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Schist happens: the secrets given up by altered rocks in the Southern São Francisco Craton, Brazil

Moreira, H.¹, Storey C.¹, Cassino L.², Lana C.², Albert C.²,³

¹School of Earth and Environmental Sciences, University of Portsmouth, UK;
²Applied Isotope Research Group, Departamento de Geologia, Universidade Federal de Ouro Preto, Brazil;
³Department of Earth Sciences, University of Cambridge, UK.

Geological research in collisional orogens tends to emphasize major geological units, tectonic features and impressive metamorphic complexity. Adjacent accreted terranes are sites of extraordinary crustal reworking, recording information about lithospheric evolution and continental crust development. At the same time, minor intrusions at outcrop scale, badly retrogressed rocks, and complex local structures are often under-studied or acknowledged to have negligible importance. In this study, we show evidence for a high grade-metamorphic event hidden by lower metamorphic grade overprint and alteration at the margins of the Southern São Francisco Craton (SSFC), Brazil. Host greenstone belt units show a wide distribution of Archaean inherited zircons overprinted by at least one high-grade metamorphic event. High-grade metamorphic zircon rims show Th/U, εHf(t) values and REE pattern consistent with eclogite/granulite metamorphic facies, reinforcing the hypothesis of a dehydrated-refractory crust formed during the stabilization of the SSFC. This event links the crustal thickening and partial melting of the Archaean lower crust. Archaean rutiles were reset during the Palaeoproterozoic event but still preserve the early Archaean high-grade metamorphic stage signature pointed out by Zr-thermometry. Slender zircon grains from the Rhyacian intrusions have low εHf(t) signature and were crystallised from partial melting of sedimentary rocks at upper crust. Detrital ilmenite of the host greenschist was replaced by Palaeoproterozoic rutile under high pressure, low temperature prograde metamorphism during the collisional stage. Accretionary events produced thicker and more differentiated crust by the end of Rhyacian time. Overall, this study brings implications for continental crust evolution and broadens the understanding of metamorphic conditions at regional scale.
Recovering P–T–t paths from ultra-high temperature (UHT) rocks that lack diagnostic mineral assemblages: A felsic orthogneiss example from the Southern Brasília Orogen, Brazil

Motta, R.G.\textsuperscript{1,2}, Fitzsimons, I.C.W.\textsuperscript{2}, Moraes, R.\textsuperscript{1}, Johnson, T.E.\textsuperscript{2}, Schuindt, S.\textsuperscript{3} and Benetti, B.Y.\textsuperscript{1}

\textsuperscript{1}Institute of Geosciences, University of São Paulo, 562, Rua do Lago, 05508-080, São Paulo, Brazil, rafagmotta@gmail.com
\textsuperscript{2}School of Earth and Planetary Sciences, The Institute of Geoscience Research (TigEr), Curtin University, Perth, Australia
\textsuperscript{3}School of Earth and Environmental Sciences, University of Portsmouth, Portsmouth, United Kingdom

Mineral assemblages that are diagnostic of ultrahigh-temperature (>900°C) metamorphism are generally restricted to Mg- and Al-rich rocks. However, in many metamorphic terrains such compositions do not occur, and the rocks are dominated by orthogneisses that typically contain high-variance mineral assemblages that are not diagnostic of particular pressure–temperature (P–T) conditions. Here we use whole-rock, thermodynamic phase equilibrium modelling, and zircon petrochronology to constrain the P–T–time history of garnet-bearing felsic from the Socorro-Guaxupé Nappe of the Southern Brasília Orogen. These rocks occur as part of a stack of Neoproterozoic nappes that were assembled during the formation of West Gondwana. Based on phase equilibrium modelling, the peak assemblage in the felsic granulite (ortho- and clinopyroxene, garnet, K-feldspar, plagioclase, quartz, ilmenite, magnetite and silicate melt) records pressures of around 11 kbar and temperatures of ~1000°C, consistent with the high-Al content of orthopyroxene. Hydrous phases were not present at the metamorphic peak, and generation of the melt phase was controlled by K-feldspar breakdown. The retrograde path records near-isobaric cooling that led to the development of coronas of hornblende around pyroxene due to crystallization of the last vestiges of melt. In the felsic granulites, sector-zoned zircon cores yield U–Pb ages of c. 625 Ma, interpreted as dating the onset of high-temperature metamorphism. In one sample, zircon rims and ‘soccer ball’ zircon neoblasts both have high U contents and yield ages of c. 615 Ma, interpreted to mark the onset of melt crystallization. In two other samples, low-U rims and ‘soccer ball’ zircons yield ages of c. 595-600 Ma, interpreted to date the end of melt crystallization. These data reveal a protracted metamorphic event in which the lower crust remained at granulite-facies conditions for at least 30 Myr during a regional metamorphism associated with collision and assembly of West Gondwana.
Reconstructing the metamorphic evolution of the Araçuaí orogen (SE Brazil) using \textit{in situ} U–Pb garnet dating and \textit{P–T} modelling

Schannor, M.\textsuperscript{1,2}, Lana C.\textsuperscript{2}, Nicoli G.\textsuperscript{1}, Cutts K.\textsuperscript{2}, Gerdes A.\textsuperscript{3}, Hecht L.\textsuperscript{4} and Buick I.\textsuperscript{5}

\textsuperscript{1}Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ, UK; mss77@cam.ac.uk
\textsuperscript{2}Applied Isotope Research Group, Department of Geology, Universidade Federal de Ouro Preto, Morro do Cruzeiro, Ouro Preto, 35400-000, Brazil
\textsuperscript{3}Institut für Geowissenschaften, Goethe-Universität Frankfurt, Altenhöferallee 1, 60438 Frankfurt am Main, Germany
\textsuperscript{4}Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Invalidenstraße 43, 10117 Berlin, Germany
\textsuperscript{5}Department of Earth Sciences, Stellenbosch University, Private Bag X1, Stellenbosch, Matieland 7602, South Africa

The Araçuaí orogen of SE Brazil consists of a suite of deformed, metamorphosed and partly migmatitic sedimentary rocks and granitoid batholiths, which predominantly formed during collision of the São Francisco and Congo cratons in the late Neoproterozoic. While widespread anatexis and a prolonged magmatic record are well-established, insufficient information exists about the overwhelming exposure of metamorphic rocks along the Araçuaí orogen. Combining information from a wide range of these metamorphic rocks is essential to reconstruct mountain-building processes and heat sources that operate in convergent tectonic settings. New petrographic observations, mineral chemistry, and phase equilibria modelling were used to constrain peak metamorphic conditions of amphibolite-facies metasedimentary rocks of the central domain of the orogen at 620–660 °C and 8.0–9.5 kbar. We applied \textit{in situ} low-U (<1 µg/g) garnet U–Pb geochronology, which yielded ages between 585–570 Ma consistent with previously established ages for peak metamorphism. Metamorphic zircon ages of c. 630 Ma are related to a cryptic terrane accretion event prior to orogenesis, whereas garnet U–Pb ages record the orogenic peak metamorphism as revealed by disequilibrium rare earth element (REE) partitioning between the two minerals. A compilation of our results with previously reported metamorphic conditions defines a clockwise \textit{P–T} evolution for the Araçuaí orogeny, characterized by slow burial to depth of 26–30 km, followed by near isothermal decompression from ~10 to 6 kbar (Fig. 1A). Substantial differences of peak temperatures in various domains of the orogen are consistent with the presence of different protoliths in the crustal sections causing a higher concentration of heat producing elements in anatectic domains, which might have triggered partial melting of metasedimentary rocks (Fig. 1B). This suggests that heat producing elements (Th, U and K) were a significant heat source for crustal reworking during West Gondwana convergent tectonics.

![Fig. 1 A) \textit{P–T} path for metasedimentary rocks of the Araçuaí orogen; B) Radiogenic heat production calculated from Th, U and K concentrations of different lithologies in the Araçuaí orogen (U* calculated with average Th/U = 5.6)](image-url)
Detrital rutile record: the preservation bias during supercontinent assembly
Pereira I.¹, Storey C.D.¹, Darling J.¹, Moreira H.¹ and Strachan R.¹
¹School of Earth and Environmental Sciences, University of Portsmouth, Burnaby Bd, Burnaby Rd PO1 3QL
Portsmouth, ines.pereira@port.ac.uk

Much of what currently is known about the early Earth has been recovered from detrital minerals. This is profoundly related to the rather incomplete rock record. Zircon has offered most of this insight, as it is physically and chemically robust and contains a multi-isotopic toolkit U-Pb, Hf and O. Thus, it has been the ideal candidate to retrieve unique information about early Earth processes. One of these, links supercontinent cyclicity with the distribution of detrital zircon, and it has been used to estimate crustal growth rates [1]. Despite the coincidence of peaks in the distribution of the uranium-lead (U-Pb) crystallisation ages of detrital zircon with the development of supercontinents, it is still unclear if this reflects episodic continental growth [2,3] or a bias due to selective preservation of new crust within collisional orogenic belts [4,5]. To better understand this conundrum, another mechanically and chemically robust mineral that records collisional tectonometamorphic processes is required.

