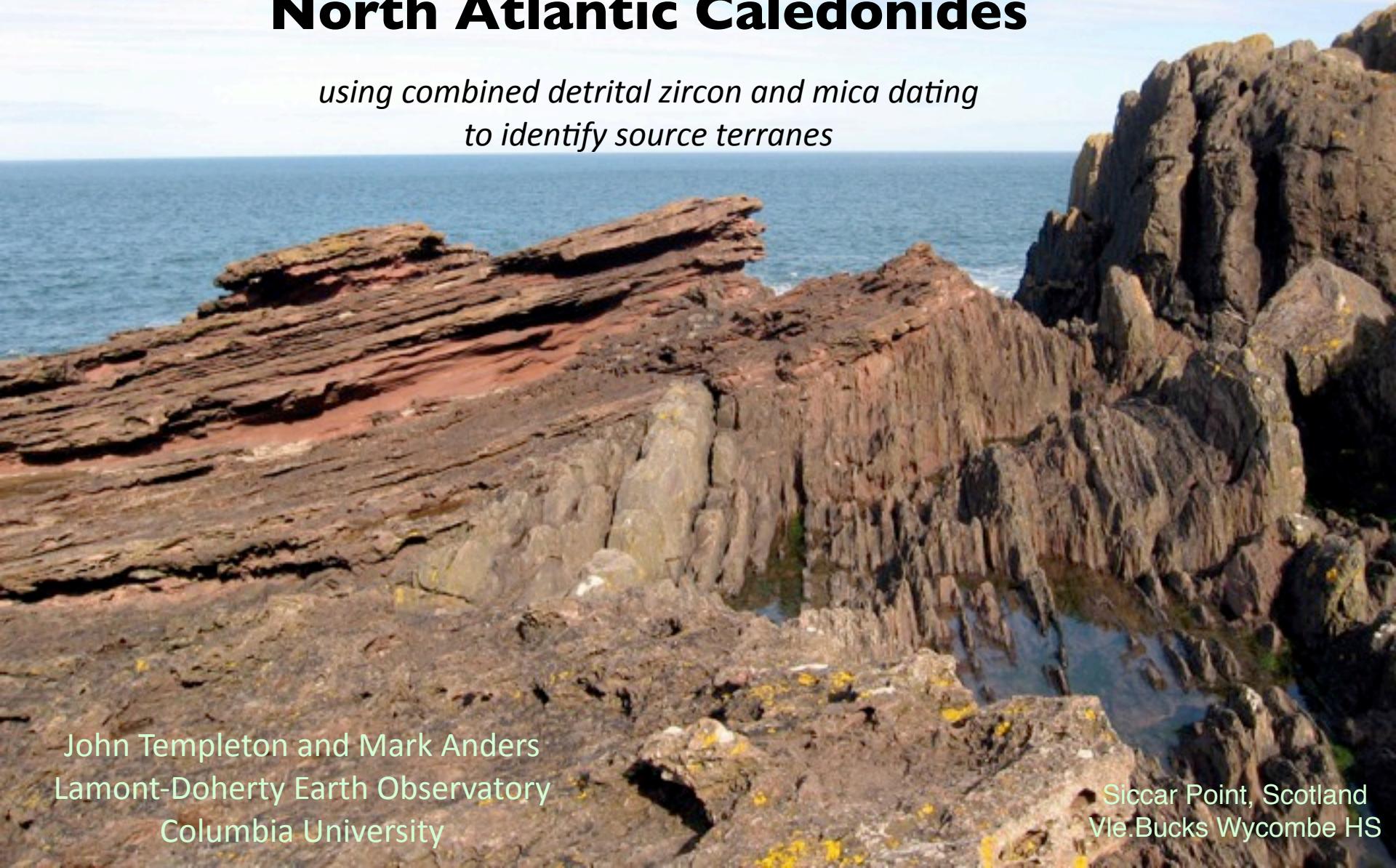


# **Evidence for a major orogen-parallel Devonian river system connecting the North Atlantic Caledonides**

*using combined detrital zircon and mica dating  
to identify source terranes*



John Templeton and Mark Anders  
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Columbia University

Siccar Point, Scotland  
Vle.Bucks Wycombe HS

# support and collaborators

Hornelen mountain, Norway  
(Devonian 'Old Red'  
sandstone & conglomerate)



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Columbia

Simon Cuthbert  
Univ. W. Scotland

Supported by the NSF, Research Council of Norway, Statoil, ExxonMobil and the Petroleum Research Fund



Mark Anders,  
primary advisor



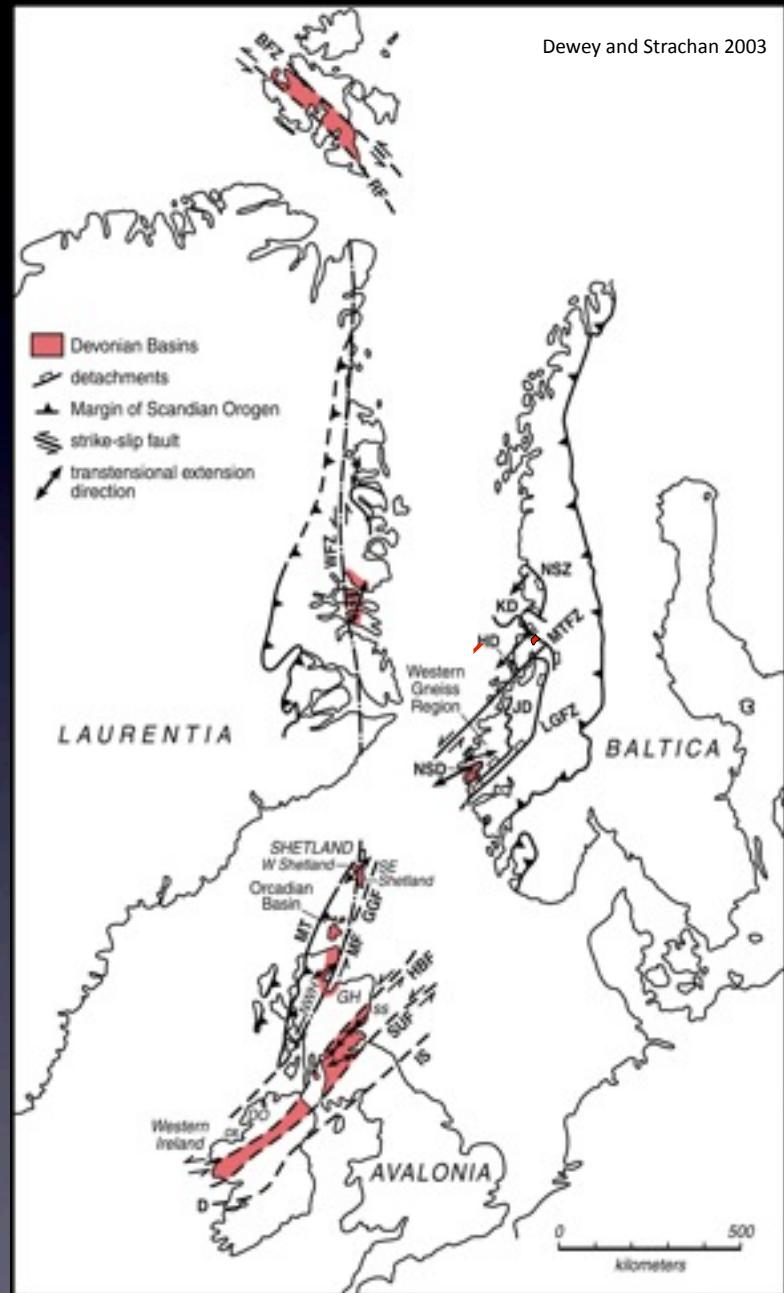
Haakon Fossen and  
Leif-Erik Pedersen  
University of Bergen

Brian Bluck  
Univ. Glasgow

# Caledonian paleogeography



# Old Red Devonian basins



Problem: Large-scale river deposits in the Old Red of the Midland Valley of Scotland have no known origin, e.g. 10 m-thick cross-stratified river bar deposits.

