian (Acadian) basin inversion. Any deviation from the primary trend in the UORS samples is related to the analysis of a basin margin sample collected beyond the CKMFZ (see Fig.1). This mica is this sample is considered to be derived from the Leinster Granite to the northeast.

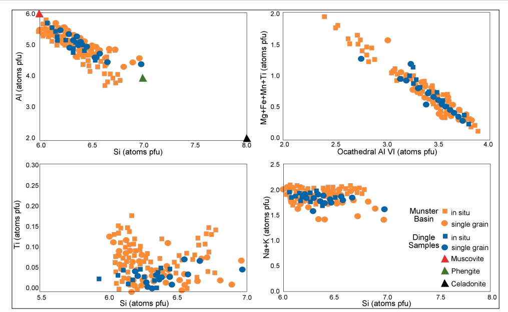


Figure 3. EPMA plots of the LORS Dingle Group & the UORS Munster Basin mica grains. Top left to right; Si vs Al (atoms pfu); Octahedral Al(vi) vs Mg+Fe+Mn+Ti (atoms pfu). Bottom left to right, Si vs Ti (atoms pfu); Si vs Na+K (atoms pfu). (Analysis carried out on single grains and *in situ* on rock tabs).

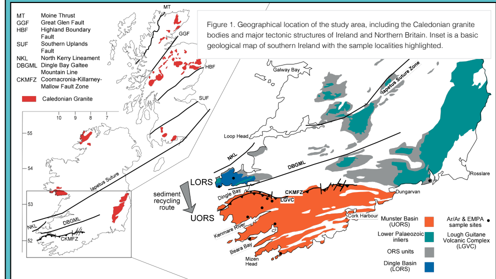


Figure 1. Geographical location of the study area, including the Caledonian granite bodies and major tectonic structures of Ireland and Northern Britain. Inset is a basic geological map of southern Ireland with the sample localities highlighted.

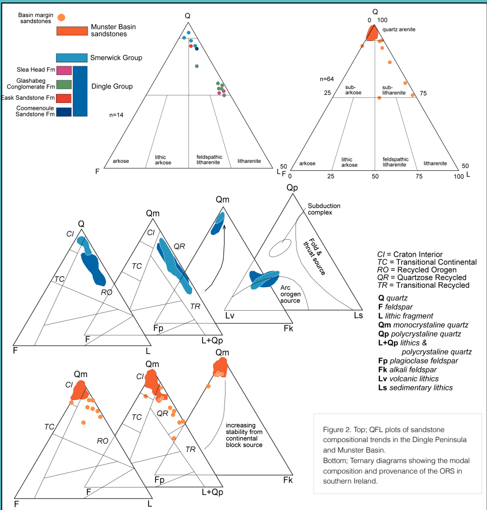


Figure 2. Top; QFL plots of sandstone compositional trends in the Dingle Peninsula and Munster Basin.
Bottom; Ternary diagrams showing the modal composition and provenance of the ORS in southern Ireland.

Primary source of the ORS micas

The LORS and UORS micas are chemically indistinguishable, however a comparison of the ORS mica chemistry with mica grains from potential source areas (Caledonian, Scandian) cannot elucidate a primary source area for the detrital mica of the Dingle and Munster Basins. Partial overlap is visible for all terrains though the lack of substantial data from the source areas make it difficult to establish a definitive relationship between the source area and the ORS micas. While the genetic link between the LORS and UORS is clearly defined the primary source area for the ORS detritus of southern Ireland remains ambiguous.

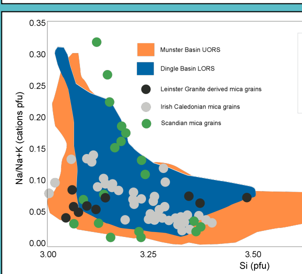


Figure 4. Plot of Si (pfu) vs NA/Na+K (cations pfu) highlighting the variation in mica composition between different areas. Data source areas; Dingle Group, Munster Basin and Leinster Granite derived mica (this study); Caledonian micas [5,6]; Scandian micas [7,8,9].

