High-spatial-resolution isotope geochemistry of monazite (U-Pb & Sm-Nd) and zircon (U-Pb & Lu-Hf) in the Old Woman and North Piute Mountains, Mojave Desert, California

STACY E PHILLIPS (*1), JOHN M HANCHAR (1), CALVIN F MILLER(2), CHRISTOPHER M FISHER (3), PENELOPE J LANCASTER (4), JAMES R DARLING (4)

(1) Department of Earth Sciences, Memorial University of Newfoundland, St. John's, NL, A1B 3X5 CANADA

(*s.phillips@mun.ca)

(2) Earth & Environmental Sciences, Vanderbilt University, Nashville, TN 37235 USA

(3) School of the Environment, Washington State University, Pullman, WA 99164 USA

(4) School of Earth and Environmental Sciences, University of Portsmouth, PO1 3QL, UK

The Old Woman-Piute Range Batholith (OWP) in the Mojave Desert, California is a suite of metaluminous and peraluminous Cretaceous granites that intrudes a long-lived and complex Proterozoic basement. It consists of a number of discrete plutons that due to regional tilting expose deeper structural levels of the batholith to the southeast. The Sweetwater Wash pluton (SWP), Painted Rock pluton (PRP) and the North Piute pluton (NPP) were chosen for this study to investigate geochemical homogeneity at the sample-, pluton- and batholith-scale. Samples taken show a magmatic differentiation sequence of two-mica granite to garnet-bearing granite to aplite.

Zircon crystals were analysed for U-Pb & Lu-Hf and monazite crystals for U-Pb Sm-Nd isotopes by in situ LA-ICP-MS and Laser Ablation Split Stream (LASS) techniques. This high spatial-resolution approach allows a detailed assessment of geochemical changes in the magmatic system at a fine spatial and temporal scale.

U-Pb data shows widespread inheritance in zircon cores, yielding ages varying between ~1400 and 1800 Ma, consistent with Proterozoic crustal building events. Only four monazite grains yield inherited cores ~1700 Ma.

Zircon and monazite rims give crystallisation ages from 70-75 Ma, with monazite rims typically slightly younger than the corresponding zircon rims for the same samples. Ages between samples and between plutons are within error. Zircon and monazite also preserve the Hf and Nd isotopic ratios of their crustal sources, however U-Pb age determinations must be measured in the same analytical volume in order for the correct interpretation of these ratios. This can be ensured by using the LASS technique. Average εHfi and εNdi for each sample are positively correlated and are consistent with a crustal isotopic signature. Isotopic data therefore is consistent with the derivation of the OWP Batholith from the ancient crust into which it intrudes, which is spatially coincident with the Precambrian North American continental crust.

Aims of the study

- To investigate the variations in monazite and zircon chemistry throughout the well characterised Old Woman-Piute Range Batholith.
- To demonstrate the usefulness of the LASS technique in studying igneous rocks.
- To use mineral-scale heterogeneity to understand magma chamber processes.

Analytical methods

- Zircon U-Pb by LA-ICP-MS performed at University of Portsmouth.
- Zircon Lu-Hf by LA-ICP-MS performed at Washington State University.
- Monazite U-Pb and Sm-Nd by Laser Ablation Split Stream (LASS) performed at Washington State University.