As an alternative approach, we interrogate the detrital record of the mineral rutile which can be used as a fingerprint for collisional orogenesis. While zircon mostly records high temperature (HT) episodes during magma formation, rutile records metamorphic events by crustal thickening. It grows in a range of P-T metamorphic conditions, from both felsic and mafic protoliths, and a minor proportion associated with magmatic-hydrothermal systems. This favours a less biased record of potential HP metamorphism unlike zircon, which mainly reflects intermediate to felsic magmatic sources. Moreover, rutile mostly records deep-crustal metamorphic processes as it progressively becomes more stable at (ultra)high pressure ((U)HP) and HT metamorphic conditions.

We collected U-Pb and trace element data from detrital rutile within two different clastic sedimentary units, one from the Neoproterozoic Torridon Group and the other from the Cambrian Ardvreck Group, both preserved at sub-greenschist facies conditions in NW Scotland. These are suitable sequences because their detrital zircon record is derived from a range of different sources from mid-Archean to Neoproterozoic in age, derived from eastern Canada and East Greenland, ideal to probe the significant period between 3 and 1 Ga. We combine our data with an increasing detrital rutile dataset and compare the age frequency distributions of detrital rutile with detrital zircon. Despite rutile being more stable at HP conditions, growing as metamorphic reactions progress in the subducting slab, exhumation of these HP-UHP rocks initiates in the subduction stage and it is prolonged through the collision stage [6]. Exhumation along the subduction channel is largely facilitated by the initiation of continental crust subduction which occurs during continental collision [6]. This implies that the U-Pb isotopic system will record this exhumation step, and, also the Barrovian-type metamorphism developed during the collisional period. When combining this with the preservation potential curve associated with each stage [4] the result highlights that rutile U-Pb age peaks are representative of the collisional stages of an orogen. By integrating both zircon and rutile frequency age distributions, the significant correlation between detrital rutile and zircon, both peaks and troughs, can only be reconciled if, indeed, the detrital zircon record is reflecting a preservation bias that occurs during supercontinent assembly.

References:
Metamorphic CO$_2$ production in Himalaya: Where? How? How much? When? And then?
Groppo C.$^{1,2}$, Rolfo F.$^{1,2}$, Rapa G.$^1$ and Mosca P.$^3$

$^1$Department of Earth Sciences, University of Torino, Italy, chiara.groppo@unito.it
$^2$IGG – CNR, Torino, Italy

Metamorphic degassing from active collisional orogens supplies a significant fraction of CO$_2$ to the atmosphere, playing a key role in the long-term global carbon cycle [1-3]. Primary geologic settings for the production of significant amounts of metamorphic CO$_2$ include “large-hot” collisional orogens, where decarbonation reactions occur at a relatively high temperature within carbonate-bearing metasediments, in which metamorphic reactions between carbonates and silicates trigger CO$_2$ production.

Being the most prominent recent and still active “large-hot” orogen on Earth, the Himalayan belt is the best candidate for the generation of a significant amount of metamorphic CO$_2$ during the Cenozoic. Moreover, the widespread occurrence of high CO$_2$-bearing hot springs and gaseous CO$_2$ discharges from the ground located along the major tectonic discontinuities [4-9] are indicators for a contemporary metamorphic CO$_2$ production in Himalaya. The nature and magnitude of the metamorphic CO$_2$ cycle in the Himalaya, however, is still poorly known.

The results of our recent studies [10-13] help answering the following key questions:
• Where? - Which are the CO$_2$-source rocks, their abundance and distribution in the Himalayan orogen? From which protoliths do they derive?
• How? - Which are the CO$_2$-producing metamorphic reactions? At which physical conditions did these reactions occur? Which was the composition of the produced fluid?
• How much? - How much CO$_2$ was produced through these reactions?
• When? - At which time(s) did the metamorphic CO$_2$ production occur?
• And then? – What about the fate of the CO$_2$ produced? Was the CO$_2$ able to reach the surface or was it sequestered through graphite and/or carbonate precipitation?

Our estimated flux of metamorphic CO$_2$ extrapolated to the scale of the whole orogen (1.4-19.4 Mt/yr [14]) is similar to that actually measured from spring waters and gaseous CO$_2$ discharges [4-5, 8-9], thus suggesting that CO$_2$-producing processes similar to those occurred in the past are still occurring along the active Himalayan orogen. Moreover, the estimated CO$_2$ flux is of the same order of magnitude as that currently emitted by the most active volcanoes on Earth [14], thus suggesting that metamorphic CO$_2$ degassing is a non-negligible process, likely underestimated so far.

References:
Exhumation of the deep crust in NW Bhutan: a case of the hare and the tortoise?
Wood, E.M. ¹, Warren, C.J. ¹, Argles, T. ¹, Roberts, N.M.W. ², Miller, I.L. ², Hammond, S.J. ¹, Halton, A.M. ¹.

¹The Open University, Walton Hall, Milton Keynes - eleni.wood@open.ac.uk.
²British Geological Survey, Keyworth.

During continental collision, crustal rocks are buried, deformed, transformed and exhumed. The rates and timescales of these processes can be constrained by linking geochemical and geochronological data in metamorphic rock-forming and accessory minerals. Many studies of metamorphic timescales focus on single lithologies to shed light on particular stages of the terrane evolution. Mafic rocks typically only record geochronological evidence for their high-grade history. Felsic rocks, on the other hand, tend to yield ages of exhumation processes.

In NW Bhutan, eastern Himalaya, metabasaltic layers and boudins record a complex history involving an early high pressure (eclogite facies, ca 600°C, >1.6 GPa) stage, a later high temperature (granulite facies, 800°C, ~1 GPa) stage and a final amphibolite facies (~600°C, 0.7-0.8 GPa) overprint. In their metasedimentary hosts, rock-forming mineral assemblages record granulite facies metamorphism, exhumation and anatexis, with little to no evidence for high-pressure prograde metamorphism. This terrane provides a rare glimpse into the evolution and exhumation of the deep eastern Himalayan crust, and a detailed case study for deciphering the rates and timescales of deep-crustal processes in orogenic settings.

Our new petrochronological dataset suggests that the metabasites and their host metasediments record different and conflicting tectonic evolutions. Monazite in the metasediments yields 20-15 Ma ages, with trace element chemistry suggesting crystallisation during anatexis and exhumation. Rare hints of an earlier prograde history up to ~34 Ma old are also preserved. On the other hand, allanite and zircon in the metabasites suggests that eclogite facies conditions still prevailed at ~ 15 Ma, well after their host rocks were apparently melting and decompressing. The age of the granulite facies overprint is still unclear in both lithologies. Detailed interrogation of conventional assumptions about how to link ‘isotopic age’ and ‘trace-element-fingerprint stage’ in different chronometers is therefore necessary to reconcile the two records.

The dataset highlights the importance of collecting evidence from a variety of different geochronometers in different lithologies in order to provide the most detailed picture of the evolution and exhumation of deep orogenic crust.
Determining kyanite provenance in Himalayan leucogranites
Phillips, S.E.\textsuperscript{1}, Argles, T.W.\textsuperscript{1}, Harris, N.B.W.\textsuperscript{1}, Warren, C.J.\textsuperscript{1} and Roberts, N.M.W.\textsuperscript{2}

\textsuperscript{1} The Open University, Milton Keynes, United Kingdom (stacy.phillips@open.ac.uk)
\textsuperscript{2} NERC Isotope Geosciences Laboratory, British Geological Survey, Nottingham, UK

The presence of aluminosilicate minerals provides good constraints on P-T conditions, and as such are used in a wide range of metamorphic rocks and peraluminous granites. In granites, however, these minerals could be xenocrysts, peritectic phases or have directly crystallised from melt: each of these occurrences provides different implications for the formation of their host. Kyanite-bearing leucogranites in the Himalaya are commonly interpreted to form by early (Oligocene) melting during prograde burial; by contrast, sillimanite-bearing leucogranites are interpreted as forming during later (Miocene) decompression melting. The petrogenesis of these aluminosilicate-bearing melts therefore carries implications for the timing of mid-crustal weakening and overall Himalayan tectonics.

