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2P Crystal accumulation induced Sr/Y variation: insights from a rear-arc pluton in the western Central Qilian Belt, NW China
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1P Quantitative characterization of orogens through isotopic mapping
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❷P Generation of isotopically enriched giant Lincang Batholith by disequilibrium melting of the heterogeneous lower crust
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❷P Petrogenesis of Early Cretaceous high-MgO diorites and granitoids in the Rangnim Massif, North Korea: Implications for tectonic setting of magmatism and gold mineralization
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❶O Diachronous collapse of the French Central Massif constrained by high-precision zircon/monazite U-Pb dating of late-orogenic peraluminous magmatism
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2P Effect of oxygen fugacity and melt composition on iron partitioning between apatite and silicate melt
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1P Tracing the provenance of inherited zircons from peraluminous granites in the Great Altai and its paleogeographic implications
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1P Tibetan Plateau growth linked to deep crustal thermal evolution
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3P The Obscuring Effect of Magma Recharge on The Connection of Volcanic-Plutonic Rocks
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2P Apatite geochemical and Sr-Nd isotopic constraints on the source and petrogenesis of alkaline volcanic-plutonic ring complex
Zhou B, Yang J, Sun J, Wang H, Zhu Y, Wu Y, Xu L

4P The efficiency of copper extraction from magma bodies: Implications for mineralization potential and fluid-silicate melt partitioning of copper
Zhou J, Wang Q

2P Continental crustal growth processes recorded in the Gangdese Batholith, southern Tibet
Zhu D, Wang Q, Weinberg R, Cawood P, Zhao Z, Hou Z, Mo X

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Zhu Y, Yang J, Sun J, Xu L, Li R

Theme 1 – Granites in geodynamic sites, planets and time

A tectonic odyssey of the granitoids and associated rocks in the Bundelkhand Craton of North-Central India

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Bundelkhand Craton of north central Peninsular India host several shear zones of varying orientation and width, deformation intensity, and signatures. These shear zones are also categorized as Intra-terrane shear zones (ITSZs) because the cratonic margin delimits the lateral extension of these shear zones. The ITSZs are characterized by zones of high strain within cratonic blocks and sites of crustal thickening due to the emplacement of large volume of silicic magma which are commonly manifested by syn- or late-tectonic granites. ITSZs might also develop during arc-accretion and typically represent decoupling zones (high and low strain) between regions of contrasting deformation intensity. The Bundelkhand Craton records the presence of four distinct sets of ITSZs along ~N-S, ~NE-SW, ~NW-SE, and ~E-W directions. Notably, the orientations of the ITSZs either mimic the fracture systems in the craton or imitate the trends of the associated rock bodies/zones/suites such as the (i)

Meso- to Neo-archean Bundelkhand greenstone complex comprising supracrustal belt and Banded Iron Formation (~E-W); (ii) Neo-archean Madawara ultramafic suites of rocks (~E-W); (iii) Paleo-proterozoic ~NE-SW and ~NW-SE trending giant quartz reefs; (iv) Paleo-proterozoic ~NW-SE trending mafic dyke swarms; and (v) several ~N-S to ~E-W trending cm- to meter-scale pegmatite and aplite dykes. While, a plethora of studies are available on the petrological and geochemical fronts of these individual suites of rocks, none explored the interrelationship between the nucleation of the ITSZs and the structural anatomy of the granitoids and associated rocks in the Bundelkhand Craton. Based on macro- to micro-scale investigations aided with analysis of magnetic fabric and vorticity analysis, it is postulated that transpression was operational in the craton over a protracted period of progressive deformation during the origin of the granites and associated rocks. Additionally, the structural analysis of the fracture networks, especially in the granitoids, indicate the role of a Riedel shear kinematics governing the architecture of the craton vis-à-vis the localization of various suites of rocks. The present contribution focuses on the understanding of the tectonic events, based on the evidences preserved in the granites and associated rocks, to constrain the Meso-archean to Meso-proterozoic history of the Bundelkhand Craton, North-Central India.

Piedra Alta terrane: the roots of a juvenile Paleoproterozoic magmatic arc in the Rio de la Plata Craton

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Rio de la Plata Craton (RPC) within the South American Platform, is located in the western portion of Uruguay, as well in adjacent regions of Argentina and southern Brazil. The craton is formed by two large tectonic units, the Piedras Altas Terrane (PAT) and the Nico Perez Terrane (NPT), separated by the large scale NNW-SSE Sarandí del Yí shear zone. The PAT is the major component of the RPC, composed of three tectonic units: granite-migmatite basement, volcano-sedimentary belts metamorphosed into greenschist to amphibolite facies and numerous slightly deformed late intrusive granites. The available geochemical and geochronological data support the interpretation that the PAT represents the remains of a magmatic arc. The entire igneous process took place in ~ 35Ma, constrained by the formation of the granite-migmatite basement around 2131+/- 16Ma and emplacement of calc-alkaline granites around 2094 +/- 17Ma. Between the development of these units occurred the deposition of the intra-arc basins (detrital zircon U-Pb ages = 2033+/-

24Ma) and the regional metamorphic episode. The juvenile characteristic of PAT is suggested by the predominance of low initial 87Sr/86Sr ratios, positive to slightly negative εNd and εHf values and TDM model ages close to the crystallization ages. These data are suggestive of a short crustal residence time of the precursor material of the studied rocks. Based in the geochemistry of zircons the tectonic environment was evaluated according to the Nb/Yb versus U/Yb diagrams (Grimes et al. 2015). The zircons from all sequences suggested a strong mantle component typical of island arcs environment. Some samples of the cover and one from the basement, indicated crystallization in association with garnet, a factor responsible for decreasing the concentrations of heavy REE, and consequently the median of the ratios of (Yb/Ce) N(ca. 63) in relation to the basement (ca. 80.60) and the granitoids (ca. 89.34). Regarding the Eu/Eu* and Ce/Ce* anomalies, it can be inferred that the basement rocks are generally more primitive, while the granitoids are slightly more differentiated than the metamorphic cover rocks. However, the median Zr/Hf ratios are “identical” for all rock assemblies. Given the compositional similarities, it is possible to interpret that all units can be related to each other with the formation and development of an island arc, subjected to a process of growth and recycling.

The tectonic regimes of the earliest continents

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Junior Keynote, Monday 11th September, 09:30 - 10:00

The transition from a stagnant tectonic regime to active plate tectonics is of great consequence to habitability, yet the circumstances and timing of the initiation of plate tectonics on Earth are enigmatic. The Acasta Gneiss Complex (AGC) of the Northwest Territories, Canada, is a complex assemblage of 4.0 to 2.9 Ga polymetamorphic gneisses, amphibolites, and granitoids that includes the oldest known intact crust on Earth. The AGC is direct evidence of the development of evolved crustal reservoirs early in Earth history and provides an opportunity to assess evolving tectonic regimes in one locality. Uranium-lead age, Lu-Hf isotope, and trace-element data in zircons from AGC orthogneisses place broad constraints on magmatic sources across one billion years of magmatism (e.g. Reimink et al., 2018 and references therein; Bauer et al., 2020a). Importantly, the zircon Lu-Hf isotope record tracks a transition from reworking of Hadean material in magmatic generations >3.6 Ga to input and reworking of juvenile source material in magmas ~3.6 Ga and younger (Amelin et al., 2000; Iizuka et al., 2009; Guitreau et al., 2012; Bauer et al., 2017). In tandem, whole-rock geochemistry is consistent with a transition at ~3.6 Ga from the emplacement of shallow-

seated magmas to a source with residual garnet, requiring melting depths >40 km (Nair and Chacko, 2008). The combination of geochemical evidence points to a transition from shallow-seated melting of a Hadean source in the oldest AGC magmas to a juvenile source and deeper melt generation at ~3.6 Ga. Similar shifts, from repeated re-melting of ancient mafic crust to the appearance of juvenile sources, are apparent in other Archean gneiss terranes and Eoarchean detrital zircon compilations at 3.8-3.6 Ga. These data suggest a planet-wide shift in tectonic regime from stagnant- to mobile-lid tectonics at ~3.8-3.6 Ga (Bauer et al., 2020b). This preliminary stepping stone toward modern-style plate tectonics would have been characterized by shallow plate subduction and an increase in the recycling of water and other volatiles between the surface and the mantle. Subsequently, the ample evidence for a transition in the rock record at 3.2-3.0 Ga (e.g. Dhuime et al., 2012; Naerra et al., 2012; Tang et al., 2016) could track the onset of modern-style plate tectonics.

We are testing if this hypothesized shift is consistent with the compositional evolution recorded in multiple early Archean terranes. Major challenges within this effort include: disentangling the effect of multiple episodes of metamorphism on zircon and whole-rock geochemistry, evaluating the suitability of the application of geochemical proxies that were empirically calibrated within modern tectonic settings to the early Archean, and complexities associated with the interpretation of detrital zircon geochemistry as an archive of the earliest crustal record.

If we can confidently apply the AGC as a benchmark for evaluating this transition in other terranes and detrital zircon suites 3.8-3.6 Ga, we can further clarify the tectonic history of the early Earth.

Amelin et al (2000). GCA, v. 64, p. 4205–4225 ; Bauer et al (2017). EPSL, v. 458, p. 37–48 ; Bauer et al. (2020a). GCA, v. 283, p. 85–102 ; Bauer et al (2020b). GPL, v. 14, p. 1–6 ; Dhuime et al. (2012). Science, 335(6074), 1334-1336 ; Guitreau et al. (2012) EPSL, v. 337–338, p. 211–223 ; Iizuka et al (2009). Chem. Geo., v. 259, p. 230–239

Naeraa et al. (2012). Nature, 485(7400), 627-630 ; Nair & Chacko (2008). Geology, v. 36, p. 583–586 ; Reimink, Bauer, & Chacko. The Acasta Gneiss Complex. Earth's Oldest Rocks, 2nd ed. (2018) ; Tang et al. (2016). Science, 351(6271), 372-375.

The oldest granitoids in terrestrial planets - A bibliographic essay

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Overview Keynote, Monday 11th September, 08:45 - 09:30

Petrological experiments show that granitic liquids may be issued from silicate systems through differentiation processes including fractional crystallisation and partial melting. Thus, granite/rhyolite melts are likely to have solidified in telluric planets and not only on Earth.

Actually, granitic clasts and glasses have been found in almost all types of meteorites expelled from differentiated as well as undifferentiated bodies (Bonin, 2012). A review of asteroidal and planetary evidence was displayed on the occasion of the Seventh Hutton Symposium at Avila (Spain) on 2011. It is time, after 11 years, to update the analysis of existing data.

The chronology of dust formation in the early solar system was recently re-evaluated at 4568.7 Ma (Piralla et al., 2023). Granitic magmas are easily produced in differentiated planetary objects, whose internal structure comprises a metallic inner core and a silicate outer shell, though silicic melts were also observed in undifferentiated meteorites (chondrites). The oldest known granite in the solar system is represented by four clasts within a polymict breccia constituting the Adzhi-Bogdo (Mongol Altai) chondritic meteorite. The clasts are made up of alkali feldspar granite with ferroan, alkaline and potassic composition. They yield a multi-mineral Pb-Pb 4533 ± 30 Ma Pb–Pb age, corresponding to solidification only 36 ± 30 Myr after the outset of the solar system.

On Earth, Hadean (> 4.0 Ga, before the Late Heavy Bombardment) materials are known since the 80's of the last century (e.g., zircon in Mt. Narryer, Western Australia, Froude et al., 1983). A Jack Hill Hadean zircon crystal yields an age as old as 4.404 Ga (Wilde et al., 2001). Hadean rocks have been found so far in only one locality (Acasta Gneiss Complex, Northern Territories, Canada, Bowring and Williams, 1999). A zircon xenocryst as old as 4.2 Ga has been found in 3.9 Ga gneiss. The Idiwhaa 4.03-4.02 Ga gneiss unit (Reimink et al., 2014) show subalkaline (tonalitic) compositions akin to anorogenic modern icelandite and differ strikingly from "younger" orogenic Archean TTGs by ferroan (A-type) features. There is no need for significant volumes of felsic crust at the time of emplacement (Reimink et al., 2016).

Lunar granite clasts have been sampled in several Apollo landing sites. In addition, remote sensing data enable to identify felsic domes, or unroofed intrusions in several areas. The largest clasts have ferroan (A-type) features and markedly potassic compositions, interpreted as resulting from silicate-liquid immiscibility. Rock-forming minerals are nominally anhydrous, which is confirmed by exceedingly low amounts of magmatic H_2O detected by nanoSIMS analyses on apatite, alkali feldspar and plagioclase. As they are almost synchronous with Earth's Hadean rocks, it was suggested that lunar granite clasts were actually ejected from the Earth during a large impact and entrained in the lunar regolith as a terrestrial meteorite (Bellucci et al., 2019). However, strongly potassic characteristics and contrasting trace element distribution argue against this hypothesis.

The occurrence of Martian granites, though suggested by indirect evidence, remained elusive for a long time. Recently, rovers analysed mafic rocks (picrobasalt, basalt and tephrite) in several craters, with the only exception of Curiosity in Gale Crater. Evolved strongly alkaline phono-tephrite (essexite), mildly alkaline trachyte (syenite) and subalkaline dacite (tonalite) compositions were evidenced. All rocks, except basalt, are ferroan and dominantly sodic, interpreted as resulting from fractional crystallisation of basaltic magmas. Silica-liquid immiscibility marked by potassic features is shown in granitic components of SNC meteorites, however. Though water was abundant during the formation of analysed samples 3.8 to 3.5 Ga ago, volatiles within apatite and amphibole are essentially chlorine and fluorine.

Taking into account that extra-terrestrial granites and Earth's Hadean rocks known so far yield ferroan (A-type) varieties, it is suggested that the magnesian granitoids so common on Earth since the Archean might be fairly unique in the solar system.

Arc thickening triggers resource-endowed continent forming

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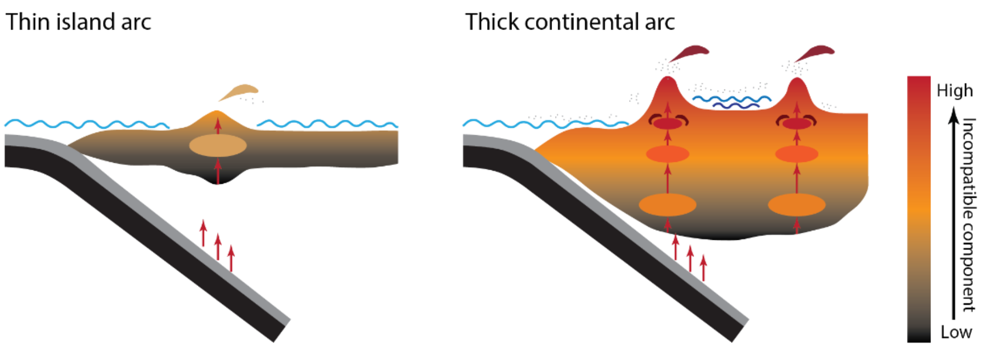
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

There are two typical crust standing on Earth, felsic dominantly continental crust and basaltic oceanic crust, with the former characteristic of thick block and corresponding above-sea-level elevations as well as geochemically enriched in most of incompatible elements, making the continent the most accessible habitat and economic resources for human. However, the exact mechanism for generating such an endowed continent is still not well understood. Here, we investigate the geochemical systematics of volcanic arcs, which are considered as the most eligible candidate to build up continental blocks on the basis of their chemical affinity. We show that arc lavas erupted on thickened crust are more enriched in incompatible metals compared with their thin island arc counterparts, which is inherited from increased incompatible element contents in primitive arc magma with rising eruption elevation. Such a metal enrichment in primitive arc magma and corresponding magmatic differentiation is enhanced with the increasing elemental incompatibility. A high compositional consistency between thickened continental arc and upper continental crust (UCC) is observed, whereas thin island arc deviates from the UCC's formula, suggesting the materials contributing to UCC predominantly derives from thick continental arc instead of thin island arc. High continental arc, because of its thickening feature, feeds humans with subaerial and economically endowed lands.



Insights into the evolution of southeastern Dom Feliciano Belt (southern Brazil and eastern Uruguay) through U-Pb and Lu-Hf isotopic data

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Dom Feliciano Belt comprises the southern segment of Mantiqueira Province in southeastern Brazil and eastern Uruguay, whose tectonic evolution is regarded as part of the amalgamation process of the blocks from Western Gondwana during the Neoproterozoic Brasiliano Cycle. The eastern Dom Feliciano Belt is composed of Pelotas Batholith and Punta del Este Terrane. The Pelotas Batholith consists of several calc-alkaline to alkaline granitic suites with subordinate mafic bodies aged between 640-550 Ma, with xenoliths of metasedimentary rocks, of which the Matarazzo and Herval complexes are the most expressive exposures. The Matarazzo Complex is composed of marbles, schists, and meta-igneous rocks, moreover, the Herval Complex comprises quartzites, schists, and metaplutonic rocks. Furthermore, the Punta del Este Terrane comprises a basement complex of granites, gneisses, and migmatites formed between 1000 and 670 Ma, and supracrustal units of metavolcanosedimentary rocks and

alkaline granitoids, formed between 650 and 570 Ma. Zircon analyses in an outcrop of granitoids of different compositions from the Pelotas Batholith yielded U-Pb crystallization ages at 691±7 Ma (granodioritic gneiss), 646±4 Ma (microdiorite), 634±4 Ma (monzogranite), 620±5 Ma (syenogranite), and 610±2 Ma (pegmatite). Samples of amphibolite and diorite from the Matarazzo Complex yielded U-Pb crystallization ages of 750±6 Ma and 602±6 Ma, respectively. The intrusive lense of biotite-muscovite granite in metasediments of the Herval Complex yielded a crystallization age of 635±15 Ma. From the Punta del Este Terrane, U-Pb ages were acquired from garnet-muscovite gneiss (748±10 Ma) and three bodies of (garnet) muscovite-biotite granites (640±7 Ma, 571±6 Ma, and 573±5 Ma). The Lu-Hf analyses between the Cryongenian-Ediacaran rocks constrained a main interval of model ages ranging from 2.2 to 1.0 Ga, with εHf(t) results varying from positive to negative (+10 to -14). While among the Tonian rocks, the model ages range from Siderian to Rhyacian (2.4-2.0 Ga) with crustal-related negative εHf(t) values (-8 to -14). The isotopic dataset implies multi-stage magmatism related to flare-up episodes within the eastern Dom Feliciano Belt, which also present isotopic signatures with a strong contribution from mixed juvenile and crustal sources with Mesoproterozoic and Paleoproterozoic model ages, related to the accretionary and collisional settings of formation of the Western Gondwana tectonic framework.

A magmatic arc legacy 1.5 billion years away: The Oligocene Mount Hillers Intrusive Center (Henry Mtns, Colorado Plateau, USA)

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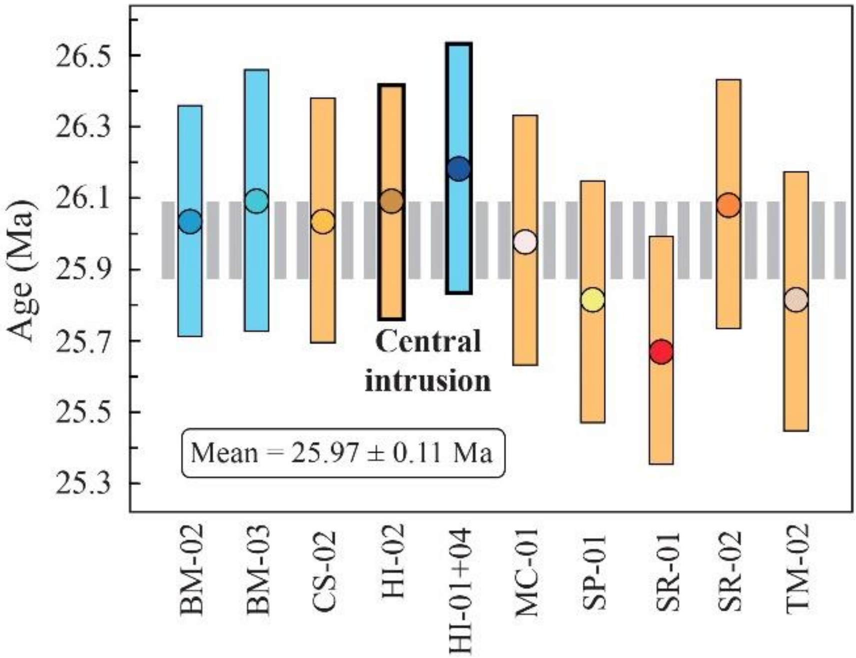
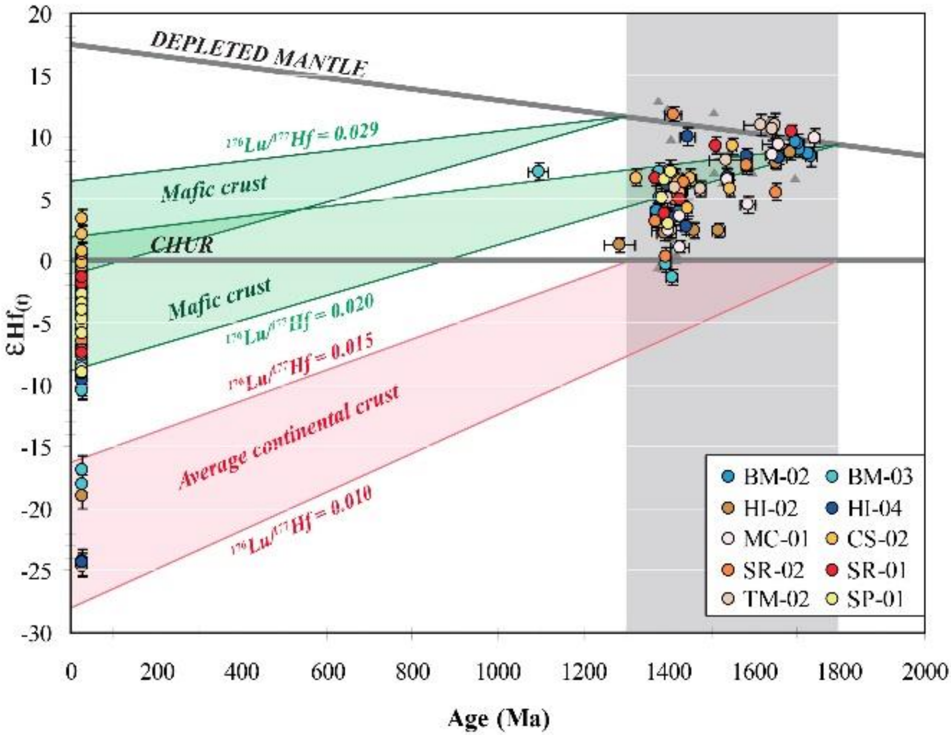
Oral, Monday 11th September, 12:00 - 12:15

The Mount Hillers intrusive center (MHIC) is one of the five intrusive center of the Henry Mountains. It consists of a large central surrounded by many smaller satellite intrusions (total volume ~35 km3). To constrain the age(s), the history of emplacement, and the source(s) of these intrusions, we have performed in-situ LA-ICP-MS U-Pb and Lu-Hf zircon analysis on samples from a cross section containing samples emplaced from the beginning to the end of the MHIC emplacement. In addition, we performed K-Ar and ^{39}Ar-^{40}Ar dating to compare zircon crystallization and diorite cooling ages. U-Pb isotopic data from zircon rims from all samples provide consistent ages and give a mean value of 25.97 ± 0.11 Ma, which indicates that the large central intrusion and surrounding satellite intrusions were emplaced within in less than 220 000 years. U-Pb dating of different magmatic pulses identified in the field display similar ages within analytical uncertainties. The consistency in ages between our high temperature U/Pb chronometer and the lower

temperature ^{39}Ar-^{40}Ar on hornblende and K-Ar on feldspar groundmass chronometers indicate that the crystallization age of the zircons rims is very close to magma emplacement at upper crustal level, and also suggests rapid cooling. An average magmatic flux of around 10^{-4} km^3/yr is proposed at the scale of both the whole MHIC and a single satellite intrusion. The zircon population is characterized by the systematic occurrence of inherited Proterozoic cores with an age range of 1.05 to 2.16 Ga. The major frequency peak is centered between 1.3 and 1.45, with several minor peaks ranging from 1.45 to 1.75 Ga. Lu-Hf analyses of most of the zircon rims are consistent with those of the cores and both can be derived from a mafic crust produced from a 1.3-1.8 Ga depleted-mantle reservoir and incorporating variable amount of a recycled continental crust component with a 1.5 Ga age. Even if both sources were partly mixed, they still can be observed in the Oligocene rims crystallized during the emplacement of the MHIC. Our preferred model for the genesis of the Mount Hillers diorites involves melting of mafic source(s) located in the lower part (below 20 km) of the Colorado Plateau crust. Given the intermediate composition of Mount Hillers diorites, this/these source(s) are compatible with metabasalts produced by a 1.3-1.5 Ga magmatic event in an active continental margin setting.


Age (Ma)
26.5
26.3
26.1
25.9
25.7
25.5
25.3
Central intrusion
Mean = 25.97 ± 0.11 Ma
BM-02
BM-03
CS-02
HI-02
HI-01+04
MC-01
SP-01
SR-01
SR-02
TM-02


DEPLETED MANTLE
176Lu/177Hf = 0.029
Mafic crust
CHUR
Mafic crust
176Lu/177Hf = 0.020
176Lu/177Hf = 0.015
Average continental crust
176Lu/177Hf = 0.010
εHf(t)
Age (Ma)
BM-02
BM-03
HI-02
HI-04
MC-01
CS-02
SR-02
SR-01
TM-02
SP-01

Remote Detection of a Lunar Granitic Batholith at Compton-Belkovich

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Oral, Monday 11th September, 14:45 - 15:00

Granites are nearly absent in the Solar System outside of Earth. Achieving granitic compositions in magmatic systems requires multi-stage melting and fractionation, which also increase radiogenic element concentrations. Water and plate tectonics facilitate these processes on Earth, aiding in remelting. Although these drivers are absent on the Moon, small granite samples have been found, but details of their origin and the scale of systems they represent are unknown. We report microwave-wavelength measurements of an anomalously hot geothermal source that is best explained by the presence of a ~50 km diameter granitic system below the Th-rich, farside feature known as Compton-Belkovich. Passive microwave radiometry is sensitive to the integrated thermal gradient to several wavelengths depth. The 3-37 GHz antenna temperatures of the Chang'E 1 and 2 microwave instruments allow us to measure peak heat flux of ~184 mWm^{-2}; ~20 times higher than the average lunar highlands. The surprising magnitude and geographic extent of this feature imply an Earth-like, evolved granitic system larger than believed possible on the Moon, especially outside of the Procellarum region.

A magmatic system of this size requires one of the following features: (a) a long-lived thermal source, such as a farside mantle plume (which appears in some models), to facilitate multi-stage magmatic processing, (b) an anomalously wet pocket of the otherwise dry Moon (consistent with C-B volcanic estimates of 2 wt.% water), which could lower the local melting point, or (c) a farside KREEP (potassium-rare earth element-phosphorous) layer that could build sufficient radiogenic material to remelt through self-heating. All scenarios imply large-scale compositional heterogeneities in the mantle and/or crust during lunar formation.

Petrogenesis of lunar granites, “felsites,” and quartz monzodiorites is subject to ongoing debate centered around four models: (1) differentiation driven by silicate-iron liquid immiscibility, (2) remelting of lunar crust in large impact events, (3) crystal fractionation of KREEP basaltic liquids, and (4) partial melting of KREEP-rich monzogabbro and alkali gabbronorite crust. Available data at Compton-Belkovich suggest scenarios 3 or 4, or likely a combination of the two, and require the initial presence of a farside KREEP component to form the Compton-Belkovich system. The distillation of radiogenic elements via remelting or crystal fractionation from KREEP components is needed to achieve the U and Th compositions that produce the observed heat flow feature.

A granitic pluton and felsic volcanism at the Aristarchus Plateau on the Moon

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Oral, Monday 11th September, 15:00 - 15:15

The Aristarchus plateau on the Moon hosts a diversity of volcanic features, including the largest pyroclastic deposit and sinuous rille on the Moon and intrusive and extrusive examples of evolved, Th-rich silicic lithologies. Analyses of the Lunar Reconnaissance Orbiter Diviner Lunar Radiometer thermal IR (TIR) data, Lunar Prospector Gamma Ray Spectrometer thorium data, Chang'e-5 Microwave Radiometer data, and hyperspectral and multispectral visible/near-infrared (VNIR) images and spectra from the Chandrayaan-1 Moon Mineralogy Mapper and the Kaguya Multispectral Imager demonstrate the rich diversity of igneous features on the Aristarchus plateau.

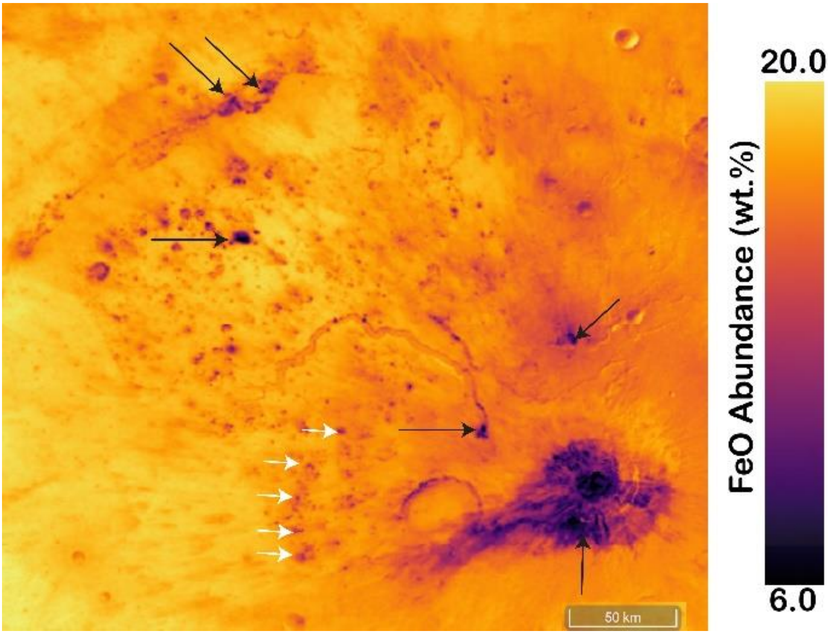
The 40 km diameter Aristarchus crater exposes a likely granitic pluton, with a floor, central peak, and ejecta that are dominated by feldspar and, likely, an SiO_2 phase. Olivine is also present in some portions of the Aristarchus ejecta, demonstrating a complex subsurface lithology.

Roughly 35 km to the northwest of Aristarchus crater is the Cobra Head, the source of Vallis Schroteri, a ~4 km wide and ~170 km long sinuous rille. While the rille was carved by a voluminous mafic eruption, bright, low-FeO deposits exposed at the Cobra Head suggest an evolution of the source magma and the later eruption of more felsic lavas.

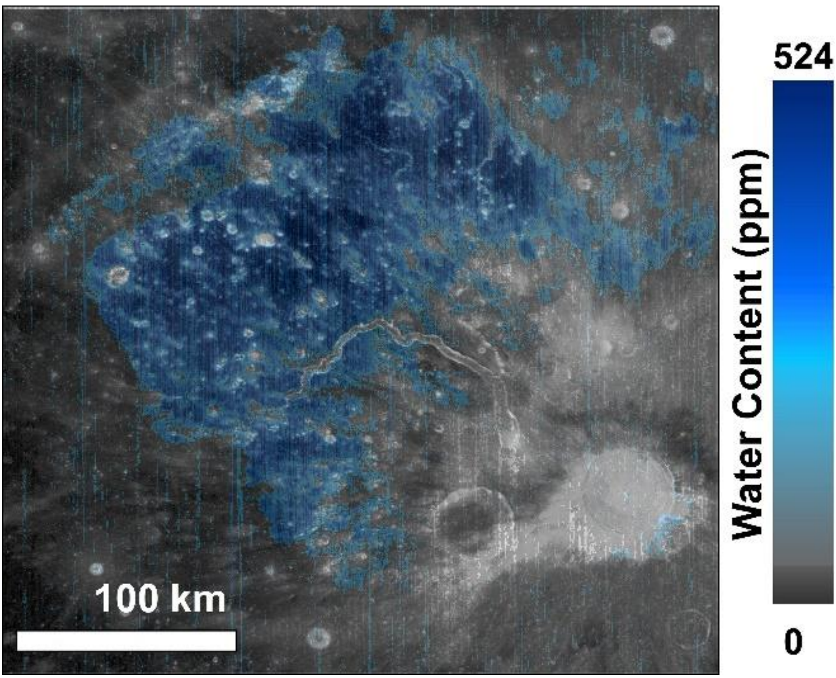
The northern two-thirds of the plateau is blanketed by a dark mantling deposit that is interpreted to be the largest pyroclastic deposit on the Moon (~50,000 km^2), formed during the early period of mare volcanism. Active radar and passive microwave radiometer data suggest that the deposit is > 5 m thick and TiO_2-poor. The deposit is composed of >90% Fe^{2+}-bearing glass, with a total iron abundance of ~19 wt.%. It is also water-bearing, with the edges of the deposit hosting ~200-300 ppm water and the central portion of the deposit having water abundances > 500 ppm.

About 170 km northwest of the Aristarchus crater, Herodotus Mons, a bright, ~900 m high, ~6.5 km long knob, emerges from underneath the surrounding pyroclastic blanket. Its shape and mineralogic remote-sensing data suggest that it is an extrusive volcanic cone with a rhyolitic composition.

Aristarchus crater, the Cobra Head, and Herodotus Mons are all intriguing targets for future robot or human exploration that would help elucidate the complex volcanic history of this region and the evolution of the lunar interior. A mission to Herodotus Mons should be considered the top priority as it would enable an investigation of both a rhyolitic volcanic dome and the surrounding mafic pyroclastic deposit.



20.0
FeO Abundance (wt.%)
6.0
50 km



524
Water Content (ppm)
0
100 km

Geophysical constraints on composition and porosity of the Moon's silicic volcanic emplacements

Peter James*, Allie North, Daniel Moriarty, Nicholas Wagner, Matthew Siegler, Walter Kiefer

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

While much of the Moon's volcanism consists of mare basalts, there are several instances of silicic volcanism, including the Gruithuisen Domes, Lassell Massif, Mons Hansteen, the Aristarchus Plateau, Compton-Belkovich Volcanic Complex, and the Wolf Crater Complex. The steepness of these terrains was recognized during the Apollo era as indications of high lava viscosity, and various remote sensing observations have confirmed silica-rich compositions of these emplacements. However, the mechanisms by which these silicic structures formed remain poorly understood. On Earth, silicic volcanism is typically associated with plate tectonics and/or water-rich melts. Since the Moon has neither plate tectonics nor abundant water, the existence of these structures implies that there is some process by which single-plate planets can generate voluminous silicic magmas. These sites are of high scientific interest, and NASA is planning to deliver scientific instruments to the Gruithuisen Domes via the Commercial Lunar Payload Service (CLPS) in 2025.

Various mechanisms have been proposed for these silicic emplacements—including basaltic underplating, fractional crystallization, magmatic intrusion, and silicate liquid immiscibility—and these mechanisms can be somewhat constrained by a knowledge of bulk density. We will present analyses of the gravity field and associated clone fields derived from the Gravity Recovery And Interior Laboratory (GRAIL) data set, along with laser altimetry data from the Lunar Orbiter Laser Altimeter (LOLA). We use a spectral band-pass to control the depth sensitivity of the investigation, and we use clone fields from GRAIL to rigorously quantify data uncertainty. Comparison of the predicted and observed gravity anomalies with a weighted regression yields a best-fit bulk density.

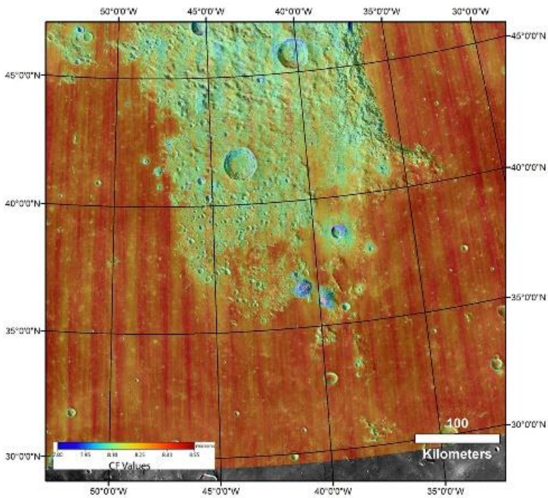

Figure 1: Diviner Christiansen Feature maps clearly delineate lunar surface materials by silica content. Here, the Gruithuisen Domes (blue, center) are distinct from surrounding low-silica mare basalts (red) and intermediate-silica highlands materials (green).

Preliminary work at the Gruithuisen domes shows that the GRAIL data confidently rule out a silicic veneer paradigm. A purely extrusive paradigm would require bulk densities to be ≲2300 kg/m³ for both domes at 95% confidence, which would imply high silica content and/or high porosity. The preferred interpretation of the domes incorporates igneous intrusion. The intrusive/extrusive ratios for Gamma and Delta are at least 0.20 and 0.52, respectively, and the total volume of silicic volcanic material associated with these domes is at least 1,081 km³.

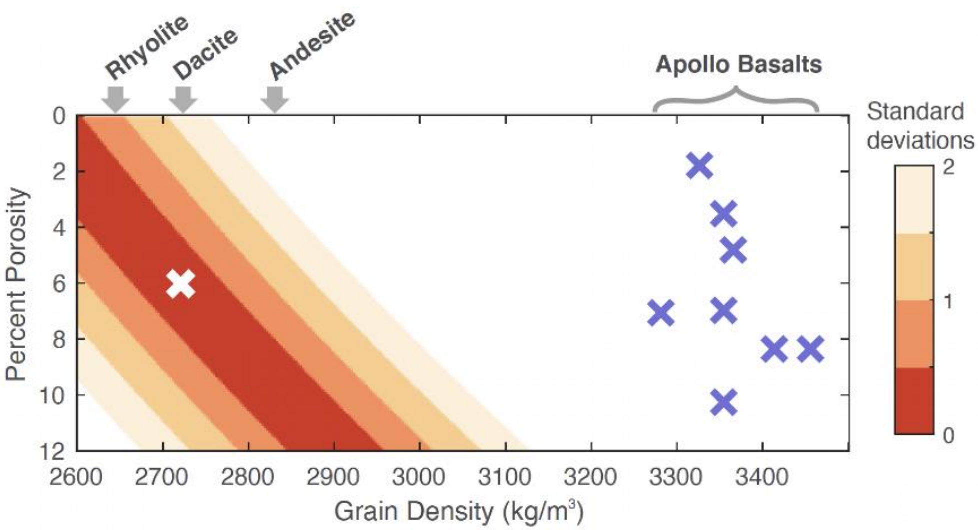

Figure 2: Example of bulk density interpretation in terms of composition and porosity, alongside Apollo basalt samples.

Variscan (ultra-)potassic magmatic rocks (Moldanubian Zone, Bohemian Massif): crustally contaminated lithospheric mantle melts showing decoupling of compatible- and incompatible-element isotopic systems during cryptic crustal growth

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Oral, Monday 11th September, 10:30 - 10:45

Attempts to quantify mantle contributions to plutonic activity in the European Variscan Belt are frustrated by the rarity of magmatic rocks clearly derived from depleted mantle sources. Most basic magmas came from lithospheric mantle domains strongly metasomatised by subducted oceanic (or even continental) crustal material and thus have mixed mantle–crustal elemental/isotopic signatures. Their differentiated products may represent a significant, hitherto largely overlooked, contributor to crustal growth barely detectable by conventional geochemical tools [1].