**TEST the hypothesis of a SCANDINAVIAN SOURCE**

Detrital zircon fingerprint of Devonian Norway established by >3000 age analyses from the collection of all Norwegian Devonian basins

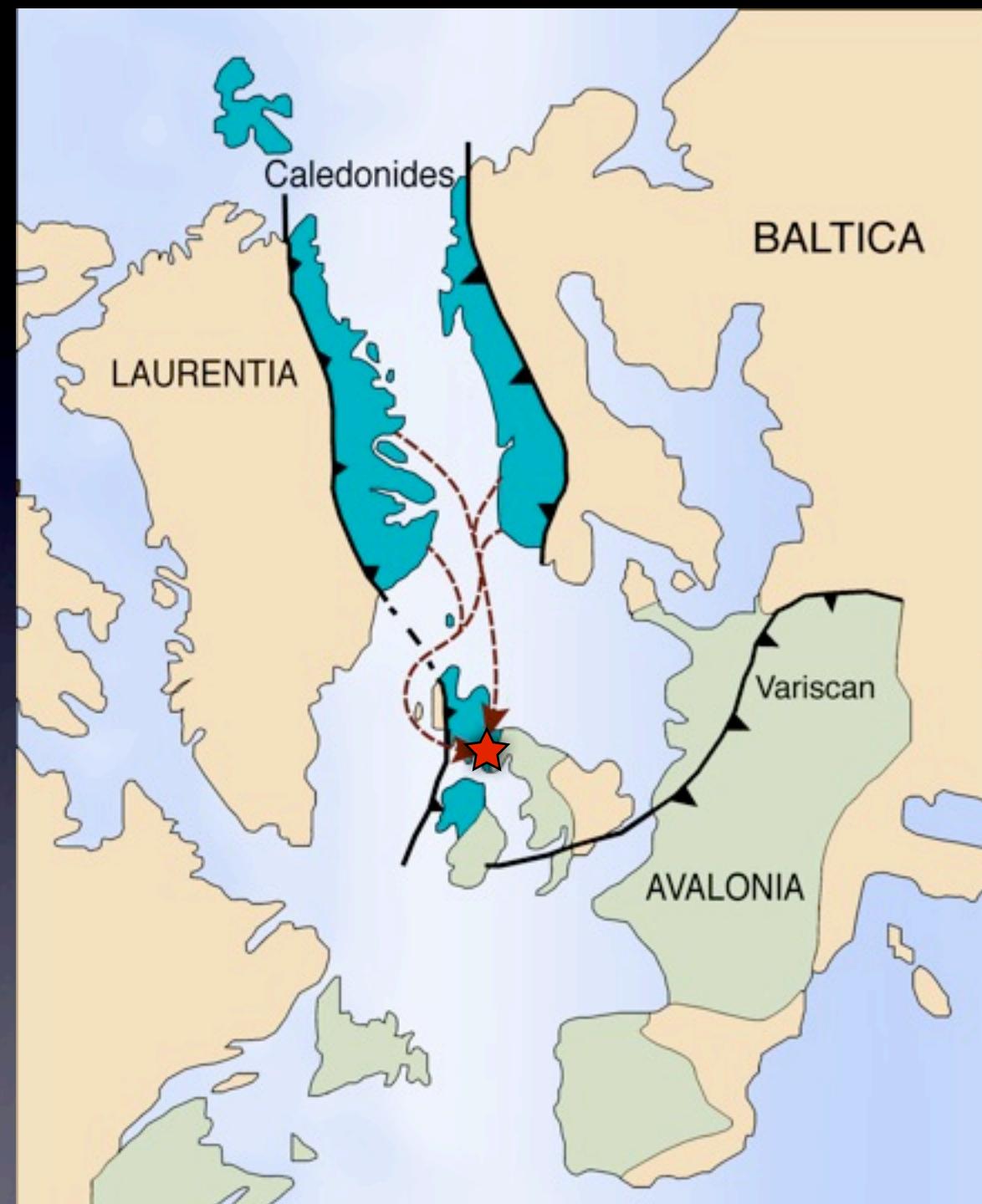
Ar/Ar muscovite age population for the Norwegian metamorphic terranes, and Hornelen basin also well established (>300 detrital mica analyses)



# Devonian Ganges-style (ogen parallel) river system draining the Scandian Highlands?

- ★ River bar deposits in Midland Valley indicate river system with >20m depth, and a source outside of Scotland

*Goal:* to use detrital zircon and mica age dating to determine the provenance of Midland Valley river deposits



# Can we identify a diagnostic zircon age population for provenance analysis?

two types of comparable datasets

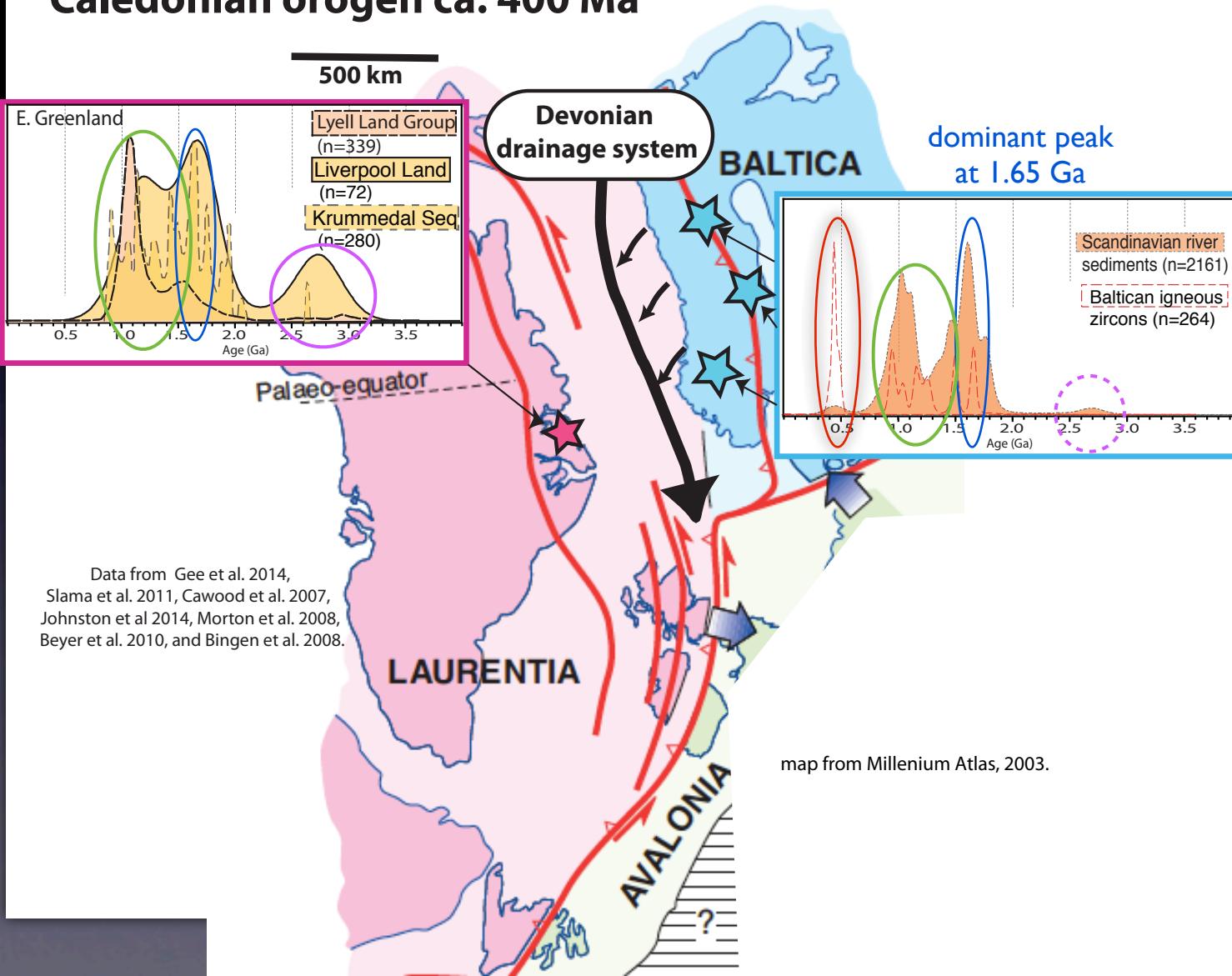
1. modern surface samples  
*>5000 published ages*