Kyanite grains found in small-scale (cm-dm), in situ leucogranites from eastern Bhutan and their host schists were investigated using cathodoluminescence imaging (CL), LA-ICP-MS trace element spot analysis and LA-ICP-MS trace element (V, Cr, Ge) mapping. Variations in kyanite morphology, internal CL zonation and geochemistry were observed. Kyanite in the schist is commonly tabular with complex internal CL zonation. Kyanite in the leucosome immediately adjacent to the schist shows similarly complex internal textures, but is corroded, skeletal and rimmed by coarse muscovite. Both the complexly-zoned kyanite in the schist and in the leucosome show similar V, Cr, Ge and Fe concentrations. Within the leucosome there are also thin and bladed kyanite crystals, with little to no internal CL zonation and higher Ge content (>7.5 ppm).

These corroded kyanite crystals in the leucosome are interpreted to be xenocrysts from the schist that retained the complex CL patterns and chemical composition of metamorphic kyanite. The thin, bladed kyanite crystals are thought to represent “igneous” kyanite that formed either peritectically or by crystallisation from the melt. Inter-sample differences in kyanite Cr and Fe content appear to represent differences in protolith composition. Both types of kyanite, and evidence for both prograde and retrograde mineral reactions, can be found in close proximity on the thin-section scale, demonstrating a localised control of composition over mineralogy.

LA-ICP-MS trace element mapping (using 10 μm square pixels) is able to resolve the features visible in greyscale CL images. The best resolution is apparent in V and Cr concentrations; high V/Cr ratios correspond to dark CL areas and low V/Cr ratios correspond to brighter CL areas. Understanding the significance of these variations in terms of reaction history and the genesis of kyanite is important for constraining future P-T-t modelling of the leucogranites, and is crucial for the tectonic interpretation of these melts as drivers for the exhumation of the orogenic mid-crust.
An integrated structural, metamorphic and geochronological study of the Hill of Faeries gneisses, Lewisian complex, Scotland

Sophie Miocevich\textsuperscript{1}, Rich Taylor\textsuperscript{1}, Owen Weller\textsuperscript{1} and Tim Johnson\textsuperscript{2}

\textsuperscript{1}Department of Earth Sciences, University of Cambridge (srm81@cam.ac.uk)
\textsuperscript{2}School of Earth and Planetary Sciences, Curtin University

The Lewisian Gneiss Complex is a fragment of polymetamorphosed Archean crust located in northwest Scotland that is thought to represent a mid-crustal Archean environment. Rare garnet-biotite felsic gneiss assemblages in the Lewisian have been interpreted as having a supracrustal protolith, and both uniformitarian and non-uniformitarian Archean tectonic processes have been invoked to explain the implied mass transfer from the surface to the mid-crust. However, there is still significant uncertainty regarding the garnet-biotite gneiss protoliths; specifically whether they truly represent supracrustal rocks.

This study aims to investigate the protolith of the garnet-biotite gneisses and what geodynamic environment they may represent, focusing on the ‘Hill of Faeries’ locality. Field mapping was conducted to analyse field associations, which confirmed that protolith relationships are obscured by subsequent deformation, and to collect samples for subsequent geochronological and thermobarometric analysis. Laser ablation split stream geochronological data were collected and reveal the garnet-biotite gneisses have a common protolith age of 2812 ± 7 Ma. Phase equilibria modelling was carried out on a mafic gneiss associated with the potential supracrustals, indicating peak metamorphic conditions of 950 ± 50 °C and 9 ± 1 kbar. Notably, this latter result indicates that the Hill of Faeries locality experienced lower pressure conditions than previously reported \cite{1}, which means that the locality is now consistent with thermobarometric data from the rest of the Lewisian.

The integrated results of this study suggest the garnet-biotite gneisses are more likely to have an igneous protolith than a sedimentary protolith, although work is ongoing to determine whether an exclusively intrusive or extrusive scenario can be established. Overall, this study indicates there is significant uncertainty in interpreting Lewisian garnet-biotite gneisses as supracrustal. Further work is needed to assess what geodynamic environments are represented by these lithologies.

References:
\cite{1} Zirkler A et al (2012) J. metamorphic Geol 30: 865–88
Seeing through metamorphic overprints in the Lewisian Complex of Scotland using two-pyroxene single crystal thermometry

Gopon P.1, Forshaw J. B.1,2, Wade J.1, and Waters D. J.1,3
1Department of Earth Science, University of Oxford, South Parks Road, Oxford, UK OX1 3AN
2Department of Geoscience, University of Calgary, 2500 University Drive, Calgary, Canada T2N 1NV
3Oxford University Museum of Natural History, Parks Road, Oxford, UK, OX1 3PW

The Archaean Lewisian Complex of northwest Scotland is composed primarily of tonalite-trondhjemite-granodiorite orthogneiss, with lesser amounts of metamorphosed mafic and ultramafic rocks [1]. Despite a tremendous amount of research into the tectono-thermal evolution of this terrane, peak pressure and temperature (P-T) conditions of the complex remain somewhat unconstrained. Previous P-T estimates span a vast range from 8 to 15 kbar and 800 to 1000 °C [2]. Much of this scatter is due to the long metamorphic history, involving slow cooling and one or more retrograde metamorphic overprints, with resulting recrystallization and diffusional resetting.

By using the relatively new technique of low keV EPMA [3] to examine sub-micron exsolution lamellae within clinopyroxene crystals, this study aims to constrain both the retrograde and peak metamorphic conditions achieved by the Lewisian mafic granulites. These exsolution lamellae formed at discrete times on the retrograde path, and more importantly, do not extend to the grain boundaries, indicating that crystals have exsolved in a closed system retaining their peak chemistry. We have obtained a retrograde T estimate (~600°C) using two-pyroxene thermometry as well as a peak T estimate (~1000°C) using single-clinopyroxene thermometry on homogenized clinopyroxene [4]–[6]. Pressure constrains where determined by pseudosection modelling.

However, analysing sub-micron phases presents a number of analytical difficulties [3], including issues with keeping the electron beam centred on the phase of interest during the analysis, carbon contamination, and secondary fluorescence from the host grain [7]. We set out analytical protocols to mitigate these issues and correct data for secondary fluorescence effects.

References:

Figure 1: PPL image of textural relationships within the Lewisian mafic granulite, showing garnet breakdown to plagioclase + orthopyroxene, and clinopyroxene breakdown with orthopyroxene exsolution lamellae.
Evidence for a Late Cambrian juvenile arc and a buried suture within the Laurentian Caledonides of Scotland: comparisons with hyper-extended Iapetan margins in the Appalachians and Norway

M. Dunk¹, R.A. Strachan¹, K.A. Cutts², S. Lasalle¹, C.D. Storey¹, I.M. Burns³, M.J. Whitehouse⁴, M. Fowler¹ H. Souza-Moreira¹, J. Dunlop¹ & I. Pereira¹

¹. School of Earth & Environmental Sciences, University of Portsmouth, Burnaby Rd, Portsmouth, PO1 3QL.
². Department of Geology, Universidad Federal de Ouro Preto, Ouro Preto, Brazil.
³. 6, McKenzie Crescent, Bettyhill, By Thurso, Sutherland, KW14 7SY
⁴. Department of Geosciences, Swedish Museum of Natural History, Box 50 007, SE-104 05, Stockholm, Sweden.

U-Pb zircon dating establishes a Late Cambrian (Drumian) protolith age of 503 ± 2 Ma for a trondhjemitic gneiss of the calc-alkaline Strathy Complex, northern Scottish Caledonides. Positive εHf and εNd values from trondhjemitic gneisses and co-magmatic amphibolites respectively, and an absence of any inheritance in zircon populations, support published geochemistry that indicates a juvenile origin in a distal setting from the Laurentian margin.

In order to account for its present location within a stack of Laurentian-derived thrust sheets, we interpret the complex as allochthonous and located along a buried suture. We propose that a microcontinental ribbon was detached from Laurentia during late Neoproterozoic to Cambrian rifting; the intervening oceanic tract closed by subduction during the late Cambrian and formed a juvenile arc, the protolith of the Strathy Complex. The microcontinental ribbon was re-attached to Laurentia during the Grampian orogeny which transported the Strathy Complex as a detached horse within a nappe stack.