The c. 390–335 Ma magmatic activity in the central Bohemian Massif provides a classic example. Regarding Nd isotopes, the mantle sources of subduction-related plutonic suites show conspicuous temporal evolution [2–4] from strongly depleted ($\varepsilon^{386}Nd$ = +5.8 to +2.3; low-K gabbros–trondhjemites), through CHUR-like ($\varepsilon^{354}Nd$ ~ 0;

normal-K gabbros–trondhjemites), slightly enriched (ε^{346}Nd ~ –3; high-K granodiorites and monzonitic rocks, HK suite) to strongly enriched (ε^{337}Nd < –7.5; (ultra-)potassic melasyenites to melagranites, UK suite). This evolution is interpreted to reflect transition from Andean-type subduction to collision and attendant deep subduction/relamination of the attenuated metaigneous Saxothuringian continental slab, contaminating/metasomatizing mantle sources of the HK and, more significantly, of the UK suite [5–6].

However, Mg isotopic compositions (δ^{26}Mg = –0.12 ‰ to –0.53 ‰) vary over similarly broad intervals within each suite. A majority of the most magnesian samples fall within the range of local orogenic mantle peridotites (δ^{26}Mg = –0.33 to –0.29 ‰) or near the global mantle average (δ^{26}Mg = –0.25 ‰) [7]. Their Mg isotopic composition was apparently buffered by the high Mg contents in the progressively metasomatized harzburgitic mantle, while their mantle-incompatible elemental/related isotopic (Sr–Nd–Pb–Hf–O) signal was overwhelmed by the recycled, crustally-derived contribution. Thus the crustal contaminant had to be dominated by Mg-poor material with ordinary Mg signature (felsic metaigneous >> clastic metasedimentary rocks). Unlike in the case of otherwise similar ultrapotassic magmatic activity in the Lhasa Terrane of Central Tibet [8–9], subducted carbonates were of secondary importance.

[1] Couzinié et al. (2016) EPSL 456, 182–195. ; [2] Janoušek et al. (1995) GR 84, 520–534. ; [3] Deiller et al. (2021) GR 99, 220–246. ; [4] Janoušek et al. (2022) IJES

111, 1491–1518. ; [5] Janoušek & Holub (2007) PGA 118, 75–86. ; [6] Schulmann et al. (2014) Geology 42, 275–278. ; [7] Teng et al. (2010) GCA 74, 4150–4166. ; [8] Liu et al. (2020) JGR 125, e2020JB020684. ; [9] Tian et al. (2020) JGR 125, e2019JB018197.

The Lunar Granite Conundrum

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Overview keynote, Monday 11th September, 14:00 - 14:45

“Lunar granite” commonly refers to assemblages of silica and K-feldspar in lunar samples. The term “felsite” is more descriptive of this usually very fine-grained assemblage. Early workers realized the tendency of lunar melts to undergo iron enrichment upon fractional crystallization and reach the field of silicate-liquid immiscibility (SLI), naturally producing a felsic assemblage with a mafic complement, commonly ferropyroxene-rich. Thus, segregations of felsite occur in many Apollo samples, and small bits occur in regolith. Evidence of SLI is clear in Apollo samples such as 14161,7373, a monomict igneous assemblage of monzogabbro with egg-shaped granophyric segregations. Sample 12032,366-19 includes barian K-feldspar, quartz, sodic plagioclase, hedenbergite, fayalite, ilmenite, and trace zirconolite, baddeleyite, apatite, and merrillite.

Relatively large Apollo samples of interest for granite petrogenesis include 15405, a 513 g KREEP-basalt breccia, and 12013, an 82 g granitic breccia. The assemblage of materials in 12013 includes an important lithologic association. Incorporation of different lithologies in a breccia suggests the lithologies occurred in proximity or together in the target of the impact that assembled the breccia. 12013 consists largely of silica plus K-feldspar clasts intimately mixed with two mafic lithologies, one of monzogabbroic composition and one of Fe-rich basaltic composition. ‘Guilt by association’ suggests a petrogenetic relationship among these three lithologies. Monzogabbro is reasonable as the mafic complement in a SLI pair. Such petrogenesis brings to mind outcrop-scale segregations such as occur in the Skaergaard complex on Earth. The basaltic component of 12013 may be related as noted below.

The “lunar granite conundrum” is twofold. Firstly, several large volcanic constructs occur as indicated by morphology (steep slopes) and composition (silica-rich) to be felsic. The Gruithuisen Domes are the largest at several tens of km in cross-sectional dimension. That such large segregations of dry, viscous felsic material could occur by SLI seems physically impossible. Secondly, the process of SLI fractionates elements such that incompatible U and Th concentrate in the mafic complementary liquid, not the silica-rich liquid, yet all lunar granitic assemblages exhibit thorium enrichment, and this is also well-established by remote sensing for the felsic volcanic occurrences, e.g., Mairan domes and Compton-Belkovich Volcanic Complex. Hence the conundrum: SLI in evidence at the microscale seems unlikely to produce the macroscale volcanic silicic features. A petrogenetic model currently under consideration is basaltic underplating, causing partial melting of "fertile" crust, which returns us to the basalt component of 12013, which we infer may represent the primary basalt.

A geotechnical study on the granitoids along the Raksa Shear Zone: Clues for the basement rock selection of Medieval Forts in the Bundelkhand Craton, India

Ankit Kumar*, Aishwarya Mohan, Ram Pratap Singh Tomar, Sayan Maity, Sayandeep Banerjee

*Banaras Hindu University - ankitgeo@bhu.ac.in

Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Globally, igneous provinces always provided stable basements for the construction of diversity of palaces, castles, monuments, mausoleums, religious places, epitaphs, etc. The Heritage Stone Subcommission, under the aegis of the International Union of Geological Sciences (IUGS), identify heritage stone resources from various continents to designate a stone as a Global Heritage Stone Resource (GHSR) based on certain parameters such as texture, mineralogical composition, colour and strength of the rocks. The Bundelkhand Craton is house to around forty Medieval age forts built by different dynasties of the North Central India, as

identified by the Archaeological Survey of India. The aesthetics, availability and cultural and religious sentiments related to a particular rock probably made the choice for these rocks for construction of these ancient structures. While, most of these forts built during the Medieval period are constructed using various rocks/stones, the basements of these forts are often recognized as deformed granitoids, which differentiates it from the surrounding undeformed to mildly deformed granitoids of the craton. Notably, our past ancestors might not have a formal training of determination of the strength of rocks over which they built fort or raised high structures until the 17th century, but they surely possessed a scientific aptitude.

The Garh Kundar Fort (~925 AD) and Karera Fort (~1300 AD) are a few examples built along the Raksa Shear Zone, a crustal scale shear zone in the Bundelkhand Craton. Though, the forts are primarily structured using Vindhyan sandstones available in the surrounding proterozoic basin, the basement rocks have been identified to be mylonitic granite variety of the Bundelkhand granitoids. To ascertain the scientific rationale behind the selection of site for the construction of these forts, petrological and geotechnical investigations have been carried out. Petrological studies suggest the basement rocks of both the forts are granite ultramylonite, which are occurring near the core of Raksa Shear Zone, bordered by undeformed granitoids. Furthermore, the Uniaxial Compressive Strength (UCS) determined from the basement mylonitic granites and surrounding granitoids range from 70.2 to 75.8 MPa and 56.4 to 67.6 MPa respectively. Thus, it can be construed that the Medieval Forts of Garh Kundar and Karera were founded upon the granite ultramylonites, which are occurring along the core of the ~E-W trending Raksa Shear Zone. This study provides clues to the understanding of basement rock selection of the Medieval Forts in the Bundelkhand Craton, and urges the Geoscience community to identify such Geo-heritage sites.

Understanding Oxygen Isotopes in Cordilleran Batholiths: A 190 Million Year, Top-to-Bottom Perspective from the Sierra Nevada, USA

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Oral, Monday 11th September, 12:15 - 12:30

Nearly two decades since the first oxygen isotope ($\delta^{18}O$) studies of zircon in the Sierra Nevada Batholith, California, USA, a far more extensive picture of spatial and temporal patterns of magmatic $\delta^{18}O$ has emerged in parallel with a tenfold increase in geochronologic coverage, and many new radiogenic isotope (Sr, Nd, Hf) analyses. Over this time, models of Cordilleran-type arc systems have sought to elucidate flare-ups of magmatism as cyclic, with radiogenic isotope “excursions” tracing variable input of crust and mantle into arc magmas [e.g., 1]. Such models haven't incorporated oxygen isotopes to full advantage because of apparent complexity in the signals they record [2]. New, single zircon $\delta^{18}O$ analyses—of plutonic, volcanic, and detrital zircon—from the Sierra amplifiing the findings of previous studies [e.g., 3], that $\delta^{18}O$ records are well-suited for detecting relatively fast (<10 million year) recycling of subducted supracrustal rock and accreted terranes in forearc settings. Such recycling is not resolved by radiogenic isotope systems. A wealth of new volcanic $\delta^{18}O$ zircon data from the Sierra, along with $\delta^{18}O$ of hydrothermal minerals like skarn garnet, also records periods of significant $\delta^{18}O$ "pull-downs" as lower-$\delta^{18}O$ hydrothermal waters alter surface rocks whose assimilation subsequently embeds these surface signals in silicic volcanic systems. Such re-melting and volcanic episodes are often brief (< 5 million years) and small volume, so have often been overlooked, however such, $\delta^{18}O$ values may be key to detecting plutonic from volcanic zircon in detrital records when used in conjunction with trace elements. Low-$\delta^{18}O$ domains are becoming recognized in other arcs and to be useful to detect episodic resampling of crustal domains [4]. Morover, discovery of fossil low-$\delta^{18}O$ systems in screens of wallrock in mid-crustal levels [e.g., 5] documents wholesale rapid burial of these domains in arcs, during transitions to episodes of shortening or transpression. All together, zircon $\delta^{18}O$ uniquely traces surface-to-source transport and recycling in Cordilleran arcs as it relates to changing arc stress regime, at periods that may fail to be recorded in excursions of radiogenic isotopes, such as relaxation of stress regimes in upper plate domains.

[1] DeCelles, P. G. et al. Nature Geoscience 2, 251-257 (2009). ; [2] Chapman, J. B. et al. Lithos 398-299, (2021). ; [3] Lackey, J. S., et. al. J. Petrology 49, 1397–1426 (2008). ; [4] Turnbull, R. E. et al. Gondwana Res. 121, 436-471. ; [5] Ryan-Davis, J. et al. Contributions to Min. and Pet 174, 19 (2019)

Petrologic Investigation of Lunar Granite Evolution: Insights from the Compton-Belkovich Volcanic Complex

Katelyn Lehman Franco*, Rita Economos, Matt Siegler, Jianqing Feng

*Southern Methodist University, USA - kmlehman@mail.smu.edu

Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Geoscientists have long been fascinated by the possibility of evolved lunar compositions, implying that magmatic evolution processes can occur in a water-poor system. The presence of granite and quartz monzodiorite clasts and felsite glass in Apollo samples triggered extensive experimental and theoretical petrologic studies. Our study reevaluates petrologic models in light of the recent discovery of a large magmatic plumbing system beneath the Compton-Belkovich Volcanic Complex (CB) on the Moon.

Initial studies suggested extensive fractional crystallization of KREEP (potassium-rare earth element-phosphorous) basalt magmas, fractional crystallization followed by liquid immiscibility, or partial melting were necessary for lunar granite production. However, the inability to effectively explain the Th-enrichment in the silicic melt and the identification of multiple silicic volcanic complexes through remote sensing raised doubts about generating large volumes of silicic materials through liquid immiscibility. Furthermore, the recent discovery of a mid-crustal, ~60 ppm Th batholith beneath the farside CB region, as well as a shallower <132 ppm Th pluton, has complicated existing petrologic models. These high Th contents are found only in evolved lunar samples and imply granitic to granodioritic composition for the lower body and granitic composition for the upper body.

This study contributes to three critical questions. (1) What are the conditions/processes for elevated Th concentrations in lunar granites? (2) Are KREEP-enriched parent melts vital to the production of high Th lunar rhyolites and granites? (3) What are the potential processes explaining CB's magmatic architecture with a lower body (~60 ppm Th) and upper body (<132 ppm Th)?

We employ a strategic, multi-stage petrologic modeling approach using the magmatic architecture of CB as a case study. Two-stage geochemical modeling is employed, where major element modeling is performed using rhyolite-MELTS and Magma Chamber Simulator, and trace element modeling is based on the results. The first stage tests whether 60 ppm Th granite can be generated by partially melting monzogabbro and alkali gabbronorite or by extensive fractional crystallization of KREEP. The second stage investigates whether the upper body can be produced through segregation of Th-enriched melt from the lower pluton, followed by fractional crystallization.

By investigating the formation mechanisms of lunar granites within this complex, we aim to contribute to a deeper understanding of lunar magmatic processes. Resolving the origin of CB has significant implications for understanding the generation of large quantities of Th-enriched magmas, batholith formation without plate tectonics, and the Moon's volatile content.

The recycling of supracrustal materials controlled the evolution of plate tectonics on Earth: Insights from the Neoarchean sanukitoids and associated adakitic suites

Jialiang Li*

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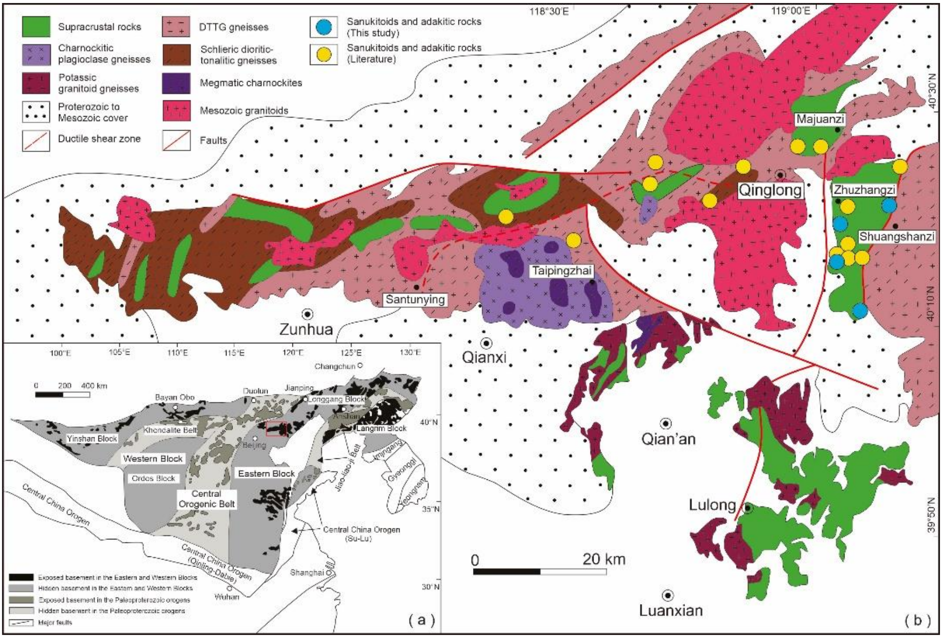
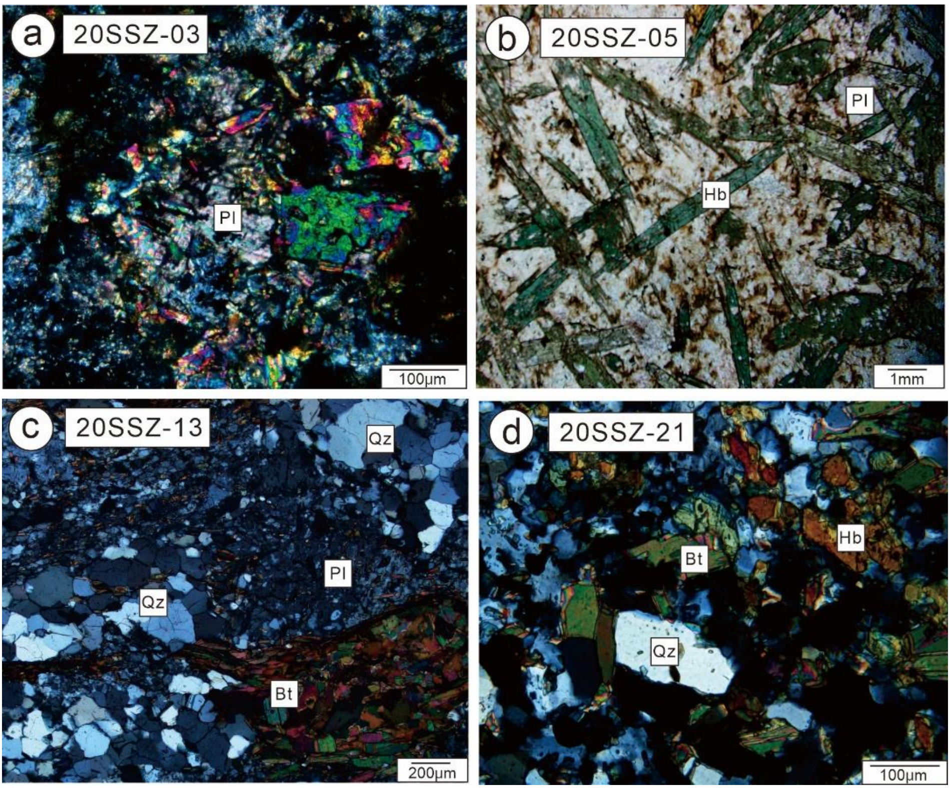
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

For early-Earth conditions, subduction is less stable and perhaps more susceptible to the lubrication effect of sediments than the modern counterpart (e.g., van Hunen and van den Berg, 2008; Sobolev and Brown, 2019).

Such prediction has not yet been verified by field-based investigations. In this work, we identified two types of rock unites, i.e., sanukitoids and associated adakitic suites, exposed in the Eastern Block of the North China Craton, and revealed their petrogenesis and tectonic context through field, geochronologic, geochemical, and isotopic investigations. Our results indicate that the sanukitoids were derived from the partial melting of subducting sediments and subsequent melt-mantle interaction, and the adakitic rocks formed by direct partial melting of subducted oceanic crust (including TTG melts and minor sediments), with only limited material exchange with mantle peridotites. Such distinct magmatic rock associations, together with the coeval charnockites and tholeiites with diverse compositions in the adjacent area, can be best explained in terms of ridge subduction and induced slab window model. Meanwhile, events associated with ridge subduction are likely to represent a transition of a quasi-plate tectonics system, characterized by multiple, sequential, stalled attempts to start the modern-style subduction on Earth. In addition, the emergence of sanukitoid and associated magmas is a good chronological symbol of the onset of supracrustal recycling into the mantle. Combined with the Nd-Hf-Zn isotopes of diverse magmatic rocks in the North China Craton comparable to the other Precambrian magmatic rock suites worldwide, we suggest that expect for the Earth's secular cooling, the supracrustal recycling is important for the subduction-driven plate tectonics.



Supracrustal rocks
Charnockitic plagioclase gneisses
Potassic granitoid gneisses
Proterozoic to Mesozoic cover
Ductile shear zone
DTTG gneisses
Schlieric dioritic-tonalitic gneisses
Megmatic charnockites
Mesozoic granitoids
Faults
Sanukitoids and adakitic rocks (This study)
Sanukitoids and adakitic rocks (Literature)
118°30'E
119°00'E
40°30'N
40°10'N
39°50'N
Majuanzi
Qinglong
Zhuzhangzi
Shuangshanzi
Taipingzhai
Santunying
Zunhua
Qianxi
Qian'an
Lulong
Luanxian
0
20 km
Yinshan Block
Khondalite Belt
Western Block
Ordos Block
Central Orogenic Belt
Eastern Block
Longgang Block
Langrim Block
Beijing
Shanghai
Wuhan
Changchun
Central China Orogen
Central China Orogen (Su-Lu)
(a)
(b)



a
20SSZ-03
Pl
100μm
b
20SSZ-05
Pl
Hb
1mm
c
20SSZ-13
Qz
Pl
Qz
Bt
200μm
d
20SSZ-21
Hb
Bt
Qz
100μm

[1] van Hunen and van den Berg (2008) Lithos 103, 217–235; [2] Sobolev and Brown (2019) Nature 570, 52–57.

Magmatic Processes Contributing to the Petrogenesis of Pyroxenites in the Beni Bousera Ultramafic Massif, Internal Rif, Morocco

Zahra Mourabit*, Abdelhalim Tabit, Fatiha Hadach, Ahmed Algouti, Abdellah Algouti

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Beni Bousera ultramafic massif located in northern Morocco are characterized by various layers of pyroxenites with varying volumes. The mineralogy and chemical compositions of these pyroxenites suggest a complex multi-stage model of formation that could involve either 1) the high-pressure cumulates or 2) residues from the re-fusion of gabbroic layers. The pyroxenite layers are chemically of basaltic composition, while mineralogically their modal compositions vary from olivine websterite to garnet clinopyroxenite. These pyroxenites can be divided into two genetically distinct groups based on their formation processes. Pyroxenite type I is Fe-rich, with low contents of Al, Si, Ti, and Cr. These rocks may result from the re-crystallization processes of peridotite/gabbro complexes under high-pressure eclogite or granulite

facies conditions. These rocks are thought to have initially crystallized at lower pressure from mafic liquids injected into crustal domains. Pyroxenite type II, equilibrated at high temperatures of 1000 ° C to 1400 ° C. They are characterized by enrichment in Al and Fe / (Fe + Mg) ratios which, however, remain very low. Further chemical signatures are negative Eu anomalies and low isotopic ratios of Sr and Nd to deduce that the pyroxenite type II may be the result of a recycled oceanic lithosphere.

The Pre- and Early Andean granitoids of the SW Gondwana convergent margin (Chile-Argentina, 20°-40°S)

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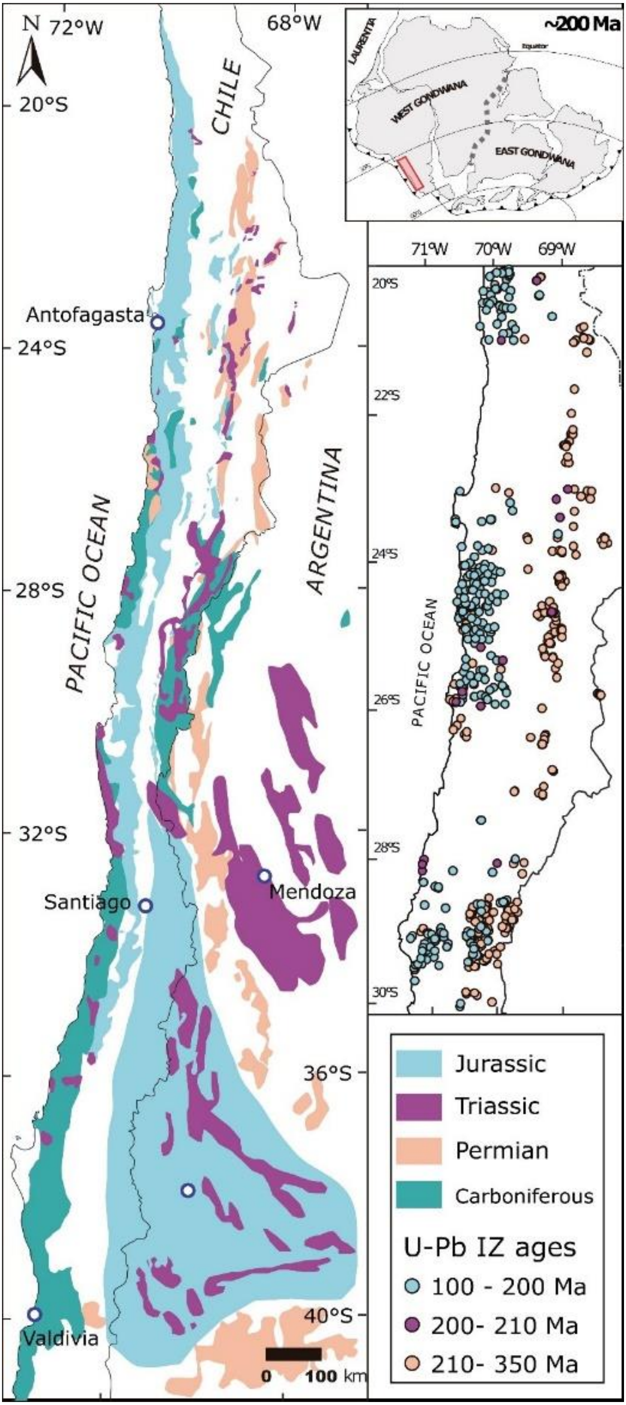
Junior Keynote, Monday 11th September, 11:00 - 11:30

The pre-Andean and Early-Andean evolution of the southwestern Gondwana margin comprises three stages: the Gondwana cycle (Late Carboniferous-Early Permian), the Pre-Andean stage (Middle Permian-Late Triassic) and the Early Andean cycle (Early Jurassic-Early Cretaceous) (Fig 1). These stages have been traditionally interpreted as the upper crustal response to major changes in the tectonic setting: Cordilleran-style continental arc (Gondwana cycle), followed by orogenic collapse and possibly slab break-off that led to continental rifting and extensive crustal melting (Pre-

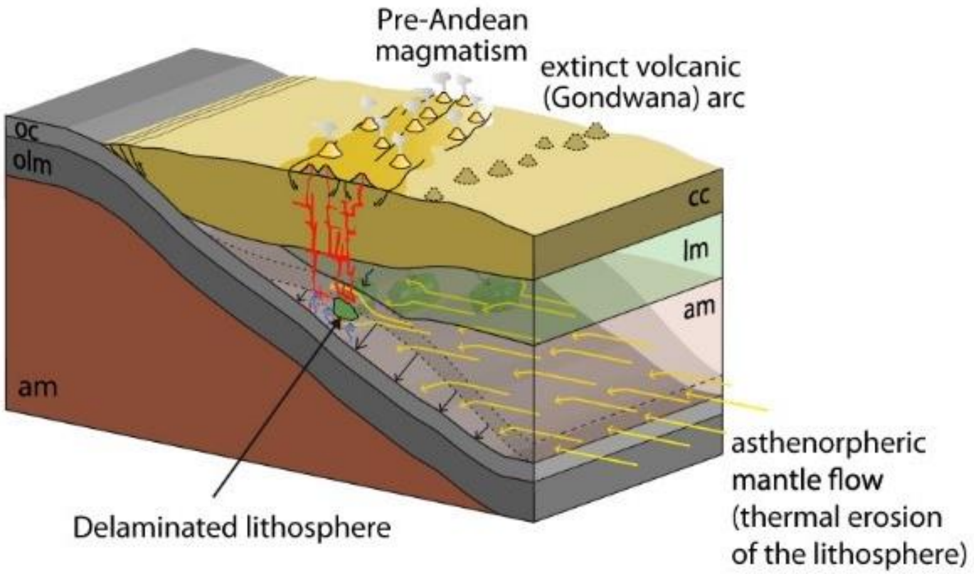


N
72°W
68°W
20°S
24°S
28°S
32°S
36°S
40°S
CHILE
ARGENTINA
PACIFIC OCEAN
Antofagasta
Santiago
Mendoza
Valdivia
0
100 km
~200 Ma
LAURENTIA
WEST GONDWANA
EAST GONDWANA
71°W
70°W
69°W
20°S
22°S
24°S
26°S
28°S
30°S
PACIFIC OCEAN
Jurassic
Triassic
Permian
Carboniferous
U-Pb IZ ages
100 - 200 Ma
200- 210 Ma
210- 350 Ma

Andean stage), and subsequent subduction re-initiation in oceanic arc-style context (Early Andean cycle). However, recent geological, geochronological, geochemical and petrological data for the Carboniferous to Jurassic igneous rocks suggest that subduction was the most likely process by which the magmatic record was generated. Sub-alkaline affinities, LILE enrichment over HFSE, Nb-Ta troughs, porphyritic textures and hornblende- and biotite-bearing lithologies are present in all studied units, whereas Sr-Nd-Pb isotopes suggest that magma sources are a mixture of depleted mantle and variable contribution from the continental crust. Chemical evolution in the magmatic record points to a decline in the contribution of crustal or lithospheric sources to the magmatism with time. Thus, SiO_2, La/Yb and $^{87}Sr/^{86}Sr_0$ exhibit a systematic decrease from the middle Permian to the Jurassic, whereas the εNd_0 parameter increases in the same period.

The geological record in the same period suggest that these changes were accompanied by the shift from dominant compressional (Carboniferous-Early Permian) to transtensional deformation (Middle Permian-Jurassic) in the upper crust with the convergent margin transitioning from advancing to retreating. Slab roll-back during the Late Permian to Triassic may have induced extension in the upper crust and lithospheric loss as a consequence of delamination or thermal erosion (Fig. 2).

At ca. 215-210 Ma, the magmatic loci advanced trenchward at least 150 km, establishing the new arc front in the present-day Coastal Cordillera, where it stayed during the Jurassic and Early Cretaceous. This trenchward shift in the arc location that marks the initiation of the Early Andean arc in Chile, may have been a continental-scale process but its causes remain unknown. The margin did not witness significant changes in the tectonic stress, maintaining its transtensional character from Late Triassic to Jurassic. However, the composition of the Pre-Andean intrusions differs from the Early Andean granitic rocks, with tonalite-granodiorite-monzogranite (M<15) in the former and dominant quartz diorite-tonalite-granodiorite lithologies (M>15) in the latter, perhaps due to distinct thickness or composition of the crust in with each arc emplaced.



Silicic arc on a retreating convergent margin: an example from the Middle to Upper Triassic magmatism at High Andes (28° - 31°S)

Javiera González, Verónica Oliveros*, Christian Creixell, Felipe Coloma, Ricardo Velásquez, Paulina Vasquez

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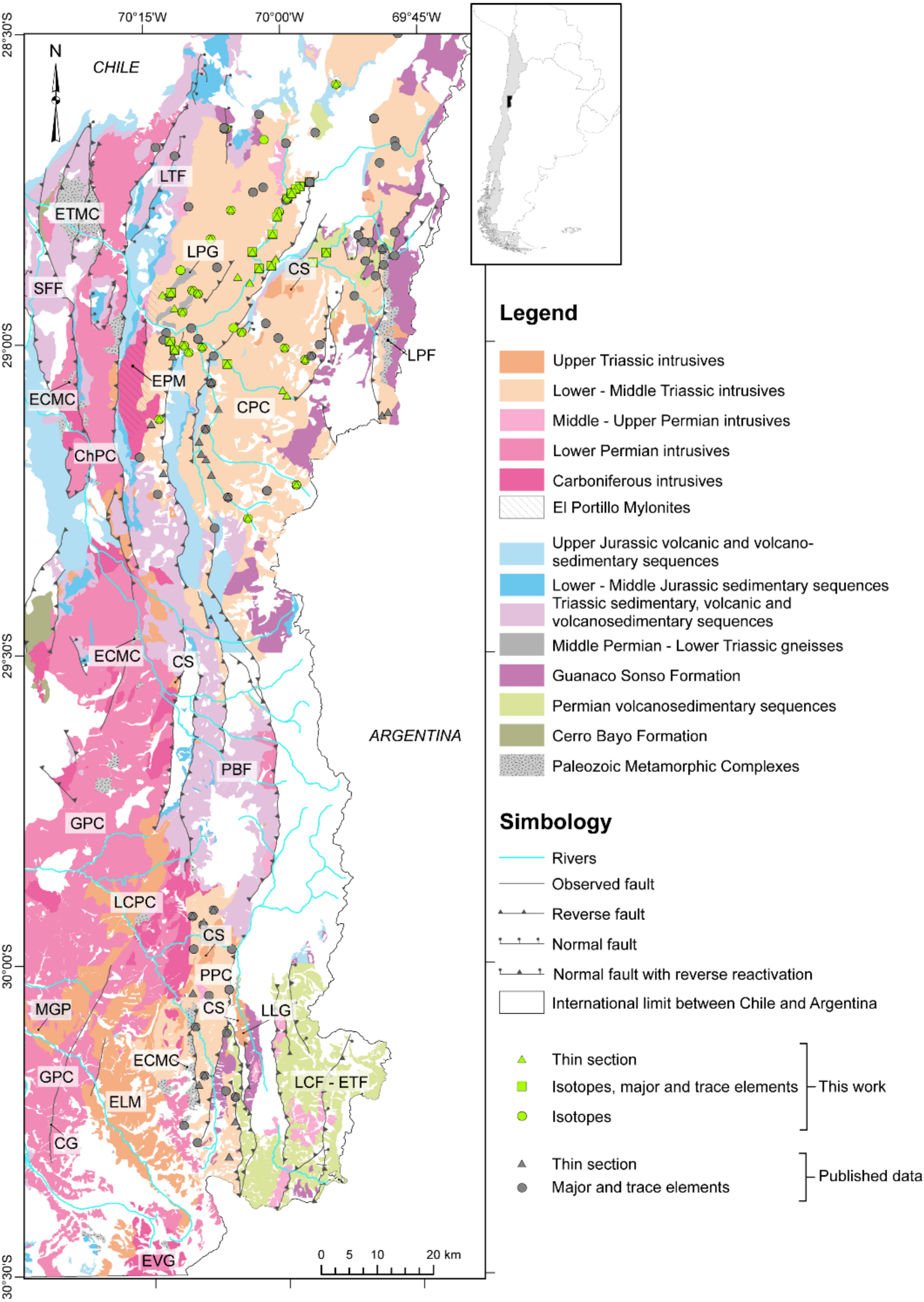
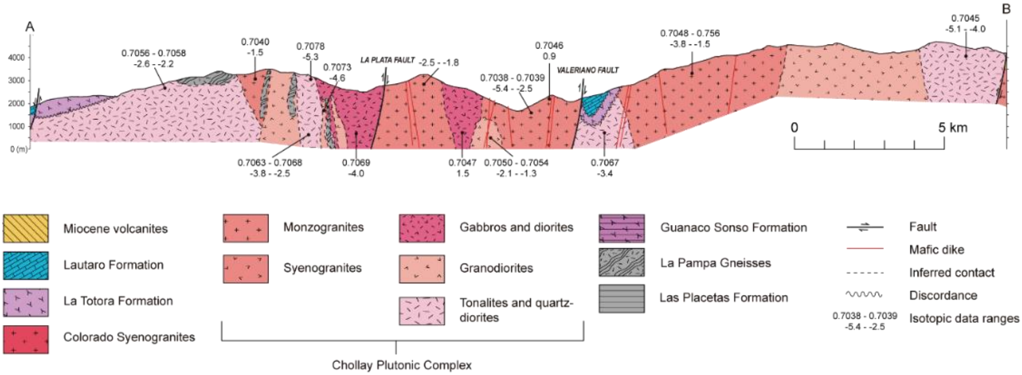
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Chollay and Piuquenes plutonic complexes compose a >3,000 km² batholith cropping out in the Frontal Cordillera at the Chile Argentina border (28°30'S – 30°30'S). They represent important part of the magmatism generated during the Lower - Middle Triassic in the western margin of Gondwana. These plutonic complexes have been interpreted as an anorogenic, post-collisional magmatism, generated by crustal anatexis during a stage in which subduction along the margin western Gondwana would have ceased (Pre-Andean Cycle, Middle Permian – Upper Triassic).

In this work, a field geology, petrography, whole-rock geochemistry and mineral chemistry characterization of both complexes was carried out to establish a geotectonic context for this magmatism. These complexes are composed of rocks with a wide compositional spectrum, ranging from diorites to syenogranites, with a predominance of hololeucocratic to leucocratic monzogranites and granodiorites with calcium amphibole and biotite as mafic minerals. They correspond to subalkaline, meta to peraluminous, calc-alkaline to alkaline-calcic rocks, with a ubiquitous enrichment in LILE respect to HFSE, depressions in Nb-Ta, Ti, Sr and P, and enrichments in Pb, characteristic of subduction-related magmatism. These rocks present relatively flat REE patterns (La/Yb: 3.40 – 13.78) and the crystallization pressures calculated by Al-in-Hbl barometer from samples of the Chollay Plutonic Complex (1.7 – 1.8 ± 0.6 kbar) suggest an epizonal emplacement. The isotopic composition (Sr-Nd-Pb) shows that the source of this magmatism requires the participation of a depleted mantle and not only the continental crust, discarding cortical anatexis as the main magma-generating process. This background allows us to propose that the southwestern margin of Gondwana was active, at least in this segment. These plutonic complexes were emplaced in an extensional context evidenced by the development of contemporaneous forearc and backarc basins, and the geochemical signals that allow us to evaluate a cortical decrease from the Carboniferous to the Jurassic. Therefore, this work allows us to characterize a silicic plutonism of exceptional volume generated in a retreating convergent margin and contrast it with the magmatism generated in advancing convergent margins.


70°15'W
70°00'W
69°45'W
28°30'S
29°00'S
29°30'S
30°00'S
30°30'S
N
CHILE
ARGENTINA
LTF
ETMC
SFF
LPG
CS
LPF
EPM
ECMC
CPC
ChPC
ECMC
CS
PBF
GPC
LCPC
CS
PPC
MGP
CS
LLG
ECMC
GPC
ELM
LCF - ETF
CG
EVG
0 5 10 20 km
Legend
Upper Triassic intrusives
Lower - Middle Triassic intrusives
Middle - Upper Permian intrusives
Lower Permian intrusives
Carboniferous intrusives
El Portillo Mylonites
Upper Jurassic volcanic and volcano-sedimentary sequences
Lower - Middle Jurassic sedimentary sequences
Triassic sedimentary, volcanic and volcanosedimentary sequences
Middle Permian - Lower Triassic gneisses
Guanaco Sonso Formation
Permian volcanosedimentary sequences
Cerro Bayo Formation
Paleozoic Metamorphic Complexes
Simbology
Rivers
Observed fault
Reverse fault
Normal fault
Normal fault with reverse reactivation
International limit between Chile and Argentina
Thin section
Isotopes, major and trace elements
Isotopes
This work
Thin section
Major and trace elements
Published data



Episodic magmatism of the Peruvian continental arc

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Phanerozoic American Cordillera provides an excellent opportunity to study processes contributing to the creation of continental crust. In this study we characterize and quantify the magmatic history of the Peruvian segment of this continental subduction system. The intensity of magmatism and therefore rate of magma emplacement into the arc over time is non-steady, being composed of a series of high magma addition “flare-ups” against an intermittent and variable lower level of background magmatism. We add new U-Pb ages for igneous bedrock samples and detrital zircons from sedimentary rocks to existing geochronological data to give a picture of the magmatic history of the Peruvian arc. Detrital zircons from three sedimentary samples collected from locations in the west, center and east of the arc show magmatism younging to the west. Flare-ups in magmatism from segments of the Peruvian Coastal Batholith (PCB) and Eastern Cordillera (EC) are analyzed to estimate the volume and rate of mantle magma addition (MMA) to the crust. Average flare-up duration is longer for the EC than for the PCB at ~80 My vs 50 My. Flare-ups are found to have variable durations from ~10 My to ~100 My. with variable periods between them, thus being episodic in nature rather than cyclic. Magma volumes are calculated using areas of GIS igneous map units, crustal thickness estimates based on element ratios, and a published calculation method based on tilted crustal sections. Total MMA volume added to the arc crust is estimated at 1070k km^3 and 1148k km^3 for the PCB and EC respectively, assuming a mantle/crust ratio of 80/20. This contributes ~6900 km^3 per My or ~1% of Permian-Paleogene global continental crust growth. We have created a web-based dashboard to facilitate interactive exploration of the mapped flare-ups.