2. detrital samples from  
contemporaneous  
Siluro-Devonian deposits  
*>4000 ages*

# Exotic sources:

Neoproterozoic metasediments, modern river sediments and igneous zircon

## Caledonian orogen ca. 400 Ma



Archean population=  
Laurentian source

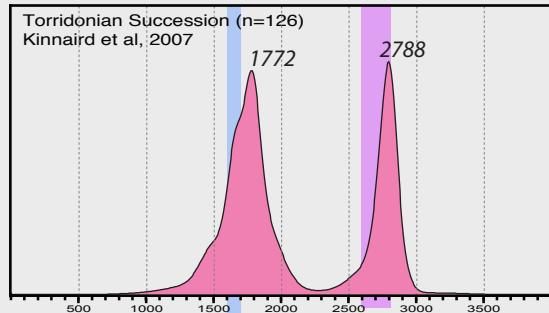
Mesoproterozoic population=  
Grenville/  
Sveconorwegian  
ubiquitous and  
non-diagnostic

Paleozoic population=  
Caledonian aged  
intrusions are ubiquitous  
and non-diagnostic

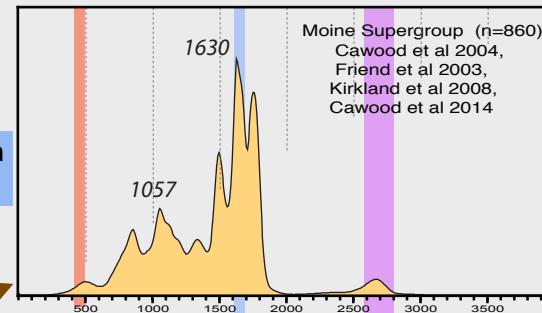
Paleoproterozoic population=  
dominant, focused  
population at ~1.65 Ga  
diagnostic of  
Balto-Scandian source?

# Local sources: terranes of Scotland

## Hebridean foreland terrane

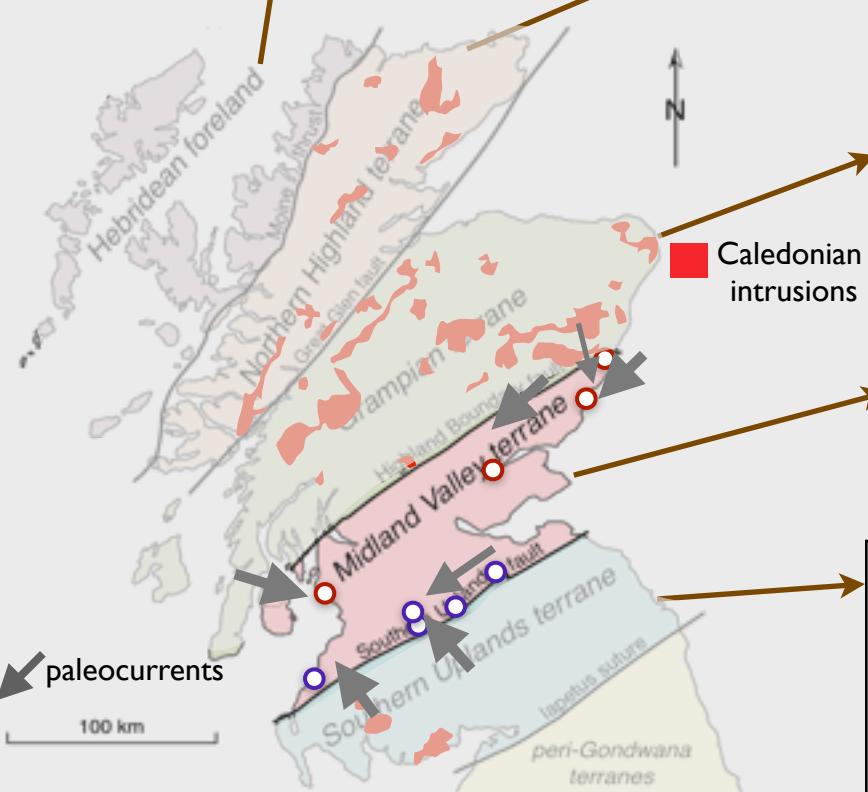


## Northern Highland terrane

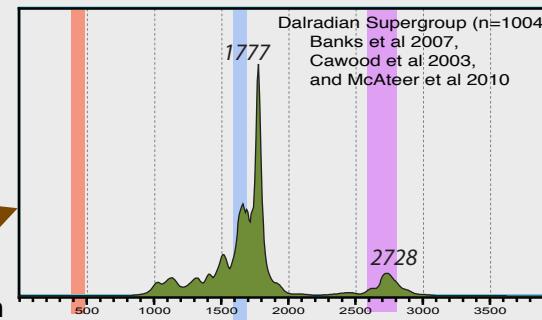


Lewisian basement  
(Laurentian affinity)

dominant Scandinavian  
peak ~1.65 Ga



## Grampian terrane

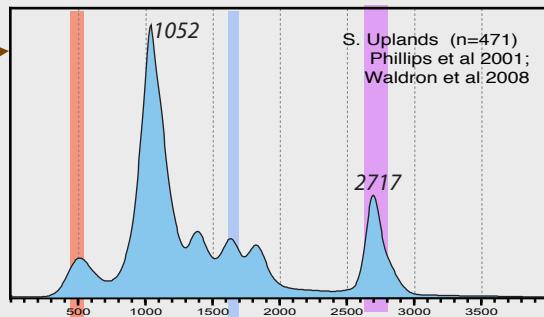


Siluro-Devonian sediments;  
provenance uncertain

### sample locations

○ this study     ○ Phillips et al 2009

## Southern Uplands terrane



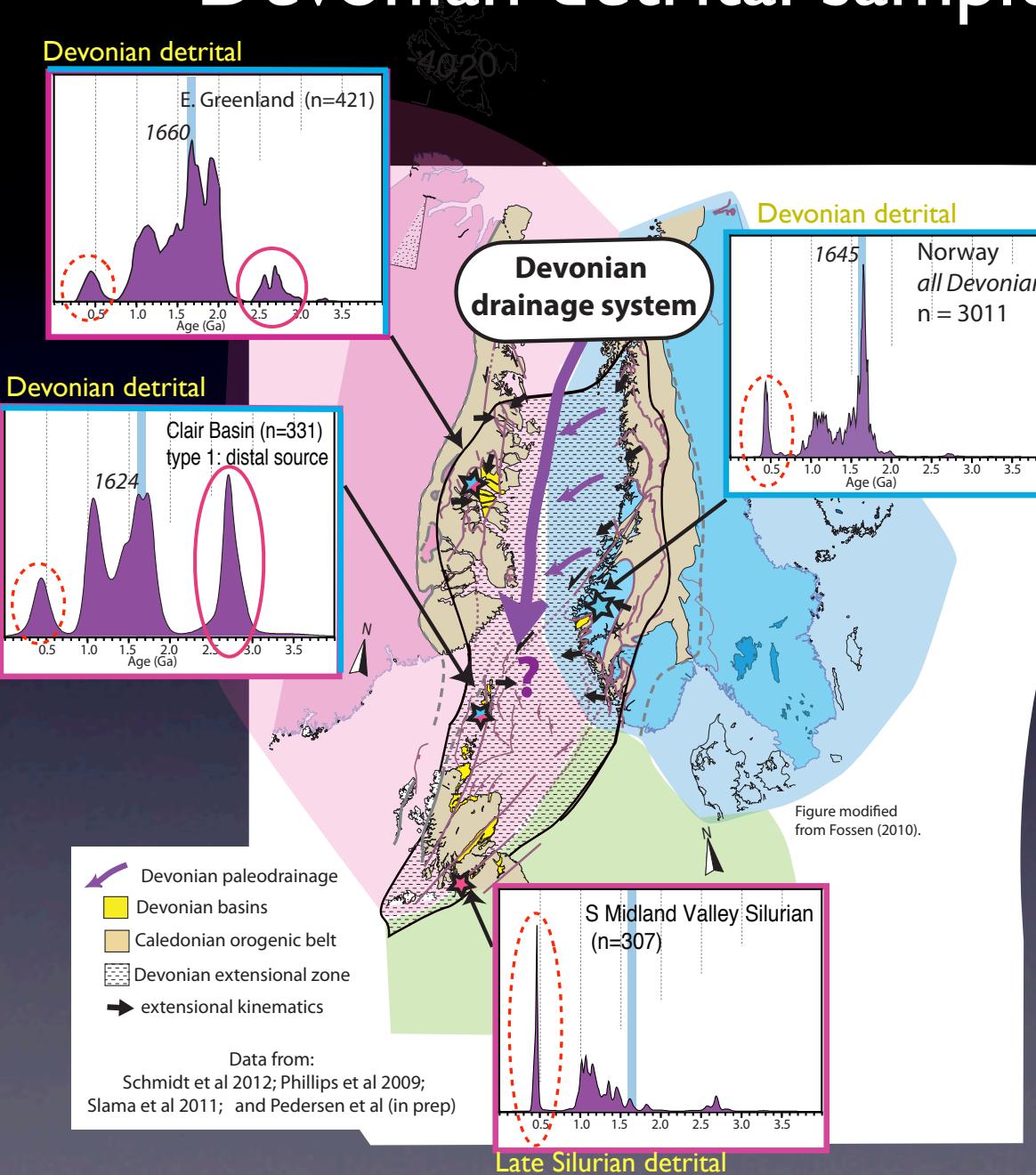
Archean  
population=  
Laurentian source