Peak metamorphic conditions for the Strathy Complex arc (650-700°C, 6-7.5 bars) are intermediate in pressure between those published previously for Grampian mineral assemblages in structurally overlying low-P migmatites (670-750°C, <4 kbar) which we deduce to have been derived from an adjacent back-arc basin, and structurally underlying upper amphibolite rocks (650-700°C, 11-12 kbar) that we interpret to represent the partially subducted Laurentian margin.

This scenario compares with the northern Appalachians and Norway where microcontinental terranes were detached from passive margins of the Iapetus Ocean during Cambrian rifting and re-amalgamated during Ordovician and Silurian orogenesis.
U-Pb zircon age dating of diamond-bearing gneiss from Fjørtoft reveals repeated burial of the Baltoscandian margin during the Caledonian Orogeny

Simon Cuthbert¹, Katarzyna Walczak², Ellen Kooijman³, Jarosław Majka¹,⁴, Matthijs A. Smit⁵

¹ School of Computing, Engineering & Physical Sciences, University of the West of Scotland, Paisley, UK
² Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Kraków, Poland
³ Department of Geosciences, Swedish Museum of Natural History, Stockholm, Sweden
⁴ Department of Earth Sciences, Uppsala University, Villavägen 16 SE-752 36 Uppsala, Sweden
⁵ Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver, British Columbia, Canada

The first find of micro-diamond in the Nordøyane UHP domain of the Western Gneiss Region (WGR) in the Scandinavian Caledonides [1] reshaped tectonic models for the region. Nevertheless, in spite of much progress regarding the meaning and significance of this find, the history of rock that the diamonds were found in is complex and still largely ambiguous. To investigate this, we report U-Pb zircon ages obtained from the same sample material in which metamorphic diamond was first found. The grains exhibit complicated internal zoning with distinct detrital cores overgrown by metamorphic rims. The cores yielded a range of ages from the Archean to the late Neoproterozoic/early Cambrian. This detrital zircon age spectrum is broadly similar to detrital signatures recorded by metasedimentary rocks of the regionally-extensive Lower and Middle allochthons elsewhere within the orogen. These results support the previously proposed affinity of the studied gneiss to the Seve-Blåhø Nappe of the Middle Allochthon, attributed to the outermost continental margin of Baltica. Metamorphic rims yielded a well-defined peak at 447 ± 2 Ma and a broad population that ranges between c. 437 and 423 Ma. The data reveal a prolonged metamorphic history of the Fjørtoft gneiss that is far more complex than would be expected for an UHP rock that has seen a single subduction-exhumation cycle. The data are consistent with a model involving more than one such cycle, with an early subduction-collision episode at least as old as late Ordovician and another during the well-known late Silurian - early Devonian Scandian collision. This provides renewed support for the multiple “dunk tectonics” model that has been postulated for this northern segment of the Caledonides [2][3].

References:
EBSD analysis of palisade quartz textures: implications for coesite-quartz transformation, Tso Morari dome, Himalaya

Bidgood, A.K.¹, Parsons, A.J.¹, Lloyd, G.E.², Waters, D.J.¹,³ and Goddard, R.M.¹

¹Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, OX1 3AN, UK. Anna.bidgood@univ.ox.ac.uk
²School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK
³Museum of Natural History, University of Oxford, Parks Road, Oxford, OX1 3PW, UK

Evidence of transformation at UHP conditions is often lacking in felsic rocks due to incomplete transformation and/or overprinting by later metamorphism and deformation. In the absence of coesite, microstructures after coesite (e.g. ‘palisade’ quartz) provide the only robust evidence of burial to UHP depths. Low strain rocks provide a potential window into the early history of these complex terrains as the lack of deformation can preserve early metamorphic features and quartz microstructures after coesite [1]. Extensive deformation in these terrains would also explain why similar textural relationships have not yet been reported from other quartz-bearing UHP rocks. Understanding such microstructures therefore plays a crucial role in the determination of the burial depths and tectonic histories of rocks in these terrains.

The application of Electron Backscatter Diffraction (EBSD) and misorientation analysis provides a quantitative tool to define and describe palisade quartz textures. In one specimen of the granite of the Tso Morari dome, in Ladakh, Himalaya, the quartz domains show microstructures comparable to previously reported palisade texture, while the overall domain shape matches that of igneous quartz in neighbouring granite specimens. This raises the possibility that igneous quartz was transformed to coesite and subsequently reverted to quartz on exhumation. The quartz domains are approximately bisected by a boundary separating subdomains of quartz with systematic single-crystal crystallographic preferred orientations (CPOs), which may be interpreted as inherited from a twinned coesite precursor. Additionally, within each subdomain, palisade quartz textures and CPO correspond to misorientations of 60° around the c-axis and may therefore correspond to dauphiné twins which have inherited some organization from the coesite precursor.

Our findings document several previously unreported textural observations including the preservation of igneous domains containing palisade quartz textures, the first detailed misorientation analysis of palisade quartz and the crystallographic control of the coesite-quartz transition, which is at odds with the initial interpretation by Lenze and Stöckhert [2]. We interpret these findings as the first reported evidence of twinning in coesite recorded in quartz and the first quantitative approach to use quartz microstructures as an indicator of burial to UHP conditions, which is due, at least in part, to the relatively undeformed nature of this sample. This study also documents the need for further EBSD analysis of undeformed, high pressure quartz-bearing rocks from other metamorphic terrains where UHP metamorphism is debated.

References:

Isotopic mapping of crustal fragments in a young accretionary orogen

Webb, M.1,2, White, L. T.1,2, Manning, C.2, Jost, B. M.2.

1 GeoQuEST Research Centre, School of Earth, Atmospheric, and Life Sciences, University of Wollongong, Wollongong, NSW 2522, Australia.
2 Southeast Asia Research Group, Royal Holloway University of London, Egham, Surrey, TW20 0EX, UK.

New Guinea represents one of the world’s youngest orogenies, having formed from a series of arc–continent collisions throughout the late Cenozoic [1, 2, 3]. The island also represents the northernmost margin of the Australian continent and has acted as a buffer zone between stable Australian continental crust to the south, and oceanic or island arc crust to the north, during periods of collision, subduction, and uplift that have been ongoing throughout the Cenozoic [1, 2, 3]. This complex tectonic activity, along with extensive strike-slip movement across the island, has created a series of terranes containing rocks of different age and crustal affinity. These terranes have previously been grouped into four tectonic belts that strike laterally across New Guinea, including: a stable platform underlain by Australian continental crust; the New Guinea fold and thrust belt (composed of Mesozoic–Cenozoic passive margin siliciclastics and carbonates); the New Guinea Mobile Belt (composed of material derived from both oceanic and continental crust); and a series of accreted oceanic island arc terranes [2, 3]. These belts are well defined on regional maps, however, determining their boundaries on a local scale, and in-turn determining the boundary between Australian continental crust and Pacific-origin oceanic crust, is hampered by a lack of outcrops and the abundance of dense tropical rainforest found across New Guinea.

This study uses Sr–Nd whole-rock isotopic analyses of rocks from these different terranes in the very NW of New Guinea (the Bird’s Head Peninsula) to further understand the nature of the underlying crust beneath New Guinea, and for use as a tool in distinguishing between complex terranes in a remote and tropical region. The results of this study have identified three distinct crustal domains underlying the Bird’s Head based on their Sr–Nd isotopic signatures; Palaeozoic–Mesozoic Australian continental crust ($^{87}$Sr/$^{86}$Sr = 0.719594 to 0.710921; $\varepsilon_{Nd} = -13.85$ to 1.373); thinned transitional crust through which Miocene to Pleistocene magmatic rocks have intruded ($^{87}$Sr/$^{86}$Sr = 0.706524 to 0.704019; $\varepsilon_{Nd} = 6.67$ to 2.13); and accreted oceanic island arc terranes ($^{87}$Sr/$^{86}$Sr = 0.704053 to 0.703759; $\varepsilon_{Nd} = 6.63$ to 4.97). These isotopic ranges, along with crustal contamination models, have been used to show that Australian continental crust continues beneath NW New Guinea to its northern-most extent of 0°30’ S, underlying the Tamrau Block.