Origin of silica-undersaturated alkaline plutonic complexes of the Kerguelen archipelago : the Monts Ballons and the Société de Géographie peninsula intrusions

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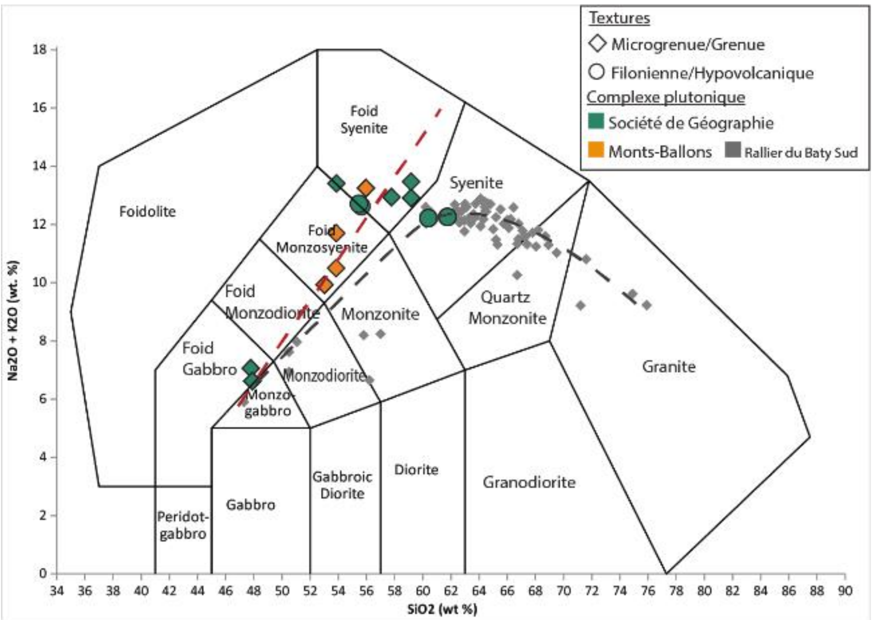
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Kerguelen archipelago hosts intrusions of under- and oversaturated in silica differentiated alkaline rocks. These two series never crop out at the same place, and surface geology suggests that the volume of oversaturated rocks is much greater. In an attempt to understand this co-existence and these spatial and volumetric dichotomies, we have realized a petrographic and geochronological study of the Société de Géographie (SdG) peninsula and Monts-Ballons (MB) undersaturated alkaline intrusions. Results will be compared with those of Ponthus et al. (2020) on the South Rallier du Baty Laccolithic Complex (SRBLC), which is the main oversaturated intrusion of the Kerguelen.

Field study suggests that these two undersaturated intrusions are small in volume (less than 1 km3) and consist of hectometric sills and vertical gashes comprising various facies (gabbros, monzonites and

syenites). A system of trachytic and microsyenitic dikes are connected with or cross-cut these intrusions. Ponthus et al. (2020) have suggested that the SRBLC is a laccolith characterised by a much larger volume of magma (300-500 km^3) than the SdG and MB intrusions. Petrographic and chemical analyses (WR major & trace) show that silica-undersaturated and oversaturated rocks are very similar. The ferromagnesians (pyroxenes and amphiboles) are identical, the major (except for Si, Na and K) and trace element spectra are strictly matching. Actually, the only difference between these rocks is the presence of quartz or nepheline in the most differentiated facies, depending on the considered series. Lastly, preliminary U-Pb geochronology results on zircons point to a synchronicity of the begining of the emplacement of magmas from the two types of magmatic series around 13 Ma.

Giret (1983) has proposed that a same parental alkaline basaltic magma for these two series, but that an early crystallisation of amphibole (undersaturated rocks) or pyroxene (oversaturated rocks) at an intermediate stage of differenciation/magma ascent, lead to the formation of the two different series. Our results are in line with his hypothesis. Questions remain however, for example, what processes lead to the early pyroxenes or amphiboles crystallization? Why don't we find the two series associated at the same place? Are the different modes of emplacement associated to the contrasted magma volume? Incoming complementary geochronology, isotopic, and geophysical studies, will provide new insights into the formation conditions of these two alkaline magmatic series.



Trench-proximal felsic magmatsim in Miocene southwest Japan

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Miocene trench-proximal igneous activity in southwestern Japan produced various granitic rocks including S-, I-, and A-types of granites. This magmatism took place in the southwest Japan arc, up to 800 km along the arc and 100 km across the arc directions, respectively. It is also noteworthy that felsic igneous activity, including large-scale caldera volcanism with a volume over 1000 km^3, occurred in the trench-proximal region. These igneous activities are generally considered to have been caused by the subduction of the young and hot Shikoku Basin of the Philippine Sea plate beneath the southwest Japan Arc immediately after the opening of the Japan Sea and the clockwise rotation of southwest Japan. The authors have conducted radiometric dating of igneous rocks of various lithologies, mainly by the zircon U-Pb method. In this presentation, we review the results of dating and discuss the tectonics of the formation of a large volume of granitic magma in the near-trench area. Most granitic magmatism in this area occurred between 15.5-13.5 Ma over a period of 2 million years. The intrusion of tholeiitic basalt magma into the area closest to the trench was at about the same time as the onset of the magmatic activity. This finding also supports the

subduction of the hot Shikoku Basin during its cessation stage of spreading started immediately after the clockwise rotation of southwest Japan. The most voluminous rock type is S-type granitic rock. S-type granitic magma seems to be formed by the melting of the accretionary sediments under high-temperature conditions during the young and hot slab subduction. In the area further from the trench, HREE-depleted dacite/rhyolite and high-Mg andesite associated with the Shikoku Basin slab melting are observed, and the timing of their activity roughly coincides with that of the granitic rocks. The ages of A-type granite and associated alkali basalts are clearly younger than those of the other granitic rocks, suggesting that magma derived from the deeper mantle was introduced from the Shikoku Basin slab tear.

Constraining Lunar Evolved Magmatism through Microwave Remote Measurement of Geothermal Heat Flux

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

On Earth, and likely also on the Moon, extrusive silicic volcanism is generally small compared to the larger magmatic system feeding it. Using visible and infrared spectral signatures ~10 highly silicic extrusive complexes

have been discovered on the Moon (such as the Aristarchus Plateau, Gruithuisen Domes, Lassell Massif, Compton-Belkovich Volcanic Complex, etc). As the intrusive roots of these systems are not expected to have a large density contrast from the bulk anorthite crust, they can be difficult to identify, even with high resolution gravity measurements or envisioned seismic networks.

However, these evolved systems also incorporate radioactive elements into their mineral structure. Silicic materials form from one or more events of partial melting of initial materials, increasing concentrations of incompatible lithophile elements like U and Th in the melt. These melts may stall within the crust, with a small portion reaching the lunar surface. This results in localized enhancements in geothermal heat production. Landed geothermal measurements atop these silicic features could aid in constraining the volume and composition of the subsurface roots below these silicic complexes.

There may be an easier way. Microwave frequency radiance results from the integrated heat over several wavelengths depth. This allows for the direct observation of subsurface temperatures, which will increase with depth due to the local geothermal gradient. As thermal conductivity of the lunar regolith is incredibly low (~10^{-3} $Wm^{-1}K^{-1}$), diurnal temperature variations are very shallow, so geothermal heat flux will dominate the temperature below ~50 cm depth. Therefore, a localized radiogenic rich source will show up as an enhanced microwave emission at frequencies receiving some of their energy below this depth.

Initial studies have reported a large microwave brightness temperature enhancement at the silicic surface feature known as Compton-Belkovich. This is based on observations at 3-37 GHz by the Chang'E 1 and 2 microwave radiometer instruments (MRM). These data were collected globally, so allow for this technique to be utilized to search for similar geothermal enhancements coincident with other silicic features. Here we report on initial efforts to measure other areas with both silicic surface features and high microwave constrained geothermal heat fluxes. We will discuss new results from Wolf Crater (which is likely not a crater, but rather a remnant of a buried caldera rim) and Lassell Massif, where a coincident 3GHz enhancement is found in the same area Lunar Reconnaissance Orbiter Diviner (LRO) Diviner infrared data show a high silica.

Tectono-magmatic origins of aligned intrusions in the Damaraland igneous province, Namibia: new evidence from high-precision zircon dating and geochemistry

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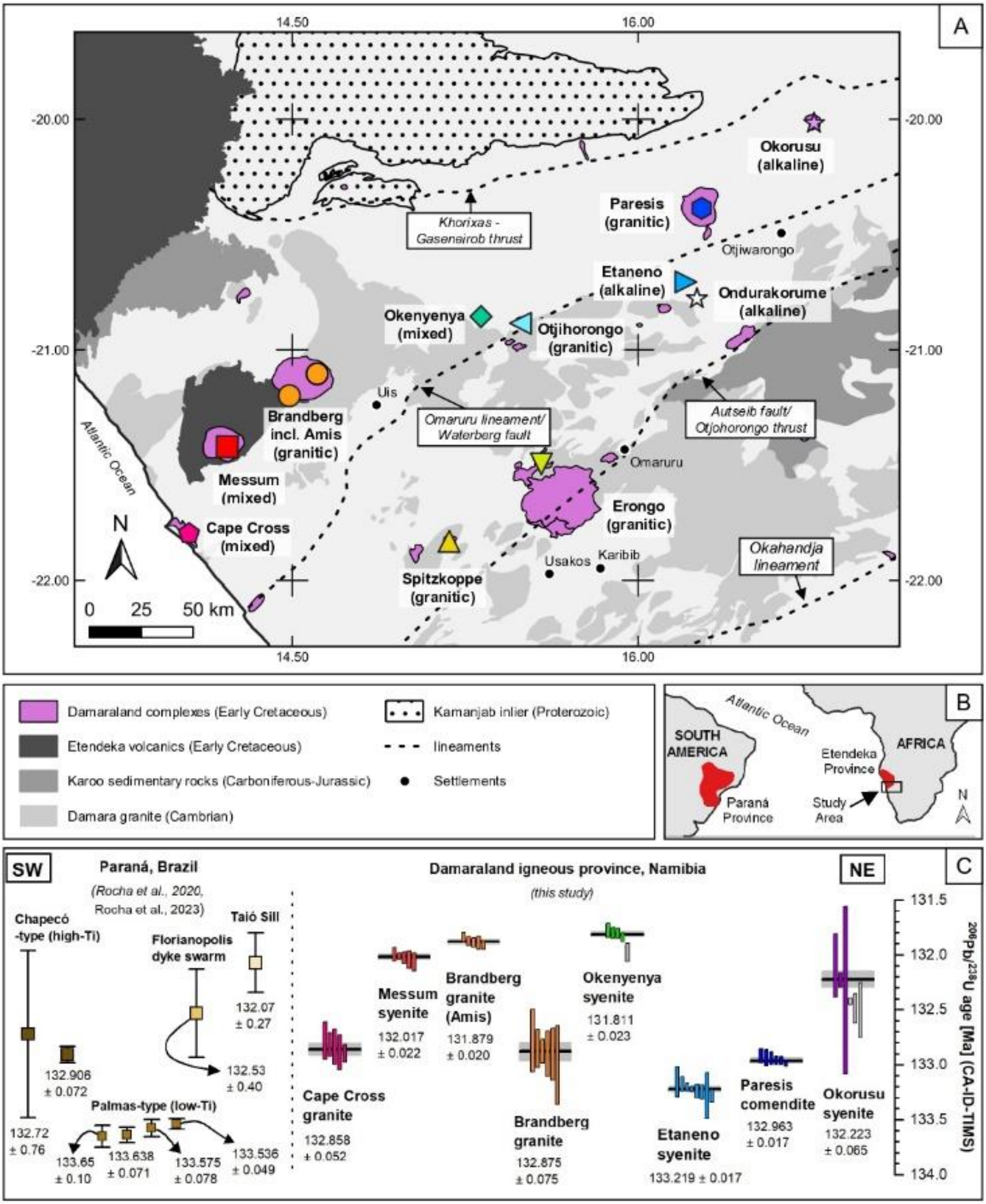
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

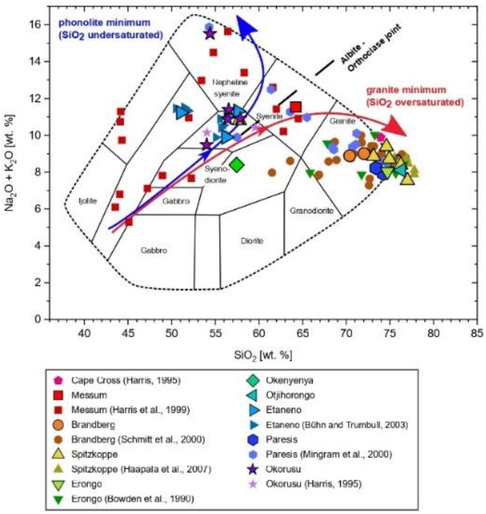
Early Cretaceous intrusive complexes in the Damaraland igneous province (Namibia), ranging petrographically from high-SiO_2 A-type granites to highly alkaline (including carbonatite) rocks, display a striking SW-NE trending alignment and are broadly related to the Paraná-Etendeka Large Igneous Province (LIP), but their magmatic origins, evolution, and relationship to the volcanic activity in the LIP as a whole are still enigmatic. Here, we use zircon geochronology, Lu-Hf isotope compositions, and bulk rock/zircon geochemistry to explore these questions.

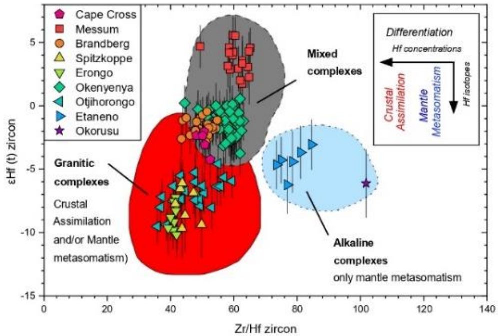
High-precision TIMS zircon ages show a coeval formation of plutons over ~1.4 My (single-crystal dates ranging from 133.22 ± 0.02 Ma to 131.81 ± 0.02 Ma) in the entire province. Damaraland intrusive magmatism started towards the end of the ca. 135-133 Ma volcanic activity peak in the southern Etendeka (Namibia) and the extrusion of the early-erupted low-Ti (Palmas-type) silicic volcanics in the Paraná province, Brazil. The youngest

intrusive units dated in the Damaraland province emplaced synchronously to widespread dykes and sills of the Southern Paraná region (high-Ti-Sr Florianopolis dykes and Taió sill), confirming that magmatism in the Paraná-Etendeka LIP lasted until at least ~132 Ma, and includes late large-scale plutonism.

In the whole Damaraland province (both W and E), intrusive rocks follow two distinct chemical evolution paths towards the granite and the phonolite minimum. The absence of geospatial trends along the aligned complexes in both geochemistry and crystallization ages argues against plate movement over the Tristan-Gough plume as the origin of these complexes. Instead, lithospheric extension along reactivated lineaments led to synchronous melt generation across the province. Negative εHf(t) in alkaline to carbonatitic intrusions (-2 to -6), which evolved towards the phonolite minimum, likely stem from source contamination by preferential melting of mantle portions metasomatically fertilized by the Tristan plume, with no significant path contamination during magma ascent. Any significant assimilation of quartz-saturated crustal rocks would shift the melts to SiO_2-richer compositions and therefore force the magma evolution towards the granite minimum, even if the original primary was silica-undersaturated. Negative zircon εHf values in the granitic complexes (down from -5 to -12), on the other hand, reflect melt contamination by old continental crust during magma ascent, or, more likely, a combination of both source and path contamination.


A
14.50
16.00
-20.00
-21.00
-22.00
Okorusu (alkaline)
Paresis (granitic)
Khorixas - Gaseneirob thrust
Otjiwarongo
Etaneno (alkaline)
Ondurakorume (alkaline)
Okenyenya (mixed)
Otjihorongo (granitic)
Brandberg incl. Amis (granitic)
Uis
Omaruru lineament/ Waterberg fault
Autseib fault/ Otjohorongo thrust
Messum (mixed)
Atlantic Ocean
Omaruru
Erongo (granitic)
Cape Cross (mixed)
Spitzkoppe (granitic)
Usakos
Karibib
Okahandja lineament
N
0 25 50 km
Damaraland complexes (Early Cretaceous)
Etendeka volcanics (Early Cretaceous)
Karoo sedimentary rocks (Carboniferous-Jurassic)
Damara granite (Cambrian)
Kamanjab inlier (Proterozoic)
lineaments
Settlements
B
Atlantic Ocean
SOUTH AMERICA
AFRICA
Etendeka Province
Paraná Province
Study Area
C
SW
Paraná, Brazil
(Rocha et al., 2020, Rocha et al., 2023)
Chapecó -type (high-Ti)
Florianopolis dyke swarm
Taió Sill
132.07 ± 0.27
132.906 ± 0.072
132.53 ± 0.40
Palmas-type (low-Ti)
132.72 ± 0.76
133.65 ± 0.10
133.638 ± 0.071
133.575 ± 0.078
133.536 ± 0.049
Damaraland igneous province, Namibia
(this study)
Cape Cross granite
132.858 ± 0.052
Messum syenite
132.017 ± 0.022
Brandberg granite (Amis)
131.879 ± 0.020
Brandberg granite
132.875 ± 0.075
Okenyenya syenite
131.811 ± 0.023
Etaneno syenite
133.219 ± 0.017
Paresis comendite
132.963 ± 0.017
Okorusu syenite
132.223 ± 0.065
NE
131.5
132.0
132.5
133.0
133.5
134.0
206Pb/238U age [Ma] (CA-ID-TIMS)





Granites in the North American Cordillera during the Sevier-Laramide orogeny: The interplay of subduction, collision, and strike-slip faulting

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Oral, Monday 11th September, 11:45 - 12:00

The North American Cordillera is full of Mesozoic-Cenozoic granites. Because it was located on the western margin of Pangea, North America faced the Panthalassan ocean and is assumed to have experienced continuous eastward subduction since the Triassic. Even during major mountain building (Sevier-Laramide), the deformation is proposed to result from shallow subduction. This model of continuous eastward

subduction is flawed – as indicated by multiple lines of evidence (seismic tomography, paleomagnetism) – and hence our tectonic models for granite generation during the Cretaceous-Paleogene in North America are also in need of revision.

North America exhibits three distinct trends of granitic magmatism, only one of which has any clear relation to subduction. The collision of the Insular superterrane on the west coast of North America initiates around ~100 Ma and extends from at least northern Mexico to southern Canada. The Insular superterrane contains a continuous magmatic arc from the mid-Cretaceous through Paleogene, leaving no slab to subduct beneath North America. Rather, all magmatic arcs from Idaho to northern Mexico undergo a period of intense dextral transpression at ~100 Ma, with continued dextral strike-slip motion in the magmatic arc until ~85 Ma when magmatism ceases. This timing is coincident with a magmatic flare up in all of these arcs, which likely relates to the ability of granitic magmatism to exploit strike-slip faults and zones of local extension in strike-slip systems to allow emplacement. The youngest voluminous magmatism in the Sierra Nevada batholith is explained with this model and the modern arc in Central America provides a compelling analog: Neither of these systems results from strike-slip partitioning caused by oblique convergence.

An inland belt of granites – consisting largely of two-mica granites – along an inferred, margin-parallel orogenic plateau. This belt initiates at ~85 Ma, after cessation of subduction/slab breakoff-related arc magmas. This granitic magmatism results from crustal thickening, a process that takes 10-15 m.y., consistent with terrane collision at ~100 Ma. The subduction-related magmatic arc and the two-mica magmatism overlap in Idaho.

There are also post-collisional granites that occur after a change in plate motion leads to a component of extensional deformation. These granites display distinct, time-dependent patterns. Magmatism occurs initially along a WSW-ENE line, which follows areas of maximum uplift along a strike-slip fault (Lewis & Clark line). Following this 5-10 m.y. episode, granitic magmatism exhibits a N-to-S progression along the trend of the orogenic plateau, suggesting a time-transgressive orogenic collapse.

Position of Precambrian magmatism and metamorphism of the High Atlas in the West Africain Craton: Petrogeochimical and Geochronological approach

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Western High Atlas is one of the richest Moroccan domains in terms of diversity of Precambrian outcrops. Among these, the Paleoproterozoic gneissic complex and the magmatic intrusions of terminal Neoproterozoic age are the most representative, especially in the axial zone of the Western High Atlas. This study is focused on the main formations exposed in the Ourika Old massif. Two metamorphic events can be recognized in this area: a first one that reached greenschist facies degree, followed by a second phase at amphibolic facies conditions. This last high-grade metamorphism is related to the Pan-Africain Orogeny.

The objective of the study is to make a comparison of the different Precambrian magmatic rocks of the High Atlas with the rocks of the same age in the Meseta and the Anti-Atlas.

The gneissic massif of Ourika represent similarities with the metamorphic rocks of the Anti-Atlas which leads to rethink about the West African Craton north limit.

In particular, in this work we studied two gneissic groups with different geochemical compositions due to various protolith natures. We carried out a compilation of field data, laboratory, and previous studies that support the presence of the two metamorphic facies. The subduction signature is supported by Nb/Zr vs Th/Zr ratios. The Nb and Th concentrations, normalized to Yb, indicate a coexistence of mantle-derived and crustal composition, characterized by higher Th/Yb ratios involving a mixture of mafic magma with crustal components.

Moreover, the Neoproterozoic (Ediacaran) magmatic facies are variable in nature; Leucogranites, Quartz Diorites, Tonalites and Potassic Granites are found, possessing a calc-alkaline magmatic affinity.

Magmatic diversity in continental rifts: A case study on the Early Tonian, plutono-volcanic Salto da Divisa Complex, Araçuaí Orogen, Eastern Brazil

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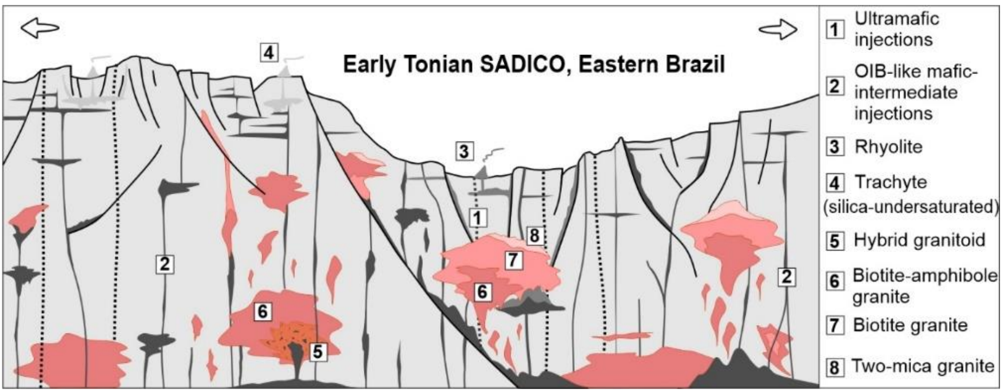
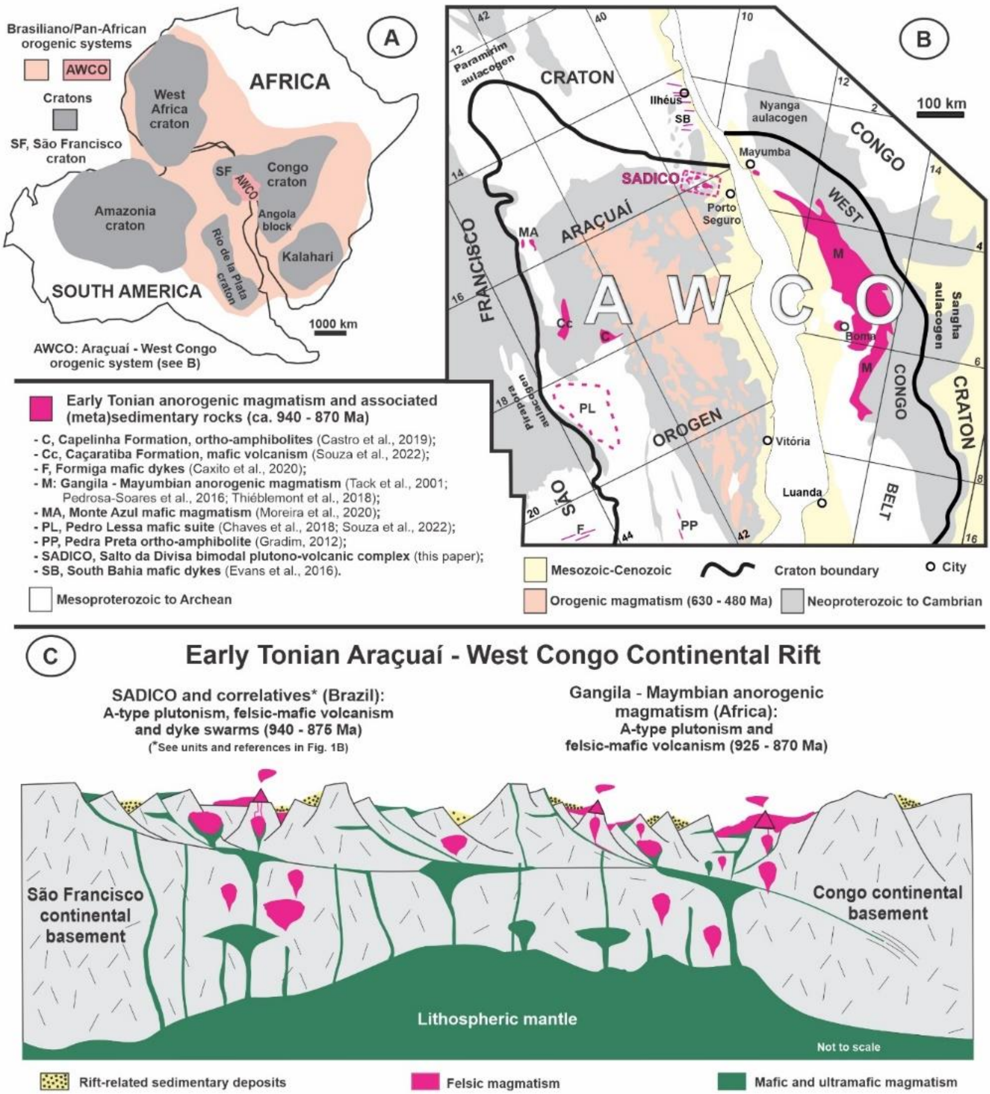
Oral, Monday 11th September, 11:30 - 11:45

It has long been known that anorogenic complexes related to continental rifts show a plethora of distinct igneous rocks, disclosing different magma sources from the mantle to the continental crust. Exposures from plutonic roots to volcanic roofs in deeply eroded regions may disclose the architecture and igneous processes in ancient meta-magmatic edifices like it is the Salto da Divisa complex (SADICO), an Early Tonian plutonic-volcanic record preserved in the northeast Araçuaí orogen, Eastern Brazil. The SADICO magmatic record comprises (with U-Pb crystallization ages, and isotopic Hf and Nd data): i) pyroxenite (εNd(t): +2.2 to -5.3; Nd TDM: 1.2–1.7 Ga); ii) mafic and intermediate dykes (εNd(t):+2.1 to -5.9; Nd TDM: 1.2–1.8 Ga) and enclaves with OIB-like signature; ii) ferroan, A-type hybrid granitoid with mafic-felsic mingling-mixing features (885 ± 9 Ma; εHf(t): -5 to -7, Hf TDM: 2.0–2.1 Ga; εNd(t): -3.2 to -4.3, Nd TDM: 1.5–1.7 Ga); iii) fluorite-bearing, metaluminous to peraluminous, ferroan A-type granites, including biotite-

amphibole granite (ca. 915 to 875 Ma; εNd(t): -2.8 to -5.8, Nd TDM: 1.6–1.9 Ga), biotite granite (894 ± 10, εHf(t): -4 to -11, Hf TDM: 1.9 - 2.3 Ga; εNd(t): -1.6 to -8.0, Nd TDM: 1.4–2.2 Ga), and amazonite-bearing two-mica granite (εNd(t): -4.0; Nd TDM: 1.7 Ga); iv) rhyolite (905 ± 24 Ma; εHf(t): -1 to -8.7, Hf TDM: 1.8 - 2.2 Ga; εNd(t): +3.1, Nd TDM: 1.1 Ga) and subvolcanic silica-undersaturated trachyte (912 ± 13 Ma, εHf(t): -14 to -18, Hf TDM: 2.5 - 2.7 Ga; εNd(t): +0.3, Nd TDM: 1.2 Ga), also with ferroan A-type signature. Our integrated petrogenetic model envisages mantle-derived magmas (ultramafic and mafic rocks) evolved by assimilation-fractional crystallization to felsic subvolcanic and volcanic rocks, interacting with granitic magmas produced by crustal anatexis (biotite-amphibole granite) and subsequently fractionated (biotite granite) and highly fractionated (two-mica granite) with the involvement of F-rich fluids up to subvolcanic levels.




A
Brasiliano/Pan-African orogenic systems
AWCO
Cratons
SF, São Francisco craton
AFRICA
West Africa craton
Congo craton
Amazonia craton
Angola block
Kalahari
Rio de la Plata craton
SOUTH AMERICA
1000 km
AWCO: Araçuaí - West Congo orogenic system (see B)
B
CRATON
Paramirim aulacogen
Ilhéus
SB
Nyanga aulacogen
100 km
CONGO
Mayumba
SADICO
Porto Seguro
WEST
ARAÇUAÍ
MA
FRANCISCO
A W C O
M
Cc
C
Boma
Sangha aulacogen
CONGO
CRATON
Pirapora aulacogen
PL
OROGEN
Vitória
Luanda
BELT
SÃO
F
PP
Early Tonian anorogenic magmatism and associated (meta)sedimentary rocks (ca. 940 - 870 Ma)
- C, Capelinha Formation, ortho-amphibolites (Castro et al., 2019);
- Cc, Caçaratiba Formation, mafic volcanism (Souza et al., 2022);
- F, Formiga mafic dykes (Caxito et al., 2020);
- M: Gangila - Mayumbian anorogenic magmatism (Tack et al., 2001; Pedrosa-Soares et al., 2016; Thiéblemont et al., 2018);
- MA, Monte Azul mafic magmatism (Moreira et al., 2020);
- PL, Pedro Lessa mafic suite (Chaves et al., 2018; Souza et al., 2022);
- PP, Pedra Preta ortho-amphibolite (Gradim, 2012);
- SADICO, Salto da Divisa bimodal plutono-volcanic complex (this paper);
- SB, South Bahia mafic dykes (Evans et al., 2016).
Mesoproterozoic to Archean
Mesozoic-Cenozoic
Craton boundary
City
Orogenic magmatism (630 - 480 Ma)
Neoproterozoic to Cambrian
C
Early Tonian Araçuaí - West Congo Continental Rift
SADICO and correlatives* (Brazil): A-type plutonism, felsic-mafic volcanism and dyke swarms (940 - 875 Ma)
(*See units and references in Fig. 1B)
Gangila - Maymbian anorogenic magmatism (Africa): A-type plutonism and felsic-mafic volcanism (925 - 870 Ma)
São Francisco continental basement
Congo continental basement
Lithospheric mantle
Not to scale
Rift-related sedimentary deposits
Felsic magmatism
Mafic and ultramafic magmatism

Quantitative characterization of orogens through isotopic mapping

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The relationship between orogens and crustal growth is a fundamental issue in the Earth sciences. Here we present Nd isotope mapping results of felsic and intermediate igneous rocks from eight representative and well-studied Phanerozoic orogens. The results illustrate the distribution of isotopic domains that reflect the compositional architecture of the orogens. We calculated the areal proportion of juvenile crust and divided the orogens into five types: (i) highly juvenile (with >70% juvenile crust); (ii) moderately juvenile (70–50%; e.g., the Altaids with ~58% and the North American Cordillera with ~54%); (iii) mixed juvenile and reworked (50–30%; e.g., the Newfoundland Appalachians with ~40% and the Lachlan Orogen with ~31%); (iv) reworked (30–10%); (v) highly reworked (<10%; e.g., the Tethyan Tibet (~3%), Caledonides (~1%), Variscides (~1%), and the Qinling-Dabie Orogen (<1%)). This study presents an approach for quantitatively characterizing orogens based on compositional architecture through isotope mapping, and for investigating the relationships between orogenesis and continental growth.

Diachronous collapse of the French Central Massif constrained by high-precision zircon/monazite U-Pb dating of late-orogenic peraluminous magmatism

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Oral, Monday 11th September, 10:45 - 11:00

The European Variscan Belt (EVB) was formed by collision between two large continents (i.e., Laurussia and Gondwana) in early Carboniferous around 350 Ma. After collision, even when shortening was still ongoing in the external zones, the internal ones experienced crustal extension and exhumation, and orogeny collapse during the Middle and Late Carboniferous with widespread magmatism. To reveal such a process, here we present high-precision SIMS U-Pb data of zircon and monazite from late-orogenic peraluminous granitic magmatism in the French Central Massif, one of the largest pieces of the EVB.

Zircon U-Pb dating gives crystallization ages of 326.9 ± 2.7 Ma, 303.4 ± 5.3 Ma, 315.2 ± 4.1 Ma for deformed monzogranite sample at the margin of the Guéret pluton, two-mica granite sample in the Brame pluton, and mylonitic two-mica granite sample in the Millevaches pluton, respectively, although these samples contain old zircon grains. Monazite U-Pb dating of two-mica granite sample show a consistent emplacement age of 311.3 ±

2.8 Ma for the Millevaches pluton. Monazite U-Pb dating of two granite samples from the Sidobre pluton gives 296.9 ± 2.5 Ma and 306.0 ± 2.0 Ma, indicating the emplacement age of pluton. Monazite U-Pb dating of garnet granite, cordierite granite, migatitic gneiss, and cordierite garnet granite samples from the Montagne Noire migmatitic dome gives consistent $^{206}Pb/^{238}U$ and $^{208}Pb/^{232}Th$ ages and shows $^{206}Pb/^{238}U$ ages of 303.3 ± 2.0 Ma, 304.5 ± 2.0 Ma, 299.8 ± 2.0 Ma and 300.4 ± 2.1 Ma, respectively. Combined with the age (315-310 Ma) of the Margeride pluton in the central part of massif, it is evident the late-orogenic peralumnious granitic magmatism becomes young from north to south, i.e., 327 Ma, 315-310 Ma to 305-300 Ma. As the migmatites and peraluminous granitic magmatism are the exhumed partially molten crust and the result of partial melting of hot crust in the late-collisional extension setting, it is suggested that the French Central Massif had experienced diachronous crustal extension, exhumation and orogenic collapse during Middle and Late Carboniferous, and the massif exhumed from north at about 327 Ma and gradually to the central and the south at 315-310 Ma and 305-300 Ma.

Granitic melt percolation in UHP continental subduction wedge (Erzgebirge, Bohemian Massif)

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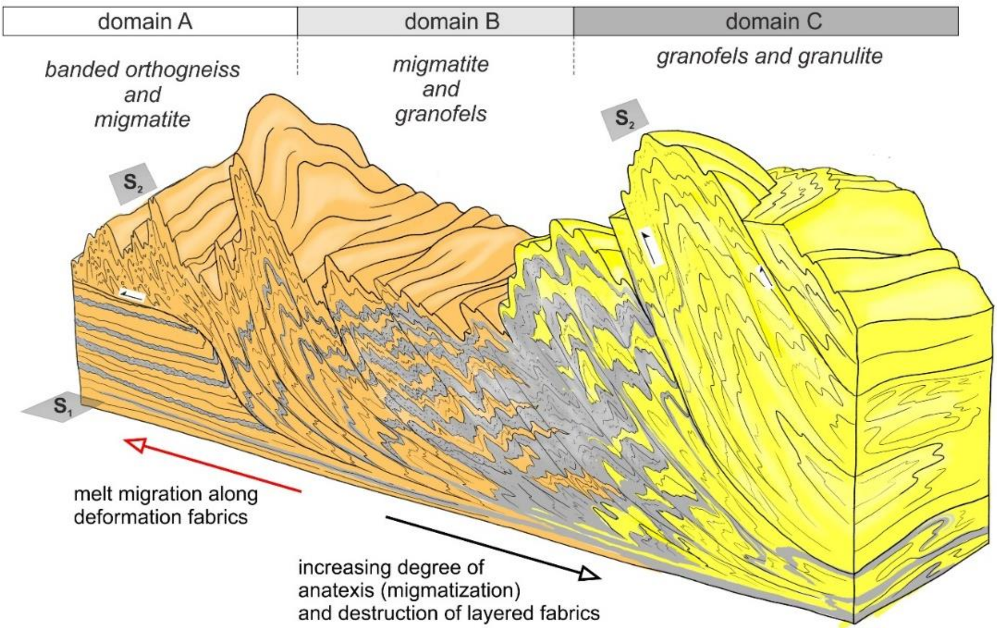
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

A section of Ultra-High Pressure (UHP) Erzgebirge domain in the Bohemian Massif exposes a sequence of anatectic felsic crust recording the progressive transformation of banded orthogneisses to migmatites, granoblastic granofelses and granulites by percolating granitic melt along single deformation fabrics. We show that the granofels layers represent high strain zones and reveal traces of localized porous melt flow that infiltrated the host banded orthogneisses and crystallized melt in the grain interstices. Transfer of melt through the deformation fabrics parallel layers is also indicated by depletion of incompatible elements in granofelses and granulites on behalf of the migmatites. The structures along this anatectic sequence reflect the detachment folding along the melt-coated deformation fabrics, associated with the development of fold axial cleavage, subhorizontal intersection lineation and local accumulation of granitic melt in the axial zones of the folds. In the fine-grained mylonitic banded orthogneiss and in the UHP granulites, the intersection lineation is

rotated to the vertical direction. This is interpreted in terms of return flow and decoupling of the subducted portions of the anatectic sequence from the subducted slab. Fabrics in the granoblastic granofelses and granulites are identified from principal directions cluster patterns of the anisotropy of magnetic susceptibility (AMS). We propose that the transfer of melt along the high-strain zones in the anatectic sequence was responsible for the significant weakening of the entire anatectic multilayer. This weakening resulted in the exhumation of the deeper parts of the sequence by detachment folding, imbrication, and backflow of the HP to UHP crustal slices. Petrochronological data suggest that the timescale of melt transfer in this anatectic sequence corresponds to ~10-15Ma.



Tracing the provenance of inherited zircons from peraluminous granites in the Great Altai and its paleogeographic implications

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Understanding the generation and subduction of crustal material in accretive orogenic belts and its relationship with the Earth's environmental evolution is a current research focus with significant challenges. The Altai orogenic belt, a key component of the Central Asian orogenic belt, has garnered attention from scholars worldwide due to its crustal formation, evolution, tectonic classification, and the formation of valuable metal deposits. However, the tectonic evolution and structural attributes of the Altai orogenic belt have been subject to substantial controversy.

Some scholars propose a genetic connection between the Altai terrane and the Gondwana supercontinent. They suggest that Precambrian detrital zircons and ancient zircons found in the Altai Habahe Group originate from the Tuva-Mongolia block and the adjacent island arc source region. In contrast, other researchers suggest that the Altai belt formed during the Neoproterozoic fragmentation of the Rodinia supercontinent from the southern margin of Siberia. Peraluminous granites, characterized by their abundance of inherited zircons, are generally derived from the partial melting of aluminum-rich rocks, such as metapelite. Therefore, analyzing the U-Pb ages of these inherited zircons provides valuable information about the provenance of clastic sediments within peraluminous granite source regions, similar to the analysis of detrital zircons in sedimentary rocks. To address these questions, this study utilized the ArcGIS platform and the granite database to compile a comprehensive map of the Great Altai granites. Additionally, a previously overlooked granite-inherited zircon database was established. The study focused on conducting detailed in-situ microanalysis of Precambrian inherited zircons identified from different types of granites in the southeastern section of the Greater Altai. The investigation aimed to clarify their origin and source, revealing that these Precambrian zircons may not have been transported over long distances but more likely originated from the recycling of materials from nearby magmatic rocks. This finding suggests the occurrence of early and concealed magmatic activity or basement rocks and provides valuable information related to the Rodinia fragmentation event.

By combining the estimation of paleocrustal thickness in Paleozoic and Mesozoic granites in the Altai region with the analysis of middle Precambrian detrital zircons found in the Habahe Group, this study offers new insights into the paleogeographic characteristics of the Altai orogenic belt from a fresh perspective. The thorough investigation and integration of these previously overlooked inherited zircons, along with their regional context, provide a deeper understanding of their significance in paleogeography and contribute to addressing tectonic attributes of the Great Altai.

Tibetan Plateau growth linked to deep crustal thermal evolution

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The topographic transition of central–northern Tibet since the early Miocene created a consistently high and flat plateau similar to that of today. However, to date, the associated deep crust/mantle events are poorly understood, mainly due to an early Miocene metamorphic–magmatic lull within the Qiangtang Block. To address this issue, we undertook a study of crustal xenoliths and zircon xenocrysts in 6.0–2.3 Ma lavas in the Qiangtang Block. The occurrence of 22.6–12.9 Ma high temperature/low pressure granulite xenoliths implies that the middle crust of the block has been very hot since that time. The studied zircon xenocrysts and granitic xenoliths in the 6.0–2.3 Ma lavas have high $\delta^{18}O$ values, supporting Miocene crustal melting and the formation of unexposed coeval felsic plutons. Together with paleoelevation data for the Tibetan Plateau, our results suggest that the early Miocene cold–hot thermal transition of the middle–lower crust was near-synchronous with topographic evolution

from high-relief mountains to a flat plateau, supporting crustal flow as the main topographic smoothing mechanism for central–northern Tibet.