$^{40}Ar/^{39}Ar$ Dating

The step-heating spectra and total fusion plots show a clear overlap in the range of detrital mica ages from both the LORS and UORS samples. A dominant ages peak can be identified at 410-415 Ma, with subordinate peaks at 430-450 Ma and 360-385 Ma. No older grains (Grampian age) or grains with a marked zonation were recorded from the Irish ORS samples unlike those recorded from the ORS in Wales[10].

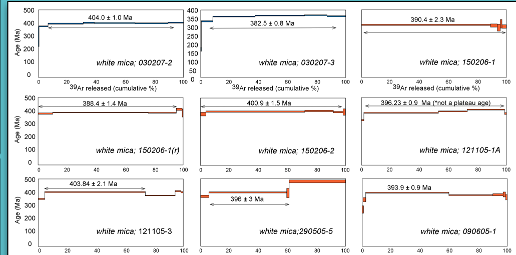
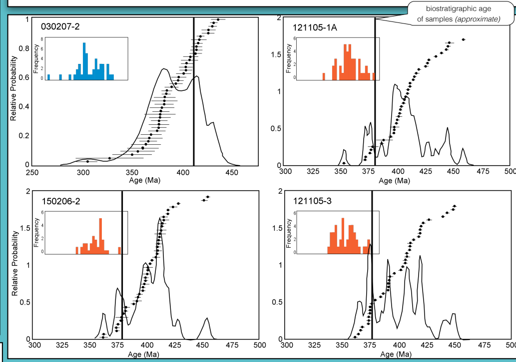


Figure 5. Argon release spectra from the step-heating go mica separates collected from the Dingle Group (blue) and from UORS Munster Basin samples (orange).

Figure 6 (below). Cumulative frequency plots of the 40Ar/39Ar total fusion from the Dingle Group (blue) and the Munster Basin (orange), (includes 1-sigma analytical uncertainty for each single grain analysis. Inset histogram plots further highlight the age distributions.



Impact of LORS to UORS Recycling

There is a clear genetic relationship between the LORS and the UORS of southern Ireland, the units show an up sequence increase in maturity and a closely comparable mica chemistry. This evidence supports a model in which the LORS is the parent material for much of the UORS Munster Basin however the long-lived stable source model used for the Midland Valley in Scotland[4] is not plausible for the basin in southern Ireland.

The Dingle Group fill is locally sourced yet it has the same mica chemistry as the younger Munster Basin, this is not possible unless a parent basin - the LORS Dingle Basin or equivalents across central Ireland - provided a second cycle of detritus to the Munster Basin.

Evidence for such a recycling model can be recognised in a number of sources

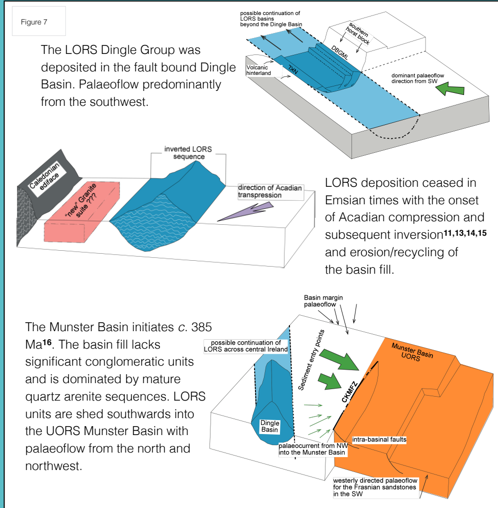
1) mid-Devonian Acadian recycling has been recognised in the Dingle Basin leading to regional scale folding and faulting[11].
2) the timing of the Acadian event in the UK (*c.* 395 Ma[12]) is consistent with the data from southern Ireland, the Acadian orogeny is considered to be responsible for the inversion of significant thicknesses of LORS (2-5 km) in the UK[13].