Mesoproterozoic  
population=  
Grenville/  
Sveconorwegian  
orogeny  
ubiquitous and  
non-diagnostic

Paleozoic  
population=  
Caledonian aged  
intrusions are ubiquitous  
and non-diagnostic

Paleoproterozoic  
population=  
dominant, focused  
population at 1.65 Ga  
diagnostic of  
Balto-Scandian source?

# Devonian detrital samples:



Archean population=  
Laurentian source

Mesoproterozoic population=  
Grenville/  
Sveconorwegian orogeny  
ubiquitous and non-diagnostic

Paleozoic population=  
Caledonian aged intrusions are ubiquitous and non-diagnostic

Paleoproterozoic population=  
dominant, focused population at 1.65 Ga diagnostic of Balto-Scandian source?

zircon: ~1.65 Ga age peak ...  
indicative of Scandinavian provenance,  
*but not diagnostic*

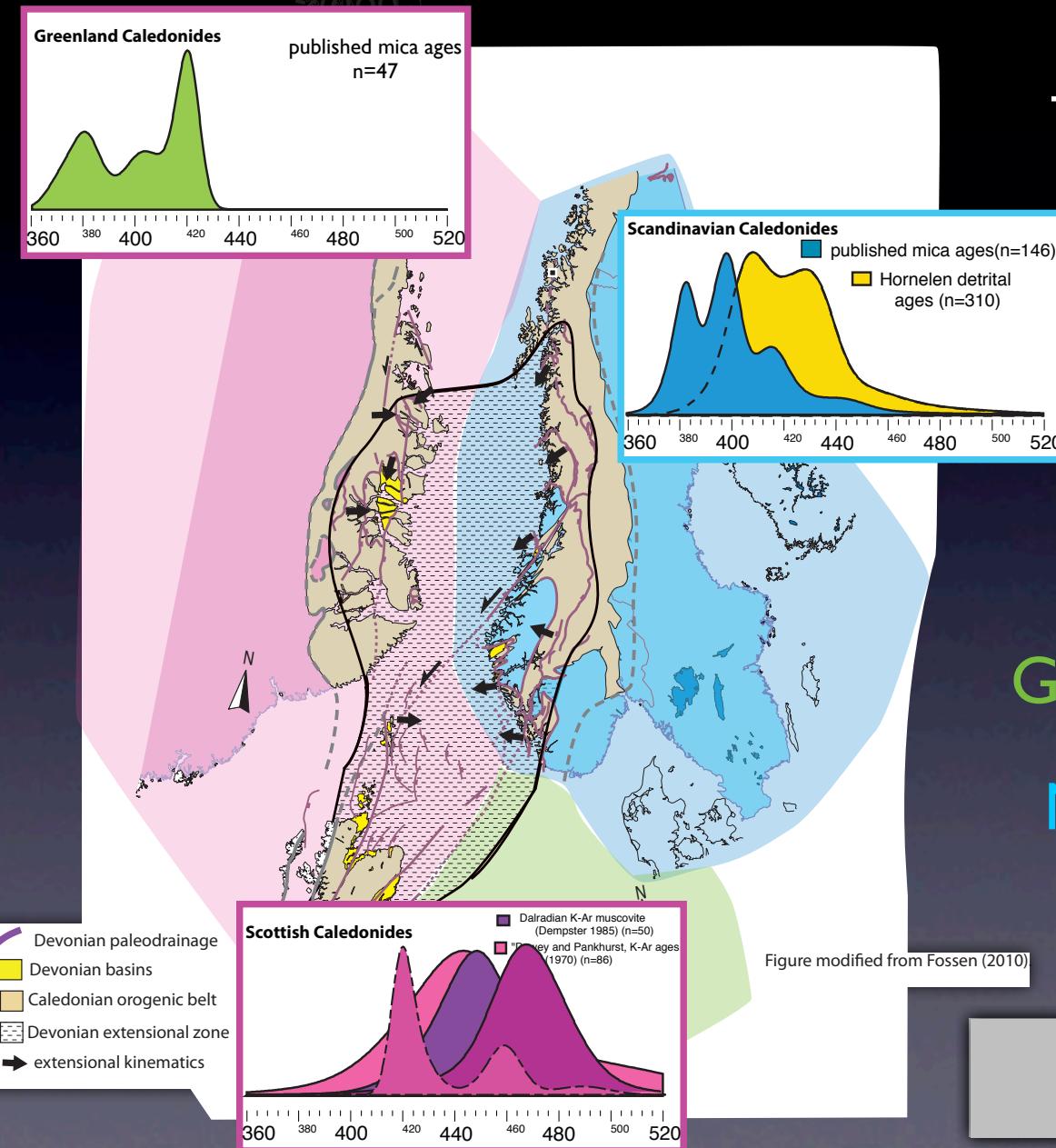
Can detrital muscovite  $^{40}\text{Ar}/^{39}\text{Ar}$   
provide additional provenance constraints?

1. modern surface samples

>200 Ar/Ar mica ages  
~ 100 K/Ar mica ages

2. detrital samples from  
contemporaneous  
deposits  
>400 ages

# Detrital mica $^{40}\text{Ar}/^{39}\text{Ar}$ dating: an additional tool



Timing of thermal pulses...

associated with

- a) peak metamorphic conditions,  
or
- b) cooling and uplift following  
eclogite-facies subduction