Theme 2 – Genesis of granitic magmas: Competing models, competing processes

Miocene leucogranite dyke and pluton sourced from Late Cretaceous calc-alkaline granites in the Pangong Metamorphic Complex, Ladakh Trans-Himalaya: Evidence from geochemistry and zircon U-Pb-Lu-Hf isotopes

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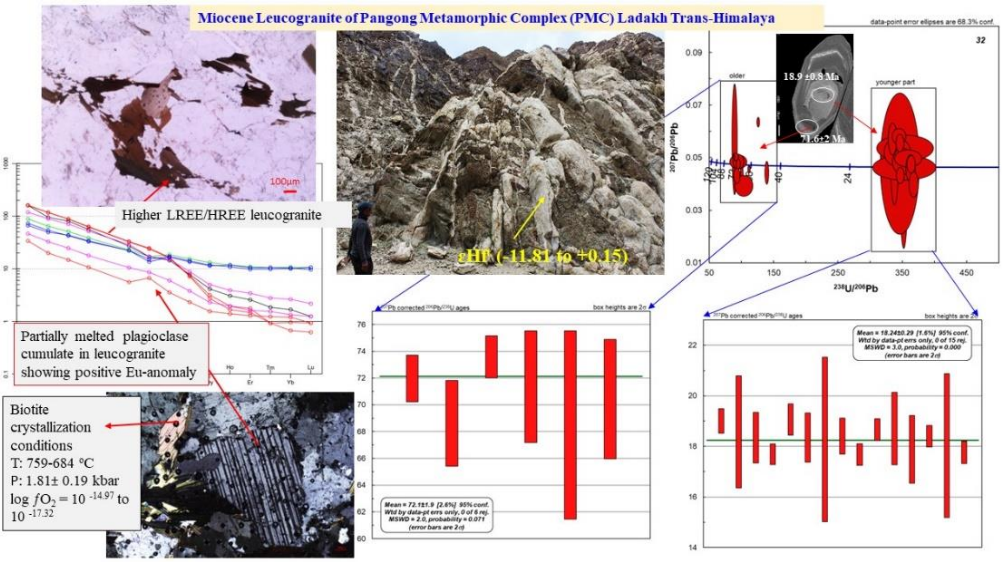
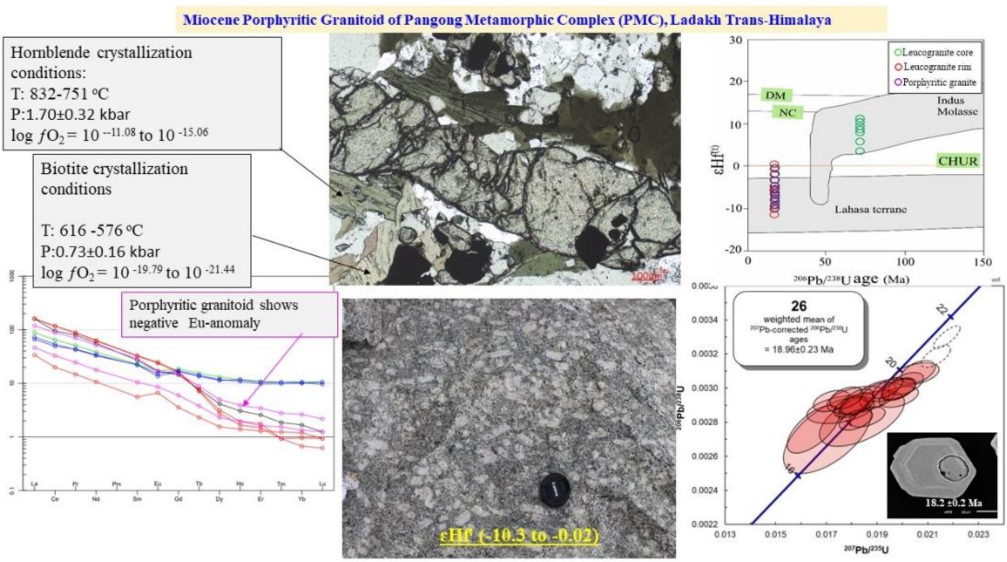
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Pangong metamorphic complex (PMC) in Ladakh Trans-Himalaya is the central part of the dextral strike-slip Karakoram Fault (KF) zone that separates the Ladakh batholith from the easternmost Karakoram terrain. The PMC is comprised of mylonite, amphibolite, granulite, calc-silicate, calc-alkaline granites, and migmatite, which are intruded by a network of leucogranite (LcG) and pegmatite dykes and veins. Tight isoclinal folding in concordant leucogranite and discordant melt generation along the folded axis and across the mesocratic, melanocratic migmatite are indicative of syn-to-post deformational melting events forming the batches of leucogranite melts. A K-feldspar megacryst bearing porphyritic granite (PG) pluton is exposed to the south of PMC. Geochemistry and zircon U-Pb-Lu-Hf isotopes of LcG (discordant), PG, and migmatite are conducted to test the hypothesis of source-to-sink melt history during the KF development. The migmatite, mylonite, PG, and LcG are metaluminous to highly peraluminous (molar A/CNK = 0.53 to 1.88), calc-alkaline to alkaline magnesian. The observed La_N/Yb_N ratios of migmatite components, mylonite, LcG, and PG point towards unmelted protolith and/or restite, and differential melting degrees of a source. The evolution of melts through fractional differentiation is exhibited by wide geochemical variations and Eu-anomalies (Eu_N/Eu^* = 0.71 to 1.50).



High to low Sr/Y ratios (11–197) suggest the discrete nature of melts originated from partial melting of thickened and normal crust. After the continental collision of the Ladakh batholith with the Karakoram terrain, partial melting of the deep crust took place, and the melt migrated rapidly upward, causing the collapse of thickened crust, which prompted the transfer of heat to the surface, causing partial melting at shallower depths. Inherited zircon (magmatic) cores from LcG yielded an older $^{206}Pb/^{238}U$ age of 72.1±1.9 Ma with εHft (+11.30 to +0.15), suggesting derivation of LcG melts from juvenile sources formed in the subduction zone, similar to the granites of the Ladakh batholith. However, zircon (magmatic) zones grown over the inherited cores provide a crystallization age of 18.24±0.29 Ma with εHft (-11.81 to +0.15), suggesting reworking of 72 Ma old granite crust in the formation of LcG melts. Zircons from PG yielded a mean age of 18.96±0.23 Ma with εHft (-10.3 to -0.02), which is synchronous and shows a source signature identical to the LcG melt. It is therefore inferred that LcG dyke melts, derived from Late Cretaceous calc-alkaline granite, acted as feeders to the PG pluton, which emplaced at shallow (ca. 1.5 kbar; Al-in-amphibole rim) crustal depth.



Defining Crustal Contributions to Granites through Time

Claire E. Bucholz*

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Overview Keynote, Tuesday 12th September, 14:00 - 14:45

The relative importance of differentiation of basalts versus crustal melting in the formation of metaluminous to mildly peraluminous granites has long been debated. The origin of this controversy ultimately arises from the fact that the thermal minimum of silicate magmas or is granitic and thus both melts of crustal lithologies or those derived through differentiation are inescapably bound to this composition. Although this topic has been enduringly controversial (albeit with moderating voices along the way), there is hope that the community is coming to the consensus that granites are diverse, and no single model will explain their genesis. Field relationships, chemistry, and thermal modeling all demonstrate that both differentiation (via fractional crystallization or otherwise) of basalts and partial melting of metaigneous or metasedimentary rocks are viable processes in the generation of granitic magmas. These processes may occur more commonly in different tectonic settings and will be dependent on the thermal regime and age of the crust, as well as the magnitude of basaltic input, which are often linked.

Thus, the primary question should not be which process is dominant, but rather how much each process contributes to the formation of any specific granite and how to quantify these contributions. Answering these questions directly impacts our understanding of crustal growth as granites are the silicic endmember in crustal igneous rocks and the primary source of zircon, which are widely used to reconstruct crustal growth curves. Principal tools to assess the relative contributions of mantle versus crust are radiogenic and stable isotopes as they often vary between the mantle and crust due to differentiation causing differential ingrowth of radiogenic daughter nuclides or low-temperature weathering or biogeochemical reactions imparting distinct stable isotopic signatures on crustal materials. A first-order input into these models is the mantle and crustal compositions at the time of granite formation. The depleted mantle composition is well-defined through Earth history thought to be either constant for stable isotopes or has evolved in a predictable way for radiogenic systems. The composition of the crust however has changed throughout Earth history in response to variable tectonic regimes resulting in different types of magmatism as well as variable surface conditions and biogeochemical cycles imparting distinct chemical signatures to sedimentary rocks.

A starting place to explore this problem is understanding how the sedimentary end member of crustal contributions to granites has varied through time. Although sedimentary rocks can be studied directly, they suffer from poor preservation, often capture only local variations in sedimentary compositions, and their original geochemistry may be modified by long residences in the upper crust. An alternative archive that has recently been explored is that of granites dominantly formed through the partial melting of sedimentary rocks and, in turn, are strongly peraluminous. These strongly peraluminous granites perhaps have the least controversial origin in of all granites (i.e., primarily through the partial melting of sedimentary rocks). Strongly peraluminous granites have an advantage over sedimentary rocks as an archive to understand the nature of crustal contributions to granite formation for several reasons: (1) they integrate large volumes of sedimentary rock, thus providing an estimate of their bulk composition; (2) they often contain refractory phases such as zircon and garnet which preserve information about primary magmatic chemistry (despite subsequent weathering), and (3) they actually preserve the process that granite petrologists are interested in, namely the incorporation of sedimentary rocks into granitic melts.

Recent studies have demonstrated that the compositions (both isotopic and trace elements) of strongly peraluminous granites are not constant with time, reflecting changes in the sedimentary rocks that they are sourced from. In particular, time variance is observed in O, S, and N isotopes and abundances of P and N. In some instances, strongly peraluminous granites can be directly linked to their source rocks through field observations. These direct links provide critical examples to study the fractionation of elements and isotopes between strongly peraluminous granites and their sources. Moving forward these observations of time-dependent chemistry of strongly peraluminous granites need to be incorporated into specific models of granite genesis and models of crustal growth whereby a crustal composition is assumed. Building a more robust record of strongly peraluminous granites and how their chemistry has changed throughout Earth history is a direct way forward. An important complexity to this problem is that strongly peraluminous granites can be sourced from sedimentary rocks with depositional ages quite different from their own formation age. Thus, characterization of strongly peraluminous granite chemistry must be accomplished through conscientious field studies, combined with rigorous assessment of source rock ages. Isotopic systems of particular importance in strongly peraluminous granites will include oxygen and silicon isotopes as these elements constitute ~25-50% of the mass of both basaltic and granitic rocks and thus provide robust estimates on total amount of mass contributed from the crust.

Nanogranitoids: tiny melts droplets and great insights into the origin and evolution of granites

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Junior Keynote, Tuesday 12th September, 10:30 - 11:00

As result of 15 years of thorough research on glassy melt inclusions and nanogranitoids (i.e. crystallized melt inclusions) found in partially melted rocks from the lower crust, these tinny objects have become a key tool in crustal petrology. Despite their very small size, these inclusions give not only constraints on anatexis and fluid regime of deep portions of the continental crust, but can also provide massive insights into origin of anatectic magmas. Furthermore, melt inclusions can be used as starting point for a better understanding of processes shaping the composition of granites during their evolution.

Up to now a wide range of crustal protoliths such as metasedimentary, metaigneous and metamafic rocks containing anatectic melt inclusions show that the latter can be linked mostly to S- and I-type granites. Yet a more recent study [Carvalho et al., 2023] documenting the occurrence of pristine melt inclusions in garnet from ultrahigh temperature (UHT) granulite from East Antarctica brings another piece of the puzzle linking anatectic melt inclusions to felsic A-type granites.

Nanogranitoids and beautiful glassy melt inclusions (Figure 1) included in garnet from a residual metapelitic granulite, show granitic composition with weakly peraluminous to weakly peralkaline affinity, ferroan character, high silica and alkali contents, high K/Na and Ga/Al, and low Ca, Ba, Sr, and H2O concentrations. These features are akin to the most felsic A-type granites from the literature. Microstructures coupled with phase equilibria calculations and Zr-in-rutile thermometry indicate that the melt inclusions represent UHT melts formed at peak conditions (930–1000 °C) from a residual metapelitic source. Geochemical modelling shows that these melts can either be primary melts of the most felsic A-type granites or even a suitable crustal component for a hybrid origin (i.e., mixing of mantle + crustal magmas).

Anatectic melt inclusions reveal therefore the missing link between A-type granites and the hottest metasedimentary crust, providing a more complete picture of processes responsible for granite formation. These new results show that a larger variability of the granite realm must be considered in models of the effect of high and ultrahigh temperature anatexis on crustal differentiation.

Carvalho, B.B., et al., 2023, Revealing the link between A-type granites and hottest melts from residual metasedimentary crust. Geology. https://doi.org/10.1130/G51097.1

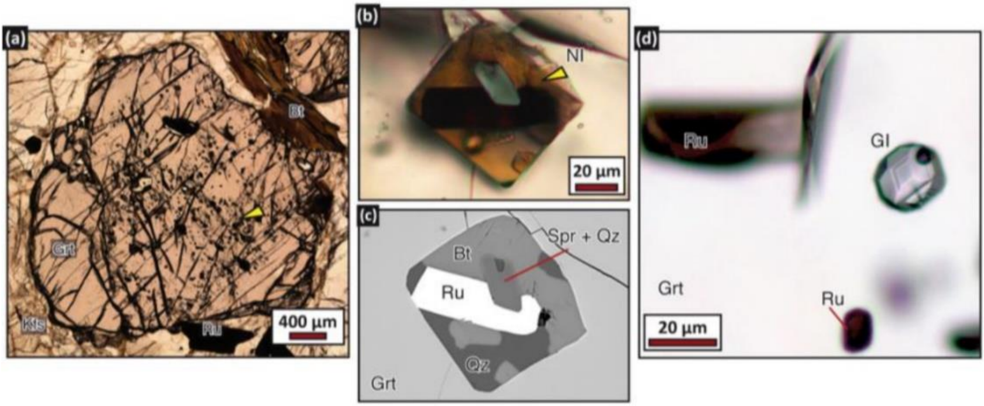

Figure 1: (a) Melt inclusion-bearing garnet (Grt) from a residual metapelitic UHT granulite, Lützow-Holm Complex (East Antarctica). Bt= biotite; Kfs= K-feldspar; Ru= rutile. (b) Nanogranitoid (NI) containing trapped rutile, sapphirine (Spr) and quartz (Qz). (c) BSE image of the inclusion in (b). (d) Glassy melt inclusion (GI) and rutile in garnet.

On the nature and composition of crustal sources for late Variscan magmatism – insights from southern Sardinia (Italy)

Leonardo Casini*, Francesco Secchi, Claire Bucholz, Tommaso Giovanardi, Alfredo Idini, Milan Kohut, Stefano Naitza, Giacomo Oggiano

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The external zone of the Variscan chain in southern Sardinia hosts several short-lived, both composite, and homogeneous plutons emplaced at shallow crustal levels during post-collisional extension. Except for Arbus composite pluton, dated 304 ± 3 Ma, the emplacement ages cluster within a narrow time interval between about 289 ± 1 and 285 ± 1 Ma. Granites show commonly a ferroan and F-bearing character (F in the range of 0.09 to > 0.01 wt.%) and are either sub-aluminous to peraluminous ilmenite (GS1 and MM), or metaluminous magnetite rock-series (GS2 and GS3). GS1 rocks contain dark siderophyllite as the only mafic phase, and ilmenite + xenotime (Y) as common accessory phases. GS2 granites contain biotite + allanite + magnetite. GS3 shows hastingsite + allanite + magnetite, with final crystallization of biotite + fluorite and rare fayalite . Finally, MM rocks are garnet and muscovite-bearing granites. The bulk-rock compositions of the granites are similar to experimental melts obtained at P < 8 kbar from crustal sources ranging from metagreywackes to meta-tonalites

(Patiño Douce, 1997). Different proportions of metasediments / metaigneous crustal sources are also supported by Sr-Nd isotopic data (εNdt in the range of -5.4 to -7.5). The occurrence of a pre-Cambrian lower crust could fit the Variscan architecture of the external Nappe zone of Sardinia, as lower Cambrian metasandstones contain abundant clasts of amphibolite-facies gneiss likely derived from an unexposed crystalline basement possibly composed of TTG as commonly observed in Proterozoic basements (Shang et al., 2007; Nehring et al., 2009). Temperatures obtained from plagioclase/whole rock and apatite saturation thermometry are about 860-870oC for both the ilmenite and magnetite-bearing granites and may be interpreted as near liquidus temperatures. Slight lower values between 730°C-785°C obtained with Crisp and Birks's (2022) zircon saturation calibration may reflect the depleted character of meta-igneous sources. Overall, the whole data set suggests that anatexis involved the dehydration melting of biotite at temperature exceeding 850oC, as commonly argued for ferroan granite magmas (Scaillet et al., 1995; Frost and Frost, 2011). Finally, the chemical and isotopic signatures of the granites are likely inherited from an heterogeneous deep crust resulting from the juxtaposition of different crustal blocks during the late Carboniferous-Early Permian shearing and rotation of the Corsica-Sardinia massif. Late Variscan shearing, likely associated to delamination and lithospheric necking, appears as the most reliable mechanism to account for mantle upwelling, triggering biotite-dehydration melting of the lower crust.

Contrasting crust-derived A-type granites and associated enclaves from the Nellore Schist Belt, Southeast India: evidence from phase petrology and whole rock geochemistry

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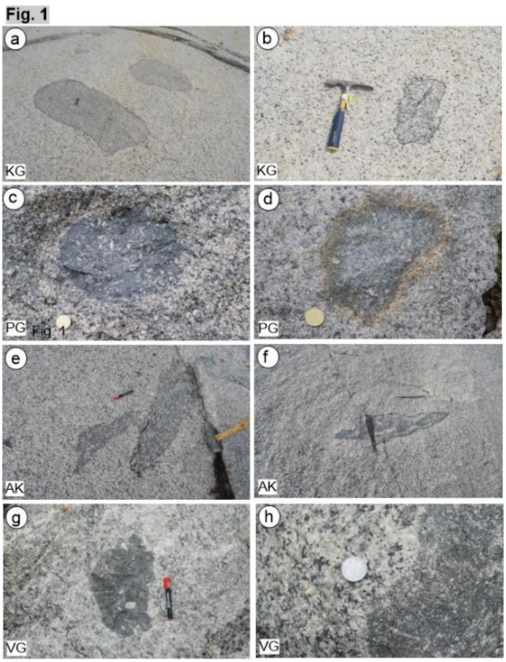
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Proterozoic felsic and related magmatism in the northern part of Nellore Schist Belt (NSB), southern India constitute a number of granite plutons viz., Kanigiri (KG: 1284±4 Ma), Punugodu (PG: 1257±6 Ma), Andhra Konda (AK: age not available), and Vinukonda (VG: 1589±6 Ma) plutons. To gain insight into the petrogenesis and tectono-magmatic development of these granite plutons, the field relations, microstructures, whole rock elemental and biotite-plagioclase geochemistry of granites and their enclaves are conducted. The presence of fine- to medium-grained microgranular enclaves (MEs) consisting of resorbed plagioclase xenocrysts, quartz ocelli, and apatite needles indicates a mixed, mingled, and undercooled origin for MEs in semi-solidified host granite magmas. The ME (bt±hbl-pl-Kf-qz-ap-zrn-mag) and host granites (bt-ms-pl-Kf-qz-ap-zrn-mag) exhibit hypidiomorphic texture and modal contrast in addition to having amphibole and being muscovite-free few ME. The compositions of plagioclases in the ME and host granites demonstrate their crystallisation in slightly distinct

magmas. The ME and host granite biotites are re-equilibrated, primary, siderophyllite, and co-precipitated with other ferromagnesian minerals and/or muscovite belonging to ilmenite (reduced) series biotites stabilised between FMQ and NNO, except a few PG biotites. The coupled exchange of Ti and Fe^{2+} in biotites yields high crystallization temperatures (>800 °C) under relatively water-undersaturated (ca. 3.7 wt.%), alkaline (A-type) host magmas emplaced at shallow (PG: 1.5 kbar, 5 km) to mid-crustal (AK: 4.25 kbar, 17 km) depths.



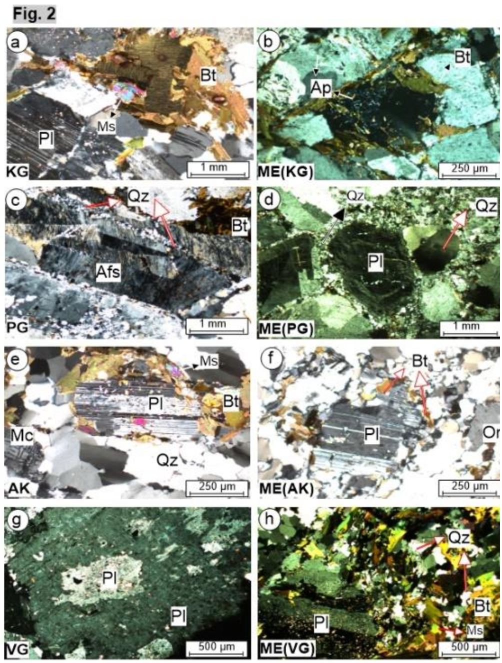


Fig. 1
(a-b) microgranular enclaves (ME) in KG with fine grained biotite rich chilled margin.
(c-d) Phenocryst bearing ME in PG showing rounded shape and rusty margin.
(e-f) elongated and lenticular ME in AK.
(g-h) Fine grained ME with plagioclase xenocryst in VG.

Fig. 2
(a) Plagioclase phenocryst showing overgrowth at ME contact margin.
(b) Biotite with zircon inclusions associated deformed twins bearing plagioclase in ME hosted in KG.
(c) Baveno-twinned perthite minerals are surrounded by fine grained quartz in PC
(d) Resorbed plagioclase in quartz groundmass in ME hosted in PG. Note. The same quartz inclusion trapped in the plagioclase crystals.
(e) plagioclase in AK well-developed and having biotite inclusions.
(f) Partially dissolved plagioclase in ME(AK).
(g) Serisitization of plagioclase within the alkali feldspar in VG.
(h) VG plagioclase contact with fine grained quartz and biotite in ME(VG).

The MEs and host granites equivocally show a nature similar to peraluminous, alkali-calcic, and ferroan A-type granites. The observed geochemical variations of granites and MEs indicate their evolution in discrete magma pulses through mixing and fractionation. The partly to nearly complete elemental diffusion between the ME and host magmas is, however, signaled by their more or less identical K2O content, trace, and REE patterns. The content of Y, Nb, Ta, Ce, Yb, and 10000*Ga/Al broadly classifies them as A-type granites. More specifically, the KG, PG, and AK granite plutons show affinity with rift-related A1-type granites, whereas the VG granite pluton is typical of post-collisional A2-type granites. All these granites are sourced from metasediments; however, their MEs magma, although chemically modified, appears to be derived from a high-K mafic crustal source. The present observations, coupled with the available zircon U-Pb ages, suggest the formation of two distinct A-type granite magmas that coexisted and interacted with relatively mafic ME magmas, and they evolved simultaneously through mixing and fractionation during the Early- to Mid-Mesoproterozoic.

Fig. 3

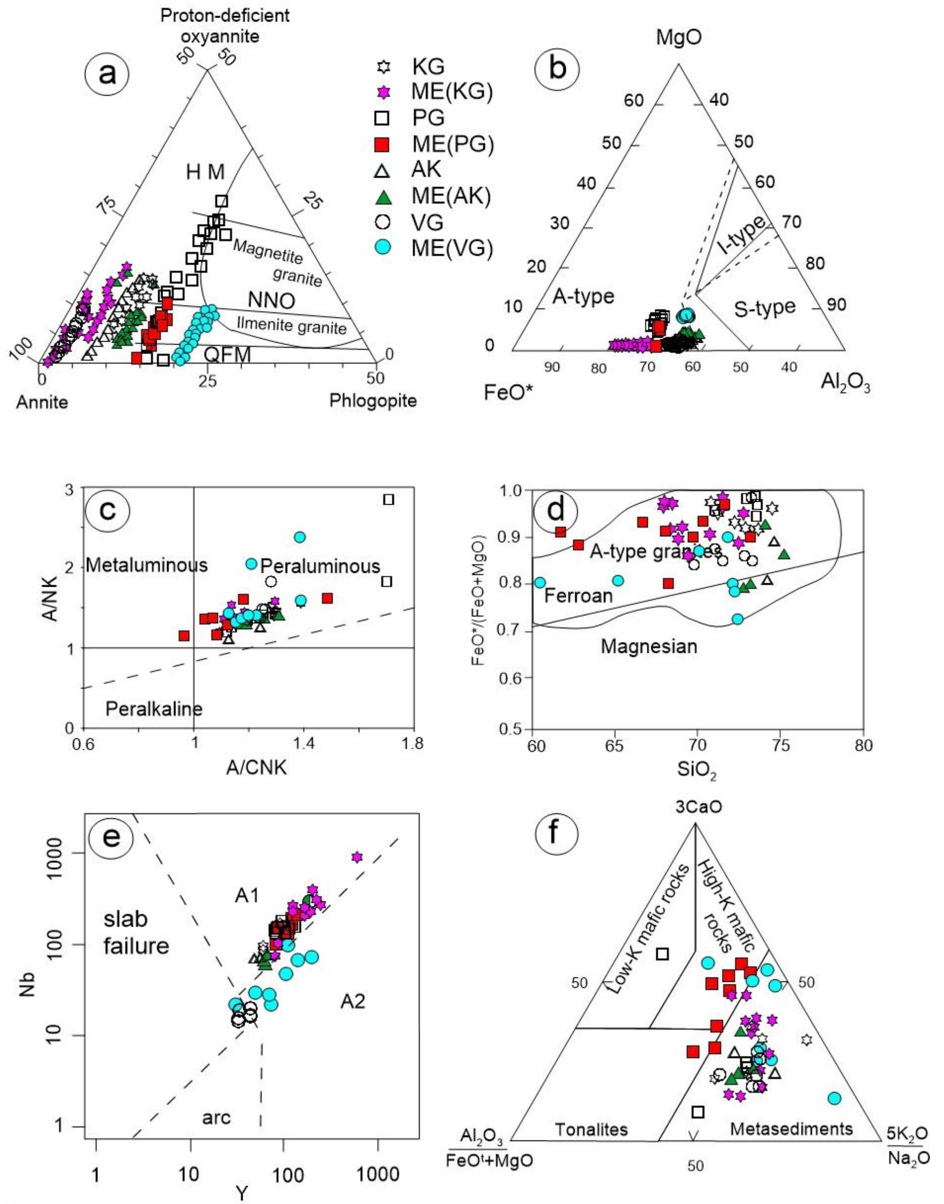


Fig.3
(a) Annite, oxyannite and phlogopite ternery diagram (after Beane, 1974; modified from Heinrich, 1946 and Foster, 1960) showing the crystallization position of ME and host granites
(b) FeO^t-MgO-Al_2O_3 ternary plot (Gion et al., 2022; after Abdel-Rahman, 1994) for the biotites which fall in the alkaline A-type suites.
(c) A/NK vs A/CNK diagram (Shand, 1943; Maniar & Piccoli, 1989) for ME and host granites showing peraluminous nature.
(d) $FeO^t/(FeO^t+MgO)$ vs SiO_2 classification diagrams of Frost et al. (2001) showing ferroan nature of the host granite.
(e) Nb vs. Y plot (Whalen and Hildebrand, 2019; modified after Pearce et al., 1984) illustrating the A1 and A2 type of ME and host granites
(f) 3CaO–($5K_2O/Na_2O$)–Al2O_3/(FeO^t+MgO) diagram (after Laurent et al., 2014) showing source composition fields.

Some granites were hot (>850°C) but most were not (<800°C)

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Oral, Tuesday 12th September, 15:45 - 16:00

If granites formed from hot (>850°C) crustal magmas, why would the crust “wait” to be heated to 850-950°C to melt, rather than melt at lower temperatures?

The highest temperature estimates for granitoid magmas are commonly interpreted as the minimum temperature of an even hotter, fractionating, more mafic magma. For example, temperatures from 2-pyroxene thermometry might yield ≥900°C, while results from “less-robust” geothermometers, including Al-in-hornblende and plagioclase-hornblende, are commonly considered to reflect equilibration during cooling. A similar interpretation typically applies to zircon saturation temperatures, even though zircon is usually an early-crystallising, complexly zoned mineral like plagioclase, both faithfully recording the thermal oscillations typical of granite magma evolution. Most interpretations of hot granite magma generation are underpinned by the assumption that granitic magmas are the long-term, end-product of fractionation from basalt, essentially mimicking Bowens Reaction Series.

Eruption temperature estimates for silicic volcanic rocks are often used as supporting evidence for hot felsic granitoid magmas, but they reflect transient thermal spikes from magma injected into a cooler, granitic magma chamber during magma pulsing. Mineral geospeedometry has shown that zoning in pyroxenes can occur in a matter of weeks, implying hybridisation with mafic magmas in granitic magma chambers is probably a rapid process and that compositional diversity in granitic magmas maybe a short-term, repeatable (oscillatory) mixing process. By contrast, many plutons in “transcrustal” batholithic systems persist on Ma-year intervals, residing in the crust under near-solidus conditions for as long as the arc flux remains focussed within that region, usually at tectonically controlled Ma-scales. A hot, dry lower crust has become axiomatic, implying crustal melts are also hot, but is this so? Thermally equilibrated mafic arc roots are eclogitic, much cooler than the granulite facies or UHT terrains predicted to form during fluid absent melting. Moreover, numerous experiments have shown that water strongly influences melting temperatures, and recent studies have suggested that some arc cumulates were derived from magmas with up to 20 wt% water, while the question of “why do arc magmas contain 4 wt% water on average” has been simply explained by pressure-controlled degassing. What happens to that degassed water? Recent thermodynamic modelling shows that water is the key catalyst for crustal melting in orogenic domains. If subduction fluids are available, the crust will inevitably melt at low-T and “less-robust” geothermometers recording temperatures <800°C are more reliable indicators of the granite magma-forming process.

S-type granites formed by assimilation-fractional crystallization of I-type granites

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Oral, Tuesday 12th September, 12:15 - 12:30

The S-type and I-type granites are generally formed by partial melting of meta-sedimentary materials and igneous rocks, respectively. Although many studies show that some other components (mantle or igneous rocks) may be involved in the S-type granites, it remains speculative that the I-type granites can be evolved into S-type granites by assimilation-fractional crystallization processes. In this study, we present detailed geochronological and geochemical analyses of the Bensong Co batholith in the Southern Qiangtang terrane, Tibetan Plateau, and reveal a petrogenesis link between I-type and S-type granites. The Bensong Co batholith consists of biotite granites, two-mica granites and mafic microgranular enclaves, all of which were formed during 217-208 Ma. Whole-rock geochemistry shows the granites have high contents of SiO_2, high A/CNK (1.1-1.3) with normative corundum, similar to S-type granites. In contrast, SIMS zircon O analyses reveal they have $\delta^{18}O$ values of 7.3-8.1‰, similar to I-type granites. Further SIMS quartz O analyses reveal they have $\delta^{18}O$ values of 10.7-12.2‰, which are not equilibrated with zircon O isotopes at a magmatic temperature of 700 ℃. These

data suggest that the original magmas are I-type granites (zircon O isotopes) and were evolved into compositions with S-type characteristics (whole rock geochemistry and quartz O isotopes) by assimilation-fractional crystallization processes during their ascent and intrusion. The assimilations are S-type granites defined by the ~490-470 Ma zircon xenocrysts with $\delta^{18}O$ values of 9.2-11.8‰. This study highlights that analysis both early and late crystallized minerals O isotopes will reveal the detailed processes to generate highly fractionated granites.

Unravelling source variations in arc and back-arc magmas with strong crustal signature: A case study in the Famatinian Orogen

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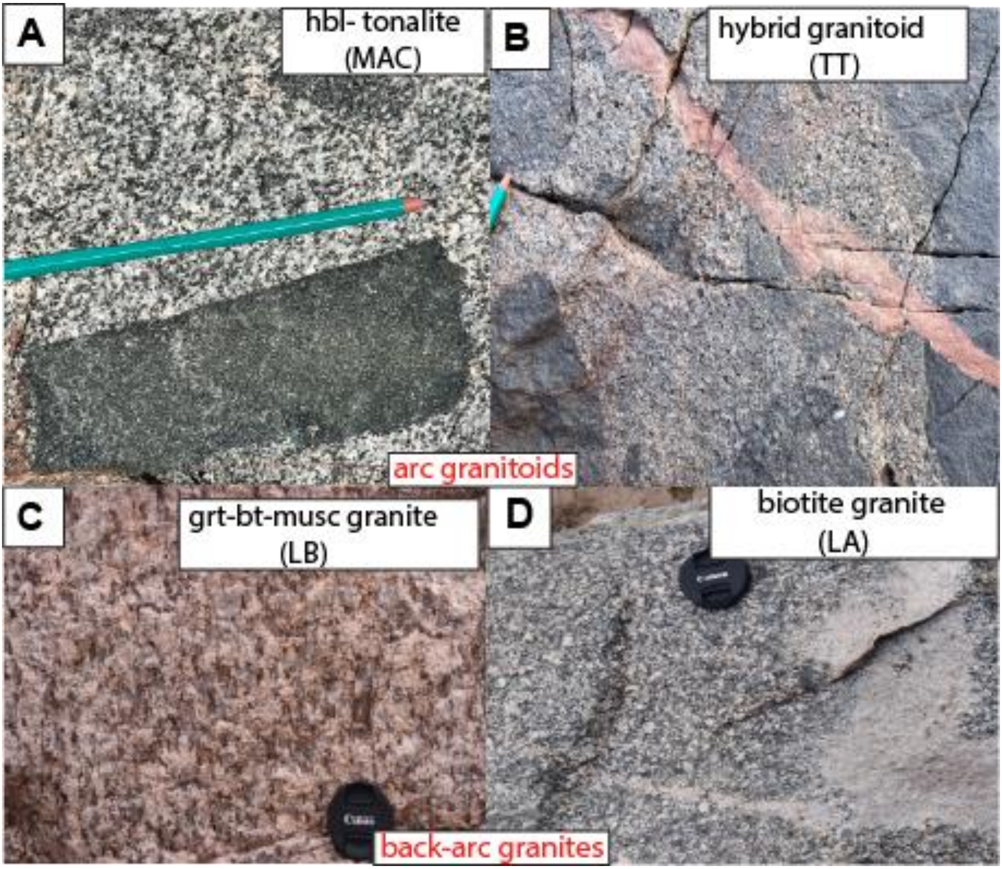
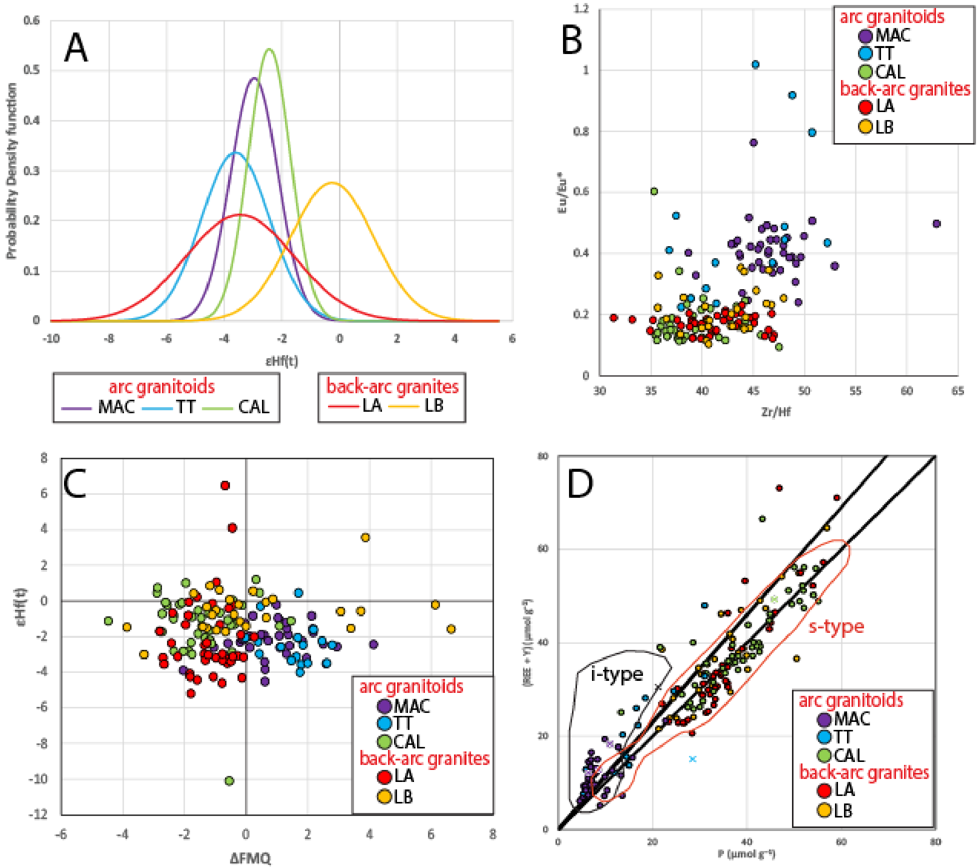
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The genesis of granitic magmas has been extensively discussed in the literature. In this work, we aim to contribute to this discussion using field-based evidence and zircon studies in arc and back-arc granitoids from Famatinian Arc, Puna Plateau, Argentina. The arc rocks are represented by a mafic enclave-bearing tonalite

(MAC – Graphic 1a), a hybrid granite (TT – Graphic 1b) and a dacite (CAL). The back-arc rocks are represented by a leucocratic garnet-muscovite-biotite granite (LB – Graphic 1c) with igneous mme and xenoliths of metasedimentary rocks, and a biotite-granite (LA – Graphic 1d).



All these rocks present a widespread range on U-Pb zircon crystallization ages, ranging from ca. 510 to 440 Ma. For the arc rocks, U-Pb titanite ages constrains the magmatic crystallization at around ca. 470 Ma. All of these granitoids present U-Pb apatite magmatic ages constrained at ca. 460-440 Ma. All these granitoids have zircon crystals presenting similar mean εHf(t) values (around -3), except for the LB granite in the back-arc domain which has mean εHf(t) values around -0.3 (Graphic 2a). This similarity could be explained by a significant crustal input that homogenizes the signature of these granitoid magmas. The significant proportion of inherited zircon crystals also corroborates with that assumption. Based on trace elements in zircon, the arc granitoids are less fractionated (Eu/Eu*=0.23 to 1.0 and lower Zr/Hf – Graphic 2b) and more oxidized (mean ΔFMQ= +0.9 to +1.3 – Graphic 2c) than the CA arc dacite and back-arc granites (Eu/Eu*= 0.11 to 0.35; higher Zr/Hf; mean ΔFMQ= -1.5 to +0.3 – Graphics 2b and c). The back-arc grt-bt-musc granite (LB) presenting a cluster of high oxidized zircon crystals (ΔFMQ: +3.0 to +6.6) and more juvenile zircon crystals (εHf(t) ~ -0.3 – Graphic 2c) possibly indicate a mafic input in the back-arc. Heterogeneities on sources from arc magmas have also been identified using molar proportions of P, Y and REE in zircon crystals (Graphic 2d). MAC tonalite crystallizes from typical I-type sources, whereas CA dacite has dominantly S-type sources, and the TT hybrid granite presents grains from both I- and S-type sources. This bimodality in the hybrid granite is corroborated by strong evidence of magma mixing in the field.