1. Friend, P.F., Williams, B.P.J. and Williams, E.A. 2000. Kinematics and dynamics of Old Red Sandstone basins. *In*: Friend, P.F. and Williams, B.P.J. (eds). *Perspectives on the Old Red Sandstone*. Geological Society of London Special Publications, **180**, 29-60.
2. Quinn, D., Meere, P.A. and Wartho, J-A. 2005. A chronology of deformation: ultra-violet laser $^{40}Ar/^{39}Ar$ dating of syn/late orogenic intrusions from the Variscides of southwest Ireland. *Journal of Structural Geology*, **27**, 1413-1425.
3. Ennis, M. 2008. *A geochronological study of the Upper Palaeozoic tectono-sedimentary and orogenic history of southwest Ireland*. Unpublished PhD thesis, National University of Ireland.
4. Bluck, B.J. 2000. Old Red Sandstone basins and alluvial systems of Midland Scotland. *In*: Friend, P.F. and Williams, B.P.J. (eds). *Perspectives on the Old Red Sandstone*. Geological Society of London Special Publications, **180**, 417-437.
5. Friedrich, A.M., Hodges, K.V, Bowring, S.A. and Martin, M.W. 1999. Geochronological constraints on the magmatic, metamorphic and thermal evolution of the Connemara Caledonides, western Ireland. *Journal of the Geological Society of London*, **156**, 1217-1230.
6. Chew, D.M., Daly, J.S., Page, L.M. and Kennedy, M.J. 2003. Grampian orogenesis and the development of blue schist facies metamorphism in western Ireland. *Journal of the Geological Society of London*, ***160**, 911-924*.
7. Chauvet, A and Dallmeyer, R.D. 1992. $^{40}Ar/^{39}Ar$ mineral dates related to Devonian extension in the southwestern Scandanavian Caledonides. *Tectonophysics*, **210**, 155-177.
8. Boundy, T.M., Hall, C.M., Li, G., Essene, E.J. and Halliday, A.N. 1997. Fine-scale isotopic heterogeneities and fluids in the deep crust: a $^{40}Ar/^{39}Ar$ laser ablation and TEM study of muscovites from a granulite-eclogite transition zone. *Earth and Planetary Science Letters*, **148**, 123-145.
9. Andersen, T.B. 1998. Extensional tectonics in the Caledonides of Southern Norway, an overview. *Tectonophysics*, **285**, 333-351.
10. Sherlock, S.C., Jones, K.A. and Kelley, S.P. 2002. Fingerprinting polyorogenic detritus using the $^{40}Ar/^{39}Ar$ ultraviolet laster microprobe. *Geology*, ***30**, 515-518*.
11. Meere, P.A. and Mulchrone, K.F. 2006. Timing of deformation within the Old Red Sandstone lithologies from the Dingle Peninsula, SW Ireland. *Journal of the Geological Society of London*, **154**, 975-985.
12. Sherlock, S.C., Kelley, S.P., Zalasiewicz, J.A., Schofield, D.I., Evans, J.A., Merriman, R.J. and Kemp, S.J. 2003. Precise dating of low-temperature deformation: Strain-fringe analysis $^{40}Ar/^{39}Ar$ laser microprobe. *Geology*, **31(3)**, pp.219-222.
13. Soper, N.J. and Woodcock, N.H. 2003. The lost Lower Old Red Sandstone of England and Wales: a record of post-Iapetan flexure or Early Devonian transtension? *Geological Magazine*, **140**, 627-647.
14. Todd, S.P., Boyd, J.D. and Dodd, C.D. 1988. Old Red Sandstone sedimentation and basin development in the Dingle Peninsula, southwest Ireland. *In*: McMillan, N.J., Embry, A.F. and Glass, D.J. (eds). *The Devonian of the World*. Canadian Society of Petroleum Geologists, Memoirs, **14**, 251-268.
15. Todd, S.P. 2000. Taking the roof off a suture zone: basin setting and provenance of conglomerates in the ORS Dingle Basin of SW Ireland. *In*: Friend, P.F. and Williams, B.P.J. (eds). *Perspectives on the Old Red Sandstone*. Geological Society of London Special Publications, **180**, 184-222.
16. William, E.A., Sergeev, S.A., Stössel, I., Ford, M, and Higgs, K.T. 2000. U-Pb zircon geochronology of silicic tuffs and chronostratigraphy of the earliest Old Red Sandstone in the Munster Basin, SW Ireland. *In*: Friend, P.F. and Williams, B.P.J. (eds). *Perspectives on the Old Red Sandstone*. Geological Society of London Special Publications, **180**, 269-302.
17. Hodges, K.V. 1991. Pressure-temperature-time paths. *Annual Review of Earth and Planetary Sciences*, **19**, 207-236.
18. Meere, P.A. and Banks, D.A. 1997. Upper crustal fluid migration: an example from the Variscides of Ireland. *Journal of the Geological Society of London*, **154**, 975-985.