....varies around the  
North Atlantic

Greenland: 420-380 Ma

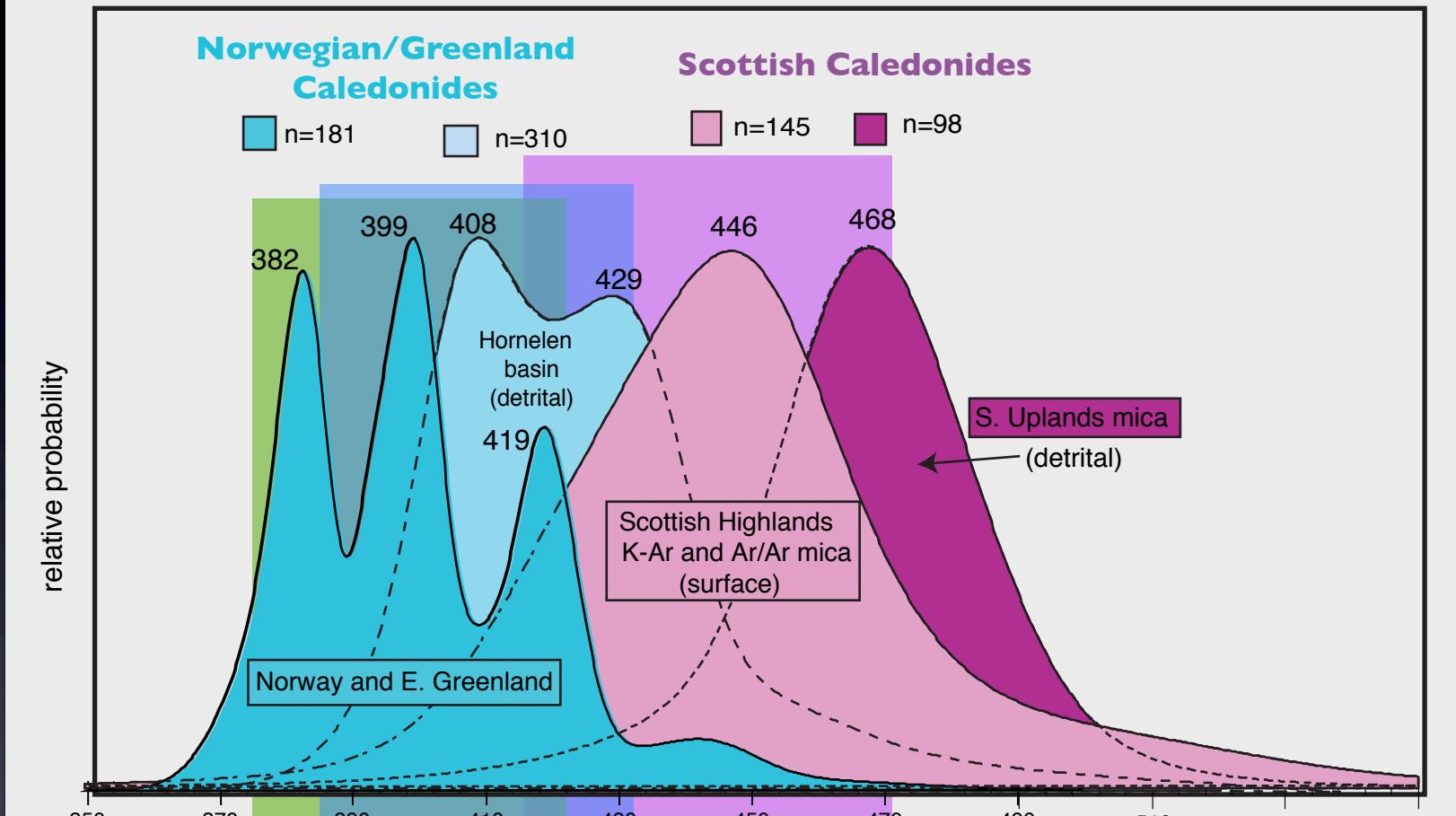
Norway: 430-380 Ma

Scotland: ~450 Ma

S. Uplands detrital mica  
peak at 468 Ma, n=98  
Kelley and Bluck, 1991

# Regional variations in muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages

## Caledonian mica Ar/Ar ages



350 370 390 410 430 450 470 490 510 530 550

Norway: Age (Ma)

390-430 Ma

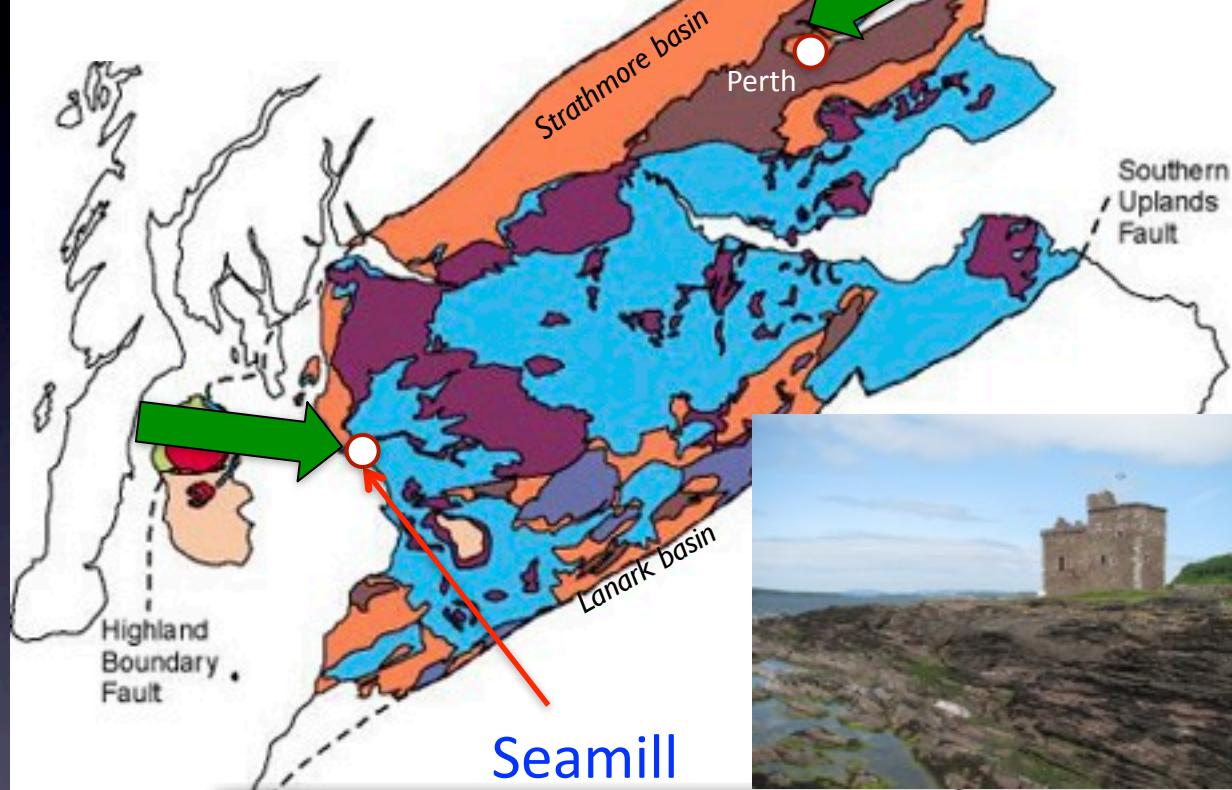
Greenland:  
380-420 Ma

Scotland:  
~450 Ma

# Midland Valley

map modified from [www.scottishgeology.com](http://www.scottishgeology.com)