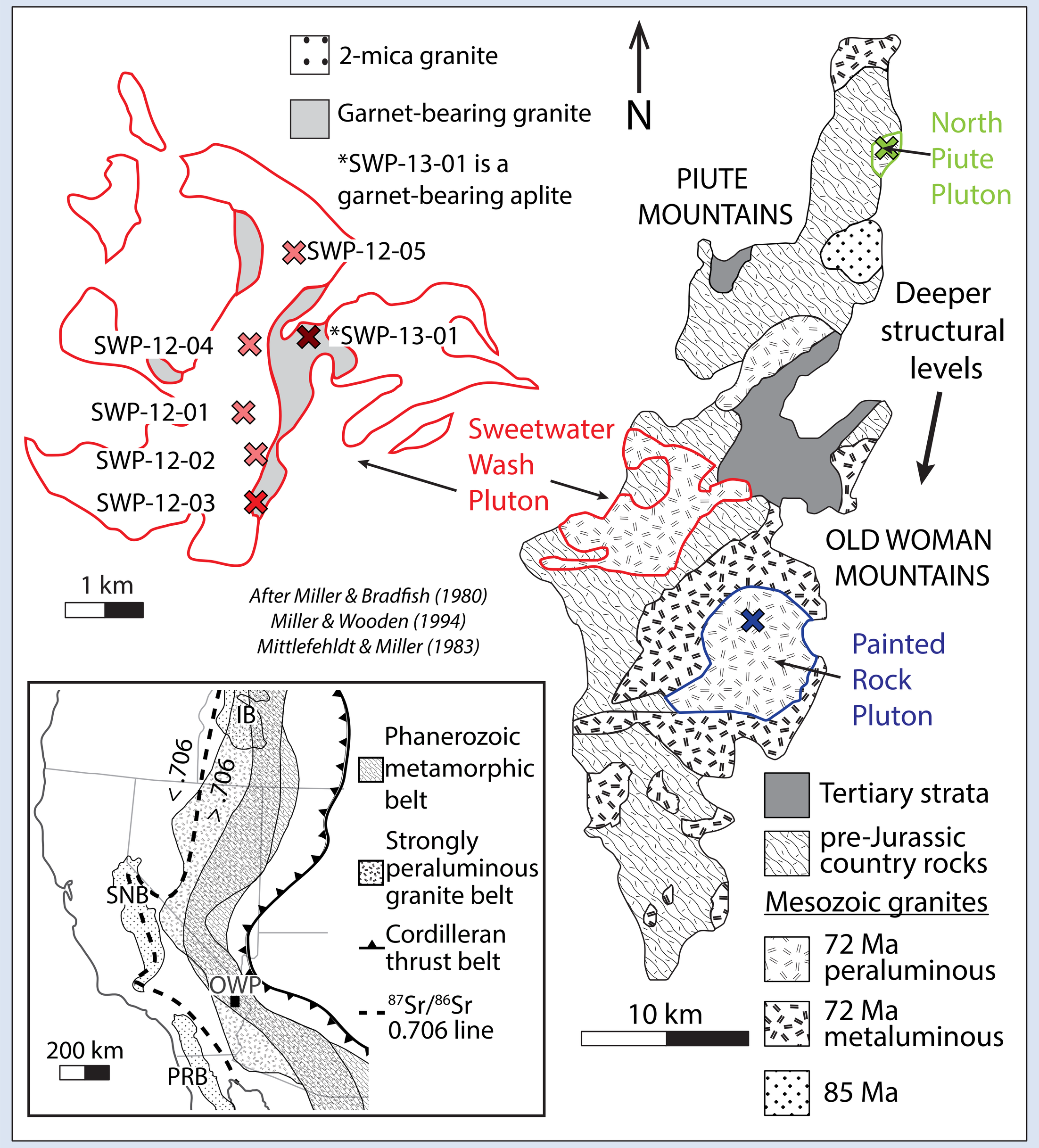


Figure 1 – Geological map of the Old Woman-Piute Range Batholith, Mojave Desert, California.
Inset shows location of OWP Batholith.

The Old Woman-Piute Range Batholith (OWP) is a suite of metaluminous and peraluminous Cretaceous granite plutons that intrude a complex Proterozoic basement, and Cambrian to Triassic metasediments.

The Sweetwater Wash pluton is a peraluminous muscovite-bearing intrusion that also includes facies of garnet-bearing granite.