A
Probability Density function
εHf(t)
arc granitoids
MAC TT CAL
back-arc granites
LA LB
B
Eu/Eu*
Zr/Hf
arc granitoids
MAC
TT
CAL
back-arc granites
LA
LB
C
εHf(t)
ΔFMQ
arc granitoids
MAC
TT
CAL
back-arc granites
LA
LB
D
i-type
s-type
arc granitoids
MAC
TT
CAL
back-arc granites
LA
LB

H_2O-fluxed anatexis of deep arc sections and its interaction with surrounding arc rocks: adding complexity to arc magmatism

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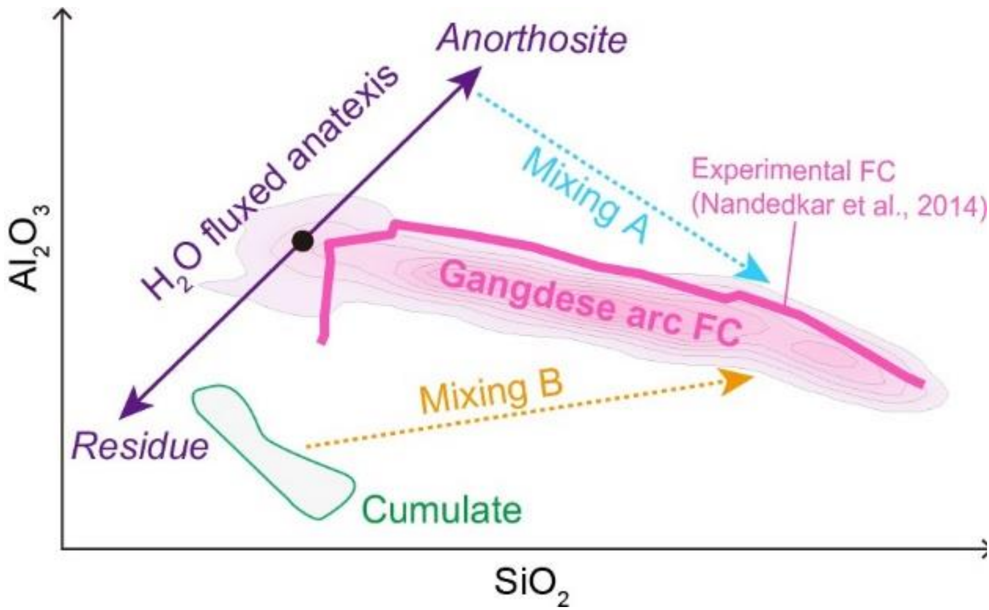
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

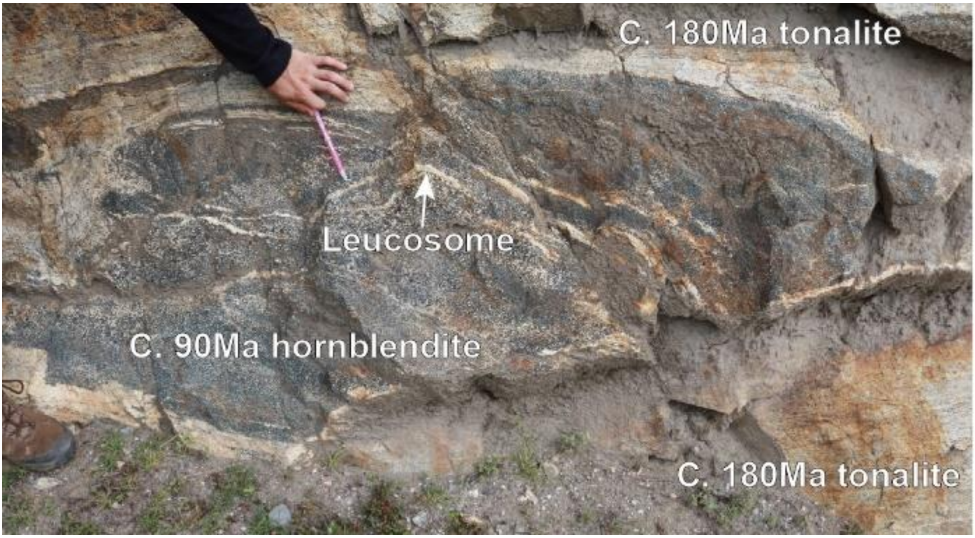
Recent debates focus on the relative importance of fractional crystallization (FC) and magma mixing in controlling the compositions of arc magmas and the main compositional trends of arc magmatic suites (e.g. Jagoutz & Klein, 2018; Moyen et al., 2021; Müntener & Ulmer, 2018; Reubi and Müntener, 2022; Zhu et al., 2022). However, field and geochemical evidence show that H_2O-fluxed anatectic melts from deep arc rocks and their hybridization with arc magmas produce deviations from the expected geochemical trends. This study presents two cases from deep sections of the eastern Gangdese arc that underwent granulite-facies (P=10-15 kbar, T=800-950℃) anatexis to illustrate the processes that cause deviations from expected trends.

The first case relates to gabbroic migmatites producing Na and Sr-rich anorthositic melts and garnet, amphibole and epidote-dominated residues. The residual assemblage suggests H_2O-fluxed melting. Zircon dating reveals that the 85-70 Ma anatexis happened in continuity with the 99-84 Ma emplacement of the gabbroic protolith. Granites coeval with anatexis (c. 80

Ma) are characterized by high Na and Sr concentrations compared with the main FC trends of the arc rocks, indicating potential mixing between granitic and anorthositic magmas (mixing A in Fig. 1).



The second case is that of a c. 90Ma hornblendite intrusive into a c. 180 Ma tonalitic granite inducing its water-fluxed remelting. The leucosomes in the hornblendite, possibly reflecting extraction paths of evolved melts, connect with leucosomes in the host anatectic tonalite (Fig. 2), indicating interaction and hybridization of the two melts within a single melt network similar to the Karakoram anatexis (Reichardt et al., 2010). Geochemistry shows that the leucosomes plot away from the FC curve and in between the hornblendite and the evolved Gangdese arc magmas, which provides evidence of a mixing process (mixing B in Fig. 1).



In these two cases, H_2O-fluxed anatexis of deep arc rocks and resulting hybridization form magmas that plot away from the expected FC trends.

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Origin of peralkaline granites: insights from Fe isotopes

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Revealing the origin of peralkaline granites (with molar (Na+K)/Al > 1) is paramount importance for understanding the evolution of continental crust and mineralization of some critical metals. However, it remains contentious as to how the peralkaline granitic magmas generate. There are two competing hypotheses for peralkaline granitic magma generation, i.e., prolonged differentiation from basaltic magmas versus fluid-fluxed melting of the lower crust. Fe isotopes have the potential to distinguish these two mechanisms in which the prolonged fractionation of Fe-bearing minerals results in more remarkable Fe isotope fractionation than that of partial melting. We report whole-rock Fe isotope data for a series of peralkaline granites from Taohuadao, SE China. They have variable but generally high δ^{56}Fe values ranging from 0.28 ± 0.03‰ to 0.62 ± 0.04‰, with a mean of 0.42 ± 0.09‰ (1SD). The values are significantly higher than those of mafic-intermediate igneous rocks (δ^{56}Fe = 0.09 ± 0.08‰; Heimann et al., 2008) and slightly higher than those of the highly evolved metaluminous granites from western Nanling Range, southern China (δ^{56}Fe = 0.31 ± 0.07‰, 1SD; Du et al., 2019). These results confirm that prolonged magma differentiation is the primary mechanism for peralkaline granitic magma formation.

Heimann, A., Beard, B.L., Johnson, C.M. (2008). The role of volatile exsolutions and sub-solidus fluid/rock interactions in producing high ^{56}Fe/^{54}Fe ratios in siliceous igneous rocks. Geochem. Cosmochim. Acta 72, 4379-4396. ; Du, D.H, Li, W.Q., Wang, X.L., Shu, X.J., Yang, T., Sun, T. (2019). Fe isotopic fractionation during the magmatic–hydrothermal stage of granitic magmatism. Lithos 350–351, 105265.

Zircon petrochronology of Plio-Pleistocene granites: insights into the formation of different granite types

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The magmatic evolution of two composite young granodiorite-monzogranite plutons was investigated integrating high precision and high spatial resolution zircon U-Pb geochronology with chemical and isotopic zircon data. These intrusions, emplaced in the shallow crust (<200 MPa), exemplify contrasting types of granites produced in different tectonic settings. The muscovite- and cordierite-bearing strongly peraluminous Larderello-Travale pluton (Italy) has a distinct crustal isotopic signature suggesting derivation by melting of metasediments in a post-collisional, continental back-arc setting. Differently, the amphibole-bearing metaluminous Takidani pluton (Japan) formed in a supra-subduction continental arc by differentiation of basaltic magmas and mixing with crustal-derived melts. Two major caldera-forming eruptions were associated to the Takidani system, with a total volume of volcanic rocks erupted of ca. 500 km^3, while effusive magmatism associated to the Larderello-Travale system is small (< 10 km^3).

Geochronological U-Pb zircon data for the Lardarello-Travale pluton reveal four distinct pulses of magmatic

activity between 3.6 and 1.6 Ma, separated by quiescence intervals of 300-900 kyr. In contrast, the Takidani pluton exhibits a continuous zircon age range spanning 500 kyr (1.1-1.6 Ma), implying protracted magma presence. However, the zircon U-Pb age distribution of individual rock samples from the two intrusions show comparable characteristics with multimodal distributions and similar age variability (ca. 300 kyr; σ = 100 kyr). In-situ zircon oxygen analyses for the Takidani pluton yield $\delta^{18}O$ in a narrow range (5.7-7.4‰), with an average of 6.6‰ (σ= 0.32‰). The $\delta^{18}O$ for zircon in the Larderello-Travale pluton is higher (average 10.3‰,) and significantly more variable (σ=1.33‰).

Zircon crystals from the Larderello-Travale pluton have higher Hf, U, Th than zircon from Takidani which in turn have higher Th/U and Yb/Dy ratios. These ratios are controlled by monazite and titanite crystallization in the peraluminous and metaluminous magmas, respectively. Zircon Ti content for the two intrusion overlaps and calculations of Ti-in-zircon temperatures yield comparable results. Finally, magmas from Takidani have oxygen fugacity close to the Fayalite-Magnetite-Quartz buffer, while those of Larderello-Travale are more reduced as shown by the Eu anomaly, which is more negative for zircon in the Larderello-Travale.

Our data show that the main differences between the intrusions are the pulsed vs. continuous magmatic activity and the degree of homogenization in the reservoirs. Takidani derived from a large, long-lived and chemical homogeneous reservoir that fed sizeable multiple eruptions. In contrasts, the Larderello-Travale pluton derived by intermittent and physically separated magma domains, reflecting the heterogeneity of the continental crust.

The complex nature of post-orogenic magmatism in the French Massif Central

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The post-orogenic Variscan magmatic rocks of the southern Massif Central in France range from at least 50 to 76 wt% SiO_2, are potassic (K_2O = 3 to 6 wt%) and generally have high Mg#s. These rocks are unusual in having high Mg and Cr contents, relative to SiO_2, interpreted to reflect a mantle origin for at least a component of the magmas from which these rocks crystalized. However, recent published work has demonstrated that at least one such suite of post-orogenic Variscan rocks associated with the Aigoual pluton, has crustal $\delta^{18}O$ values, irrespective of SiO_2 content. The rocks sampled in this study cover an extensive area and are all considered to represent post-orogenic magmas with ages of ~300 Ma. Based on their major and trace element compositions, the different rock types can be categorized into three groups: (1) mafic rocks with SiO_2 < 56 wt%, and variable porphyritic textures with large K-feldspar and smaller quartz phenocrysts. The matrix is characterized by a micro-porphyritic texture with phenocrysts of a former likely ferromagnesian mineral having been ubiquitously replaced by biotite and amphibole; (2) intermediate to felsic rocks with 62.5 – 75 wt% silica content, showing a variety of different porphyritic textures with phenocrysts of variable size and appearance, set in fine to coarser grained matrix, as well as fine to coarser grained, rather equigranular textures; (3) high silica (> 75 wt% SiO_2) felsic rocks with very low Mg# (< 13). These rocks display rather equigranular, fine to coarser-grained textures with intergrowths between different feldspars. The very low Mg#s of the group (3) rocks, compared with ~ Mg# = 40 in rocks of group (2) at similar SiO_2, Na_2O and K_2O content and similar Ca/Na ratio, indicates that the group (3) rocks must be derived from a different magma. The rocks of groups (1) and (2) show reasonably linear trends on most compatible element plots against SiO_2, but a substantial mismatch in the position of the group (1) rocks relative to the Cr and Ni trends in group (2), indicating that the magma that formed the array of rock compositions in group (2) was not produced by simple mixing with group (1).

Crustal vs. mantle origin of post-collisional granitoids: insights from geochemistry and zircon Hf isotopes of late Variscan quartz diorites-tonalites from Capo Vaticano (Serre Batholith, Italy)

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Dominant tonalites and minor quartz diorites with I-type affinity make up the oldest and deepest magmatic unit of the 13-km thick late Variscan Serre Batholith, which also includes progressively shallower and younger two-mica granodiorites-granites and Bt±Am granodiorites. The Serre Batholith is mostly considered the result of intracrustal differentiation rather than accretion of new continental crust (e.g., Fiannacca et al., 2015, 2017) but, in order to further explore for possible mantle contributions, a geochemical and U-Pb and Hf isotopic zircon study has been carried out on the most mafic granitoids of the batholith, i.e., quarz diorites-tonalites and their hosted mafic microgranular enclaves (MME). SHRIMP U-Pb zircon data highlight a superposition of multiple processes. Emplacement ages range from 302±1 Ma to 297.3±1.9 Ma for two quartz diorite samples, from 298.9±2.6 Ma to 296.8±1 Ma for five tonalites, and from 295±1.2 Ma to 292.4±1.4 Ma for two MME. In addition, ubiquitous zircon recrystallization appears to have occurred at c. 290 Ma, and Carboniferous dates up to c. 315 Ma are tentatively considered as reflecting anatectic conditions at the magma source. All the studied granitoids show similar initial Sr isotopic ratios and negative εNd values (0.7098-0.7102 and -7.48 to -6.33, respectively) defining, in a Sri vs. εNd diagram, a vertical array consistent with partial melting of a slightly heterogenous crustal source. Similar εNd values and Sr isotopic compositions are actually known for mafic granulites dominating the deepest levels of the c. 7 km-thick lower crustal section underlying the batholith (Caggianelli et al., 1991). Hafnium isotopic compositions of magmatic zircon are also similar in the three granitoid types, with dominant negative εHf values, mostly spreading in the range -4 to -15, a few less negative values and 4 spots (over 134) giving positive values. Isotopic data therefore mostly point to a dominant crustal contribution in the generation of the studied granitoids. This crustal contribution might be related to assimilation of metasedimentary crust, widely documented in the granitoids from the batholith floor, which may have obscured the mantle isotopic signatures of the tonalitic magmas. On the other hand, a direct crustal origin is supported by a number of evidence, including the presence of isotopically and geochemically compatible potential source rocks and the temperatures exceeding 900 °C documented for the Serre lower crust (Acquafredda et al., 2008), able to produce extensive melting of those mafic sources.

Insights into the deep crust during partial melting and extraction of granites, Valpelline Series, western Alps

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Permian granulites, migmatitic gneisses, amphibolites, and pegmatites of the Valpelline Series offer a unique opportunity to study the processes and mechanisms involved in the partial melting of the lower crust and the generation of granites. In the Valpelline Series, orthopyroxene- and cordierite-bearing migmatitic gneisses and mafic migmatites are spatially associated but retain contrasting peak temperatures. Moreover, U-Pb zircon dating performed by LA-ICP-MS consistently shows that partial melting in the hotter amphibolites and orthopyroxene-bearing migmatitic gneisses (T ~ 780 – 850°C) occurred earlier at 291 ± 2 Ma. Then, the cordierite-bearing migmatitic gneisses experienced partial melting at a lower temperature (T ~ 700 – 750°C) at around 285 ± 2 Ma. The ages obtained for the emplacement of pegmatites also show a similar trend: the pegmatites intruding into the orthopyroxene-bearing migmatitic gneisses and amphibolites gave dates ranging from 292 ± 4 Ma to 287 ± 2 Ma, while those found in the cordierite-bearing migmatitic gneisses yielded an age of

284 ± 2 Ma. The final stage of the Permian evolution of the Valpelline Series is marked by the emplacement of intermediate pegmatites at 277 ± 3 Ma. The major and trace element WR compositions of most of the leucosomes and pegmatites in the Valpelline Series differ significantly from those of peraluminous granites, in particular, due to the very low K-content of the former. Instead, they show chemical characteristics (e.g. high Eu and Sr contents) indicating that these rocks are mostly composed of plagioclase, with accessory phases in varying amounts. The pegmatites and leucosomes of the Valpelline series are thus residual products from which granitic melts were extracted over time possibly feeding middle-to-upper crustal plutons. These observations indicate that processes of melt-crystal separation characterize the lower crust likely playing a crucial role in determining the granite chemistry and the compositional zonation of the continental crust.

Investigating the volcanic-plutonic connection: Insights from sedimentary layers

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

While the connection between volcanic and plutonic rocks is widely accepted by most Earth scientists, numerous aspects of this relationship remain enigmatic, including the volcanic-plutonic ratio and its variation throughout the planet's history. This challenge stems mainly from the scarcity of exposed systems that include both volcanic and plutonic counterparts, particularly in ancient terrains, which are more likely to have undergone extensive erosion or metamorphism. However, if volcanic layers have been eroded, evidence of extrusive activity could be found in the siliciclastic rock record in the form of detrital volcanic crystals. Quartz and zircons are likely the best candidates for this type of study, given their abundance in sedimentary rocks and resistance to erosion. In this study, we introduce a novel approach that utilises Ti-in-quartz and Ti-in-zircon thermometers to recognise and quantify the occurrence of different magmatic sources of the same age in sedimentary rocks. Ti content, serving as a temperature proxy, is key to

statistically discriminate quartz and zircons from different environments, as volcanic crystals crystallise at higher temperatures. Fast and accurate Ti quantification in quartz grains from an entire thin section of sedimentary rock is achieved by calibrating Ti thermometry against cathodoluminescence data in the blue wavelength range (300-500 nm), obtained from scanning electron microscopy. Additionally, LA-ICP-MS analyses of previously separated zircon crystals provide both the Ti distribution and crystallisation age. To develop and test the method, we used samples of the 1.1 Ga-old Pikes Peak Batholith (CO, USA) and the associated Tava sandstone, a series of Cryogenian intra-granite sedimentary dikes. The analysis of quartz and zircon Ti distributions successfully discriminates plutonic from pegmatitic crystals and reveals that crystals in the Tava Sandstone crystallised at statistically higher temperatures compared to those observed in the Pikes Peak Batholith, implying potential contribution from a volcanic source that is no longer exposed on the surface. The proposed workflow therefore has great potential to identify eroded magmatic lithologies and to estimate proportions of different magmatic components (volcanic, plutonic, pegmatitic) in sediments.

Compositional variability of Andean-type magmatism: a model involving subducted mélange and restite entrainment

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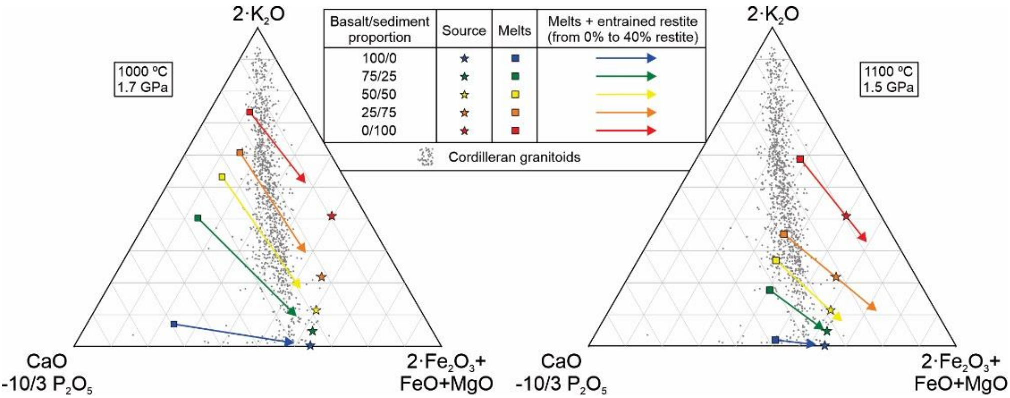
Oral, Tuesday 12th September, 15:00 - 15:15

A recent model (e.g. Castro et al., 2010; Vogt et al., 2013) explains Andean-type magmatism as produced when subducted mélange (basalt + sediment) rises from the slab as diapirs and undergoes partial melting via decompression and heating from the surrounding mantle. The diapirs relaminate to the base of the continental crust, from which magmas ascend and form batholiths. Compositional variability in this model is produced via fractional crystallization or cotectic evolution along a liquid line of descent at the relamination and/or emplacement levels.

The major-element composition of Andean-type rocks is intriguing as there is a compositional gap in maficity (FeOt + MgO = 10.5-12.5 wt.%) that separates the rocks into a linearly correlated felsic group and a scattered mafic group. Castro et al. (2013) interpreted this gap as the composition of an andesitic parental melt prior to evolution, and the felsic and mafic groups represent evolved melts along liquid lines of descent (linear correlation) and cumulates (scattered correlation), respectively. However, Castro et al. (2010)

experimentally found that melts from the relaminated mélanges are too felsic to be the andesitic parental melts. Finally, the felsic rocks are too abundant to be produced solely by fractionation of andesitic melts (García-Arias et al., 2022).



To investigate this model further and to explain these apparent contradictions, we conducted thermodynamic modelling on the evolution of a mélange with variable basalt:sediment proportions from subduction to ascent and relamination (García-Arias et al., 2022). Our results show that 1) mélanges with ~50:50 basalt:sediment proportion have a composition matching the gap and could be the parental body; 2) melts from the mélanges are too felsic to be the parental melts except from volumes at 1100 ºC, and 3) the high melt proportion in the relaminated diapirs makes entrainment of restites to the segregated magma pulses very likely. Consequently, the segregated pulses have variable compositions due to restite entrainment, and the restite proportion depends on the temperature of the particular volume within the diapir from which the pulse segregated (lower temperature, more restites). Thus, the gap should not be interpreted as the composition of the only parental magma but the composition of the most mafic parental magma.

Castro, A. et al. (2010) J. Petrol. 51, 1267-1295.

Castro, A. et al. (2013) Gondwana Res. 23, 1554-1566.

García-Arias, M. et al. (2022) Lithos 430-431, 106881.

Vogt, K. et al. (2013) Geochem. Geophys. Geosyst. 14, 470–487.

Accessory mineral geochemistry of the Idaho batholith

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Idaho batholith formed in the northern US Cordillera in the Late Cretaceous through Paleocene and records two magmatic cycles, each defined by emplacement of metaluminous I-type granitoids followed by peraluminous granitoids that defy easy I-S classification. A switch from a compressional to extensional tectonic mode in the early Eocene was accompanied by the emplacement of the Challis intrusive province, including granites with A-type characteristics.

Here, we present initial results of a survey of the geochemistry of zircon, monazite, and titanite from the Idaho batholith and Challis intrusive province and compare temporal trends in the chemistry of these minerals to those observed in existing whole-rock data. Fundamentally, we seek to answer the question: if these minerals were found in a detrital setting without the context of their source rocks and analyzed for their trace element compositions, could we construct an accurate portrait of the magmatic evolution of their source?

Cold storage conditions of the pre-caldera high-SiO_2 rhyolites of Long Valley, CA: the generation of geochemical gradients and preservation of Rb-Sr isochrons

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Glass Mountain (GM) high-SiO_2 rhyolites (precursors to the Bishop Tuff eruption at Long Valley, CA) are characterized by exceptionally low contents of Sr (~4 - 0.1 ppm) and ~2-fold variation in several trace-element contents, including Rb. This produced a variable range of Rb/Sr ratios among the Older (2.1-1.3 Ma) GM units, which defined two Rb/Sr isochrons (Davies et al., 1994) interpreted to date distinct differentiation events at 2.047 ± 0.013 and 1.894 ± 0.014 Ma. Only one Older GM unit has an eruption age (2.045 ± 0.020; Simon et al., 2014) that is indistinguishable from its isochron age; all other Older GM units erupted up to ~360 kyr after (Davies et al., 1994). This introduces two outstanding questions: (1) What differentiation mechanism produced the wide range in Rb/Sr ratios? (2) What allowed these Rb/Sr ratios to be undisturbed for up to 360 kyr prior to eruption? In this study, new analyses and high-resolution Fe-Ti oxide thermometry were used to test whether differentiation of the Older GM units occurred through segregation of variable melt fractions from a parental granitic mush, which contained the same nine mineral phases found as phenocrysts in the GM units. Because element concentrations in the interstitial melt of the parental mush were controlled by bulk partition coefficients, mineral-melt partition coefficients from the literature can be used to infer the average stoichiometry of the crystallizing/melting reaction. The deduced proportions for allanite, zircon and apatite were ~0.044, ~0.013, and ~0.015%, respectively. The proportion of titanomagnetite exceeded that of ilmenite in the reaction, and temperatures were too cool (<725 °C) to involve biotite. Eutectic melting of ~33% quartz, ~24% K-feldspar, and ~43% plagioclase is consistent with segregation at ~660°C and ~385 MPa under hydrous conditions (Wilke et al., 2017). It is proposed that the remaining Older GM units, which segregated at higher melt fractions and temperatures (680-720°C), were held in cold storage as dikes, analogous to the high-SiO_2 rhyolite dike swarm (5-20 m wide) associated with the Miocene Searchlight pluton in the Colorado River extensional corridor (e.g., Hodge et al., 2006). Over the ensuing 360 kyrs, the influx of hot (>680°C), hydrous fluid (from degassed basalts at depth) led to episodic remelting of GM high-SiO_2 rhyolite dikes that exceeded critical widths (>5 m; Petford et al., 1993), leading to their rapid ascent and eruption; evidence of which is seen in the erupted phenocryst abundances and rapid growth textures.

Low pressure crystal accumulation and melt segregation within the Western Adamello tonalite (Italy)

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Oral, Tuesday 12th September, 12:00 - 12:15

The final differentiation of intermediate to felsic magmas plays a fundamental role for magmatic systems, linking crystallising plutons, volcanic activity, volatile exsolution and ore deposits. However, our understanding of the nature of these links is limited by the scarcity of outcrops exhibiting clear relationships between the plutonic roots that feed its volcanic counterpart. One way to better characterise the physicochemical evolution of evolved melts is to precisely determine their liquid lines of descent and quantify the amount and rates of melt segregation within a crystallising plutonic body. Here we investigate the processes of interstitial melt segregation in the calc-alkaline Western Adamello pluton (Southern Alps), a

~670 km² intrusive body emplaced at 2.5 kbar in ~1.2 Myr (Floess, 2013). The WAT exhibits a coarse-grained, equigranular texture and is composed of hornblende partially replaced by biotite, plagioclase, quartz, K-feldspar, apatite, zircon, ilmenite, magnetite and secondary epidote. K-feldspar, quartz and albite-rich plagioclase are interstitial phases. The WAT comprises crystal accumulation zones composed of hornblende-biotite-gabbros spatially related to plagioclase-rich leucotonalites whose mineral texture and composition are the same as the host tonalite. Granitic dikelets originate from these accumulation zones and segregate to form wider dikes. The observations indicate that the WAT chemical evolution is controlled by a biotite-forming peritectic reaction, and physically differentiate through deformation-driven crystal-melt segregation. Quantitative modal compositions and mass balance calculations indicate that the hornblende-biotite-gabbros lost 70-90 vol.% of their plagioclase and quartz phenocrysts and 30-70 vol.% interstitial melt. The segregated plagioclase and quartz from the hornblende-biotite-gabbros accumulate to form leucotonalites. These calculations indicate about 40 to 55 % melt segregation in the WAT, the remainder being trapped within the crystal framework of hornblende-biotite-gabbros and leucotonalites. Based on phase relationships and major element modelling, it is proposed that the peritectic relationship hornblende + $melt_1$ = biotite + quartz + $melt_2$ controls the composition of the hornblende-biotite-gabbros. Such a reaction is known from experimentally derived phase relationships (Marxer and Ulmer, 2019) and rapidly consumes the interstitial melt, hence inhibiting large melt volume to be segregated and extracted. This biotite-forming peritectic reaction controls the final differentiation to peraluminous felsic melts, whereas a crystallisation path dominated by feldspars and quartz occurs in metaluminous environments. We evaluate biotite- and K-feldspar-dominated melt evolution for various batholiths and discuss the impact on melt segregation.

Mg-Hf-Sr-Nd isotopes constrain two contrasting mélange origins for andesitic arc magmas

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Mélange diapirs are increasingly regarded as an important mechanism for the direct generation of arc andesites, and thus have important implications for understanding the andesitic model for crustal growth. Experimental results show that different types of mélanges can produce a range of primary arc andesites (from tholeiitic, calc-alkaline to shoshonitic), yet these experimental results have not been verified in the natural arc rock record, due to the difficulty in discriminating between the differing nature of the mélange sources (e.g., sediment-dominated mélange vs. serpentine-

dominated mélange). Here we examine early Cretaceous (ca. 124 Ma) dioritic porphyries in the southern Qiangtang block of central Tibetan plateau. The porphyries are divided into two types: low-K type-1 and high-K type-2. Type-1 has higher δ26Mg values (-0.16 to -0.08‰) than MORB. Their heavy Mg isotopes can be ascribed to the contribution of subducted bulk/un-differentiated serpentinite, which indicates their serpentine-dominated mélange origin. Compared to type-1, type-2 shows similar arc-like trace element patterns, but has higher Th contents and La/Sm and Th/Nd, more enriched Nd-Hf isotopes, and lower (mantle-like) δ26Mg (-0.28 to -0.17‰) values. This indicates more recycled sedimentary materials and minor serpentine in the source of type-2, suggesting a sediment-dominated mélange origin. Overall, the two types of rocks originate from contrasting mélange sources. This study therefore provides clear evidence from natural rocks that the mélange model is an important mechanism for generating various andesitic arc magmas.

Reevaluation of the relationship between granite and pegmatite: insights from the Ke'eryin-Taiyanghe plutons

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Lithium is one of the most important low-carbon energy metals. As one of the key sources, lithium pegmatite is becoming the focus of the study of petrology and economic geology. The pegmatite-related granite is generally regarded as the parental magma of the rare-metal pegmatites. However, the relationship between granite and pegmatite is still under hot debate. The Songpan-Ganzi belt is one of the most important lithium metallogenic belts in China with several large lithium ore deposits. Ke'eryin lithium ore deposit is located in the eastern part of the Songpan-Ganzi belt and is believed to be related to the Ke'eryin two-mica granite. In the neighborhood, there is a diorite-granodiorite pluton named Taiyanghe. According to our newly obtained SIMS zircon U-Pb ages, the Ke'eryin two-mica granite was formed at ~203-202 Ma, which is younger than the published ages of some lithium pegmatites (~210-205 Ma). In the meantime, the Ke'eryin porphyritic biotite granite and Taiyanghe diorite and granodiorite were formed at ~211-210 Ma. It is interesting that the Taiyanghe diorite shows a very high Li content (up to 600

ppm) with low Ta content (< 1 ppm), and its Li content is even higher than the Ke'eryin two-mica granite (<300 ppm), which cannot be explained by partial melting or fractional crystallization. Notably, there is a lithium pegmatite reported within the diorite, and the high Li nature of diorite could be the result of lithium diffusion. The Taiyanghe granodiorite shows a very low Mg# value with high Ba and Zr contents. Such a feature is most likely formed by accumulation. Therefore, we suggest that the Taiyanghe granodiorite is the accumulated rock, and the fractionated part could be the Ke'eryin granite. This is also supported by the zircon isotopic data and calculated P-T conditions. Some inherited zircons from the Ke'eryin granite have identical Hf-O isotopic composition to the Taiyanghe granodiorite. Notably, the Hf-O isotopic composition of Ke'eryin porphyritic biotite granite is plotted between the Taiyanghe granodiorite and Ke'eryin two-mica granite, indicating continued magmatic assimilation and fractional crystallization processes. The calculated P-T conditions of Taiyanghe rocks are clearly higher than the Ke'eryin granite. In consideration of the lithium pegmatite intruding into the Taiyanghe diorite, the pegmatite should be derived from a deeper magma chamber. The outcropped pegmatite-related granite, therefore, may not be the parental magma of rare-metal pegmatite.

Partial melting mechanism of peraluminous felsic magmatism in a collisional orogen: an example from the Khondalite Belt, North China Craton

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Sedimentary-derived (S-type) granites are an important class and product of collision-related melting, and a range of subtypes can be recognized by differences in field occurrence, mineralogy, and geochemistry. These subtypes might either reflect variations of initial melt compositions caused by different protolith lithologies, partial melting reactions, or be driven by magmatic processes that occur during ascent through the crust (e.g. mineral fractional crystallization or crustal assimilation), which complicates interpretation of the partial melting history of peraluminous felsic melt fractions in orogenic settings. To assess the influence of these factors, we performed integrated field investigation, petrology, geochemistry, geochronology, and phase equilibria modeling on a series of leucosomes within migmatite associated with different S-type granites within the Khondalite belt, North China Craton, which is an archetypal collisional orogen. Three types of leucosomes are recognized in these units, listed in increasing order of

abundance: leucogranitic leucosome, K-feldspar (Kfs)-rich granitic leucosome, and garnet (Grt)-rich granitic leucosome. Phase equilibria modeling of partial melting and mineral fractional crystallization calculation indicate leucogranitic leucosome are produced through fluid-present melting, Kfs-rich granitic leucosome are produced through muscovite dehydration melting with 3 vol% of garnet fractional crystallization, and Grt-rich granitic leucosome are produced through biotite dehydration melting with 20–30 vol% of K-feldspar fractional crystallization and up to 20 vol% of peritectic garnet entrainment. Mineral fractional crystallization and peritectic mineral entrainment occur at the very beginning of granite formation, and play important roles in affecting the geochemical compositions of the granitic melts, as well as partial melting mechanism. Our results suggest that peraluminous felsic magmas are dominantly produced by fluid-absent melting during collisional orogenesis, although fluid-present melting can also generate small amount of granitic magma.

Disequilibrium partial melting: revisiting Pb isotopes in granitic systems

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Isotopic data provide valuable clues about the sources of magmas, but isotopic heterogeneity can have many causes, such as source characteristics, different forms of mixing and disequilibrium effects. In order to understand the implications of disequilibrium for Pb isotope data, particularly from granites, we revisit the idea of disequilibrium partial melting, focusing on the U-Th-Pb system, and accounting for major and accessory phase behaviour in a model consistent with previous studies. This model generates inter-mineral Pb-isotopic heterogeneity through radiogenic in-growth in a variety of protoliths. Under disequilibrium conditions, partial melting of these protoliths, according to experimentally determined partial melting reactions, produces modelled melts whose Pb isotope compositions are distinct from and more diverse than their sources and vary with melting degree. Analyses of the Pb isotope compositions of K-feldspars from A-, I- and S-type granites from the Lachlan Fold Belt (LFB), Australia, reveal arrays in $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios. The spread and shape of these arrays are dominated by the diversity of the K-feldspars from I-type granites. The pattern of widening diversity towards the radiogenic end of uranogenic vs

thorogenic Pb plots observed in the data is broadly similar to the patterns exhibited by the modelled melt arrays. The influences of changing the initial conditions of the model and the U/Pb and Th/Pb ratios of key accessory minerals has been explored in order to further investigate the patterns in the data. It is shown that introducing greater variety into the protolith initial Pb isotope compositions and crustal residence time will introduce a spread in the melt compositions in $^{206}Pb/^{204}Pb$- $^{207}Pb/^{204}Pb$ space, as observed in the data, while maintaining the essential shape of the arrays on the $^{206}Pb/^{204}Pb$- $^{208}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$- $^{208}Pb/^{204}Pb$ plots. Furthermore, the slopes of the upper and lower bounds of the K-feldspar compositions on a plot of $^{206}Pb/^{204}Pb$ vs $^{208}Pb/^{204}Pb$ can be reproduced in the model by changing the accessory mineral's U/Pb and Th/Pb ratios within reasonable ranges. The modelling thus shows that the observed Pb-isotopic heterogeneity in granites can be generated by disequilibrium melting of isotopically diverse source rocks with inter-mineral Pb-isotopic heterogeneity. This implies that individual granites with isotopic heterogeneity could form simply from partial melting of individual sources and do not require the effect of mixing to account for their compositions.

Magmatic evolution and hybridization in Variscan Granitoids of the Western Alps

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

We present a study of Variscan granitoids in the External Crystalline Massifs of the Western Alps. Our focus is on the Belledonne, Pelvoux, and Grandes-Rousses massifs in France. By combining a large set of newly acquired and existing geochronological, geochemical, and isotopic data, we investigate the timing of magmatism, magma origin, and the evolution of geochemical and isotopic composition over time. We identified two distinct magmatic series: (i) high-K subalkaline granitoids, which range from magnesian (MgG) to ferro-magnesian (FeMgG) rocks and contain variable amounts of mafic enclaves; (ii) high Mg – ultra-high-K metaluminous series, commonly referred as "durbachites" in the Variscan Belt. Geochronological data reveal a magmatic activity spanning approximately 50 million years, with multiple episodes occurring 5 to 10 Ma apart. The emplacement ages of the subalkaline granitoids range from approximately 348 to 299 Ma, with major episodes during the Visean and the late Carboniferous - early Permian.

The ultra-high-K plutonic intrusions range from approximately 328 to 307 Ma, but the abundance of Mg-K mafic enclaves in the Visean granitoids suggests synchronous emplacement of the two series from ca. 348 Ma. The coexistence of these series indicates coeval involvement of crustal anatexis and melting of LILE-LREE-rich metasomatized mantle. Hybridization between these magmatic sources is evidenced by field observations and similarities in trace element patterns and Sr-Nd isotope composition of the two series, which is believed to arise from processes such as coupled assimilation – fractional crystallization, magma mixing, or assimilation of solidified mafic enclaves within the granitoids. The composition of the granitoids exhibits variations over time, particularly in SiO2, Mg#, and certain trace element ratios such as Sr/Y, La/Yb, and Nb/Na. These changes may be attributed to multiple mechanisms, including increasing magma differentiation over time, variations in the mass balance of crustal and mantle sources, and decreasing melting pressure as the Variscan Belt collapses. The εNdi values of both subalkaline granitoids and durbachites show a progressive decrease from approximately [-3.8; -2.85] to [-6.4; -5.2] between 345 and 320 Ma, indicating an increasing influence of subducted crustal material in the mantle source. Subsequently, εNdi values increase to [-3.7; -0.51] during the late Carboniferous pulse, possibly due to the depletion of enriched mantle through prolonged melt extraction or the influx of non-metasomatized asthenosphere with more isotopically-depleted εNdi composition.

Trace-element chemistry of apatite from silicic magmas: a comparative study of high-temperature volcanic rocks and slow-cooling granites from south Brazil

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Much effort has been made in recent years to extract geochemical information from apatite to support petrological research. This is particularly appealing in the case of silicic magmas, which are typically apatite-saturated, meaning that this mineral can potentially witness their full crystallization histories (unlike, for instance, titanite and zircon, which are often late-crystallizing). The possibility of estimating parameters that are especially determinant for magma behavior, such as H_2O content and redox conditions, has been given special attention. Additionally, there is a reasonable set of experimental data for partition and diffusion coefficients that allow exploring the chemical diversity of apatite to infer the composition and cooling history of magmas. Chemical analyzes were obtained in situ on thin sections (to preserve the original textural relationships) by combining EPMA and LA-ICPMS on apatite from high-temperature (950-1000°C) silicic volcanic rocks from the Paraná Magmatic Province (PMP) and from a diverse set of Neoproterozoic metaluminous granites from SE Brazil.