Old Red Sandstone  Flow Direction 



## Seamill

Large river bar deposit,  
paleoflow from WNW

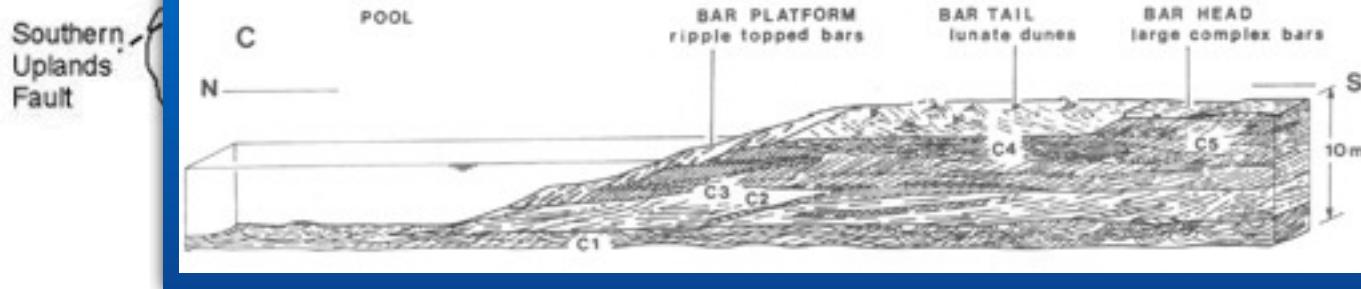
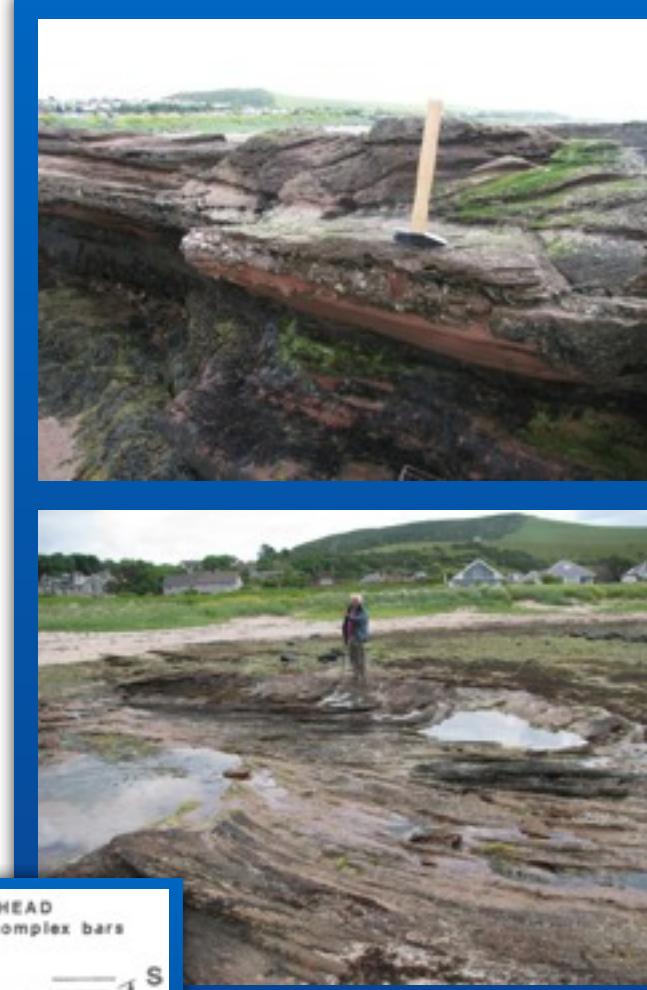
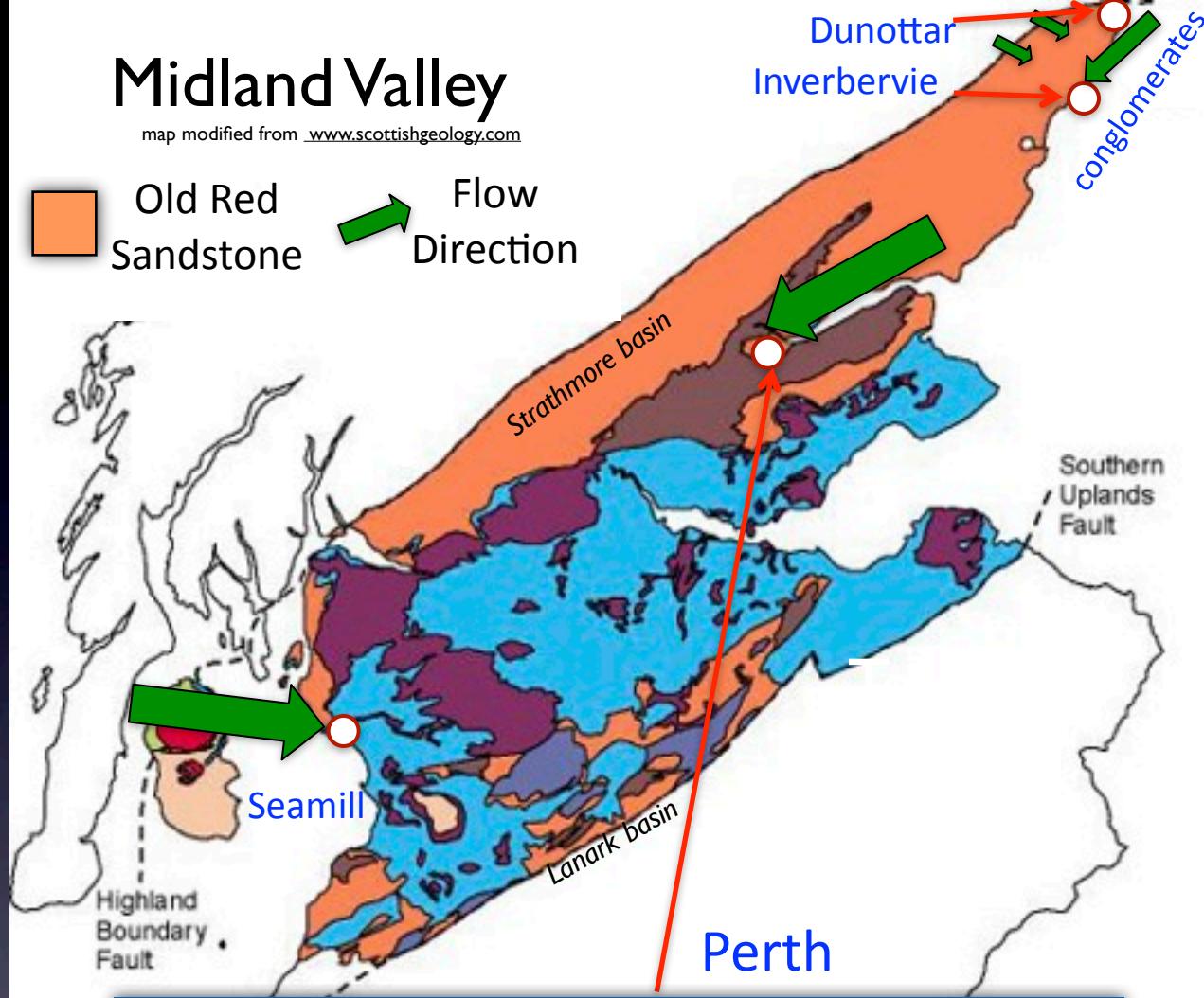


Figure by B. Bluck (2000),  
also pictured above.

# Midland Valley

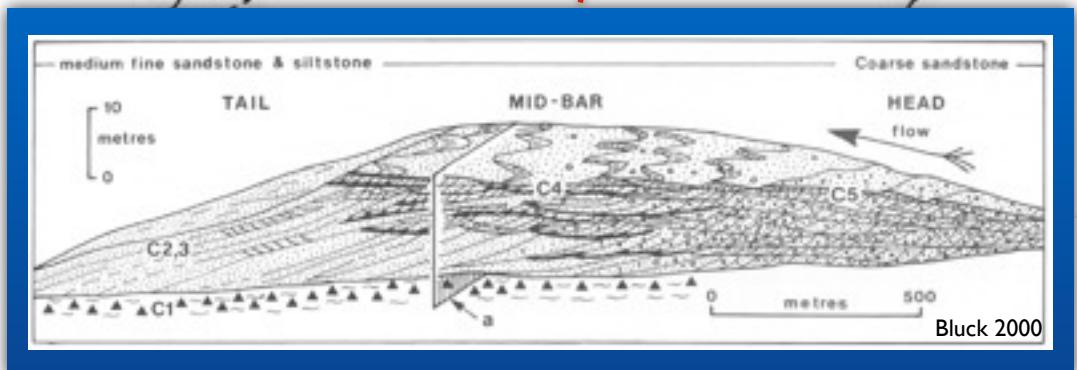
map modified from [www.scottishgeology.com](http://www.scottishgeology.com)