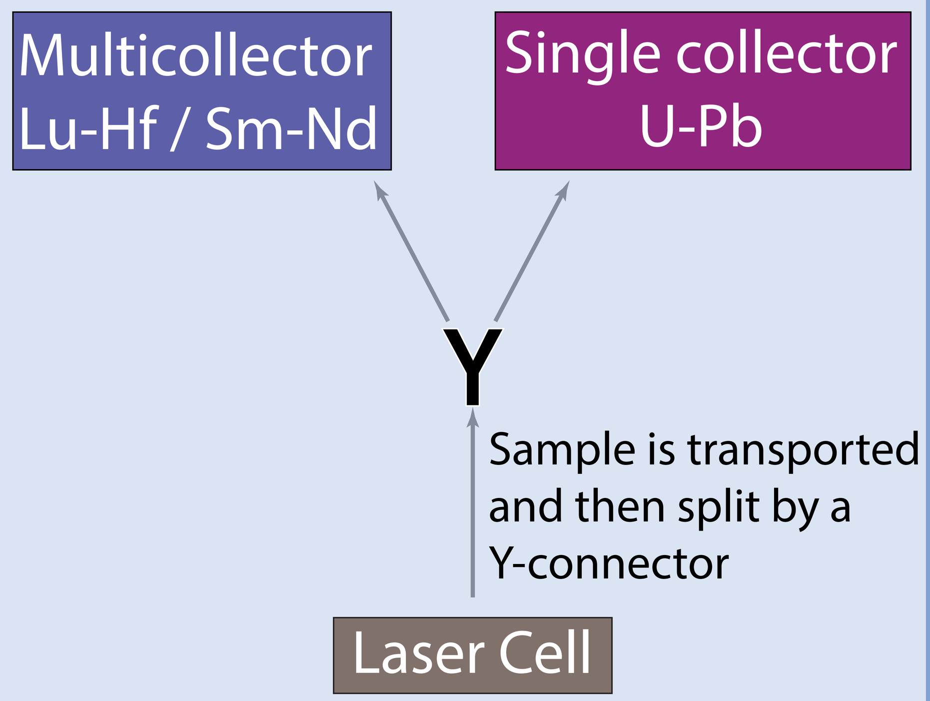
The Painted Rock pluton is peraluminous with less muscovite and is completely enclosed by the metaluminous Old Woman pluton.

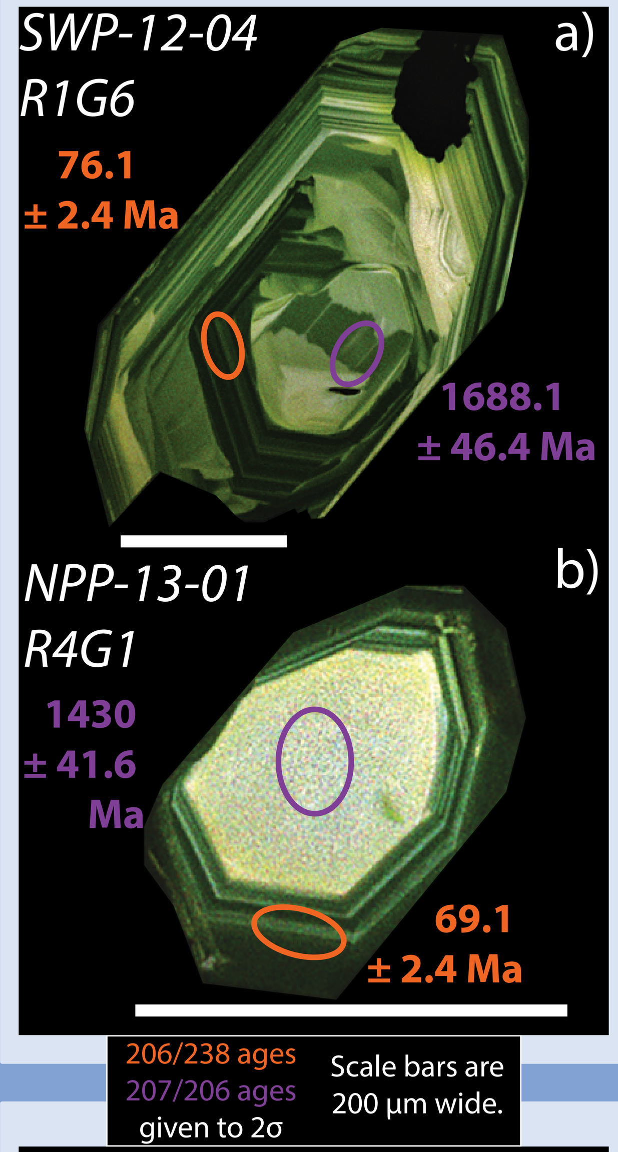
The North Piute pluton represents the shallowest level of the batholith.

11 samples were taken across a transect of the batholith, sampling 2-mica granite, garnet-bearing granite and an aplite facies.

Figure 2 - Schematic setup of Laser Ablation Split Stream (LASS).