In addition, the isotopic ranges derived from different crustal blocks in the Bird’s Head have been compared to previous isotopic studies across New Guinea to image the location of continental, transitional, and oceanic crust along the island. This has also shown a potential change in the age of Australian continental crust underlying New Guinea from east to west, with Archean–Proterozoic crust present in the east and Proterozoic–Palaeozoic crust in the west and has implications for understanding the crustal architecture of remote or understudied regions.

References:

Fluid metasomatism of garnet-bearing blocks in mélange: relative timing from in situ analysis of oxygen isotopes reveal contrasting histories from two Mesozoic subduction complexes, California, USA

Page F.Z. ¹

¹Department of Geology, Oberlin College, Oberlin, Ohio, U.S.A.

The high-pressure, garnet-bearing blocks of eclogite, blueschist, and hornblendite hosted by the lower-grade Franciscan Formation of northern California record profound oxygen isotope disequilibrium at the mineral grain scale. A series of recent studies using large-radius ion microprobes have shown that garnets in these rocks are typically zoned in $\delta^{18}$O, with broad, homogeneous cores recording the oxygen isotope ratio of the altered oceanic crust protolith and thin (<100µm) rims that record either an increase or decrease in rock $\delta^{18}$O due to fluid infiltration [1,2]. In contrast, garnet amphibolite blocks in mélange from Santa Catalina Island in southern California, a locality known for pervasive fluid flow, have unzoned garnet recording protolith $\delta^{18}$O [3].

Why is some garnet in mélange-hosted eclogite and related rocks zoned in $\delta^{18}$O and some homogeneous? In order for garnet to record a shift in rock $\delta^{18}$O, not only must the rock be metasomatized, but the rock must remain in, or return to, the garnet stability field.

In the Catalina mélange, garnet that formed within metasomatic rinds on mafic blocks [5] and in metasedimentary blocks [6] is zoned in $\delta^{18}$O, suggesting that the differential permeability of the host rock and position of neoformed garnet within a block offer controls on when garnet will record fluid infiltration. Unlike blocks from Catalina, Franciscan eclogite garnet appears to record zoning throughout the tectonic blocks. Additionally, these samples have a texturally late, low-T overprint including rims of matrix sphene surrounding rutile and glaucophane surrounding omphacite. In some cases, retrograde P-T conditions from inclusions in garnet rims zoned in $\delta^{18}$O show that metasomatism took place between peak P-T and the blueschist facies overprint [2]. Cation zoning from other samples in the Franciscan show that the shift in rock $\delta^{18}$O took place during prograde metamorphism [1].

Some garnet in eclogite from the Franciscan records multiple events of resorption and regrowth with and without shifts in $\delta^{18}$O [2]. Similar $\delta^{18}$O zoning patterns in garnet from different size populations in samples from Catalina show that there were different garnet nucleation events before fluid infiltration [5,6]. Recent work on oscillatory-zoned garnet from the Franciscan with multiple episodes of resorption and regrowth has been attributed to pulses of fluid overpressure and release during subduction [6], that present one mechanism for the observed zoning patterns. Alternatively, tectonically driven flow within the mélange ie. “subduction undertow”, offers a different mechanism for the same observations [2,7].

References:
Sinking slabs through time: the relationship between mantle potential temperature and oceanic lithosphere buoyancy

*Weller, O.M. 1, Copley, A. 1, Miller, W.G.R. 1, Palin, R.M. 2, and Dyck, B.J.D. 3

1Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK
*ow212@cam.ac.uk
2Department of Geology and Geological Engineering, Colorado School of Mines, Golden, 80401 Colorado, USA
3Department of Earth Sciences, Simon Fraser University, University Drive, Burnaby, V5A 1S6, Canada

Earth’s ambient mantle potential temperature ($T_P$) has cooled by ~250 °C since the Archean, causing a progressive change in both the structure and composition of oceanic lithosphere. These variables affect the negative buoyancy of subducting slabs, which is known to be an important force in driving plate motions. However, the relationship between $T_P$ and slab buoyancy remains unclear. Here, we model the formation and subduction of oceanic lithosphere as a function of $T_P$, to investigate how $T_P$ influences the buoyancy of subducting slabs, and by extension how buoyancy forces may have changed through time.

First, we simulate isentropic melting of peridotite at mid-ocean ridges over a range of $T_P$ (1300–1550 °C) to constrain oceanic lithosphere structure and composition. Second, we model the thermal evolution of oceanic plates undergoing subduction for a variety of scenarios (by varying lithospheric thickness, slab length and subduction velocity). Finally, we integrate the structural, compositional and thermal constraints to forward model subduction metamorphism of oceanic plates to determine down-going slab density structures. When compared with ambient mantle, these models allow us to calculate buoyancy forces acting on subducting slabs.

Our results indicate that oceanic lithosphere derived from hotter mantle has a greater negative buoyancy, and therefore subduction potential, than lithosphere derived from cooler mantle. This conclusion supports models of subduction zone initiation in the early Earth that invoke the concept of oceanic lithosphere being primed to subduct. However, we also show that decreases to lithosphere thickness and slab length, and reduced crustal hydration, progressively reduce slab negative buoyancy. These results highlight the need for robust estimates of early Earth lithospheric properties when considering whether subduction was operative or not at this time.
High-grade collisional tectonics in an offshore palaeoproterozoic basement: Geology of the Lonely Isles

Anna Bird¹, Eddie Dempsey¹, Tim Armitage², Bob Holdsworth²

¹ Department of Geography, Geology and Environmental Sciences, University of Hull
² Department of Earth Sciences, Durham University

The Lonely Isles are series of well exposed, yet extremely remote islands that give a unique and previously unknown insight into the ancient geology of northern Scotland. These rocks are part of the Precambrian basement that underlies much of northern Scotland, including Orkney and Shetland, and parts of Greenland.

These Precambrian rocks also underlie the Clair Oil Field, which is situated to the west of Shetland, and represents the largest hydrocarbon resource in the UK continental shelf and Europe. The hydrocarbons of the Clair field are found within Devonian-Carboniferous sandstones sitting on a ridge of this Precambrian metamorphic basement as well as within fractures in the basement rocks themselves. Despite the economic and scientific importance of these rocks, our understanding of the basement geology in these regions is extremely limited. Recent work that has been undertaken basement core samples retrieved from over several hundred km² beneath the Atlantic Ocean suggest that the basement rocks here are granodioritic to granitic orthogneisses and are Neoarchaen in age (ca 2-7-2.85 Ga). They lack the widespread Proterozoic “Laxfordian” event (ca. 1.6-1.75 Ga) seen in mainland Scotland and Outer Hebrides. This requires the presence of a northern “Laxford Front” somewhere north of the Scottish mainland.

The Lonely Isles are the only place where these basement rocks outcrop above sea level providing a rare opportunity to examine and understand these enigmatic rocks. As such, understanding the geology of these islands is key to understanding the location and nature of this theorised terrane boundary between the Scottish Mainland and the basement rocks found under the Clare Oil Field.

In November 2018, a team of geologists from University of Hull and Durham University went to the Flannan Isles, North Rona and Sula Sgeir. The team, Dempsey, Bird and Armitage, (funded by Prof Holdsworth of Durham University) are the first geologists to examine the Flannan Isles since 1933 or North Rona since 1958. Many geological fundamental concepts have been developed or refined (including plate tectonics) in this time. This presentation will show the highlights of the expedition and some of the initial findings of this study as well as future research and fieldwork plans.
Structural and metamorphic evolution of the Zanskar Himalaya in the Suru Valley region (India), from crustal thickening through to melting and exhumation

Cawood, I.P.*1, Searle, M.P.1, Weller, O.M.2, Ahmad, T.3, Roberts, N.M.W.4, St-Onge M.R.5, Waters D.J.1

*Email: ian.cawood@worc.ox.ac.uk
1Department of Earth Sciences, University of Oxford, South Parks Road, Oxford, OX1 3AN, UK
2Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ, UK
3University of Kashmir, Srinigar, Jammu and Kashmir, 190 006, India
4NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK
5Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

The Himalaya is an unrivalled natural laboratory to investigate orogenic processes involved in continental collision as it is one of the youngest, best exposed and most intensively studied mountain belts on Earth. However, questions remain concerning the evolution of the highest-grade metamorphic component of the Himalayas—the Greater Himalayan Sequence (GHS)—with implications for our understanding of how crustal deformation is accommodated in collision zones. Mapping of metamorphic isograds has characterised the base of the GHS as a zone of inverted Barrovian-style metamorphism above the Main Central Thrust (MCT), and the top of the GHS as a zone of condensed right-way-up metamorphism below the Zanskar Shear Zone (ZSZ). The central core preserves migmatites and crustal melt leucogranites. The Suru Valley in western Zanskar (NW India) cuts through the top section of the GHS, providing an ideal transect in which to analyse at least 20 km of structural depth through the thickened crust of the Himalaya. Fieldwork was undertaken in August 2018 to conduct reconnaissance mapping, understand the regional structural framework and collect key samples for thermobarometry, geochronology and thermochronology. Data will be presented from the first field season, focusing on the results of petrographic analysis over a range of metamorphic grades. Two more field seasons are planned in 2019 and 2020.