## Dunottar & Inverbervie

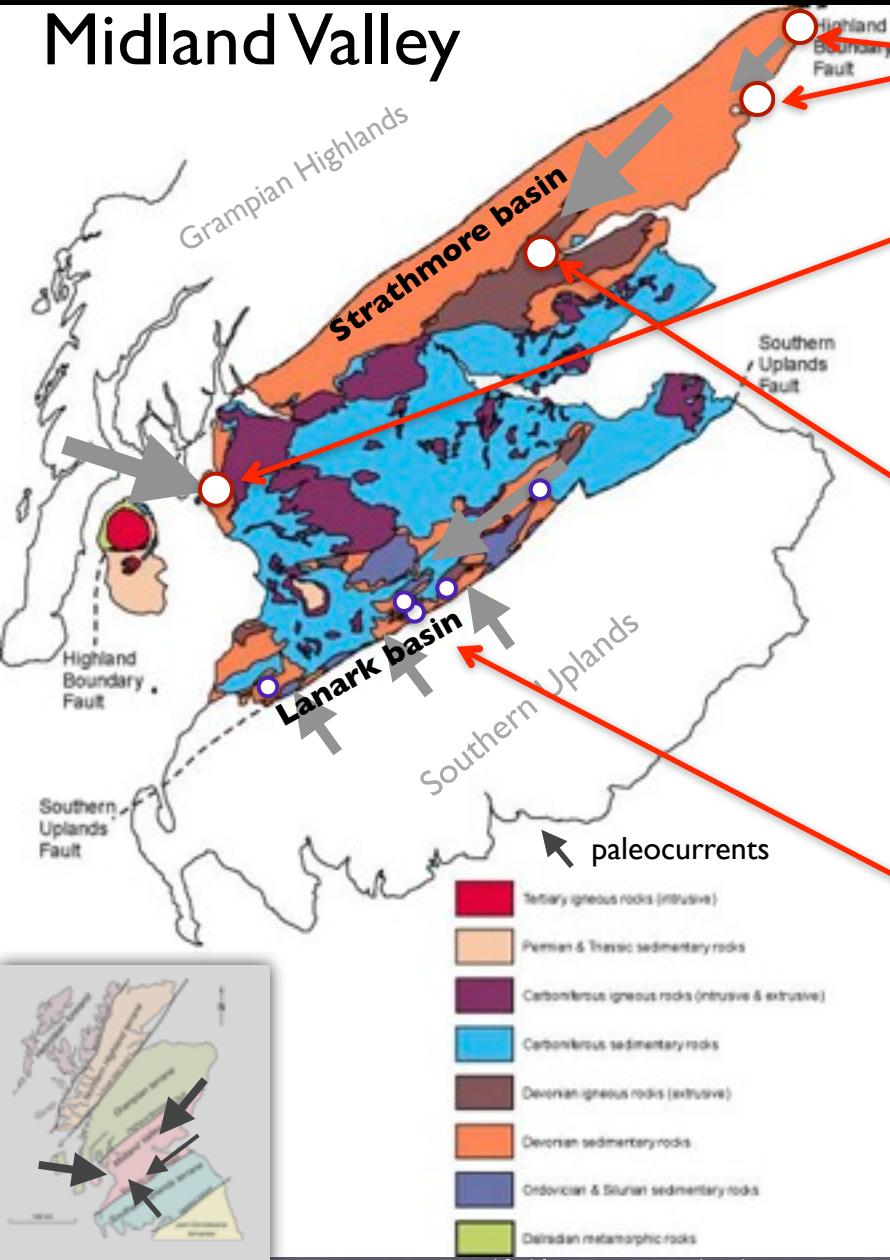


- conglomeratic matrix from  
NE coast deposits  
sampled for detrital mica



-large river bar deposit  
near Perth sampled for  
detrital zircon and mica

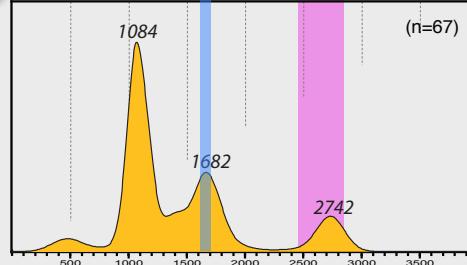
# Midland Valley



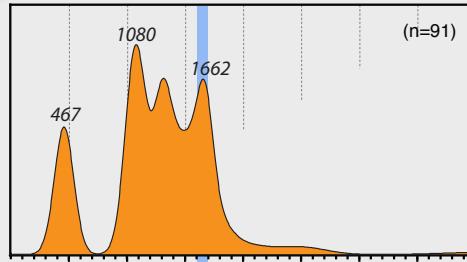
map modified from [www.scottishgeology.com](http://www.scottishgeology.com)