Analysis of multiple isotopic systems (U-Pb, Lu-Hf, Sm-Nd, and O) in accessory minerals have proven to be useful petrogenetic tools for studying granitic rocks. These minerals are often zoned and thus full characterization of the nature of the zoning through BSE and CL imaging is required, and multiple analyses must be carried out within the same zone in order to succesfully integrate the isotopic systems. The Laser Ablation Split Stream (LASS) method allows the simultaneous measurement of two isotope systems from the same ablation volume, thus overcoming some of the multi-spot sampling issues.



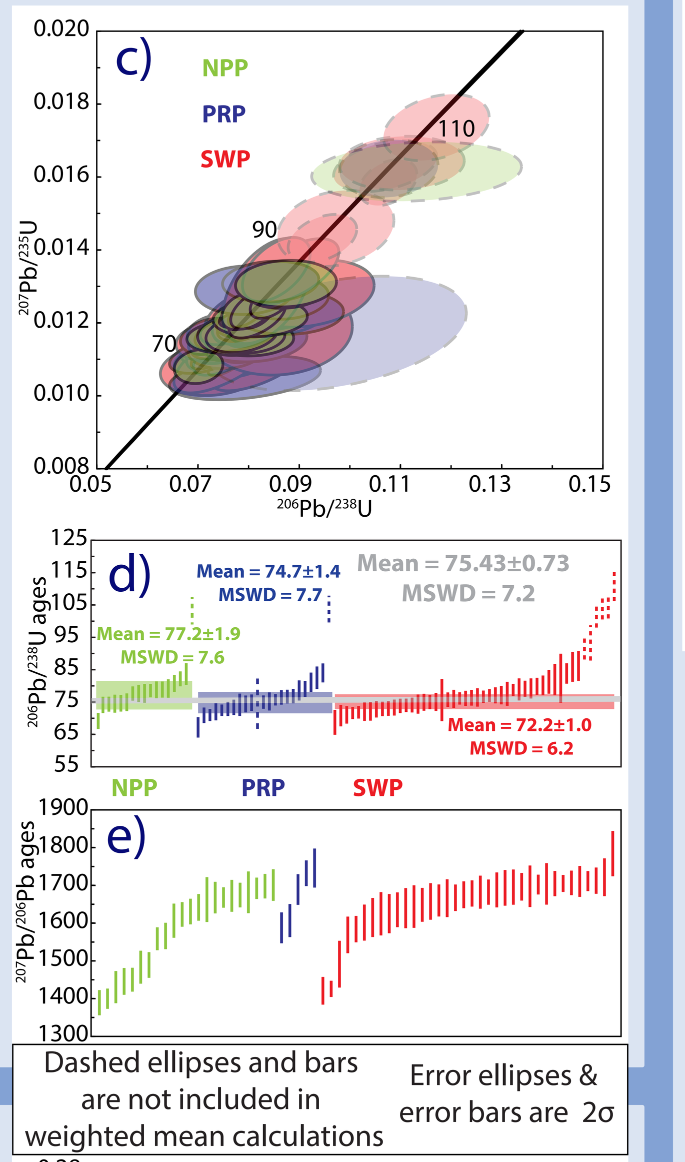


"Young" = ~70-75 Ma magmatic ages, "Old" = >1400 inherited ages.

Figure 3 – Zircon U-Pb data.
a) & b) Representative CL images of OWP grains, showing dated inherited cores of differing morphologies.
c) Concordia diagram showing all "young" zircon ages.
d) & e) Weighted mean plot of all "young" and "old" zircon ages.

All samples show evidence of inherited zircon cores ranging in age between ~1400 -1800 Ma, consistent with ages from the local Proterozoic crust.

Zircon rims typically range from ~70-75 Ma consistent with the published crystallisation age of the batholith. There is no difference within error between the age of each of the plutons.