Important contrasts between the PMP silicic units in terms of redox conditions and H2O contents, previously estimated from other proxies (plagioclase Eu^{2+}/Eu^{3+} and An content), are confirmed by the volatile contents of apatite phenocrysts from dacites and rhyolites. Apatite/whole rock trace-element partition coefficients determined for Guarapuava-type trachydacites (D(Sr)= 3; D(Y)= 11; D(Ce)= 17; D(Sm)= 22; D(Th)= 1.5; D(U)= 1.9) are consistent with literature data. These values were used to investigate the petrogenesis of the Paraná silicic volcanism and also as references for granites with similar (~64-67 wt%) silica content. Exploring the chemical data from apatite of slow-cooling granites requires special care, owing to potential diffusion of an array of elements (Sr, Pb, Mn, F-Cl-OH) at magmatic temperatures and uncertainties on the extent to which whole-rocks represent original magma compositions. A careful exploration of the results, however, yielded fundamental support to inferences on crystallization conditions (e.g., from volatile contents and Eu^{2+}/Eu^{3+} relative to whole-rocks), identification of sources and depths of magma equilibration (e.g., from Sr/Y and Ce/Y ratios) and investigation of cumulate components in granitic rocks.

Input of mafic magma triggered the early Eocene magmatic flare-up in southern Tibet

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Gangdese arc underwent a magmatic flare-up in the early Eocene, which developed the most widespread magmatic activity both along and across the arc in southern Tibet. And it could be one of the most intense magmatism worldwide during that period, which released large amounts of greenhouse gas and resulted in the development of Early Eocene Climate Optimum (EECO). Although there are many researches devoted to this stage of magmatism, studies about the detailed magmatic process are few, and the mechanism of the flare-up is enigmatic. Our recent fieldwork found out that there is synchronous development of mafic magmatism, including magma mixing between granitic and mafic rocks and widespread intrusions of gabbro/dolerite dykes. The various mafic rocks yield similar U-Pb ages by LA-ICP-MS and SIMS methods. Together with radiometric dating and magnetostratigraphy of volcanic rocks in the study area, it is proposed that the input of mafic rocks triggered the early Eocene magmatic flare-up in southern Tibet.

Magmatic evolution of the Early Paleozoic flare-ups in the Central Qilian belt and its role in the orogenic cyclicity

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Flare-up events are characterized by the emplacement of large-volume granodiorite-tonalite batholiths periodicity in Cordilleran-style accretionary systems. Magmatic flare-ups are constrained by magmatic sources from the mantle, pre-existing metasedimentary rocks, and various basement rocks of the upper plate, as well as tectonic mechanisms in convergent margin processes (subduction cycles, crustal thick-ening, lithospheric delamination, and tectonic underplating in orogenic cyclicity). Here we use zircon dating, whole-rock geochemistry and Sr-Nd isotopes, to track spatiotemporal changes in the Central Qilian belt of the northern Tibetan and to evaluate models of flare-ups behavior and crust formation in Cordilleran-type arc systems. Zircon U-Pb age data record early arc magmatism from ca. 520–410 Ma with three flare-ups: ca. 466~457 Ma, ca. 448~442 Ma and ca. 421~418 Ma.

Granitic pluton formed at ca. 466~457 Ma flare-up is dominated by diorite - gabbro - MEE with high Mg, Mg# and enriched Sr isotopes, which implies strong crust-mantle interaction in the source. At ca. 448~442 Ma flare-up, Magmatism formed by partial melting of the sub-arc lithospheric mantle mixed with crust to form adakitic rock. In the last stage (ca. 421~418 Ma flare-up), A-type granite is widely found in the Central Qilian belt, which is consistent with an extension setting triggered by removing the thickened arc crust root. Studies of Early Paleozoic flare-ups in the Central Qilian belt may help to link irregular magmatic production in continental arcs with geodynamic models for orogenic cyclicity.

Constraints on the generation of large felsic batholiths from the liquid lines of descent of arc magmas

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Junior Keynote, Tuesday 12th September, 16:00 - 16:30

Volcanic arcs are the primary locations where new continental crust is created. To generate this new crust, primary melts initially in equilibrium with the mantle must undergo significant differentiation to generate felsic compositions. In this talk, I examine the processes and conditions necessary to efficiently produce large volumes of felsic crust through this process. When differentiation occurs via (fractional) crystallization, the evolution of the fractionating liquids is controlled by a series of cotectics, where the melt compositional trends are determined by the co-crystallization of multiple minerals. These compositional trajectories are commonly referred to as liquid lines of descent. Using a large compilation of experimental data, I will show that the dominant cotectics followed by typical arc magmas are sensitive to intensive properties including crystallization pressure and magma hydration state, and that liquid lines of descent can thus be used to infer fractionation conditions. Specifically, near-primitive basaltic magmas evolve along the olivine-clinopyroxene cotectic, which is strongly pressure sensitive: clinopyroxene stability is enhanced at higher pressures, and therefore higher pressure differentiation produces melts that are more depleted in clinopyroxene components. In contrast, differentiation of more evolved melts is controlled by the clinopyroxene-plagioclase cotectic, which is strongly sensitive to the hydration state of the magma: differentiation of more H_2O-rich magmas suppresses plagioclase crystallization and thus produces melts enriched in plagioclase components. Finally, I will also use a similar approach to show that the MnO/MgO ratio of basaltic lavas can be used to uniquely identify garnet fractionation, which if present implies fractionation pressures of at least 1.2 GPa.

Using these proxies to interrogate the compiled record of arc lavas globally, we can identify a dichotomy between the liquid lines of descent at continental and island arcs: continental arcs dominantly produce H_2O-rich magmas that begin to differentiate at higher pressures, while island arcs are characterized by more H_2O-poor magmas that differentiate at shallower levels. This observation raises a series of questions critical to the generation of felsic continental crust. First, what is the fundamental mechanism that produces this dichotomy? Does it result from differences in the crustal architecture of island and continental arcs, or from changes to processes primarily rooted in the mantle wedge or subducted slab? And finally, how do island arcs characterized by H_2O-poor magmas that differentiate at shallow pressures eventually evolve to produce thick continent-like felsic crust? By comparing the proxy data to various arc physical parameters and geophysical observations, I will explore some of these questions and highlight processes critical to the formation of continental crust.

The formation of granitic rocks in the oceanic crust: Experiments and natural occurrences

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Oral, Tuesday 12th September, 16:45 - 17:00

Although in general basic in composition, the lower oceanic crust consisting of gabbro also contains evolved, SiO2-enriched lithologies, but generally only in small amounts (< 1 vol% of the crust). Because rocks of the ocean crust are generally very low in potassium, only plagioclase plays a role as feldspar mineral in these rocks. Therefore, the corresponding rocks are often called "plagiogranites" with the prefix "oceanic". The generation of such silica-rich magmas in the ocean crust has been debated for decades. Four different models are suggested: (1) Crystal fractionation in basaltic magmas resulting in highly differentiated melt; (2) Re-melting of gabbroic rocks in the deep oceanic crust; (3) anatexis of hydrothermally altered basaltic rocks of the dike/gabbro transition in the shallow oceanic crust; (4) liquid immiscibility in an evolved MORB system. Experimental studies showed that all these models are possible, but comparison with natural rocks from the ocean crust showed that only the first three processes are relevant. For each process we present the relevant experimental approach and the corresponding rocks from the oceanic crust, recovered by ship expeditions. Examples for process (1), the extreme differentiation of MORB, are shown from felsic rocks formed at the East Pacific Rise and at the Pacific Antarctic Ridge. Process (2), the remelting of gabbros, is best established from slow-spreading ridges, where deep hydrothermal circulation triggers hydrous partial melting processes in the gabbros, resulting in felsic veins, cutting the gabbroic source rocks at many places. The example presented is from the Southwest Indian Ridge. For process (3), the anatexis of hydrothermally altered basalts from the dike/gabbro transition, we present an example for felsic rocks formed at the Equatorial East Pacific Rise drilled at Site 1256 by IODP (International Ocean Discovery Program). Concerning this process, very focused experimental studies were performed, which also include challenging in-situ measurements of trace elements in tiny melt pools generated in these experiments, in order to constrain quantitatively this very special process.

Mafic to hybrid synplutonic dyke magma injection into subvolcanic granitoid magma chamber of Ladakh batholith, Trans-Himalaya, India: constraints from petrology, geochemistry, and zircon U-Pb-Hf isotopes

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Oral, Tuesday 12th September, 11:30 - 11:45

The Ladakh batholith is an assembly of multiple plutons formed by calc-alkaline arc magmatism ranging in composition from gabbro-diorite-tonalite to granodiorite-granite-leucogranite. The magmatic pulses of Ladakh batholith are recorded mostly between 70 and 45 Ma, with a few at 100 Ma, produced due to the subduction of north-dipping Neo-Tethyan oceanic crust beneath Asian plate. The mafic to hybrid synplutonic dykes are hosted in the granitoids of Ladakh batholith, whose origins are debated as cogenetic or magma-mixed and mingled. We investigated the disrupted mafic to hybrid synplutonic dykes and host granitoids of Ladakh batholith to deduce the timing, physico-chemical conditions, and processes in their formation. Fine-grained (mafic) to porphyritic (hybrid) composite and brecciated synplutonic dykes exhibit sharp and pillow-like contacts with host granitoids

and are disrupted to form platy, rounded, elliptical, and brecciated enclave swarms, which are oriented in the same strike direction. The hybrid dykes contain felsic xenocrysts that are sourced and injected from hybrid magma zones hidden at depth. The host granitoids show medium- to coarse-grained equigranular textures. Mafic to hybrid dykes bear an hbl-bt-pl-Kf-qz-mag-zrn assemblage similar to that of host granitoids, but they are modally disequilibrated. Field and microstructural features strongly suggest injection of mafic to hybrid magmas into a mostly crystallised (>65%) host granitoid magma. Biotite from the dykes and host granitoids represents Mg- and Fe-biotites and is moderately reduced (FMQ) to strongly oxidised (NNO), typically crystallising in a metaluminous (I-type) calc-alkaline host magma. However, biotite from granitoids hosting the brecciated dyke still has higher FeOt and Alapfu. Al-in-amphibole rims suggest subvolcanic levels (75–135 MPa) of mafic to hybrid dykes and host granitoid emplacement, whereas brecciated dykes solidified at relatively deeper crustal levels (250–360 MPa). SHRIMP U-Pb zircon data provide the same mean 206Pb/238U ages of mafic (57.61±0.67 Ma), hybrid (57.08±0.45 Ma), and host granitoids (57.19±0.38 Ma) that strongly underline their coeval nature. Brecciated dykes did not yield zircons and are chemically similar to arc basalt, whereas mafic to hybrid dykes represent basaltic andesite. Geochemical features oppose their cogenetic relations; rather, they are chemically modified. Zircon εHf(t) of mafic (+2.7 to +25.19), hybrid (+8.48 to +18.08) dykes, and host granitoids (+3.27 to +15.16) indicate dominant juvenile sources. It is thus inferred that injections of mafic to hybrid magmas into mostly crystallizing granitoids formed swarms of disrupted mafic to hybrid synplutonic dykes, coeval with granitoids formed in a subduction zone, evolving through synchronous mixing, fractionation, and elemental diffusion.

Geochemical characteristics of apatite in magmatic rocks

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Magmatic rocks are the 'probes' of the deep Earth, recording complex events, such as plate motion, geotectonic environment and mineralization. Thus, magma sources and evolutionary processes are enduring scientific issues in geological studies. Numerous studies have shown that different magmatism resulting in variations of magma compositions, temperature and/or pressure, which can be recorded during mineral growth. With the advancement of instrumental techniques, compositional variation of minerals in grain and/or sub-grain scales can be accurately measured, establishing microanalysis of geochemistry and isotopes on mineral grain and/or zonation, which could effectively compensate for the inability of whole-rock geochemical analysis to trace complex magma sources and process.

Magmatic apatite has been gradually focused in recent years. Since most rock-forming minerals cannot accommodate large amounts of phosphorus into their lattices, apatite has become a widespread phosphorus-rich mineral in magmatic rocks. It is saturated and precipitated in different magmatic environments, forming at different stages of magmatic evolution, thus could provide a relatively complete recording of magmatic evolution history. Moreover, due to its widespread isomorphism substitution in lattice, apatite is rich in many geochemical indicator elements (e.g. Sr, Mn) and is sensitive to the variation of the host magmatic environment, thus could be excellent potential tool for tracing magmatic processes and identifying petrogenesis. Based on geochemical compositions of apatite in magmatic rocks, a variety of discrimination methods have been promoted to trace magma sources and magmatic processes, including trace elemental compositions of apatite in different rocks, geochemical compositions and variations of apatite zonation formed during magma evolution, Sr-Nd isotopic compositions of apatite grain and/or sub-grain formed during complex magmatic processes. However, understanding the mineralogical and geochemical characteristics of apatite in different types of rocks is the basic issue for upper mentioned studies, as well as further studies.

In this study, the available apatite trace element composition data from the GEOROC database were collated, screened and analyzed, and the characteristics and differences of various types of magmatic apatite were analyzed using principal component analysis (PCA), and typical examples were researched in depth. It was found that apatite has strong potential in tracing magma sources, with significant differences (e.g. Eu*, LREE/HREE) in trace element composition among apatite in ultrabasic, basic, intermediate, felsic and alkaline rocks, and in I, S, and A types granites (Figure 1 and 2).

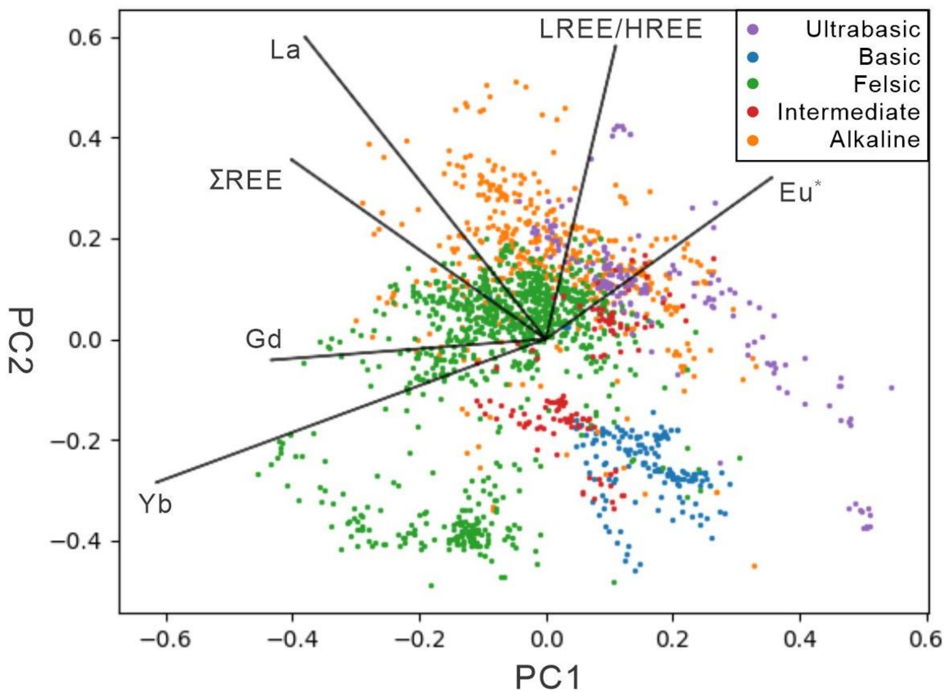

Figure 1: Biplot of apatite compositional data from different types of magmatic rocks

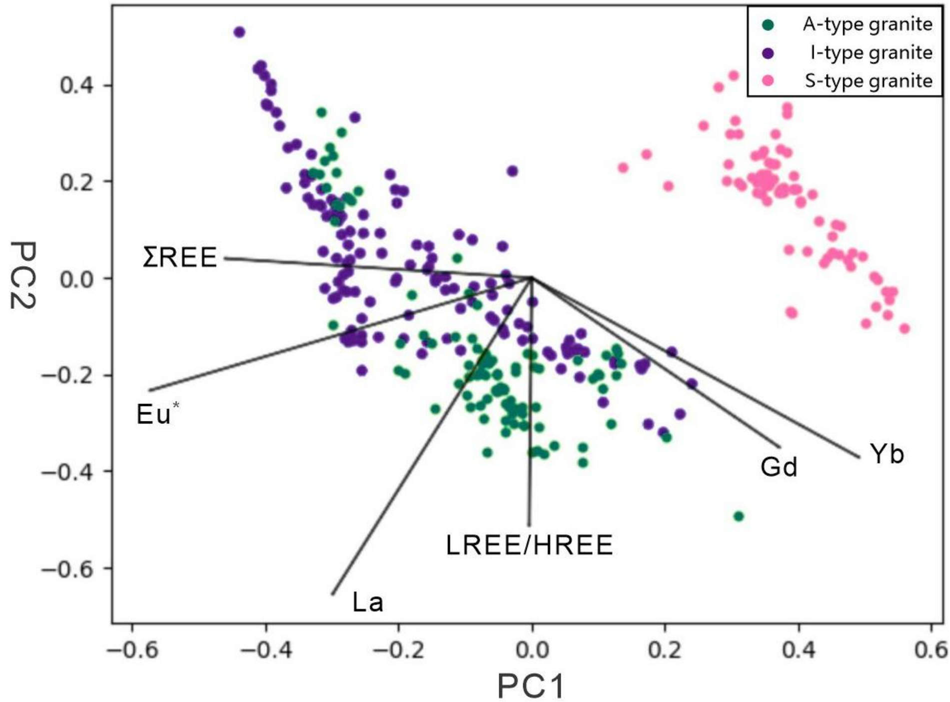

Figure 2 : Biplot of compositional data for different types of granite apatite

Zircon and garnet compositional constraints on the nature of extension-related peraluminous silicic magmas in the Northern Pannonian Basin

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Mid-Miocene volcanism in the northern Pannonian basin, eastern-central Europe, has a peculiar nature. The first volcanic products are unique since they contain almandine garnet, which is a rare phenomenon, worldwide. We studied the earliest volcanic rocks in a section where both peraluminous dacite-rhyodacite and metaluminous andesite occur. Majority of almandine crystals have moderate Ca content (CaO=4.5–8.1 wt%) and low MnO (MnO<3 wt%) and are regarded as crystallized from a peraluminous magma, although low-Ca (CaO<3 wt%) almandine derived from lower crustal metapelites is also found. In the primary almandine crystals, a progressive depletion of heavy REE is observed (from low Dy_N/Yb_N to $Dy_N \approx Yb_N$), similarly as in the zircon crystals. This suggests crystal fractionation at high-pressure (>700 MPa) and co-crystallization of garnet and zircon. This is reflected also by the strongly heavy REE-depleted glass composition. Zircon in the

subsequent metaluminous andesites has distinct trace element composition, having no garnet-signature and implying progressive and coeval amphibole fractionation.

Zircon in the garnet-bearing rhyodacites has a unique compositional feature, showing an elevated Al content (Al=5–18 ppm), which is not found in other silicic volcanic rocks in this region. This is a typical peraluminous character and confirms the primary origin of almandine. Interestingly, zircon in some of the garnet-free andesites has also elevated Al content indicating an inheritance from peraluminous magmas. Amphibole is often joined to garnet in the dacites and has overlapping composition with that of experimental data. However, they show a strong heavy REE enrichment, atypical in magmatic amphibole worldwide. This feature as well as the glass trace element variation can be explained by remelting of garnet at shallow depth and further crystallization of amphibole and zircon.

The epsilon Hf values of zircon show a variation from -4 to +2, suggesting mixing of mantle-derived and crustal-derived magmas. This is consistent with petrogenetic modelling calculations based on bulk rock isotope and trace element data, implying interaction between mafic magmas derived from enriched lithospheric mantle and metasedimentary lower crust. Remarkably, this volcanism has no relationship with coeval subduction, but it occurred in response to continental rifting. Preservation of high-pressure garnet can be explained by fast magma ascent enhanced by crustal extension. In contrast, some magmas stalled at shallow crust. They also contain Al-bearing zircon crystals suggesting peraluminous character of their parental magmas, whereas garnet phenocrysts were likely dissolved at low pressure as reflected in the amphibole and glass composition.

Syn-collisional crustal anatexis in Himalaya: a response to lithospheric flexure

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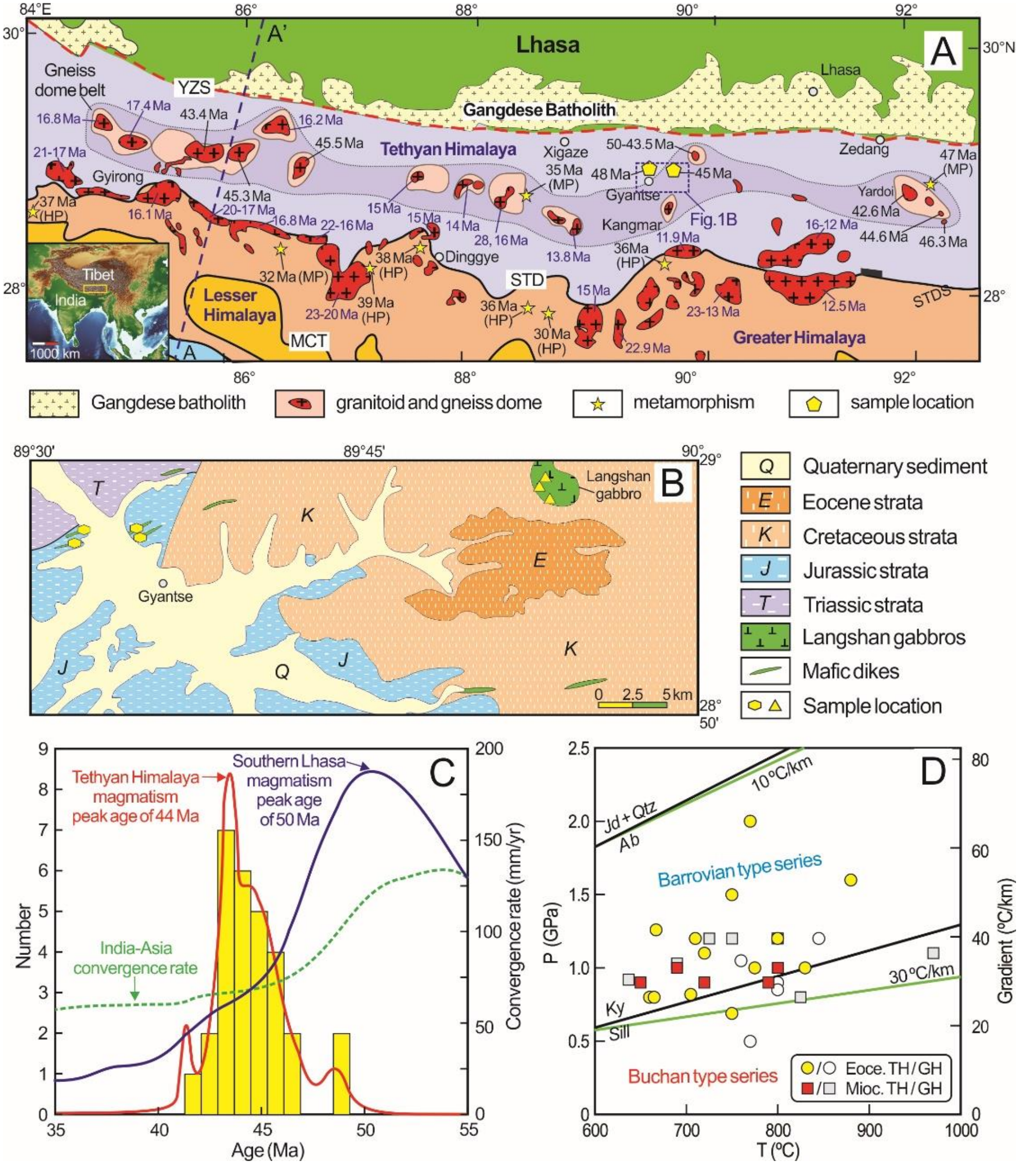
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The Himalaya belt is the most active collisional orogen in the world and is characterized by two Cenozoic crustal anatexis belts spatially overlap with the cores of gneiss domes, which provides a crucial window for probing the evolution of crustal anatexis processes within the lower plate in a collisional orogen.

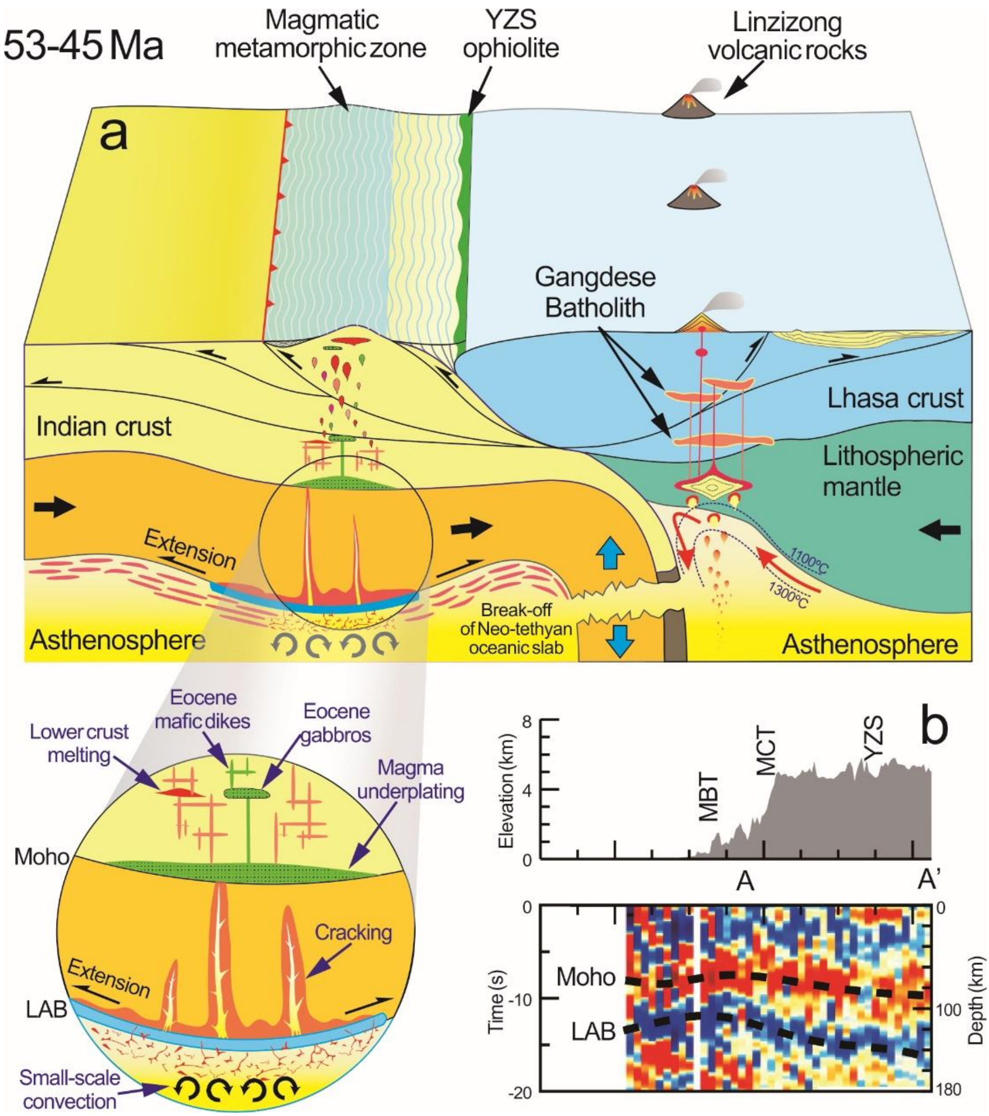
In Himalaya orogen, the syn-collisional crustal anatexis occurred on both sides of the suture zone with different features. The southern margin of the Asian plate is characterized by thickened juvenile crust and a relatively high crustal thermal state. In contrast, the northern edge of the Indian plate is marked by a thickened ancient crust with a moderate geothermal gradient during the early stage of collision. The 48–35 Ma Tethyan Himalaya magmatism, consisting of high Sr/Y granitoids within gneiss domes and coeval gabbro and mafic dike, is slightly younger than the magmatic peak in the Lhasa block (51 ± 3 Ma). However, the petrogenesis and dynamics of syn-collisional crustal anatexis is poorly understood due to the lack of critical evidence.

Here, based on our study of newly found Eocene Himalaya OIB-like mafic dykes and existing evidence of magmatism, metamorphism and tectonic, a new model is proposed to understand the mechanisms of magma generation and orogenic evolution within the lower-plate (a previous passive margin) side of a convergent orogen.

During early continental collision, break-off of the Neo-Tethyan oceanic slab and/or lithospheric delamination of the southern Lhasa terrane caused melting to produce the ca. 51 Ma magmatism in the southern Lhasa block along the suture zone. After the 51 Ma magmatic event, lithospheric flexure formed along the northern Indian continent parallel to the suture, causing brittle cracking (i.e., bending-induced faults) and the 48–45 Ma melting in the northern Himalaya. The melts derived by decompression melting of the lithosphere-asthenosphere boundary intruded to shallow levels of the lithosphere along extensional fractures below a neutral plane of downwarped lithosphere. Emplacement of these mafic magmas likely provided the heat source for the formation of coeval (51–40 Ma) orogen-parallel crustal anatexis, and thus the orogen-parallel gneiss domes. This study may provide new insight into generation of syn-collisional granitoids.



84°E
86°
88°
90°
92°
30°
30°N
28°
A
A'
Lhasa
Gneiss dome belt
YZS
Gangdese Batholith
Tethyan Himalaya
Xigaze
Zedang
Gyirong
Gyantse
Kangmar
Fig.1B
Dinggye
STD
STDS
MCT
Lesser Himalaya
Greater Himalaya
Yardoi
Tibet
India
1000 km
16.8 Ma
17.4 Ma
43.4 Ma
16.2 Ma
45.5 Ma
21-17 Ma
45.3 Ma
20-17 Ma
16.1 Ma
37 Ma (HP)
16.8 Ma
22-16 Ma
15 Ma
15 Ma
14 Ma
28, 16 Ma
13.8 Ma
35 Ma (MP)
48 Ma
50-43.5 Ma
45 Ma
36Ma (HP)
11.9 Ma
16-12 Ma
42.6 Ma
44.6 Ma
46.3 Ma
47 Ma (MP)
32 Ma (MP)
38 Ma (HP)
39 Ma (HP)
23-20 Ma
36 Ma (HP)
30 Ma (HP)
15 Ma
22.9 Ma
23-13 Ma
12.5 Ma
Gangdese batholith
granitoid and gneiss dome
metamorphism
sample location
89°30'
89°45'
90°
29°
28° 50'
B
T
K
E
J
Q
Gyantse
Langshan gabbro
0 2.5 5 km
Quaternary sediment
Eocene strata
Cretaceous strata
Jurassic strata
Triassic strata
Langshan gabbros
Mafic dikes
Sample location
C
Tethyan Himalaya magmatism peak age of 44 Ma
Southern Lhasa magmatism peak age of 50 Ma
India-Asia convergence rate
Number
Convergence rate (mm/yr)
Age (Ma)
D
Jd + Qtz
Ab
10°C/km
30°C/km
Barrovian type series
Buchan type series
Ky
Sill
Eoce. TH/GH
Mioc. TH/GH
P (GPa)
T (°C)
Gradient (°C/km)


53-45 Ma
Magmatic metamorphic zone
YZS ophiolite
Linzizong volcanic rocks
a
Gangdese Batholith
Indian crust
Lhasa crust
Lithospheric mantle
Extension
1100°C
1300°C
Break-off of Neo-tethyan oceanic slab
Asthenosphere
Asthenosphere
Eocene mafic dikes
Eocene gabbros
Lower crust melting
Magma underplating
Moho
Cracking
Extension
LAB
Small-scale convection
b
Elevation (km)
MBT
MCT
YZS
A
A'
Moho
LAB
Time (s)
Depth (km)

A synthesis of the Peruvian Coastal Batholith: An exploration of temporal histories, causes of compositional diversity, and tectonomagmatic links in arcs

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Driving mechanisms behind spatial and temporal geochemical trends in the Central Andes of Peru have been investigated since the early 1970s. Analyzing the across-arc chemical changes observed in the Peruvian Coastal Batholith (PCB) played an integral role in formulating models for the evolution of the Pacific margin of South America. But still, details about the origins of these trends and the mechanisms that control magma composition along this arc remain unresolved. This research addresses the issue by using an up-to-date database of high quality geochemical and geochronological data in order to: 1) investigate PCB-wide variation of parameters previously studied in the Ica-Pisco plutons, 2) corroborate preexisting proposed chemical trends, 3) examine spatial and temporal changes along and across PCB segments over more than 170 million years, and 4) explore possible relations to the tectonic regime, subduction, magma sources, and crustal assimilation.

Our results show that the PCB has a clear non-steady-state pattern at variable temporal and spatial scales and the chemistry of arc magma varies depending on magmatic processes, sources, and mechanisms. In the PCB, the flare-ups exhibit a duration of 30-40 m.y. with some discrete but others synchronous between the three segments. We propose that this observed diversity in magma composition along and across the arc is due to various factors, such as changes in magma input from the mantle (0-20% crust vs. 80-100% mantle), different basement types, different assimilated materials, changes in crustal thickness, degree of differentiation, arc migration, and transitions from depleted mantle to lithospheric mantle. These observations favor an “internal forcing” model with upper plate episodic mantle processes likely responsible for episodic magmatism.

Unveiling Complex Reactions During Granitic Magma Interaction: An Experimental Perspective

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Oral, Tuesday 12th September, 09:30 - 09:45

It has been argued that large volumes of granitic/rhyolitic magmas may result from amalgamation of several magma batches of similar chemistry. Yet, the extension and possible consequences of the physical-chemical interactions during the coexistence of compositionally similar magma remain elusive. To decipher the intricacies of these interactions, we performed rapid-quench cold-seal pressure vessel experiments at 2 kbar using variably hydrated and partially crystallized magmas. Our experimental method involved a two-step experimental approach where at first, 21 day-long crystallization experiments were conducted using two compositionally distinct rhyolitic glasses at 725 and 700 °C resulting in a total of four partially crystallized "end-members". In a second step, these "end-members" were mixed in different proportion and seven magma mixing experiments were performed over 21 days at temperatures calculated considering the mass ratio and the equilibrium temperature of each "end-member". Our results indicate that mixing efficiency depends mainly on the ratio of the different magma batches. In most interaction experiments involving the mixing of 10/90% and 50/50% of each end-member, we observed that the fabric of the individual magma batches remains intact. In addition to that, we noticed the presence of features such as crystal accumulation, heterogeneous mineral distribution, corona texture, and zoned crystals. In particular, two charges with a mass ratio of 70/30% (performed at 703 °C and 718 °C) resulted in complete (70% MA - 30% FC) or partial (70% FC - 30% MA) obliteration of the initial fabric as we observe extensive dissolution and recrystallization of plagioclase crystals, resorption of amphibole, and increase in melt fraction. Surprisingly, the resulting fractions of melt and crystals do not scale with the anticipated fraction based on the mixing end-members or the mixing temperature in our experimental setup. In three cases, we have produced more melt than expected, while in two cases, we have crystallized more than expected. These observations provide insights into the nature and physicochemical processes which control the internal texture of igneous rocks, which can be applied to the formation of large magma reservoirs, eruptible magma, and the chemical and petrologic evolution of plutons.

Sr-Nd-isotopes documenting granite genesis through crystal fractionation without crustal assimilation: the post-collisional Plutons from the Araçuaí belt, SE Brazil

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Oral, Tuesday 12th September, 16:30 - 16:45

Mineral and bulk Sr-Nd-isotopic and geochemical analyses were acquired for the ~500 Ma post-collisional plutons Venda Nova and Várzea Alegre, Araçuaí belt, SE Brazil. Isotopes were measured by a Nu Plasma II MC-ICP-MS (for Nd) and by TIMS (for Sr) on clinopyroxenes, amphiboles, apatites and bulk-rocks on the entire suite of lithologies along the liquid line of descent.

The mildly alkaline Venda Nova inner domain comprises gabbros-diorites-syenomonzonites and granites with εNd (485 Ma) values ranging from -12 to -10 and $^{87}Sr/^{86}Sr$ (485 Ma) ratios from 0.7070 to 0.7080, scattering without correlation with melt chemistry; minerals and bulk giving consistent values in each sample. Instead, one leucogranite has a highly variable $^{87}Sr/^{86}Sr$ (485 Ma) of 0.7063-0.7096 in bulk and minerals. The more calc-alkaline (but also post-orogenic) Várzea Alegre Pluton contains gabbros-monzodiorites-charnockites-granodiorites-syenogranites and granites with εNd (485 Ma) values ranging from -10 to -7.8 and $^{87}Sr/^{86}Sr$ (485 Ma) ratios from 0.7070 to 0.7100, again scattering without correlation with melt chemistry. In both cases melt evolution is not accompanied by a systematic change in εNd or $^{87}Sr/^{86}Sr$ (albeit by a high scatter in Várzea Alegre), suggesting that differentiation from gabbros to granites occurred without (isotopically) significant crustal assimilation.

Potential assimilants are from the partially molten granulite facies metasediments of the Nova Venécia Complex, three migmatitic cordierite-sillimanite-garnet-gneisses gave εNd (485 Ma) values of -8.3 to -6.8, and $^{87}Sr/^{86}Sr$ (485 Ma) of 0.7166-0.7257.

So far, the isotopic results show that the least differentiated gabbroic rocks of Venda Nova and Várzea Alegre already have a crustal imprint. We therefore posit that the lithospheric mantle source leading to the gabbros was previously metasomatized by crustal material, likely from the 630-580 Ma subduction culminating in the

Araçuaí orogen. This process produced heterogeneous mantle domains manifested by the isotopic and geochemical differences found in each of the post-collisional plutons (even if minor). Granite genesis in these plutons is hence predominantly a product of crystal fractionation of a mafic melt derived from a contaminated mantle source.

First identification of intermediate-silicic cumulates in the Emeishan large igneous province, SW China

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Oral, Tuesday 12th September, 09:45 - 10:00

Silicic igneous rocks with ubiquitous crystal accumulation signature are hard to discern because the signature is subtle in viscous silicic magmas. However, the presence of intermediate-silicic cumulates is required to explain the formation of silicic igneous rocks by fractionation-dominated mechanisms. In large igneous provinces, such rock record is very scarce if ever reported. In this study, we document a case example of identifying such cumulates in the end-Guadalupian (~260 Ma) Emeishan large igneous province, SW China. We demonstrate that syenitic rocks associated with the Panzhihua layered gabbroic intrusion have trace element geochemistry consistent with origins involving both crystal

accumulation and extraction of residual liquids. Rocks showing positive Eu anomaly have relatively low concentrations of SiO_2 (<61 wt.%) and most incompatible trace elements, and relatively high concentrations of TiO_2, Fe_2O_3, CaO, Na_2O, Sr and Ba. Rocks showing negative Eu anomaly have essentially the opposite features. Both groups of the syenitic rocks have restricted Sr-Nd-Pb isotopic ratios that are grossly similar to rocks of the Panzhihua layered gabbroic intrusion, requiring minimal contamination by Archean continental basement of the Yangtze block in magma genesis. Comparing to apatite-hosted melt inclusions in the upper part of the intrusion, we propose that the magma forming both groups of the syenitic rocks was originally equilibrated with a mush column of Fe-rich olivine, Fe-rich clinopyroxene, intermediate plagioclase, apatite, ilmenite and titanomagnetite that exists in the upper part of the intrusion. Accumulation of an alkali feldspar-dominated assemblage from the magma formed the syenitic rocks showing crystal accumulation geochemical signature. The residual liquid after cumulate extraction (and any rocks formed from it) displays the complementary geochemical signature. Our model is consistent with rock textures and results of micro-X-ray fluorescence mapping, both of which are promising in identifying cumulates hidden in felsic plutons.

Tracking magmatic hybridization processes with zircon and apatite chemical-isotopic systematics, the case of the Sesia Magmatic System (northern Italy)

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Oral, Tuesday 12th September, 11:15 - 11:30

Genesis of granitic magmas can be explained by three main processes: fractionation of mantle-derived magmas; partial melting of crustal lithologies; and hybridization, which produces magmas with mixed mantle and crustal signatures. The relative importance of each component's contribution is however highly debated since access to the source regions in the mantle and lower crust is limited and because upper crustal granitic magmas generally show homogeneous compositions. In northern Italy, the Permian Sesia Magmatic System (SMS) offers a nearly continuous crustal section from the lower crust (mantle-derived magma reservoir and migmatites/granulites) to the upper crust (granites and rhyolites), representing an exceptional opportunity to investigate translithospheric magmatic processes.