The overall project has four principal objectives: (1) map regional fold-nappe structures in detail and determine the relationship of the folds to metamorphic mineral isograds, (2) determine the precise pressure–temperature (P–T) conditions of metamorphism in this part of the GHS using petrology, thermobarometry and phase diagram modelling through a ~20 km-thick structural section along the top of the GHS beneath the ZSZ, (3) determine the timing of peak metamorphism by U–Th–Pb dating of monazite across all metamorphic grades, and (4) integrate the above data to constrain the metamorphic evolution of the GHS and by extension regional structural and thermal models for the core of the Himalayan orogen. This work will build upon previous studies in the region [1-5], and result in the construction of valid and field-tested models of how the continental crusts thickens, is buried and then exhumed during collisional orogenesis.

References:
Geochemical discrimination of metabasites from a Neoproterozoic accretionary complex in Anglesey, North Wales

Groome N.T.¹, Buchs D.M.¹, Fagereng A.¹, Wood M.², Campbell S.¹ and Horák J.⁴

1 School of Earth and Ocean Sciences, Cardiff University, Main Building, Cardiff CF10 3AT, UK
2 GEOMON Geopark, The Old Watch House, Amlwch Port, Amlwch, Anglesey LL68 9DB, UK
3 Natural Resources Wales, Maes y Ffynnon, Penrhosgarnedd, Bangor, Gwynedd LL57 2DW, UK
4 Department of Geology, National Museum of Wales, Cardiff CF10 3NP, UK
GroomeNT@cardiff.ac.uk

The Isle of Anglesey, North Wales, is home to a Neoproterozoic blueschist belt with a peak metamorphic age of 550-560 Ma [1]. The blueschist belt is part of the Mona Complex, an ancient accretionary complex at the margin of the Avalonian microcontinent that extends from Anglesey to Lleyn Peninsula. A geodynamic model of this accretionary complex [2] suggests that the blueschist belt is a tectonic lens within the Gwna Group (or Gwna mélange), a kilometre-scale mélange ranging from sub-greenschist to greenschist facies metamorphic grades. Both the blueschist belt and the Gwna mélange contain numerous elongate lenses of metabasites, varying in metamorphic grade and deformation extent, which locally exhibit deformed pillow lava remnants. Despite a recent geochemical study of Mona Complex greenschist basalts on the Lleyn Peninsula [3], the geochemistry and therefore the origin(s) of metabasites on Anglesey, most notably the blueschists, is poorly constrained.

Blueschists and greenschists from across Anglesey and pillow basalts from Newborough and Lleyn Peninsula have generally consistent immobile trace element contents, suggesting that they originated from intra-oceanic magma sources. A wedge of Gwna mélange found in Newborough area on Anglesey hosts numerous lenses of relatively undeformed sub-greenschist pillow basalt sequences along with dismembered units of overlying seafloor sediments. The geochemistry of these undeformed pillow basalts is similar (albeit not identical) to that of modern MORB. Metabasites (schists to pillows) in the Mona Complex mostly show compositions within a MORB-OIB array. Within this array, metabasites can be split into two groups close to the composition of modern E-MORB and N-MORB. A third distinct group of rarer metabasites has continental arc affinities. Elemental mobility within the geochemical groups found in different parts of the Mona Complex is being assessed based on ratios of major and minor elements against Zr, which is known for its relative immobility during alteration and metamorphism [4]. This approach will benefit from the occurrence of different metamorphic grades within the geochemical groups, which offers an interesting opportunity to test whether sub-greenschist, greenschist and blueschist metamorphic conditions (and more cryptic ocean floor alteration) are correlated to specific chemical changes. Ongoing geochemical analysis has been more focused on the sub-greenschist basalts of Newborough, analysing variations between different basalt lenses, and how factors such as volcanic glass content affects geochemical alteration. More greenschist and blueschist samples are scheduled to be analysed to focus more on the effects of metamorphism on element mobility in the near future.

References:
Boron isotopic record of devolatilization and retrogression in (ultra)-high pressure metamorphic rocks (Lago di Cignana, Western Alps)

Halama, R.¹, Konrad-Schmolke, M.² and De Hoog, J.C.M.³

¹Keele University, William Smith Building, Keele, ST5 SBG, UK; e-mail: r.halama@keele.ac.uk.
²University of Gothenburg, Guldhedsgatan 5a, 41320 Göteborg, Sweden
³University of Edinburgh, James Hutton Road, Edinburgh EH9 3FE, UK

Boron (B) and the B stable isotope system are useful tracers of fluid-mediated mass transfer in subduction zones [1,2]. In subduction-related metamorphic rocks, white mica (phengite/muscovite or paragonite) is a major host of B and useful to track prograde dehydration and retrograde fluid-rock interaction [3,4]. In this contribution, we investigate the B geochemistry of white mica coupled to major element mineral chemistry in (ultra)high-pressure (UHP) metamorphic rocks from Lago di Cignana (Western Alps, Italy).

The tectonic units at Lago di Cignana are slices of eclogite-facies meta-ophiolites from the Zermatt-Saas zone, comprising an UHP unit characterised by the presence of coesite (Lago di Cignana unit, LCU). Ages (ca. 49-40 Ma) and peak P-T conditions (550-630 °C and 2.5-3.0 GPa) of the LCU and other Zermatt-Saas meta-ophiolites are similar, pointing to a similar tectonometamorphic evolution [5].

Three samples from the HP/UHP units at Lago di Cignana were investigated, with each sample representing a specific metamorphic process relevant to the formation of white mica: (i) A phengite garnet quartzite containing euhedral, peak metamorphic phengite; (ii) an eclogite containing paragonite that occurs in pseudomorphs after lawsonite [5]; and (iii) a pervasively retrogressed metabasite comprising a greenschist-facies mineral assemblage with phengite.

Phengite in a phengite garnet quartzite has relatively high B contents (up to 265 ppm) and negative δ¹¹B values (-2 to -9 ‰). Boron concentrations and δ¹¹B show a positive correlation that can be modelled as a Rayleigh distillation process, which we interpret to reflect prograde devolatilization. The data provide a unique example confirming the theoretically predicted evolution of [B]-δ¹¹B relationships during prograde subduction zone metamorphism. Paragonite in pseudomorphs after lawsonite has typically low B contents (< 20 ppm) and scattered δ¹¹B values (-4 to +4 ‰). In the retrogressed metabasite, δ¹¹B of phengites scatters from -3 to +5 ‰ and B contents are moderately low (≤ 50 ppm). The data of these rocks, in which white mica reflects formation on the retrograde P-T path either by reaction or recrystallization, can be modelled by fluid-rock interaction where white mica equilibrated to variable degrees with a retrograde fluid with positive δ¹¹B.

Our observations and data underline the value of in situ isotope analyses of metamorphic minerals. The [B]-δ¹¹B systematics of white mica in this study provide evidence for prograde devolatilization and loss of boron. Moreover, white mica formed on the retrograde path exhibits B geochemical characteristics that provide constraints on retrograde fluid-rock interaction processes in (U)HP metamorphic rocks. Deciphering the P-T-X record in metamorphic minerals contributes to our understanding of the links between metamorphic processes in subduction zones and the geochemistry of arc magmatic rocks.