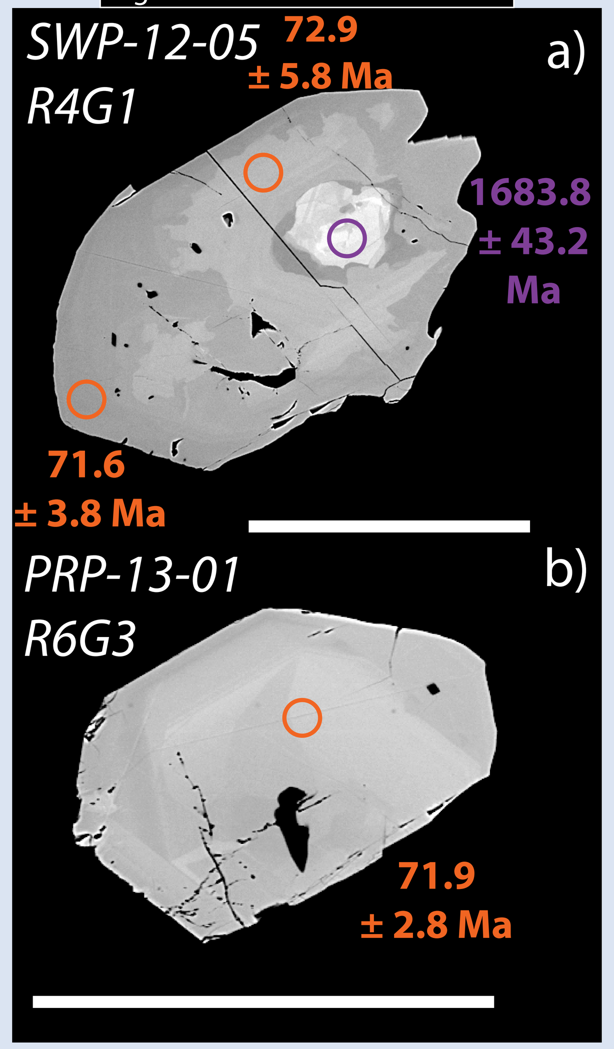
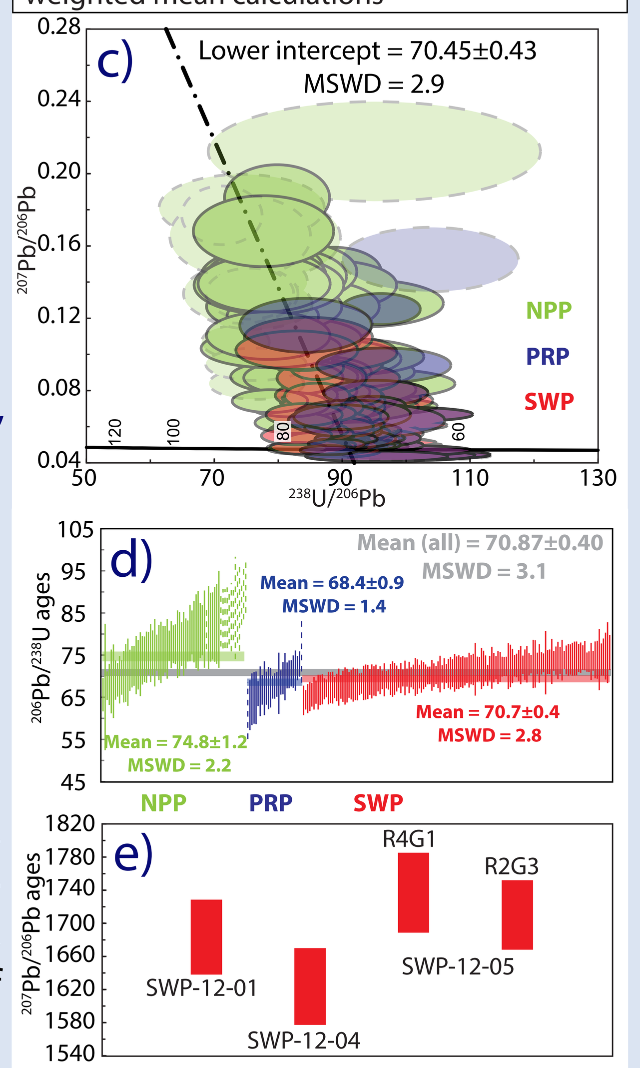


Figure 4 – Monazite U-Pb data.
a) One of the four analysed monazite grains showing an inherited older core, identifiable by the bright BSE core.
b) BSE image of typical of OWP monazite grains, showing faint zoning.
c) Terra-Wasserburg diagram showing all "young" monazite ages.
d) & e) Weighted mean plot of all "young" and "old" monazite ages.

Only four analysed grains show inherited ages, these being consistent with the local Proterozoic crust.

Monazite rims typically range from ~70-75 Ma, consistent with the suggested crystallisation age of the batholith. Ages from monazite for each pluton tend to be younger than those calculated from zircon, and also show variation in ages outside of analytical error.