In the SMS, upper crustal granites display hybrid bulk-rock geochemical features, with isotopic composition between the mantle-derived Mafic Complex (MC) and

lower crustal metasedimentary rocks. Zircon ages from the MC and leucosomes from high-temperature metasedimentary rocks present a coeval peak with those obtained in hybrid granites. However, the nature of the physical-chemical processes that produce homogeneous hybrid magmas in the lower crust are still unclear. Accessory minerals such as zircon and apatite represent candidates to track these processes and understand the formation of granitic magmas. In this study, we combine field and petrological investigations with U-Pb dating of these minerals, trace elements composition as well as isotopic systematics, specifically Lu-Hf in zircon and Sm-Nd in apatite.

In the southern MC, a region of interaction between mafic magmas and crustal lithologies (i.e. paragneiss) is observed, where charnockites, previously assigned to crustal melts, occur spatially at the interface between both lithologies. Locally, charnockites present intermingling textures with amphibole gabbronorites. Accessory mineral systematics show that charnockites and amphibole gabbronorites are comparable in terms of textures, age, and chemical-isotopic composition. In these rocks, the variety of zircon textures and chemical-isotopic compositions indicate a long-lived history of hybridization, crystal accumulation, and eventually re-equilibration, as suggested by the development of zircon rims preferentially along ilmenite crystals. When compared with data from an isotopically uncontaminated gabbro from the deepest MC, gabbro and charnockite from the intermingled zone display hybrid composition.

These preliminary results from the lower crustal section suggest that the interaction between mantle-derived magma from the MC and crustal melts occur in a hybridization zone, that produces charnockitic rocks. Therefore, rather than pure crustal anatectic products, we argue that charnockites may represent the "missing" link between the lower crustal rocks and the granites at the upper crust.

Concordance and chemical abrasion as pathways to improved trace element data from zircon in igneous rocks

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Trace element compositions of zircon are increasingly used to understand the petrogenesis of both the analysed zircon grains and their host rock. In most cases the assumption is made that the obtained trace element composition is representative of the grain composition at the time of formation, with trace element partitioning into the zircon matrix considered to be indicative of petrogenetic history. This information is applied at the pluton or suite scale, but also at the global scale for inferring the evolution of magmatic processes throughout Earth history.

We have used thermal annealing and chemical abrasion of Mesoproterozoic igneous zircon to investigate the utility of these processes for trace element studies of zircon. The chemical abrasion process dramatically improves the quality of the obtained trace element data and removes the majority of otherwise erroneous data influenced by inclusions or metamict and/or altered zircon domains. In the studied samples, this results in unimodal Ti-in-zircon thermometer temperatures, removal of LREE enrichments and coherent trends in indicators considered to represent progressive crystallization trends (e.g. Hf v Th/U). Chemical abrasion is arguably a highly effective tool to help ensure that the obtained trace element compositions represent crystalline zircon representative of the host magma composition.

If chemical abrasion is not undertaken, the results of this study highlight that only U-Pb age concordant analyses (i.e. within uncertainty of concordia) should be used for trace element studies in accessory minerals. Concordance provides a simple but highly efficient method for excluding erroneous trace element information and it is recommended that strict concordance is applied as a primary filter in all trace element studies.

Extensive reworking of old and heterogeneous crust at continental arc: Perspective from inherited zircons and Sr-Nd-Hf-O isotopes of late Paleozoic granitoids from North China Craton

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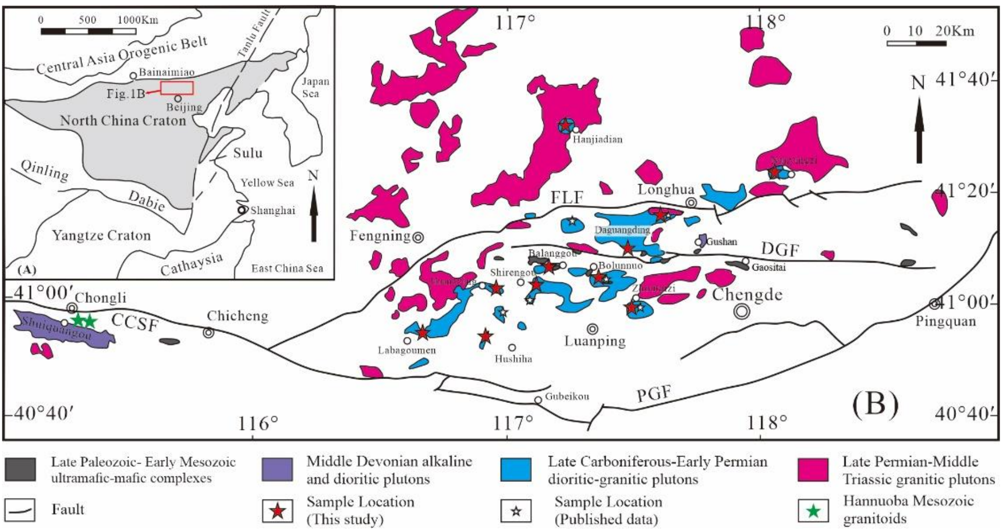
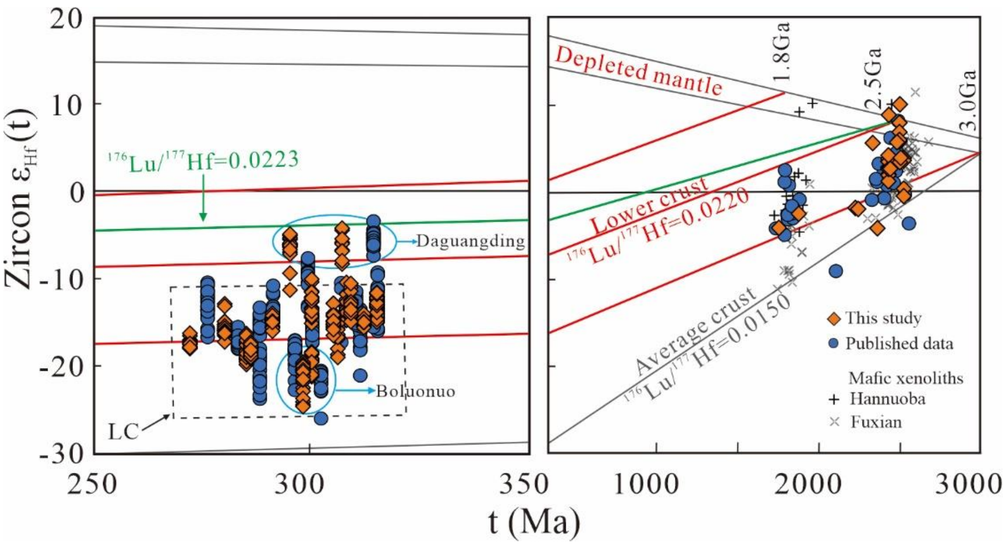
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The granitoid magmatic rocks in Continental arcs show extremely similar geochemical feature to those of the continental crust. However, there is no consensus on whether these magmatic rocks are just the results of reworking of continental crust or manifest the growth of new continental crust. The northern margin of North China craton was a continental arc during the Late Carboniferous to Early Permian with widespread arc-like plutons, making it an excellent place to address this issue. Granitoids and their mafic enclaves from ten plutons were studied with formation ages from 315Ma to 272Ma, varying SiO_2 contents of 53 to 72 wt.%, and low K_2O/Na_2O of 0.2 to 0.9. Their show typical arc-like trace element features with enrichment in light rare earth and large ion lithophile elements and depletion in heavy rare earth and high field strength elements. These granitoids have large variations in La/Sm ratios (2.6 to 10.4), initial Sr isotopic ratios (0.705 to 0.713), εNd (t) values (−16.8 to −11.3), and εHf (t) values (−20.2 to −5.7). The Sr-Nd-

Hf isotopes are not related to SiO_2 contents, and there is no correlation between Th, Zr and MgO, indicating that they cannot be formed by mantle-derived magma with assimilation of crustal material. These granitoids have compositions consistent with those of lower crustal melts in terms of SiO_2, Mg#, and trace elements. They also have ISr, εNd (t), εHf (t), and $\delta^{18}O$ values consistent with those of lower crustal material. The studied granitoid samples contain a large number of inherited zircons with ages (2.5 and 1.8 Ga), εHf (t) (−4.4 to +10.0 and −4.2 to −2.6), and $\delta^{18}O$ (5.81‰ to 5.87‰) consistent with those of lower crust. These findings indicate that these granitoids were derived from partial melting of the ancient heterogenous lower crust of the North China craton, without need of mantle material. Therefore, continental arcs may not be the primary site for continental crust growth.





Rift related silicic magmatism in Southern Central Chile (34º-37ºS): Evidence of an ancient slab tear under Gondwana

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The transition between the two most important orogenic cycles documented in western Gondwana (Gondwanan and Andean) has been a matter of debate in terms of the existence of continuous subduction or a temporal interruption in the convergence.

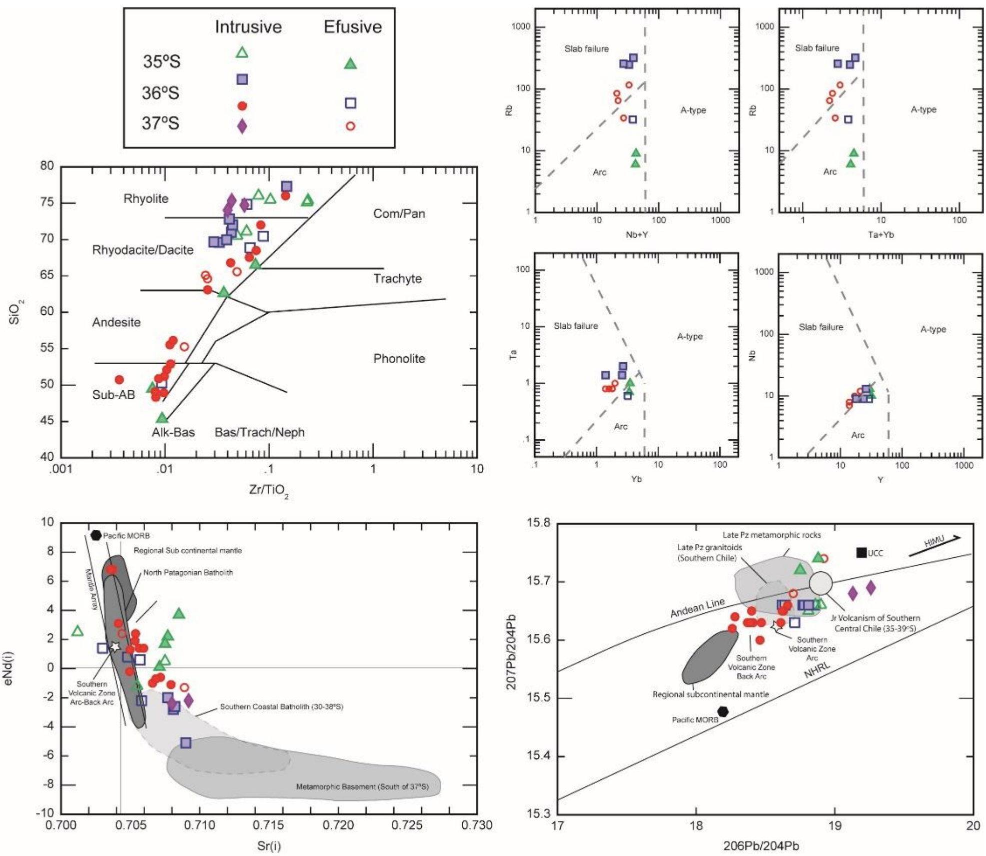
In this work, we present a series of new geochemical, geochronological, and isotopic data from late Triassic volcanic and granitic rocks cropping out between 35º and

37º latitude S in Central Chile, in order to enhance the petrotectonic model of the Gondwanan Early Mesozoic Subduction System.

Geochemical results show a high dominance of evolved compositions in the studied rocks, with a small amount of basaltic and andesitic rocks. All studied samples show typical subduction-related patterns, but intraplate signatures can be observed. Sr-Nd-Pb-Hf and O isotopes suggest an important participation of crustal components, probably from a metapelitic source, in the genesis of the magmas, and locally anomalous values under the mantle zircon value suggest the participation of rocks previously affected by high-temperature hydrothermal alteration. Discrimination diagrams suggest a dominance of arc-related rocks, with some samples plotting in the slab tear and A-granites field.

Geochronological SHRIMP and TIMS U-Pb results performed on the studied granitic and volcanic rocks suggest that this particular magmatic event took place in a restricted period of time between 220-210 Ma, and the presence of small amounts of inherited Paleozoic zircons in the granitic rocks confirms the participation of significant amounts of older crustal components in the genesis of the magmas.

Recent geophysical data provide evidence that the segment at the actual 35º and 37º latitude S in Southern Central Chile and Argentina represents an anomalous area influenced by a major tear of the subducted slab under the continent. In this context, we suggest that the highly heterogeneous Upper Triassic magmatism in the studied area is a reflection of this process, which produces an anomalous heat influx at the supra subduction zone, melting of the partially matasomatized asthenospheric mantle, and subsequent assimilation of the lower crust. Additionally, we believe that this event not only generates anomalies in the nature of the magmatic products but also probably influences the structural characteristics and patterns of deformation in the upper crust of this area.



Identifying the granitic composition water-saturated solidus

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The granitic water-saturated solidus (G-WSS) is the lower temperature limit of magmatic mineral crystallization. The accepted water-saturated solidus for granitic compositions was largely determined >60 years ago. More recent advances in experimental petrology, improved analytical techniques, and recent observations that granitic systems can remain active or spend a significant proportion of their lives at conditions below the traditional G-WSS necessitate a careful experimental investigation of the near-solidus regions of granitic systems.

Natural and synthetic starting materials were melted at 10 kbar and 900°C with 4-8 wt% H_2O to produce hydrous glasses for subsequent experiments at lower P-T conditions used to locate the G-WSS. We performed crystallization experiments and melting experiments at temperatures ranging from 575 to 800°C and 1, 6, 8, and 10 kbar on 12 granitoid compositions. First, we ran a series of isothermal crystallization experiments along each isobar at progressively lower temperatures until runs completely crystallized to identify apparent solidus temperatures. Geochemical analyses of quenched glass compositions demonstrate that progressive crystallization drives all starting compositions towards silica-rich, water-saturated rhyolitic/granitic melts (e.g., ~75-78 wt% SiO_2).

After identifying the apparent solidus temperatures at which the various compositions crystallized, we then ran series of reversal-type melting experiments. With the goal of producing rocks with hydrous equilibrium microstructures, we crystallized compositions at temperatures ~10°C below the apparent solidus identified in crystallization experiments, and then heated isobarically to conditions that produced ~20% melt during the crystallization experiments. Importantly, crystallization experiments and heating experiments at the same P-T conditions produced similar proportions of melt, crystals, and vapor. A time-series of experiments 2-30 days at P-T conditions previously identified to produce ~10% to 20% melt did not reveal any kinetic effects on melt crystallization.

Experiments at 6 to 10 kbar crystallized/melted at temperatures close to the published G-WSS. However, at lower pressures where the published G-WSS is strongly curved in P-T space, all compositions investigated contained melt to temperatures ~75 to 100°C below the accepted G-WSS. The similarity of crystallization temperatures for the higher-pressure experiments to previously published results, similar phase proportions in melting and crystallization experiments, and the lack of kinetic effects on crystallization collectively suggest that our lower pressure constraints on the G-WSS are accurate. The new experimental results demonstrating that the lower-pressure G-WSS is significantly lower than unanimously accepted estimates will help us to better understand the storage conditions, evolution, and potential for eruption in mid- to upper-crustal silicic magmatic systems.

Mafic contributions across the Sierra Nevada batholith, California, USA

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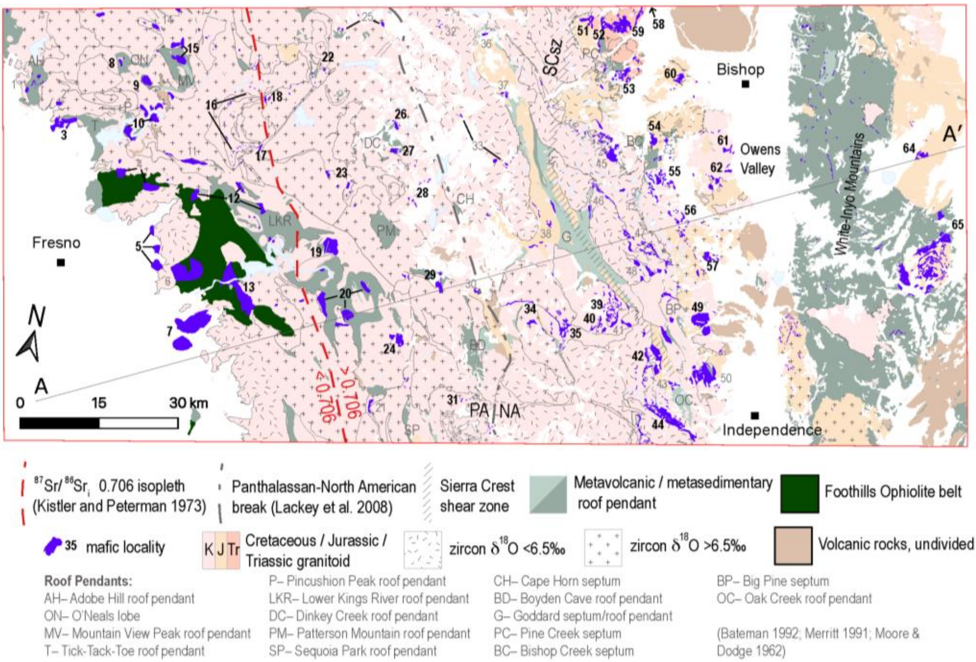
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

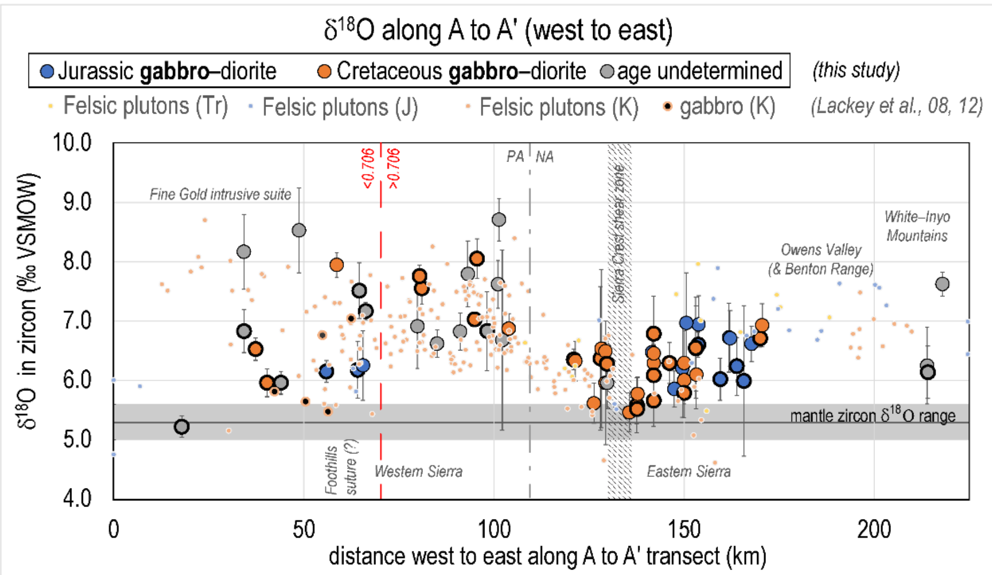
We have targeted mafic plutons across the Sierra Nevada batholith to define the chemistry and timing of mafic input at the batholith scale. These small-volume upper-crustal gabbro to quartz diorite plutons (~42–63wt.% SiO_2) are penecontemporaneous with associated granodiorite to granite (s.l.), contrary to their early characterization as an older stage of the batholith. They represent crystallization products of high-Al, low-Mg mafic magmas that contributed heat and/or mass to generate the silicic batholith.

Oxygen isotope ($\delta^{18}O$) analyses of zircon from the gabbros-diorites range from ~5.2 to >~8.0‰ (VSMOW), and vary systematically across the batholith in strikingly similar ways to previously characterized intermediate to

felsic samples (~60–78wt.% SiO_2)[1,2]. Like the more evolved rocks, the mafic plutons also display distinct ranges in $\delta^{18}O$(zircon) values within lithospheric belts that were tectonically assembled prior to arc magmatism: mantle-like signatures west of the concealed Foothills suture, significant crustal recycling in the western Sierra, minor crustal involvement in the eastern Sierra and White-Inyo Mountains.



Further, mineralogic and isotopic differences between Jurassic and Cretaceous mafic plutons may be linked to arc-wide geodynamics. Mineralogic variations among mafic plutons suggest that their parental melts varied compositionally (e.g., orthopyroxene and limited amphibole versus early-crystallizing amphibole in drier versus wetter basalts, or with different sources or amounts of crustal assimilation, etc.). Basalts parental to the Jurassic mafic plutons had potentially drier compositions based on mineralogy, and $\delta^{18}O$(zircon) values have a more limited range ($\delta^{18}O$ = 5.8–6.9‰) in the Jurassic compared to those from the Cretaceous mafic plutons. Ages of nearly all Jurassic mafic intrusions overlap with the timing of extensional stress regimes, whereas the Cretaceous arc was compressional to dextral transpressional with localized extensional regions along the Sierra Crest shear zone. The regional and localized stress state of the pre-existing arc crustal structure may determine compositional (and isotopic) characteristics of the mafic plutons.



Thus, our results show that despite their mafic composition, the petrology and geochemistry of these plutons is linked to the structure, composition and stress state of the upper-plate lithosphere (rather than mantle wedge or spatial relationship to the slab) which modulate both compositional consequences and degree of crustal assimilation. By linking these mafic inputs to associated granitoids, our findings have direct implications for the controls on mantle input versus crustal recycling in the formation of arc batholiths.

[1] Lackey et al. (2008) Journal of Petrology v. 49(7).;

[2] Lackey et al. (2012) Geosphere v. 8(2).

Melt inclusion in zircon geobarometry: a new approach to estimate crystallization pressures of granitic rocks

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Granitic rocks (sensu lato) are a major rock type in orogenic belts. The crystallization pressures of granitic rocks can help to unravel the magmatic processes and tectonic evolution of these regions. However, geobarometric techniques that are suitable for granitoids are quite limited. The most widely applied geobarometer used for granitoid samples has traditionally been the Al-in-hornblende geobarometer, although this cannot be used for hornblende-free lithologies. Consequently, it has been difficult to constrain crystallization pressures directly from hornblende-free samples. Thus, an alternative geobarometric technique that can be used for a broader range of compositions and mineralogy is in great demand. In the case of felsic volcanic rocks, melt compositions obtained by the analysis of matrix glass and/or glass inclusions are extensively used for estimating pressure. In this presentation, we propose a new approach to estimate crystallization pressures of granitoid magmas using melt inclusions in zircon, a ubiquitous accessory mineral in these lithologies.

The studied samples are hornblende-free granitoid samples from two localities including Cretaceous Gamano Granodiorite in the Ryoke Belt and the Miocene Miuchi pluton of the Outer Zone Granitc Rocks of southwest Japan. Zircon grains are concentrated by panning and further processed with a hand magnet, and the remaining fractions were purified using heavy liquid separation. Rounded inclusions of variable size (mostly 3–30 μm) are abundant and comprise quartz, plagioclase and K-feldspar. These polymineralic quartzofeldspathic inclusions are interpreted as crystallized melt inclusions trapped during crystal growth within a granitic melt. Homogenization experiments of the polymineralic inclusions hosted in zircon have been conducted under high-pressure using a piston-cylinder high-pressure–high-temperature apparatus. Major element analyses of the homogenized (glass) inclusions are carried out using a SEM-EDS after the homogenization experiments.

The homogenized compositions of the inclusions in both samples have high SiO_2 contents (76–80 wt%) implying that they represent fractionated interstitial melts trapped in growing zircon crystals. The rhyolite-MELTS geobarometer for the homogenized melt inclusions in zircon yields pressures ranging from 293 to 158 MPa (the Gamano Granodiorite) and from 114 to 80 MPa (oscillatory-zoned rim, the Miuchi pluton), interpreted as the crystallization pressures of these intrusions. These results are consistent with field and petrographic observations suggestive of relatively shallower emplacement level of the Miuchi pluton than that of the Gamano Granodiorite. The approach presented here would be applicable to most granitoids, which could provide fundamental data to better understand granite petrogenesis and the tectonic evolution of orogenic belts.

Granites with a fever - Taking the high temperature of ~ 1 Ga granites in N. America and 1.8 Ga granites in Australia

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Granitoids produced during the formation of the supercontinent Rodina, i.e. "Grenvillian" granitoids, have surprisingly high zirconium abundances. As a result, many ~ 1 Ga granites have an extremely large abundance of zircon which has flooded sedimentary systems in North America. One likely explanation for this is the apparent extremely high temperature of Grenvillian granitic magmas based on thermodynamic modelling and Ti-in-zircon temperatures. A second suite of granitoids, the 1.8 Ga granitoids in the Kimberly region of NW Australia, also appear to have surprisingly high temperatures despite having much more 'mortal' Zr abundance. Perhaps very high temperatures of granitic magmatism generated during supercontinent cycles is a unifying aspect of these bodies? Further tests of granitic magmatic temperatures are needed from other supercontinent cycles, such as the formation of Gondwana and Pangea.

An explicit solution for magmatic TiO_2 activity from tandem zircon and titanite thermometry

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Oral, Tuesday 12th September, 09:15 - 09:30

Thermobarometry is an important tool for tracing thermal histories in the geosciences. In granitoids and related rocks, two common thermometers are Ti-in-zircon [1] and Zr-in-titanite [2]. One of the difficulties in implementing these and other 4+ cation thermometers (Ti-in-quartz and Zr-in-rutile[1]) is estimating various system variables, particularly the activities of TiO_2 and SiO_2 (αTiO_2 and αSiO_2). Accurate estimates of the activity of αTiO_2 are critical to most thermometers, but αTiO_2 has been proposed to range from 0.2-1 [3] using various methods. When rutile is present, the system can easily be assumed to have an αTiO_2 of 1, yet rutile is commonly absent from calc-alkaline magmas, leading to a wide range of possible activities less than 1 [4]. Moreover, because the thermometers are functions of log(α), calculation with inaccurate activities results in large temperature disparities (50-100 °C) [5]. Here we present a new analytical framework that allows us to explicitly determine two of the more difficult parameters, temperature and αTiO_2.

We analyzed zircons from five rock suites in the Tuolumne Intrusive Suite (TIS), Sierra Nevada, CA by laser ablation-split stream–inductively coupled plasma–mass spectrometry depth profiling (LASS-DP). Each suite of zircon chemical profiles shows an inflection in the Yb/Dy ratio between 2-4 ppm Ti, which arises from the onset of titanite saturation. A zircon-derived titanite saturation allows for the use of Ti-in-zircon and Zr-in-titanite in tandem (using more reliable estimates on pressure and αSiO_2), yielding a system of equations to explicitly solve for both temperature and αTiO_2 at the point of titanite saturation. For three of the TIS rocks, the solutions are 0.40-0.45 ± 0.05 αTiO_2 and 690-710 ± 20 ℃. These values provide a robust point to extrapolate up- and down-temperature from the zircon-derived titanite saturation and to evaluate other geochemical variables in relation to evolving magmatic temperature. This method can be applied to other rutile-absent, titanite-present systems to explicitly determine the activity of TiO_2.

[1] Ferry & Watson, Contrib. Mineral. Petrol. 154, 429–437 (2007).

[2] Hayden et al., Contrib. Mineral. Petrol. 155, 529–540 (2008).

[3] Thomas & Watson, Reply to Contrib. Mineral. Petrol. 164, 369–374 (2012).

[4] Schiller & Finger, Contrib. Mineral. Petrol. 174, 51 (2019).

[5] Ackerson, & Mysen, Am. Mineral. 105, 1547–1555 (2020).

Characterising crustal conditions of granite formation in the central Taupō Volcanic Zone (New Zealand): trace element and isotopic insights

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The central Taupō Volcanic Zone (TVZ) in the North Island of New Zealand is an area of vigorous Quaternary silicic volcanism, with rhyolite output from caldera-forming events alone exceeding 6000 km³ over the past 1.85 Myr. Our understanding of the geochemical evolution and magmatic processes operating within the modern TVZ rhyolitic volcanoes (Taupō and Ōkataina) comes primarily from the study of past eruptive products. These volcanic products provide a snapshot of the magma system immediately prior to and during eruption but lack the insights into processes and timescales that the study of plutonic rocks offers.

Within the central TVZ, rare plutonic fragments have been incorporated as lithic clasts in several silicic and mafic eruptions. This work focusses on granitoid lithics from several central TVZ eruptions, with a specific focus on those from the caldera-forming ~54 ka Rotoiti event at Ōkataina. Petrographic investigation (mineralogical and textural), geochemical and isotopic analyses have been undertaken to better understand the environment of crystallisation, petrogenesis, and links to volcanic products.

Trace element variations suggest that central TVZ granitoid compositions are dominantly controlled by plagioclase fractionation. Variations in Eu/Eu* correlate with Rb/Sr ratios both across the whole suite of central TVZ granitoids and among granitoids from the same eruptive unit. The central TVZ granitoids are divided into two compositional groups: one with higher SiO_2, lower Sr (>77 wt% SiO_2; <50 ppm Sr) and the other with lower SiO_2, higher Sr (<75 wt% SiO_2 and >100 ppm Sr). The granitoids show a narrow range of $^{87}Sr/^{86}Sr$ isotope ratios (0.7050 – 0.7070), typical of the central TVZ rhyolitic eruptives. Pb isotope ratios indicate that the granitoids have assimilated variable amounts of the Kaweka terrane, one of the local greywacke basement lithologies.

A subset of granitoids from the Rotoiti event show evidence of interaction with hydrothermal fluids. These granitoids contain epidote, chlorite, and hydrothermal biotite. They also show low δ18O values for whole-rock (~2-5‰) and plagioclase crystals (~0.5-6‰), compared to phenocrystic and vug quartz values (~8-9‰). These altered granitoids are associated with elevated $^{87}Sr/^{86}Sr$ isotope ratios (0.7060-0.7065) compared to the rest of the Rotoiti granitoids and volcanic products, and they form a tight cluster of elevated values in Pb-isotope space. Therefore, the elevated Sr and Pb isotope ratios could be due to interaction with fluids that have been circulating within the greywacke basement.

Petrological study on the Cretaceous plutonic rocks in Kajishima, southwest Japan: an exposed gabbroic deep crust of Cretaceous continental margin of East Asia

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Various plutonic rocks including dominant granitic rocks with related mafic rocks are widely distributed in southwest Japan, which have been formed during the Cretaceous magmatic flare-up event along the continental margin of East Asia. In Kajishima, one of the uninhabited islands in central area of Seto Inland Sea of southwest Japan, various types of Cretaceous gabbroic rocks associated with granitic dykes are well exposed. Because gabbroic rocks are likely formed related to mantle activity, petrological investigation on genetic link between gabbroic rocks and granitic rocks in Kajishima will shed new lights on the crust-mantle process in this area ultimately contributing to crustal differentiation in the continental margin of East Asia. In this study, we present field, petrographic, whole-rock major, trace and Sr-Nd isotopic, and zircon Hf isotopic data of the plutonic rocks in Kajishima to investigate the genetic relationship between gabbroic rocks and granitic rocks.

In outcrops, granitic rocks in Kajishima occur as dykes intruding into host gabbroic rocks. Small scale (cm size)

granitic veins/networks also occur within gabbroic rocks. The granitic networks in gabbroic rocks show gradual contact with host gabbroic rocks. They connect each other and form pools and dykes implying accumulation of granitic interstitial melt in solidifying gabbroic magma. The gabbroic rocks locally contain poikilitic hornblende hosting subhedral to anhedral pyroxene and plagioclase and olivine with corroded shapes. The ranges of whole-rock Sr-Nd isotopic compositions in the granitic rocks (εSrI = +48.0 – +64.3 and εNdI = -10.3 – -5.9) are broadly comparable to those in gabbroic rocks (εSrI = +44.4 – +63.8 and εNdI = -14.6 – -4.2). Zircon Hf isotopic compositions of granitic rocks (εHf (t) = -13.1 – +0.4) also show similar range with those of gabbroic rocks (εHf (t) = -7.1 – +1.9).

Identical Sr-Nd-Hf isotopic signatures between granitic rocks and gabbroic rocks in Kajishima strongly suggests their genetic relationship. Field occurrence and microscopic observations imply that the granitic interstitial melts, formed through extreme crystal fractionation of gabbroic magma or partial melting of gabbroic rocks, join together and form granitic rocks in Kajishima. Furthermore, the negative to slightly positive εNdI and εHf (t) values of the gabbroic rocks suggest that the source mantle of gabbroic rocks were enriched during the Cretaceous magmatic flare-up event in this region. These data collectively illustrate that Kajishima is an exceptional study area to understand deep crust-mantle processes at Cretaceous continental margin of East Asia.

Field and experimental perspectives on the deep origins of convergent-margin plutonic magmas

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Overview Keynote, Tuesday 12th September, 08:30 - 09:15

Plutons are defined in the field, usually with a sharp perimeter enclosing intrusive rocks of similar composition, mineral assemblage and proportions, and with a characteristic texture defined by some aspect or combination of phenocrysts, megacrysts, grain size (etc.), exposed across distances of kilometers to tens of kilometers; these features may also change gradually within an intrusion. Second-order characteristics can accompany, such as mafic inclusions (enclaves) of particular abundances, sizes, and distributions. Internal contacts, where present, are generally few and difficult to trace for long distances because flanking rocks are similar, a contact may end internally, and where a contact can be traced across a pluton, field geologists use it to subdivide and define additional plutons. Many plutons are zoned modestly in composition, and some belong to zoned intrusive suites whose members are arranged in a nested succession, becoming younger and more evolved inward toward a central location.

The relative uniformity within plutons and their spatial-temporal-compositional organization must be reconciled with growing evidence for the protracted (100 kyr to multi-

Myr) production, accumulation, and emplacement of plutonic magmas, sometimes referred to as "incremental assembly" [Coleman et al., 2004, Geology]. If increments are small, as the word implies, then the processes creating plutonic magmas at depth must be highly regular, yielding a limited range of compositions over long spans of time that solidify similarly upon emplacement, creating a pluton's distinguishing texture across broad expanses. Alternatively, some "increments" may not be small at all, instead being large enough to remobilize, mix, and partly homogenize their predecessors. Within this is the possibility of periods of magma supply, and energy derived therefrom, sufficient to poise the emplaced body in a partly molten state across distances approaching those of the final pluton. That supply magmas are commonly uniform, or evolve gradually and modestly (with minor, brief transients), is indicated by the limited compositional ranges and textural uniformity of many plutons and of their constituent minerals. Examples from the Sierra Nevada batholith (USA) include that the interiors of zoned plagioclase are in the vicinity of An46 across broad distances of the enormous Mount Givens Granodiorite [Bateman & Nockleberg, 1978, J. Geol.], plagioclase in granodiorites of the Mount Whitney Intrusive Suite have compositions hovering near An35–An40 from crystal interiors nearly to their rims [Hirt, 1989, U.C. Santa Barbara Ph.D.], and plagioclase core compositions of members of the Tuolumne Intrusive Suite shift smoothly with location inward across the suite from about An_{42} to An_{20} along with whole-rock composition [Bateman & Chappell, 1979, GSA Bull.]. K-feldspar megacrysts characterizing some Sierran plutons always contain repetitive, concentric “sawtooth” Ba zones with similar peak and trough Ba concentrations from crystal interior to margins [Moore & Sisson, 2008, Geosphere]. Prolonged feeding of the plutons by magmas of limited compositional ranges, temperatures, and degrees of solidification would produce these features, and if so, the causes of uniformity must be sought deeper.

Experimental studies crystallizing convergent-margin magmas at deep crustal and shallow mantle pressures bear on this. Primitive basaltic melts crystallized dry at such pressures mostly yield alkalic derivative liquids, whereas hydrous basalts and basaltic andesites, so-crystallized, consistently produce SiO_2-enriching liquid lines of descent. Melts with basaltic andesitic (gabbronorite, diorite) and andesitic (diorite, quartz diorite) SiO2 concentrations are readily produced, but these differ from nearly all natural counterparts in approaching or attaining peraluminous compositions, this resulting from calcic clinopyroxene crystallizing abundantly near the high-pressure liquidī. Natural arc igneous suites, in contrast, pass gradually from metaluminous to peraluminous with increasing SiO_2, transitioning among dacite (granodiorite, tonalite) to rhyolite (granite) compositions. Upon becoming dacitic, the high-pressure experimental liquids rejoin the arc plutonic-volcanic compositional array. Such dacitic liquids form along amphibole-pyroxene peritectics, typically around 900–1000□ C, and experiments across 400–1600 MPa show that the compositions of dacitic peritectic melts are relatively insensitive to pressure [Blatter et al., 2017, 2023, Contrib. Mineral. Petrol.]. Conditions of magma replenishment that would sustain such temperatures in the deep-crustal portions of active arc igneous complexes would yield granodiorite–tonalite liquids that feed many arc plutons. Near-absence of natural peraluminous basaltic andesites and andesites, and their intrusive counterparts, gives further insights: Arc magmatic systems are now known to commonly remain active in about the same locations for □ Myr durations, so magmas replenishing their deep roots transit related, still-hot predecessor intrusions, allowing entrainment of SiO_2-rich near-solidus residual liquids and low-degree partial re-melts (plus from country rocks). Such hybridism can bridge the peraluminous basaltic andesite–andesite interval that deep, progressive crystallization-differentiation, acting alone, otherwise produces. The scarcity of peraluminous intermediate arc magmas signals that such hybridism is ubiquitous, or nearly so, in the deep crustal roots of their magmatic systems. Last, the felsic-younger compositional evolution of plutons and zoned intrusive suites can be understood as recording the waning limb of prolonged magmatic events rather than the emplacement-level differentiation of single, active magma reservoirs.

Not all S-type Granites are Created Equal

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Oral, Tuesday 12th September, 14:45 - 15:00

Sediment-derived melts and the detrital products derived therefrom have been present in the geologic record since the Hadean Eon. However, it is often assumed that melts of (meta)sedimentary material represent small volumes of melt compared to other felsic melts such as those formed in arc settings. Nevertheless, constraining the mode and volume of sediment assimilation plays a fundamental role in our understanding of the interplay between Earth’s surface where sediments are formed and Earth’s depths where surface-derived materials are melted. Recent work has demonstrated that changes in sedimentary compositions through time are reflected in the composition of sediment-derived melts. This means any detrital mineral proxy used to constrain the volume of sediment-derived melts through time will be a moving target.

The clastic sedimentary record is also extremely diverse in its isotopic signatures and degree of maturity. This compositional diversity is reflected in sediment-derived melts that reflect specific isotopic features of various petrotectonic settings. Sediment-derived melts are present across the spectrum of orogenies from oceanic and continental arcs to continental collisions. Oceanic arc settings like the Central Asian Orogenic Belt and the Birimian Greenstone Belt record sediment-derived melts with elevated $\delta^{18}O$ but depleted εHf. Collisional settings like the Himalayan and Pan-African Orogenies produce melts with elevated $\delta^{18}O$ and enriched εHf. In contrast to the end-member oceanic arcs and continental collisions, long-lived continental arc systems yield dramatic swings in isotopic signatures during the oscillations of retreating and advancing phases of arc magmatism. Ophiolites also host sediment-derived granites intruding peridotite that carry isotopic signatures akin to biogenic sediments implying subduction and melting of deep marine sediment.