References:
Decoding the Ptarmigan Fiord thrust imbricate zone, Baffin Island, Arctic Canada

Harris, B. J. R. 1, Weller O. M. 2 and Miller W. G. R. 3

1 Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ
2 Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ
3 Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge, CB2 3EQ

Ptarmigan Fiord, on the Hall Peninsula, south Baffin Island, Canada, exposes a mid-crustal thrust imbricate zone comprising Archean orthogneiss basement and Paleoproterozoic metasedimentary cover, which forms part of the Quebec-Baffin section of the 1.8 Ga Trans-Hudson Orogen (THO). Such thrust imbricate zones are typically thought to form during prograde metamorphism. This work builds on recent structural mapping of the area [1] by integrating petrological studies and phase equilibria modelling to infer the relative timing of metamorphism and deformation in the thrust imbricate zone to constrain models of its formation. Map-scale structures, and petrographic fabric analysis suggest E-SE-vergent thrust imbrication on ductile shear zones (D1 PF) followed by folding (D2 PF) and a late, out-of-sequence thrust (D3 PF). Phase equilibria modelling is conducted using bulk compositions derived from combining mineral compositions and modal abundances, the validity of which is tested in this work. Constraints from observed assemblages and garnet compositional isopleths suggests peak metamorphic conditions ranging from 7.4 kbar, 660 °C in the basal thrust sheet to 8.4 kbar, 765 °C in the highest structural level. Petrographic fabric analysis and thermal considerations based on the thickness of thrust sheets suggest that all three deformation events were post-thermal peak, and associated with fluid-fluxed retrogression, providing evidence of thrust imbricate formation during retrograde metamorphism. Retrogressive assemblages indicate that deformation took place over a temperature interval of ≈100 °C, suggesting deformation over a protracted time period, posing questions about the thermal history of late tectonism in the THO.

References:
Emplacement, burial, exhumation – deciphering the fate of the Lévézou massif via petrochronological studies of felsic and mafic eclogites

Lotout C.\textsuperscript{a,b}, Pitra P.\textsuperscript{b,c}, Poujol M.\textsuperscript{b}, Ruffet G.\textsuperscript{b}, Anczkiewicz R.\textsuperscript{d}, Van Den Driessche J.\textsuperscript{b}

Corresponding author: Caroline Lotout, caroline.lotout@gmail.com
\textsuperscript{a}Géosciences Le Mans, Le Mans Université, Avenue Olivier Messiaen, 72085 Le Mans CEDEX 9, France
\textsuperscript{b}Univ. Rennes, CNRS, Géosciences Rennes - UMR 6118, F-35000 Rennes, France
\textsuperscript{c}Česká geologická služba, Klárov 3, CZ-118 21 Praha 1, Česká republika
\textsuperscript{d}Institute of Geological Sciences, Polish Academy of Sciences, Kraków Research Center, Senacka 1, PL 31-002, Kraków, Poland

Determining timescales, rates and duration of metamorphic processes together with the pressure–temperature (P–T) evolution of metamorphic rocks is a prerequisite for deciphering the geodynamic evolution of mountain belts. We present here a complete study from the Lévézou massif (French Massif Central), based on the investigation of mafic and granitic rocks that preserved various metamorphic stages during the variscan orogeny.

Both rocks types emplaced during Ordovician times at ca. 470 Ma (zircon U-Pb dating). Phase diagram modelling performed on the whole rock composition of undeformed granites allowed to constrain the emplacement conditions at ca. 2 kbar and 670°C. The underformed granites locally developed metamorphic textures, as tiny garnet coronae surrounding magmatic biotite, rutile aggregates pseudomorphing magmatic ilmenite or rare rectangular clusters dominated by phengite, kyanite, garnet and quartz that pseudomorphcordierite. Pseudosections calculated for the local bulk composition of the cordierite pseudomorphs suggest that they developed at 15-17 kbar and 650-670°C, i.e. under eclogite-facies conditions. The neighbouring mafic eclogites recorded slightly higher pressure conditions at 18-23 kbar and 680-800°C, and were later equilibrated at 8-9.5 kbar and ca. 600°C.

A large panel of geochronometers (U-Pb on zircon, rutile and apatite, Lu-Hf and Sm-Nd on garnet) were investigated and combined to tightly constrain the P–T conditions of the mafic metamorphic rocks. Lu-Hf garnet dating from a fresh and a retrogressed eclogite yield identical dates of 357 ± 13 Ma and 357.5 ± 4 Ma, that approximate the age of the HP metamorphic peak. Fresh and retrogressed samples yield respectively 367.8 ± 9.1 Ma and 354.9 ± 9.5 Ma for U-Pb rutile dating. Apatite grains from the retrogressed sample give a mean age of 351.8 ± 2.8 Ma, while garnet Sm-Nd dating yield an age of 350.4 ± 7.7 Ma. The similarity between all recorded ages from distinct chronometers and radiometric methods testify to very fast exhumation, highlighting a major nearly adiabatic decompression, ranging from 8.5 to 15 kbar (av. 12 ± 3 kbar) in less than 6 My. Finally, a campaign-style Ar-Ar study on granitic rocks highlights localized migmatisation enhanced by fluid circulation, contemporaneous with two deformational events at ca. 350 and 342 Ma, and constrains the final geodynamic evolution of the massif. Further details can be found in [1] and [2].

References:
Thermal and Metamorphic Modelling of a Barrovian Sequence from Eastern Tibet

Maltby, M.J.¹, Weller, O.M.¹, Holland, T.J.B.¹, Copley, A.¹

¹Department of Earth Sciences, University of Cambridge, Downing Street, Cambridge CB2 3EQ (mjm232@cam.ac.uk)

The Danba Structural Culmination (DSC) reveals a complete cross-section of metamorphism in the Songpan-Garzê Fold Belt, located in Eastern Tibet, with a continuum of metamorphic grades observed across a large anticlinal structure ranging from chlorite-grade rocks at its flanks through to sillimanite-grade migmatites at its core [1]. A detailed petrographic study was made using eight samples ranging from biotite-grade through to sillimanite-grade migmatites. This found the majority of the growth of the Barrovian index minerals to have occurred during a single stage of deformation, with only minor retrogression noted, making the DSC an ideal case study for metamorphism.

Expanding on the study of Weller et al. [2], pseudosections were constructed using THERMOCALC, making use of up to date activity-composition models for metapelites and metabasites [3,4] as well as a newly-developed fluid model with a lowered water activity to account for graphite present in the samples. Seven of the eight samples were modelled in this way to identify peak metamorphic P–T conditions that allowed for the reconstruction of the regional metamorphic field gradient (MFG) in the P–T range 580 °C and 5.8 kbar for a staurolite-grade sample to 740 °C and 7.8 kbar for a sillimanite-grade migmatite. Notably, the prograde P–T path derived was found to lie subparallel to a linear MFG.

Thermal modelling was done to simulate metamorphism in the Danba region via two different mechanisms: thin-skinned thickening of only sediment above a décollement structure previously identified in the field, and homogeneous thickening of both the crust and overlying sediment. The results from metamorphic modelling can be explained by the thickening of only the sediments above a décollement structure.

References:
Metamorphic controls on Earth’s deep crustal CO₂ budget

Nicoli, G.¹ and Dyck, B.³

¹Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, United Kingdom, ng422@cam.ac.uk
²Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada

The global carbon cycle plays an important role in the long-term self-regulation of the Earth’s surface conditions. However, the circulation of volatiles through the continental crust and, in particular, the capacity for the Earth’s continental crust to store and release CO₂ remains a subject of ongoing debate. Efforts have been made by volcanologists to determine the upward flux of carbon at plate margins, and through this work, the behaviour of carbon in the lithospheric mantle is relatively well understood. These studies, however, often overlook the role played by the continental crust (~30 vol.% of Earth’s crust), and the mechanisms responsible for the fate and budget of carbon-rich fluids in the middle-to-lower continental crust remain unknown. Supracrustal rocks (i.e., sediments and erupted materials) are an important interface between Earth’s hydrosphere and the deep lithosphere. Erosion and weathering of silicate-rich supracrustal rocks can sequester a significant quantity of CO₂ [1]. Consequently, in convergent settings, the tectonic burial of supracrustal rocks can draw down large volumes of volatile elements to deep crustal levels.

Metamorphic reactions by phase equilibria modelling provides us with a new tool to evaluate the role that rock composition plays in the cycling of volatile elements within the deep Earth. Using the approach we previously developed for H₂O [2], we quantify the volume of mineral-bound CO₂ contained in supracrustal rocks during prograde metamorphism in convergent settings. We investigate two P-T path: a high-temperature and moderate pressure path typical of accretionary orogens (A) and a clockwise Himalayas-type collisional orogen path (B; Fig. 1a).