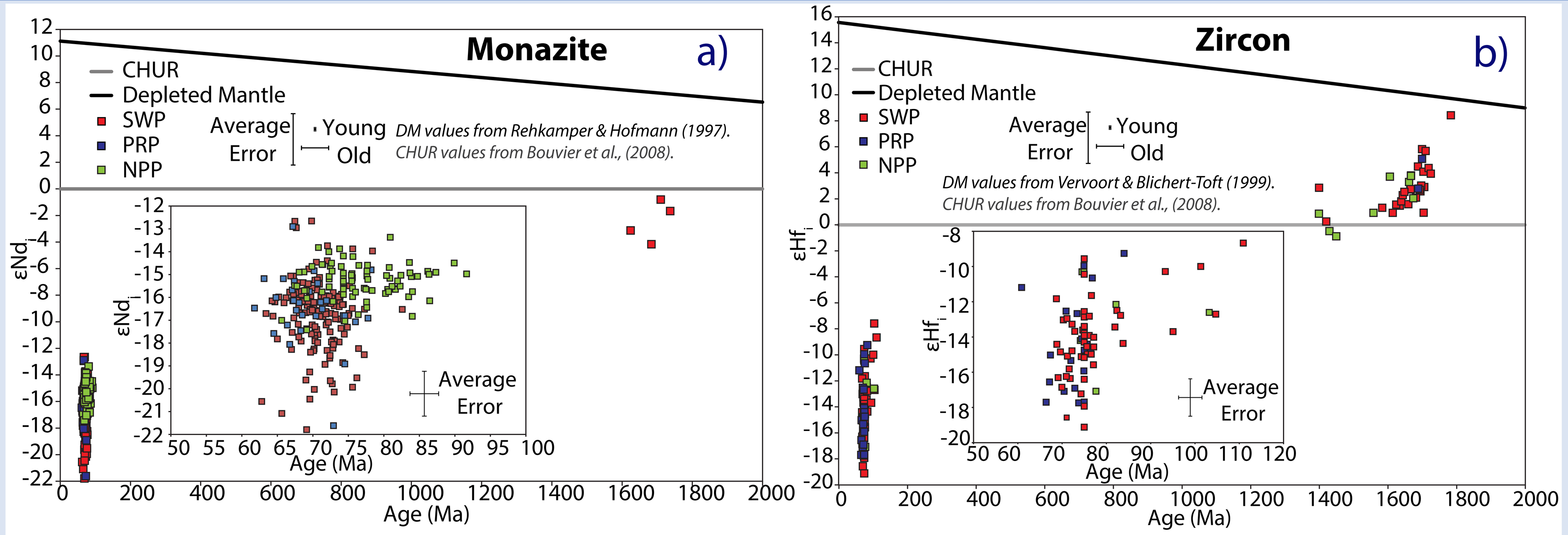


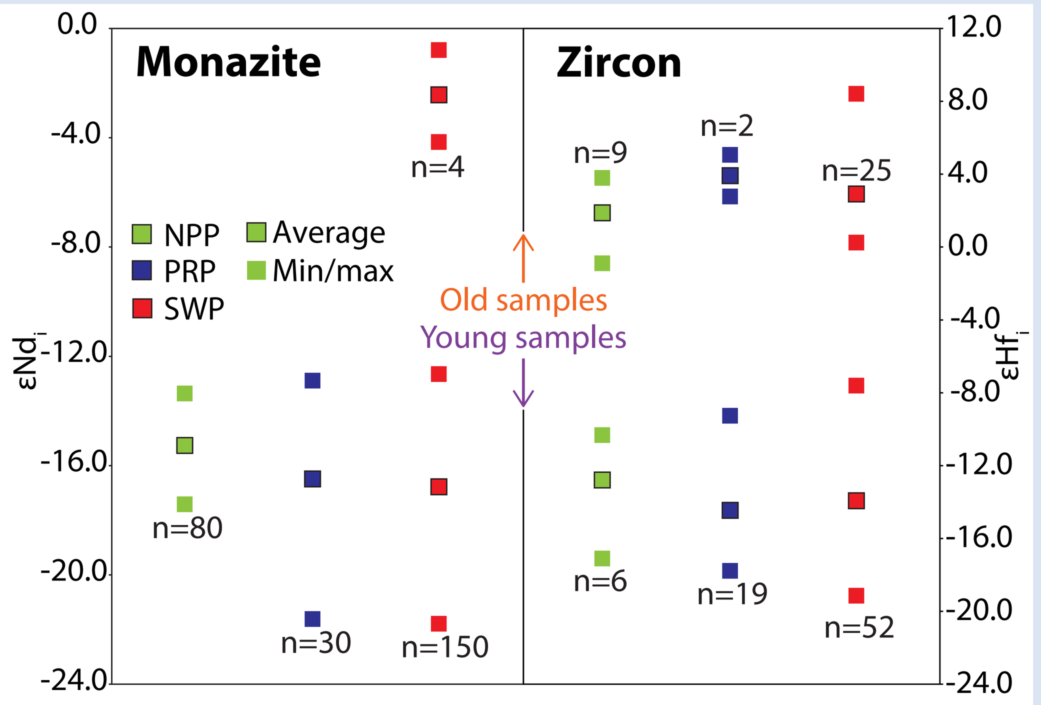
Figure 5 – In situ Nd and Hf isotope plots.
a) & b) εNd_i- and εHf_i-age plots for monazite and zircon from all samples. Inset shows a magnification of the "young" data.