detrital mica additional samples

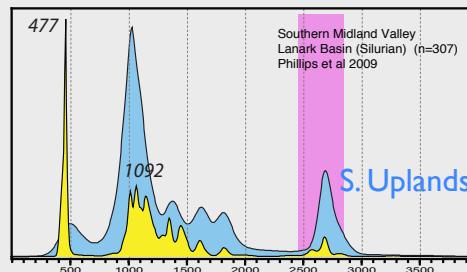
Seamill Upper ORS



W Perth Lower ORS



Lanark Basin: Lower ORS



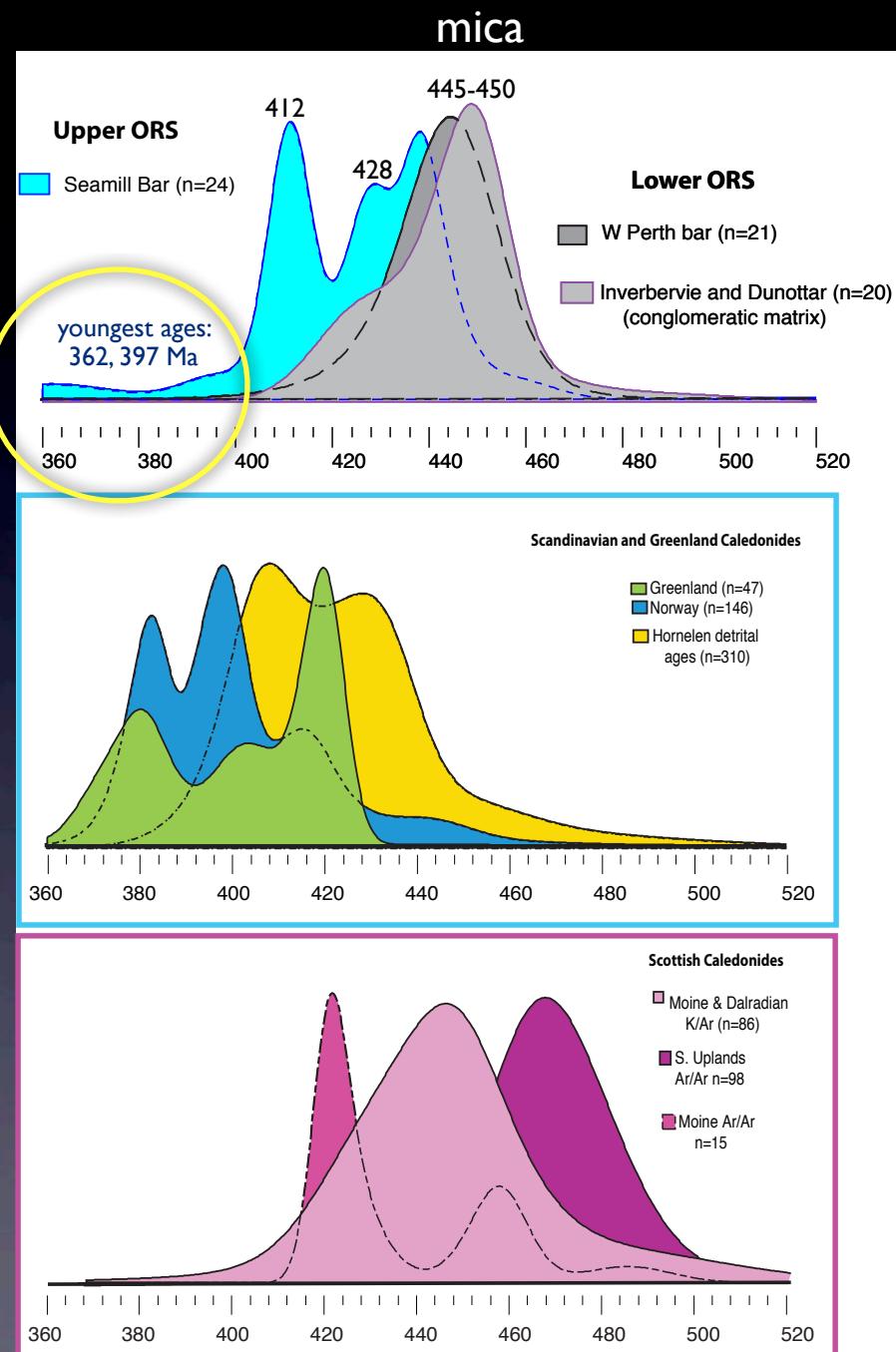
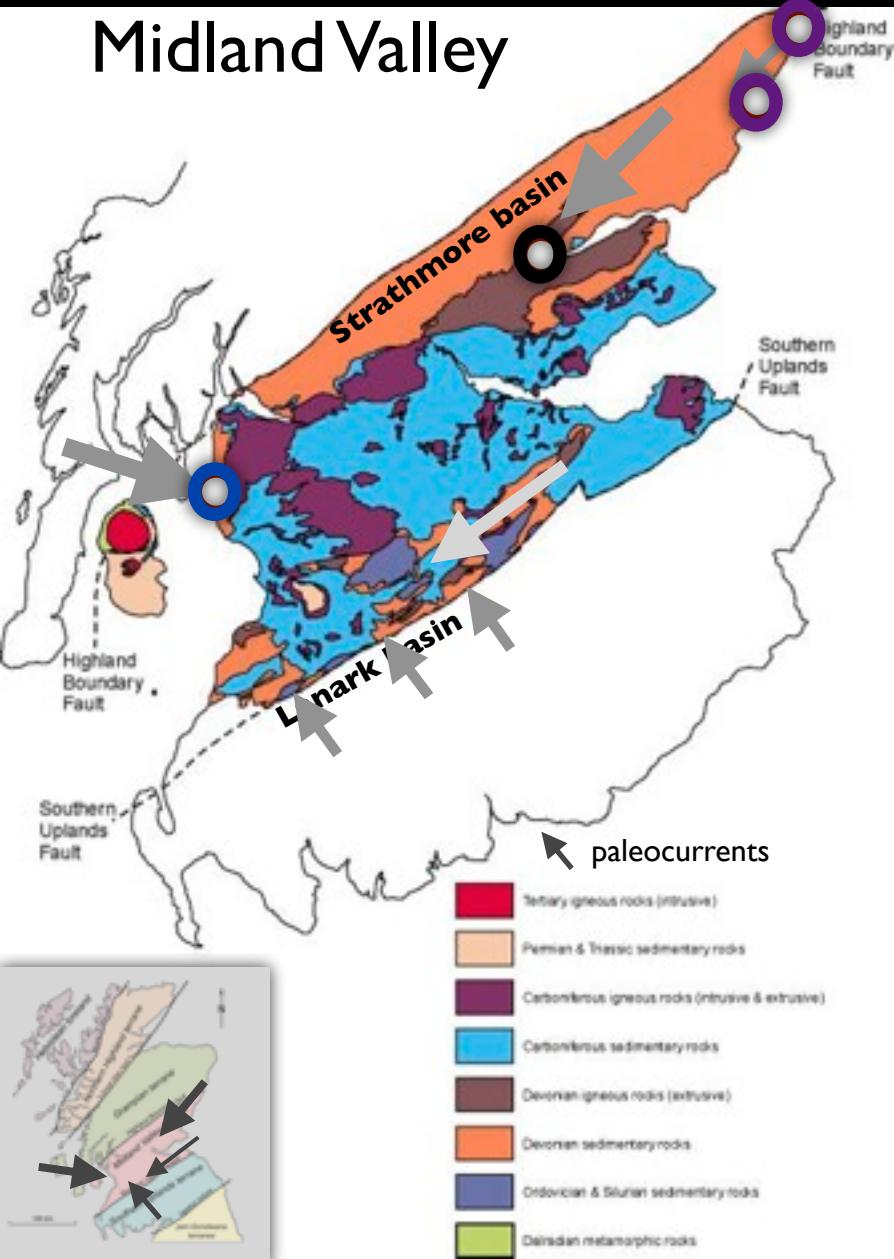
Lower-Middle Devonian

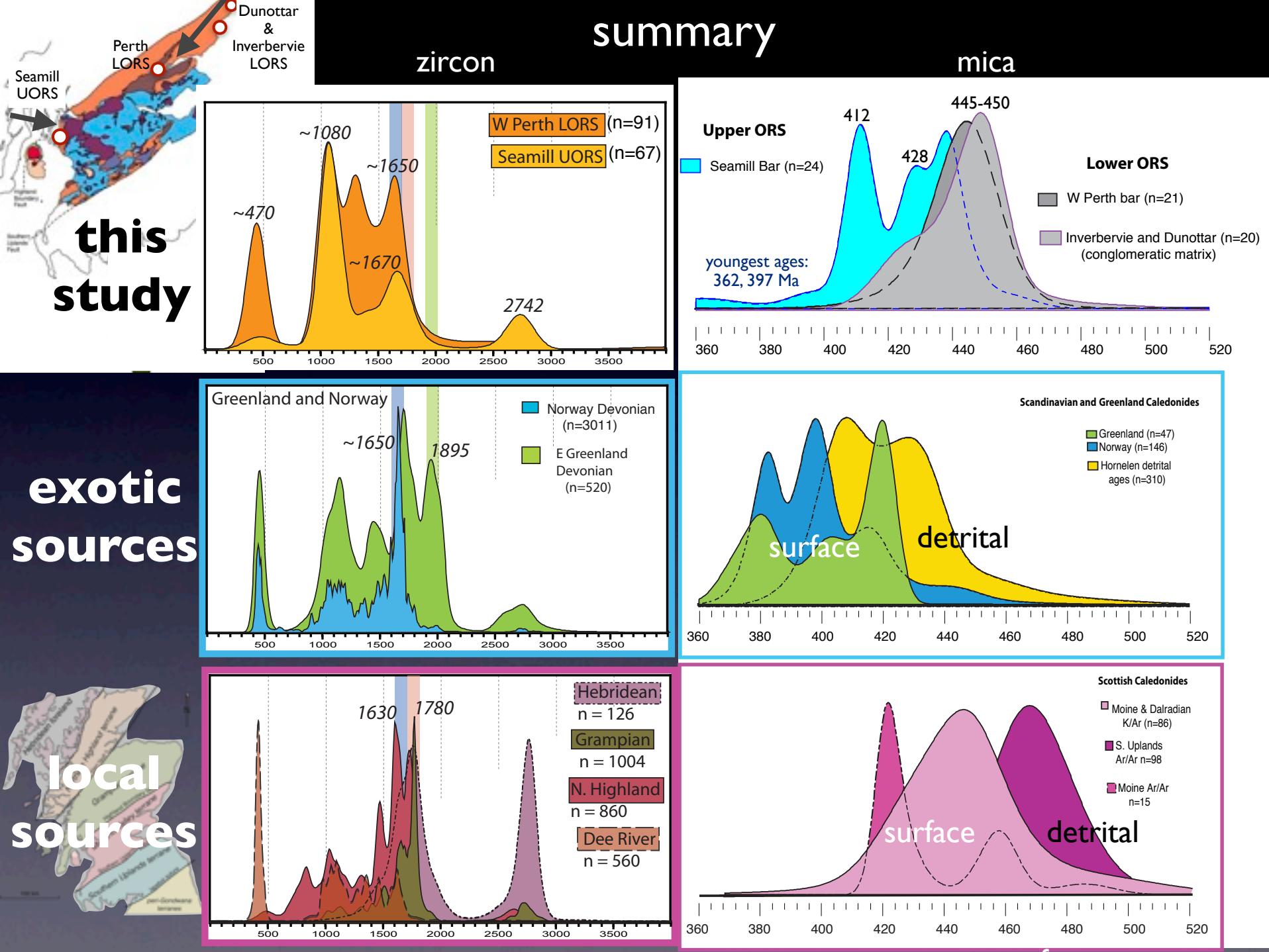
Siluro-Devonian

Silurian

this  
study

# Midland Valley





# Conclusions

Presence of  
~1.65 Ga zircon population  
+  
~410 Ma mica population  
in Upper Old Red Sandstone:  
***supports a Norway/Greenland source  
for major river deposits***

Upper Old Red Sandstone,  
Seamill, Scotland

- inconclusive evidence supporting a Norway/  
Greenland source for the major river deposits in the  
Lower Old Red Sandstone

The End