A revised model - recycling of the LORS into the UORS Munster Basin

Following the model developed by Soper and Woodcock[13] in which sequences of LORS were lost during Acadian inversion in the UK (*c.* 395 Ma[12]), a similar scenario can be envisaged for the "lost" LORS of southern Ireland.

Figure 7



The LORS Dingle Group was deposited in the fault bound Dingle Basin. Palaeoflow predominantly from the southwest.

LORS deposition ceased in Emsian times with the onset of Acadian compression and subsequent inversion[11,13,14,15] and erosion/recycling of the basin fill.

The Munster Basin initiates *c.* 385 Ma[16]. The basin fill lacks significant conglomeratic units and is dominated by mature quartz arenite sequences. LORS units are shed southwards into the UORS Munster Basin with palaeoflow from the north and northwest.

Evidence for thermal rejuvenation of detrital mica

A number of age dates which are younger than the biostratigraphic age of the host rock are recorded in the detrital mica populations in both the Dingle and Munster Basin samples (see Fig. 6). As there is no correlation between stratigraphic position and age, these ages can be attributed to variable resetting of the Ar level in the detrital mica by a post-Acadian event - this suggests a continued post-depositional relationship between the LORS and UORS.

The metamorphic evidence from the Munster Basin suggests that temperatures were elevated during Munster Basin extension and it's associated diastathermal metamorphism to allow and continued throughout the subsequent end Carboniferous Variscan tectonothermal event to allow for this variable resetting of the Ar signature in the detrital mica grains. Closure temperature for Ar in white mica is 350°C[17], palaeo-temperatures for the Munster Basin indicates thermal conditions of c. 325°C[18]. While this is below the required temperature, the duration of the heating event (~60 Ma) and the fluid rich basin environment suggest Ar loss could progress at lower temperatures. Using $^{40}Ar^*$ as a proxy for grain size (see Fig. 8) a crude correlation between age and grain size is revealed. This suggests that the larger grains have retained a greater volume of $^{40}Ar^*$ while the smaller thinner grains record the youngest ages due to increased Ar loss.

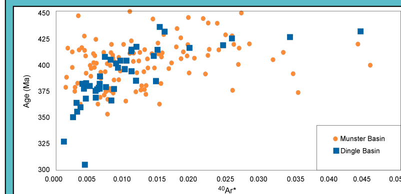


Figure 8. Plot of 40Ar* against age (Ma) highlighting the relationship between mica grain size and age yielded during total fusion analysis (see Fig 6).

Conclusion

This study highlights the importance of Acadian inversion as it was the driver for sediment recycling from the LORS basins into the UORS Munster Basin to the south. Evidence from petrographic and chemical analysis establishes a clear genetic link between the LORS and UORS of southern Ireland.

Age dating yields a detrital mica age peak at 405-415 Ma. Ages younger than the biostratigraphic ages of the host rock can be attributed to the variable resetting of the Ar signature in white mica by Munster Basin diastathermal metamorphism and the subsequent Variscan tectonothermal event.