Zircon and monazite grains showing U-Pb inherited ages also preserve the Hf and Nd isotopic compositions respectively, of the source material.

Figure 6 – Zircon εHf_i and monazite εNd_i ranges.

Ranges of εHf_i and εNd_i for each pluton calculated at time of crystallisation. CHUR values from Bouvier et al., (2008).

Large variations in both Nd and Hf are seen in all plutons with NPP showing the smallest range. Variation is also seen in "old" samples suggesting a heterogeneous source. Epsilon values are also consistent with derivation from ancient crustal source.



Conclusions

- Monazite U-Pb ages are typically younger than zircon U-Pb ages, but suggest crystallisation of the OWP at ~70-75 Ma.
- Inherited zircon and monazite ages range from 1400-1800 Ma, consistent with the major crustal forming events of the Proterozoic crust, into which the OWP was emplaced.
- Inherited "old" analyses of zircon and monazite preserve the Hf and Nd isotopic characteristics of the source region, with "young" zircon and monazite growing in a melt of different isotopic composition.
- Epsilon Hf and Nd values suggest that both "old" and "young" zircon and monazite were derived from an isotopically heterogeneous crust.
- LASS is an effective technique to investigate isotopic systematics of magmatic systems.

Acknowledgements

Thanks to analytical staff at Memorial University of Newfoundland, University of Portsmouth and Washington State University. SEP thanks friends and colleagues at Memorial University for helpful discussions and support and to Charles Knack at WSU for help during the analytical work. Research supported by an NSERC Discovery Grant to JMH, and a MSA Grant for Student Research in Mineralogy and Petrology to SEP.

Bennett & DePaolo (1987), Proterozoic crustal history of the western United States as determined by neodymium isotopic mapping, GSA Bulletin, 99, 674-685.

Bouvier et al., (2008) The Lu–Hf and Sm–Nd isotopic composition of CHUR: Constraints from unequilibrated chondrites and implications for the bulk composition of terrestrial planets, EPSL, 273, 48-57.

Miller et al., (1990) Petrogenesis of the composite peraluminous-metaluminous Old Woman-Piute Range batholith, southeastern California; Isotopic constraints, GSA Memoir, 174, 99-109.

Miller, C. F. & Bradfish, L. J., (1980) An inner Cordilleran belt of muscovite-bearing plutons. Geology, 8(9), 412-416.

Mittlefehldt, D. W. & Miller, C. F., (1983) Geochemistry of the Sweetwater Wash Pluton, California: Implications for "anomalous" trace element behavior during differentiation of felsic magmas. Geochimica et Cosmochimica Acta, 47(1), 109-124.

Rehkämper, M. & Hofmann, A., (1997) Recycled ocean crust and sediment in Indian Ocean MORB. Earth and Planetary Science Letters, 147(1-4), 93-106.

Vervoort, J. D. & Blichert-Toft, J., 1999. Evolution of the depleted mantle: Hf isotope evidence from juvenile rocks through time. Geochimica et Cosmochimica Acta, 63(34), 533-556.