Our calculations demonstrated that the amount of CO₂ that can be held in supracrustal material is primarily influenced by bulk rock composition, mainly in response to CaO, FeO + MgO and SiO₂ contents. Pelitic and mafic volcanic compositions can sequester 4-5 times more CO₂ than their felsic volcanic counterparts (Fig. 1b). The style of orogenesis (accretionary vs collisional) is of second-order importance. If the compositions remains the same, collisional orogens can sequester 2-3 times more CO₂ than accretionary orogens. However, CO₂ bearing minerals are stable to a greater depth in collisional orogens (~35 km) than in accretionary orogens (~15 km).

Figure 1 – (a) P-T paths. (b) Decarbonation along the two P-T paths for three lithologies pelite, felsic volcanic (FV) and mafic volcanic (MV).

References:
Not just another dating site...
Roberts, N.M.W

1Geochronology & Tracers Facility, NERC Isotope Geosciences Laboratory, British Geological Survey, Keyworth, Nottingham, NG12 5GG

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\(^1\)bar the cost of writing the proposal
Calculated phase equilibria in Barrovian metapelites – are we nearly there yet?

Waters, D.J.\(^1,2\)

\(^1\)Dept. of Earth Sciences, University of Oxford, S. Parks Road, Oxford, OX1 3AN (dave.waters@earth.ox.ac.uk)
\(^2\)Oxford University Museum of Natural History, Parks Road, Oxford, OX1 3PW

Petrologists today rely heavily on calculated phase diagrams for interpreting the pressure-temperature evolution of metamorphic terrains. Fundamental thermochemical data are available for end members of many complex solid solutions, and activity–composition (\(a–X\)) models of increasing sophistication have been developed in recent years. Thermobarometry can now be conducted by matching observed phase assemblages and mineral compositions with fields and isolines on isochemical phase diagrams (pseudosections) [1]. Success depends on the ability of the models to reproduce natural phase compositions (as well as on the state of equilibrium in the investigated sample). This contribution draws attention to discrepancies between calculated and observed phase relationships in Barrovian metapelites, reminding us that the formulation of \(a–X\) models is still “a work in progress” [1, p. 158].

Examples are drawn from metapelitic rocks in the Mt Everest region of the Himalaya [2]. They reveal issues and discrepancies that relate to: (a) the dramatic variation in the area and \(P–T\) extent of garnet stability according to the dataset and \(a–X\) models used; (b) the failure of calculated Fe–Mg partition between biotite and garnet, using the latest set of models, to match natural data in the \(P–T\) region of interest; and (c) discrepancies between calculated and natural biotite compositions in both tschermak (AlAl–MgSi) and Fe–Mg exchanges distort the chemographic relationships in metapelites so that modal abundances are poorly matched, mineral composition isopleths do not intersect, and the boundaries of assemblage fields may be significantly displaced [2].

It is evident, therefore, that isochemical phase diagrams should be interpreted with caution, and that activity models for certain key minerals require further refinement for consistency with natural data. A further complication is that kinetic factors, notably the probability that overstepping of equilibrium conditions is required for the nucleation of porphyroblasts such as garnet [3], are not generally taken into account. The core composition of a garnet grown after overstepping [3,4] cannot be placed in \(P–T\) space using an equilibrium diagram, and segments of \(P–T\) path based on equilibrium core to rim isopleths in garnet could be significantly in error [2]. The answer to the question posed in the title may have to be “no”.

References:
Granulite-amphibolite transitions: quantifying fluid ingress in high-grade metamorphic terrains and its effects on crustal rheology

Whyte, A.J.1*, Weller, O.M.1, Copley, A.C.1, Taylor, R.J.M.1 and St-Onge, M.R.2

1University of Cambridge, Department of Earth Sciences, Downing Street, Cambridge, CB2 3EQ
*e-mail: ajw291@cam.ac.uk
2Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8, Canada

The retrograde transition from granulite- to amphibolite-facies mineral assemblages is an important control on the strength of the lower crust [1]. However, our current understanding of the source and mechanism of fluid ingress – required to catalyse this transition – is poor. The relative contributions of fluid channelisation (e.g. by shear zones), grain boundary diffusion and volume diffusion as pervasive hydration mechanisms are unclear. Moreover, different granulite terrains show strongly heterogeneous relationships between deformation, rehydration and retrogression. Controls on the rates and length scales of fluid flow through granulite rocks need to be investigated if we are to understand the effects of fluid ingress on crustal rheology.

In this study, we analysed a portion of the Superior craton crystalline basement in northern Quebec, Canada, which was metamorphosed at granulite-facies conditions in the Archaean and later retrogressed to amphibolite facies during the middle Palaeoproterozoic Trans-Hudson orogen [2]. This retrogression occurred in association with the development of an overlying thrust belt, the dehydration of which is thought to be the fluid source for retrogression of the underlying basement. The basal décollement to the overlying thrust belt likely acted as a fluid conduit from which fluids percolated into the basement down a thermal and/or chemical gradient [2]. The aim of this study is to assess the fluid budget required to hydrate the retrogressed basement using integrated microstructural analysis and phase equilibria modelling. This, when combined with observed length scales and the timescale of metamorphism, will provide insights into the mechanism(s) of fluid infiltration.

Petrographic observations on samples from the footwall crystalline basement in northern Quebec indicate that rocks with a strong deformation fabric contain more hydrated assemblages, suggesting that deformation assists fluid flow through granulite rocks. However, retrogression from granulite- to amphibolite-facies assemblages also occurs in samples devoid of clear deformation fabrics, which suggests fluid can permeate granulite rocks (up to a certain distance) in the absence of deformation. Here, we present preliminary models of the structurally-bound hydration of key basement samples. Further work will place updated constraints on the pressure-temperature conditions, water activities and fluid budget of the granulite-amphibolite transition at varying distances below the proposed fluid source: the overlying middle Palaeoproterozoic thrust belt. This work will feed into a broader investigation of the sources and styles of fluid ingress that weaken the cratonic cores of ancient crustal terrains.

References:
DELEGATE LIST

B
Bersan, Samuel, UP918800@myport.ac.uk
Bidgood, Anna, anna.bidgood@univ.ox.ac.uk
Bird, Anna, a.bird@hull.ac.uk
Bruno, Henrique, henriquebruno.uerj@gmail.com

C
Cabrita, Dina, dina_cabrita@yahoo.com
Cawood, Ian, ian.cawood@worc.ox.ac.uk
Chapman, Glenn, gchapman@dal.ca
Cliff, Bob, bob@earth.leeds.ac.uk
Cuthbert, Simon, simon.cuthbert@uws.ac.uk

D
Darling, James, james.darling@port.ac.uk
Dempsey, Eddie, e.dempsey@hull.ac.uk
Dunk, Mike, michael.dunk@myport.ac.uk

G
Gopon, Phillip, philipp.gopon@earth.ox.ac.uk
Groome, Niall, GroomeNT@cardiff.ac.uk
Groppo, Chiara, chiara.groppo@unito.it

H
Halama, Ralf, r.halama@keele.ac.uk
Harris, Benedict, bjrh3@cam.ac.uk

L
Lotout, Caroline, caroline.lotout@univ-lemans.fr

M
Maltby, Matthew, mjm232@cam.ac.uk
Miller, William, wm248@cam.ac.uk

Miocevich, Sophie, srm81@cam.ac.uk
Moreira, Hugo, hugo.moreira@port.ac.uk
Motta, Rafael, rafagmotta@gmail.com
Mottram, Catherine, catherine.mottram@port.ac.uk

N
Nicoli, Gautier, ng422@cam.ac.uk

O
Oldman, Charlie, charlie.oldman@open.ac.uk

P
Page, Zeb, zeb.page@oberlin.edu
Pereira, Ines, ines.pereira@port.ac.uk
Phillips, Stacy, stacy.phillips@open.ac.uk

R
Roberts, Nick, nirob@bgs.ac.uk

S
Schannor, Mathias, mss77@cam.ac.uk
Schuindt do Carmo, Sheila, sheila.schuindt@port.ac.uk
Storey, Craig, craig.storey@port.ac.uk
Strachan, Robin, rob.strachan@port.ac.uk

W
Waters, Dave, dave.waters@earth.ox.ac.uk
Webb, Max, max.cm.webb@gmail.com
Webster, Timothy, timothywebster@hotmail.co.uk
Weiss, Leonie, leonie.weiss@port.ac.uk
Weller, Owen, owenmweller@gmail.com
Whyte, Andrew, ajw291@cam.ac.uk
Wood, Eleni, eleni.wood@open.ac.uk