The mechanisms of sediment melting are also diverse with specific mineral proxies that can differentiate between fluid-present melting versus muscovite- and biotite-dehydration melting. The identification of the melt-producing mechanisms goes far beyond addressing petrologic minutiae but provides a clear context for deciphering the melt-reaction control, pressure-temperature conditions of melt generation, and compositional diversity of sediment-derived melts from the outcrop to the orogen scale.

Sediment-derived melts record plate tectonic-driven mass transfer and form a clear connection between evolving surface conditions and the deep Earth. These relatively low-volume granitoids play an important role in understanding the long-term evolution of both the plate tectonic processes that form them and the sedimentary systems that provide the fodder for melting.

Magmatism transition from low-angle subduction to slab rollback of oceanic plate

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Granitic rocks constitute the essential part of continental crust, and are commonly used as means to constrain the evolution of continental crust, as well as tectonic settings. Vast amounts of Late Mesozoic granitic rocks were developed in the eastern North China Craton (NCC), with zircon U-Pb ages showing a westward younging trend in the Jurassic and a reverse trend in the Early Cretaceous, which usually thought to be related to the westward subduction followed by a rollback of the Paleo-Pacific plate. Thus, understanding the detailed crustal evolution and melting process during oceanic subduction is an important issue to study the tectonic evolution, as well as the decratonization of the NCC. Late Mesozoic granitic intrusions in the Liaodong Peninsula are focused in this study. Zircon U-Pb ages indicate that the Early Cretaceous magmatism occurred between 118.3 to 129.5 Ma (N = 47), with a sequence of arfvedsonite K-feldspar granite (Peralkaline A-type, ~126 Ma), to alkali-feldspar

granite (Aluminum A-type, 121.0 to 129.5 Ma), to K-feldspar granite and related rocks (I-type, 118.3 to 125.1 Ma). According to titanium in zircon (TTi) and zirconium saturation (TZr) temperature calculations, the petrological evolution occurred during Late Mesozoic in the Liaodong Peninsula, from Jurassic I-type granite with low temperature, to Early Cretaceous A-type granite and syenitic rocks with high temperature, to Early Cretaceous I-type granite with low temperature. Geochemical and zircon Hf-O isotopic studies show that source materials and melting mechanisms were changed: Jurassic magmatism was dominated by the dehydration and partial melting of the basaltic lower crust, introducing an anhydrous and refractory residual lower crust. Such early formed lower crustal materials, together with felsic rocks in the shallow crust, were heated and melted with the upwelling of mantle-derived magma to form the Early Cretaceous A-type and syenitic rocks. After that, the water-rich juvenile and ancient lower crust were melted to form the Early Cretaceous I-type granites, which widely accompanied and mixed with mantle derived magma. Such magmatic evolution history indicates that crustal melting beneath the Liaodong Peninsula was transformed along with the continuous westward subduction of the Paleo-Pacific plate during the late Mesozoic, from melting of ancient lower crust related to low-angle subduction of oceanic plate, to melting of shallow and/or dehydrated lower crust related to slab rollback of oceanic plate, to melting of water-rich lower crust related to normal high-angle subduction of oceanic plate and decratonization.

Protracted and progressive crustal melting during continental collision in the Pamir and plateau growth

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Determining crustal melting in parallel with geodynamic evolution provide critical information on crustal thickening and plateau uplift for the Pamir. In situ analysis of zircon U-Pb ages and Hf isotopes of the leucogranites, record protracted crustal melting for both Central Pamir (c. 43 – 33 Ma) and South Pamir (c. 28 – 10 Ma). Our results, for the first time, reveal that different temporal evolution in the source regions for the Central and South Pamir leucogranites and involvement of components from different crustal levels, and importantly, Indian crustal materials are incorporated into the melt region for the South Pamir leucogranites from c. 20 Ma. They were related to chain of events, including lithosphere thinning, slab breakoff, lithosphere delamination and underthrusting of Indian lithosphere, through time and space. These series of processes all played a key role in crustal thickening and plateau uplift, and constructed a comprehensive model on the Pamir geodynamic evolution.

A-type granites from East Junggar, NW China

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

A-type granite (A denoting of anorogenic, or anhydrous), defined by Loiselle and Wones (1979), generally have higher total alkalis than other granitoids. Whalen et al. (1987) and Eby (1990) summarized the general characteristics of the A-type granites, and used plots employing Ga/Al, various major element ratios and Y, Ce, Nb, and Zr. Subsequently, many papers classified A-type by these characters and diagrams. And, volume aluminous granites are not alkaline with A-type characteristics and also classified as A-type. A-type granites are classified into aluminous and alkaline subgroups. A-type granitoids were emplaced into extensional post-collisional setting and within plate. Eby (1992) suggested that A-type granitoids could be divided into two groups. A1 group were interpreted as differentiates of basalt magma derived from an OIB-like source while A2 group were derived from the subcontinental lithosphere or lower crust. A1-types invariably are associated with true anorogenic setting while A2-types are often emplaced in post-collisional, post-orogenic setting.

East Junggar is located in the West CAOB. Volume A-type granites are distributed along three fault zones of Irtysh, Ulungur -Armanty, and Karamaili from north to south in this area. They are composed of Agegirine granite, Arfvedsonite granite, K-feldspar granite, biotite granite, syenogranite, monzonite, monzogranite, and granite porphyry. A-type granites were intruded in three periods of 410-325 Ma, 325-280 Ma, and 280-255 Ma. The earliest and latest A-type granites are aluminous A2 type and appeared in the Karamaili belt and Ulungur belt, separately. Earliest A1 granites (358 Ma) are alkaline and emplaced in Bulgen belt, and aluminous A1 granites (327Ma) also emplaced in this belt, but most 360-330 Ma aluminous A2 granites are occurred in Ulungur belt. All the 325-280 Ma A-type granites are aluminous or alkaline A2 and distributed in Ulungur and Karamaili belts. Few A-type granites are intruded at 280-255 Ma, and belonging to aluminous A2 and A1. All A-type granites in East Junggar have positive εNd(t) values of +4.2 to +6.4, suggesting sources of mantle-derived juvenile material. Temporal and spatial distribution and characters of A-type granites from East Junggar show that the aluminous and alkaline A-type granitoids can occurred closely, and A1 and A1 also can be coexisted in same area. They can be derived from similar source, and the magmatic evolution play very important role in generation of different A-type granites in same environments. The significance of A-type granites should be critically reexamined.

Crustal production in the early Earth: constraints on the sources of water using in-situ oxygen isotopes of zircon from the Archean Lewisian Gneiss Complex

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Oral, Tuesday 12th September, 11:00 - 11:15

Much of Earth's oldest continental crust is thought to have been derived from partial melting of hydrated mafic crust, leaving hornblende, pyroxene and/or garnet as residual phases. During this process, water played a crucial role in transforming primitive mantle-derived magmas into buoyant and evolved continental crust as it influences melting temperatures, residual mineralogical and melt compositions [e.g., 1]. Fundamental questions, including the source of water allowing the production of voluminous Archean sodic granitoids of the Tonalite-Trondhjemite-Granodiorite (TTG) suite at lower pressure and temperature conditions than previously proposed, remain still unresolved [2].

In this study, we investigate TTG samples from the mainland Lewisian Gneiss Complex (LGC) in NW Scotland to evaluate the origin of water by coupling in-situ oxygen isotopes and U-Pb geochronology in zircon with major and trace element bulk-rock geochemistry. The TTG samples show elevated Sr/Y, low heavy rare

earth elements and low high field strength element contents which have been interpreted to reflect a 'high-pressure'-TTG signature [5] or, alternatively, a plagioclase-out reaction under fluid-flux melting conditions [2]. Low Nb/Ta, low Zr/Nb, low Gb/Yb and moderate Zr/Sm ratios indicate that residual amphibole played an important role pointing towards an amphibolitic-type [3] source rather than eclogitic. Partial melting of the latter should reflect increasing Nb/Ta ratios from the mafic source to the sodic melt produced. Within the source discrimination diagram [4], high CaO and Al_2O_3 hornblende-bearing TTGs from the central region of the LGC resemble melts derived from a low-K basaltic source, whereas high Al_2O_3 and low CaO biotite-bearing TTGs from the northern and the southern regions plot towards the tonalite field indicating a more evolved source. Preliminary oxygen isotope analysis of zircon for ca. 3.0–2.8 Ga Lewisian TTGs range from 4.9 to 6.6‰, overlapping with previously reported Archean igneous zircon [6]. The median $\delta^{18}O$ value (5.8 ± 0.6‰) is in accordance with hydration of TTG source rocks by mantle-derived water to generate voluminous amounts of sodic crust in the Archean LGC.

[1] Foley et al., 2002. Nature, 417(6891).

[2] Pourteau et al., 2020. EPSL, 550(116548).

[3] Hoffmann et al. 2011. GCA 75:4157–4178.

[4] Laurent et al., 2014. Lithos205,208–235.

[5] Moyen & Martin, 2012. Lithos, 148:312–336.

[6] Valley et al., 2005. CMP, 150:561–580.

Geochemical characteristics of granitic rocks in Goto Islands, Japan

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The island arc of Japan was separated from the Asian continent in the middle Miocene age. This phenomenon is known as the expansion of the Japan Sea. Igneous activity was active during this period, and acidic rock intrusions in this age are distributed in southwestern Japan. The granitic rocks distributed in the Goto Islands are one of such granitic rock types. However, there have not been many geochemical studies of these granitic plutons. In this research, geochemical characteristics of granitic rocks in Goto Islands, southwestern Japan have been studied by whole-rock chemical composition of major and minor elements including rare earth elements. We focused on the granite in Hisakajima Island, where granitic rocks are abundantly distributed in Goto Islands. Whole-rock major and trace elements compositions were measured by wavelength dispersive X-ray fluorescence spectrometer, and rare earth elements compositions were measured by inductively coupled plasma mass spectrometer. The geochemical characteristics of granitic rocks are divided into two groups, which are named as GD and HFG on the SiO_2 vs. FeO*/MgO diagram. The SiO_2 contents of GD and HFG rocks are from 63.3–72.4

wt.% and 72.0–75.6 wt.%, respectively. The alumina saturation index of GD and HFG ranges from 0.95 to 1.02 and 0.99 to 1.10, respectively. GD samples are plotted on volcanic arc granite field and HFG samples are plotted on volcanic arc granite and within-plate granite field on a geochemical discrimination diagram. Both GD and HFG samples are enriched in light REE, relative to heavy REE on the REE patterns diagram normalized by CI-chondrite. These results suggest that GD and HFG might be generated from different magmatic origins, although they are distributed in close proximity.

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A geochemical perspective to understand the petrogenesis of alkaline rocks from Angadimogar intrusive in Kasaragod district of Kerala, India

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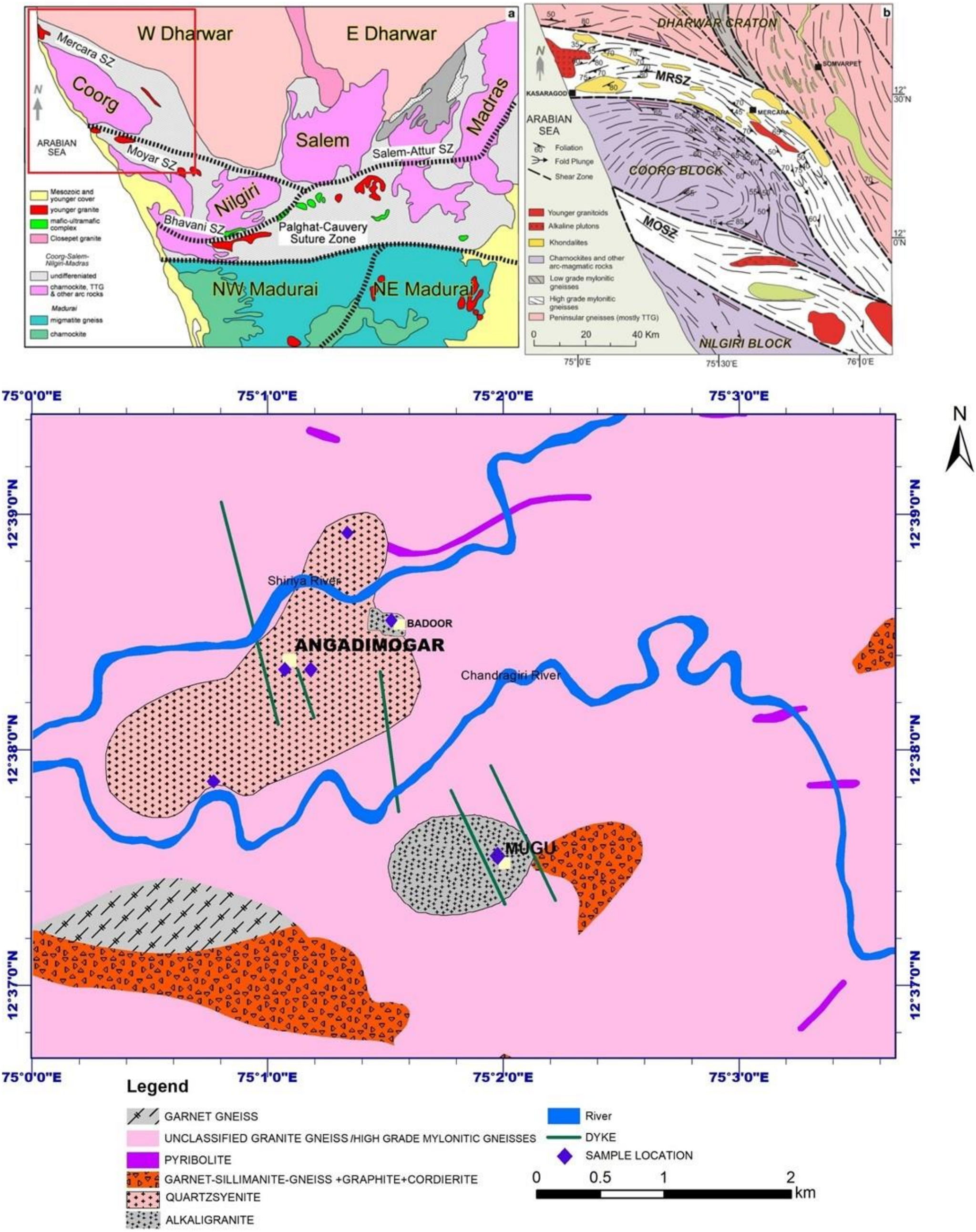
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Intrusives of syenite and alkali granite with strong alkaline affinities are found emplaced within the Precambrian granulitic terrain in Coorg block of Kerala state, southwest India. The intrusive at Angadimogar (AM) in Kasaragod district of Kerala [12°38’N - 75°00’E] is one amongst the

18 bodies that invaded the SW part of Peninsular shield of India, providing the evidences of prominent felsic magmatic events during Pan African period. The AM pluton has an aerial extent of 10 sq kms, is an undeformed and unmetamorphosed intrusive, and got emplaced along a NW-SE trending fault lineament that is confined to the Marcara shear zone, implying its close spatial association with taphrogenic faults and regional lineaments. The AM pluton is made up of coarse-grained rocks that vary from alkali-granites to quartz-syenites and quartz-monzonites: emplaced within gneissic country rock (Fig. 1). The rocks are dominated by K-feldspar (58-61%), plagioclase (12-24%), distinctly followed by quartz (8-14%) and ferromagnesian minerals are represented by amphibole (7-10%) and brownish biotite (5-6%) that exhibit clustering tendency indicating the high fluidity of the parental magma, and with accessory amounts of magnetite, sphene, apatite and zircon. The EPMA studies revealed that the K- feldspars present is predominantly orthoclase (Xor: 88-97) along with plagioclase feldspar represented by albite (Xab: 89-99) suggests subsolvus conditions of crystallisation. Micas correspond to biotite, while amphiboles present have an Edenite-Magnesio Hornblende composition.

The presence of normative hypersthene and corundum in these rocks suggest their subalkaline and peraluminous nature of the parent melt. The AM rocks are silica oversaturated peraluminous ferroan rich alkaline rocks with Na_2O (~5.5 wt. %) > K_2O (~4.3 wt. %). Mantle-normalized trace element patterns reveal the subduction-


a
W Dharwar
E Dharwar
Mercara SZ
Coorg
ARABIAN SEA
Moyar SZ
Salem
Madras
Salem-Attur SZ
Nilgiri
Bhavani SZ
Palghat-Cauvery Suture Zone
NW Madurai
NE Madurai
Mesozoic and younger cover
younger granite
mafic-ultramafic complex
Closepet granite
Coorg-Salem-Nilgiri-Madras
undifferentiated
charnockite, TTG & other arc rocks
Madurai
migmatite gneiss
charnockite
b
DHARWAR CRATON
MRSZ
KASARAGOD
MERCARA
SOMVARPET
ARABIAN SEA
Foliation
Fold Plunge
Shear Zone
COORG BLOCK
MOSZ
NILGIRI BLOCK
Younger granitoids
Alkaline plutons
Khondalites
Charnockites and other arc-magmatic rocks
Low grade mylonitic gneisses
High grade mylonitic gneisses
Peninsular gneisses (mostly TTG)
0 20 40 Km
75°0'E
75°30'E
76°0'E
12°30'N
12°0'N
75°0'0"E
75°1'0"E
75°2'0"E
75°3'0"E
12°39'0"N
12°38'0"N
12°37'0"N
N
Shiriya River
BADOOR
ANGADIMOGAR
Chandragiri River
MUGU
Legend
GARNET GNEISS
UNCLASSIFIED GRANITE GNEISS /HIGH GRADE MYLONITIC GNEISSES
PYRIBOLITE
GARNET-SILLIMANITE-GNEISS +GRAPHITE+CORDIERITE
QUARTZSYENITE
ALKALIGRANITE
River
DYKE
SAMPLE LOCATION
0 0.5 1 2 km

related signature with high LILE/HFSE ratios as well as fractionated LREE/HREE patterns, with pronounced troughs at Nb, Sr, P, and Ti which indicate retention of their concentration in the source. However, the geochemical signatures more appropriately point to variation from active continental margin to within plate volcanic zone. Further, the rock has high Zr, Nb, Th and U, and low Rb, Sr, Cu, V and Ba indicate the mixing of the melt. The ∑REE of the AM rocks range between 60 to 715 ppm and are characterized by negative Eu anomaly indicating differentiation of plagioclase feldspar in the genesis. They also display enriched LREE and depleted HREE pattern indicating low degree of partial melting. The intrusive under study displays similar features to the Pan-African plutons from the Afro-Arabian shield.

Evaluating the role of mafic recharge on the rejuvenation of silicic mushes: A rhyolite-MELTS approach

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Oral, Tuesday 12th September, 11:45 - 12:00

Under the current paradigm, silicic magmas within the upper crust are dominantly stored in a crystal-rich (>50-60% crystals), melt-poor, state. These uneruptible magma mushes require a mechanism by which they can transition to eruptible states (<50-60% crystals). Based on observations of mineral textures and geochemistry, that suggest dissolution preceded eruption, petrologic studies of crystal-rich silicic volcanic deposits commonly invoke recharge via hotter more mafic magma as a driver for mush rejuvenation. Therefore, constraining the effects of mafic recharge on a silicic mush is critical to understanding how eruptible magmas are generated within the upper crust and can provide context from which to interpret the geophysical signals associated with such recharge events. In this study, we integrate field and textural observations from silicic magmatic systems, as constraints, with rhyolite-MELTS modeling to explore how recharge of a silicic mush with hotter, more mafic, magma affects the crystal content within the mush by conserving enthalpy in the recharge-mush system.

Our models demonstrate that when heat transfer from a mafic recharge magma into a silicic mush is perfect (i.e., 100%), only small amounts (as low as 10% mafic recharge) of hotter more mafic magma are required to significantly reduce the crystal content of a locked mush, bringing it into a more eruptible state (Fig. 1). Lower proportions of heat transfer require larger proportions of mafic recharge to unlock a silicic mush (Fig. 1). Similarly, if the silicic mush remains water saturated over the extent of thermal equilibration, then smaller amounts of mafic recharge magma are required to bring the mush into an eruptible state when compared to a mush that is only initially water saturated. Our results suggest that only small volumes of mafic recharge magma are required to rejuvenate silicic mushes, if the region of emplacement (i.e., into the silicic mush “filter”) is conducive to the transfer of heat from the recharge into the mush.

Furthermore, by using rhyolite-MELTS we can track the evolution of the systems thermodynamic properties (including phase chemistry, melt composition, volatile content) during its approach to equilibrium with the mafic recharge magma. We utilize these modeled results to re-evaluate the textural evidence in crystals from large silicic magmatic systems to gain insight into the pre-eruptive evolution of the system. Our results suggest that recharge of silicic mushes with hotter more mafic magmas is central to the production and maintenance of eruptible magmas within the upper crust.

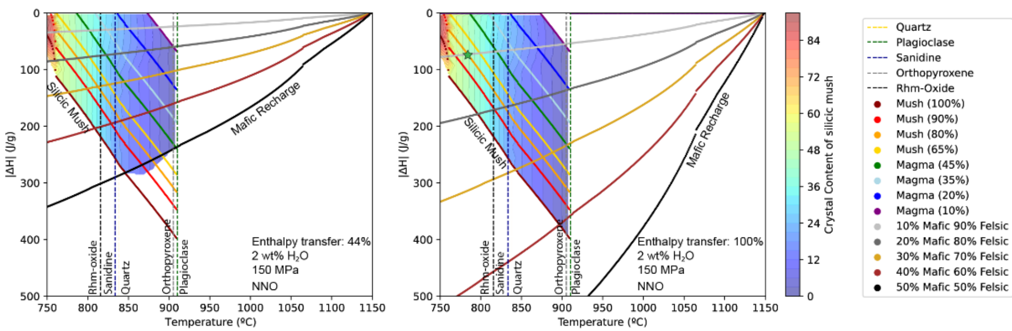

Figure 1: Results from rhyolite-MELTS models using a starting water content of 2 wt% with 44% (left) and 100% (right) enthalpy transfer between a mafic recharge (1 wt% H_2O) magma and a silicic magma/mush. Models contoured for the crystal content of the mush at the point of equilibrium between the mafic recharge and silicic mush. Vertical dashed lines reflect the saturation temperature of mineral phases as determined by rhyolite-MELTS. Numbers next to “magma” and “mush” reflect the starting crystal content of the silicic component in the model. **Worked example**: Right panel; mafic recharge of ~10% by volume of silicic mush, with initial crystal fraction of 80%. The recharge (gray line) crosses the orange line at ~790 ºC (green star). At this temperature, the silicic mush has a crystal content of 44% and a near invariant melt composition ~76.4 wt% SiO_2.

Crystal accumulation induced Sr/Y variation: insights from a rear-arc pluton in the western Central Qilian Belt, NW China

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Granitic plutons are interpreted as the product of melts, cumulates or crystal-rich mush. The different hypotheses yield distinct interpretations on the diversity of geochemical compositions, particularly the Sr/Y ratio. Here, we carried out detailed field and petrographic observations, geochronology, geochemistry, and isotopic studies of the Wulanyaodong pluton (WP) in the western Central Qilian belt of China to address these issues. Our results indicate that WP is composed of granodiorite, quartz diorite, syenogranite, monzogranite, felsic vein/dyke and microgranular enclaves that formed between 474 and 460 Ma. Pressure estimates suggest that the granodioritic and granitic units of the WP represent a magma evolution in the upper crust that formed between 14.1–1.0 km in depth, and reflects a change in crustal architecture that was emplaced incrementally. Petrographic observation and geochemical analyses suggest that the granodiorites at WP with different Sr/Y ratios are likely to be the products of a magma mush with different degrees of plagioclase ±

amphibole ± apatite accumulation, indicating crystal-melt separation processes. The microgranular enclaves and granite units represent late mafic magma injection, rejuvenation of granodioritic mush, and extracted melts, respectively. Rejuvenation of mush allowed for remobilization of residual melts to form small felsic veins and wide dykes that cross-cut the granodioritic unit. Our results highlight that crystal accumulation and melt segregation in the magma mush play a dominant role in triggering compositional variation in granite pluton.

Generation of isotopically enriched giant Lincang Batholith by disequilibrium melting of the heterogeneous lower crust

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Deciphering the origin of granitoids with enriched isotopic compositions is essential to understanding the mechanism of continental growth and reworking and is also an effective solution to the decoupled interpretations between geochemical and isotopic observations in competing petrogenetic models. This paper reports on the whole-rock major and trace elements, Sr-Nd-Pb-Hf isotopic, and zircon U-Pb age and Hf isotope data of samples from the Lincang Batholith in the eastern

Changning-Menglian suture zone of southwest China. The coeval Late Triassic hornblende-bearing granodiorites and biotite monzogranites belong to metaluminous to weakly peraluminous and weakly to strongly peraluminous granitoids, respectively. They have identical and dramatically enriched isotopic compositions with (87Sr/86Sr)i ratios varying from 0.71991 to 0.74302, whole-rock εNd(t) and εHf(t) values of –13.5 to –10.1 and –13.4 to –10.3, respectively, and variable zircon εHf(t) values (–17.6 to +0.6). The inherited zircons from both granitoids have 950 ± 20 Ma and a weakly ca. 1150 Ma age peaks, trace elements concentrations, and εHf(t) variations to the detrital zircons from the Lancang Group. Therefore, these magmatic rocks are most likely derived from the Lancang Group, which is mainly composed of quartz schist, sericite schist, greenschist, chlorite albite schist, and minor eclogite. However, the Lancang Group is characterized by more enriched isotopic compositions with whole-rock εNd(225 Ma) and εHf(225 Ma) values of –13.3 and –19.1, respectively, identical to the average εHf(225 Ma) values of inherited and detrital zircons (–18.1 and –16.3). This isotopic fractionation is mostly resulted from disequilibrium melting of the Lancang Group with different dissolution behavior of accessory minerals (i.e., zircon, monazite, apatite, titanite, etc). The Lincang Batholith is on average more silicic and rich in incompatible elements than the upper continental crust suggesting that the isotopically enriched giant granitic batholith is a mature response to continental reactivation and reworking.

Petrogenesis of Early Cretaceous high-MgO diorites and granitoids in the Rangnim Massif, North Korea: Implications for tectonic setting of magmatism and gold mineralization

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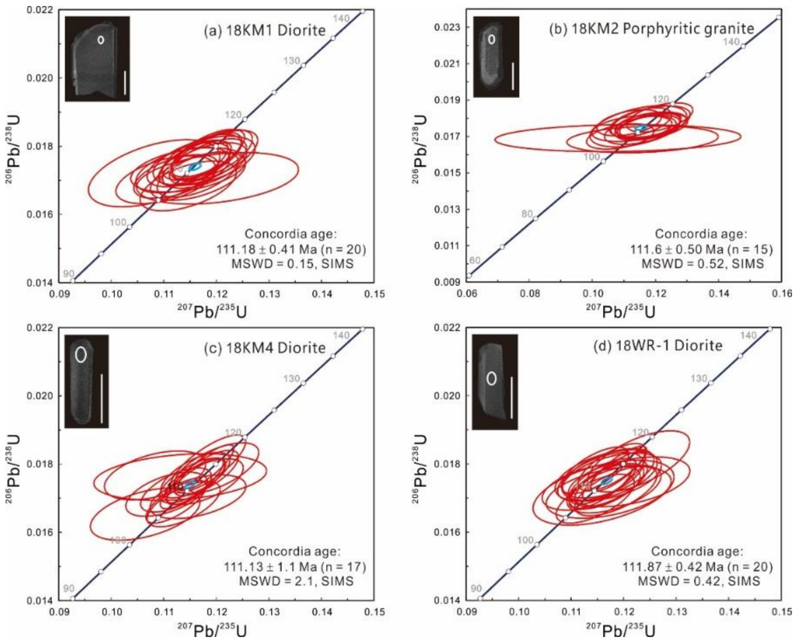
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

A large scale of gold deposit-hosted intrusive rocks are distributed in North Korea. A combination of whole-rock major and trace elements, Sr-Nd-Hf isotopes and zircon U-Pb and Hf-O isotope data are reported for the Early Cretaceous granitoids from the Rangnim Massif, North Korea, in order to constrain their sources, petrogenesis and tectonic setting. The intrusive rocks mainly consist of high-MgO diorites to granodiorites and porphyric granites. Zircon SIMS U-Pb dating gives coeval emplacement ages of 111-112 Ma for the magmatism. The high-MgO diorites and granodiorites have high MgO (up to 4.8 wt.%) at intermediate SiO_2 contents, indicating a mantle source. They have high initial $^{87}Sr/^{86}Sr$ rations and negative εNd(t) and εHf(t) values, suggesting that the mantle source had been metasomatized by continental crustal materials for a long term or by ancient crustal materials before magma generation. However, the coupling whole rock Nd and Hf isotopes and high $\delta^{18}O$ values of the high-MgO diorites argue for the later. The

high-MgO diorites and granites have variable major and trace elements and whole rock Sr-Nd-Hf isotopes. The well relationship between SiO2 (or MgO) and Sr, Nd or Hf isotopes suggest that the Ealy Cretaceous high-MgO diorites to granodiorites and granites were the result of pyroxene- and amphibole-dominated crystal fractionation of mafic magma, coupled with extensive crustal assimilation. Importantly, the identification of ancient continental crustal materials in the mantle reveals a lithospheric delamination event in North Korea before or at the timing of magma generation. Therefore, our new data suggest that the Early Cretaceous magmatism of Rangrim Massif is generated by AFC of enriched lithospheric mantle-derived magmas, and the magmatism and metallogenesis are the result of lithospheric delamination in North Korea during Early Cretaceous.



Disclosing the effect of accumulation and fractional crystallization of hornblende on arc magma evolution

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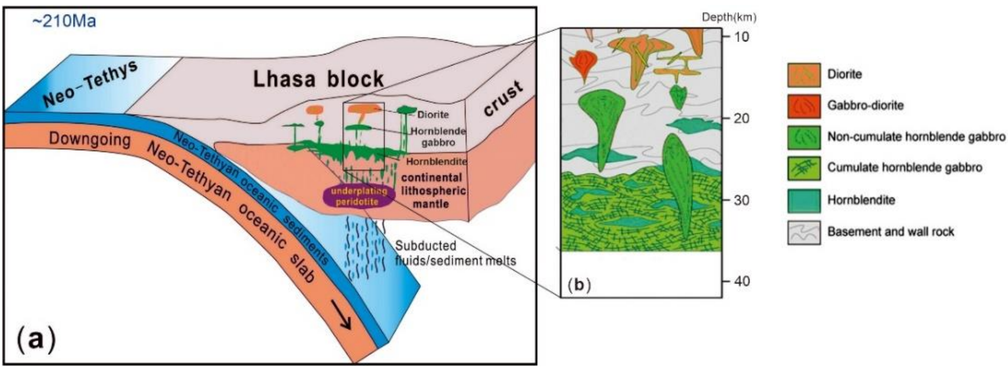
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Hornblende is one of the most important rock-forming minerals. Despite its importance in arc magmatic differentiation, the fundamental mechanism (i.e., accumulation and fractional crystallization) that hornblende controls magmatic evolution remains enigmatic. Hornblende-rich rocks are widely exposed in the Gangdese magmatic belt of southern Tibet. Among them, the Quxu batholith provides important information for understanding these above-mentioned disputes. The Quxu batholith mineral distribution has an obvious vertical variation, and the content of hornblende gradually decreases from the bottom to the top with rock types varying from hornblendite through hornblende gabbro to diorite. In this study, combined with new geological observation and literature data, we carried out detailed petrological, chronological, and geochemical studies on these hornblende-bearing intrusive rocks. The zircon U-Pb dating results yield ~210 Ma. The Sr and Nd isotopic compositions indicate that the different types of rocks types are derived from the same parental magma, formed

by partial melting of a water-enriched depleted mantle that was metasomatized by subducted slab–derived fluids/melts. Hornblendite is relatively enriched in medium rare earth elements (MREE), while diorite is relatively depleted in MREE, indicating the separation of hornblendes. Coupled with petrographic and geochemical features, hornblendite is generated by accumulation of hornblendes, and hornblende gabbro and diorite are formed by fractional crystallization of the post-accumulation residual melt. Therefore, the way in which hornblende influences arc magmatism changes progressively from accumulation to fractional crystallization, both of which play important roles in the formation of felsic arc magmas and the evolution of the crust.



Identification of fractionation processes in the Himalayan leucogranites-The case study from the Nyalam region

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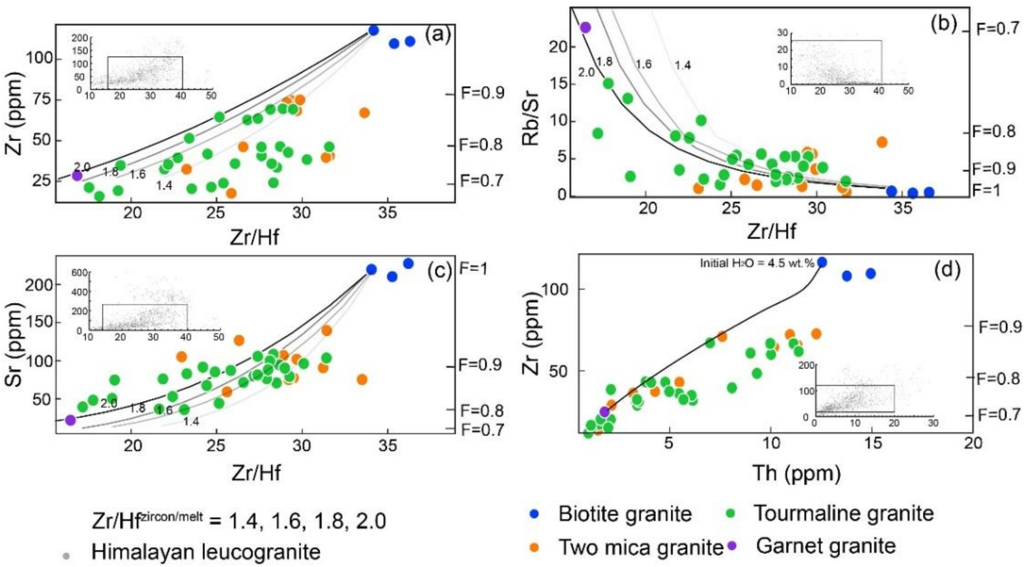
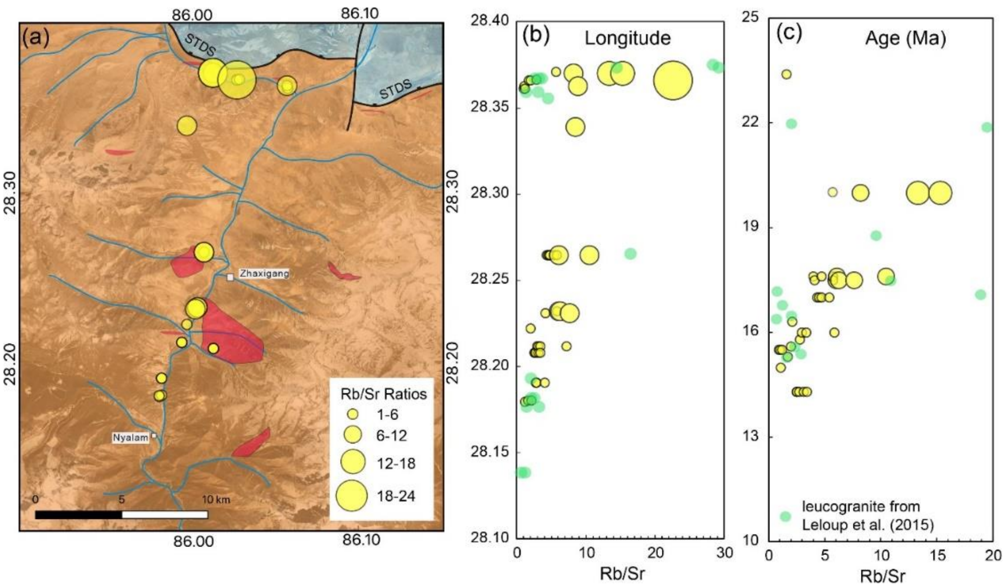
Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

As the product of a collisional belt, Himalayan leucogranites provide insights into the geodynamic and thermal evolution of the tectonically thickened crust. Nevertheless, the petrogenesis of the Himalayan leucogranites is still a much-debated topic. Normally, leucogranites are interpreted as the primary melt formed by partial melting of the Greater Himalayan Crystalline Complex (GHC). There is another view that the leucogranites are the product of less evolved melt that experienced fractional crystallization. This study aims to explore these competing petrogenetic models. We collected biotite granite, two-mica granite, tourmaline granite, and garnet granite in the Nyalam region for mineralogical and geochemical studies. The granites occur as small laccoliths, sills, and dikes in the upper GHC and the South Tibet Detachment System (STDS). The plagioclase in biotite granite is oligoclase but is albite in other rocks. From biotite granite to two-mica granite to tourmaline granite, Mg and Ti in biotite and Zr/Hf in zircon gradually decrease, and AlVI and XFe in biotite and HfO_2

in zircon increase correspondingly. Garnet is normally euhedral spessartine, and it only appears in garnet granite, suggesting an increase of Mn/(Fe+Mg) in the melt. Variations in the mineral assemblages and composition of the granite are associated with systematic changes in SiO_2, CaO, FeO, and MgO content in the whole rock. These suggest that biotite granite is the least evolved rock, and that the fractionation of two-mica granite, tourmaline granite, and garnet granite is gradually increasing. Increasingly fractionated character is supported by trace elements. Rb-Sr-Ba trace element modeling suggests that the feldspars (plagioclase and k-feldspar) are the main fractionated minerals. Zr-Hf-Sr modeling indicates that the decrease of the Zr/Hf ratio in the melt is related to the fraction of zircon fractionated, which is controlled by the change of temperature and melt composition.



Additionally, very high Rb/Sr (>20), low Zr/Hf (<20), and negative Eu anomaly (0.2) in garnet granite indicate that the melt has experienced extensive fractionation. Compiled Himalayan leucogranite geochemistry presents a similar pattern to our data and modeling result, suggesting that the variety of Himalayan leucogranites might relate to fractional crystallization. In addition, the composition of leucogranites in the Nyalam is a function of spatial position and age. The leucogranites that were produced during the activity of STDS and developed close to STDS have more evolved compositions, indicating that the development of STDS might play an essential role in the differentiation of leucogranite in the Himalayas.



Effect of oxygen fugacity and melt composition on iron partitioning between apatite and silicate melt

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Apatite is an accessory mineral widely used in terrestrial and extraterrestrial geological studies because of its common occurrence in various rocks and ability to incorporate many chemical elements sensitive to physical and chemical conditions. Understanding how chemical elements partition between apatite and melt is critical for applications of apatite. Here, we compiled a comprehensive dataset of apatite and coexisting melt compositions from phase equilibrium experiments to study the partition coefficient of Fe between apatite and silicate melt (D-Fe). We find that D-Fe varies with melt oxygen fugacity (fO_2) and melt composition, in particular, the degree of melt polymerization characterized by the ratio of non-bridging oxygens to tetrahedrally coordinated cations (NBO/T). D-Fe increases with decreasing melt fO_2, implying that both ferrous and ferric Fe enter apatite and that ferrous Fe is more compatible than ferric Fe. D-Fe also increases as melt becomes more polymerized (decreasing of NBO/T), suggesting that decreasing availability of NBO in evolved melt causes Fe to be more

compatible. Apatite FeO contents can be used to estimate fO_2 of melt during apatite crystallization and apatite with high FeO contents (>2 wt%) in natural rocks is likely an indicator of fO_2 below the FMQ buffer.

Apatite geochemical and Sr-Nd isotopic constraints on the source and petrogenesis of alkaline volcanic-plutonic ring complex

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Alkaline rocks commonly occur as volcanic-plutonic ring complexes, but the petrogenetic mechanism for the coexistence between volcanic and plutonic rocks remains controversial. The Early Cretaceous Houshihushan alkaline ring complex in the Yanshan Fold and Thrust Belt, China, contains arfvedsonite granites surrounded by syenites, trachytes and alkali rhyolites. In situ trace elements and Sr-Nd isotopic compositions of apatites from these rocks are presented to constrain the petrogenetic link between coeval alkaline volcanic and plutonic rocks. Petrographic and geochemical features suggest that apatites in the trachyte crystallized from the melt at an early stage. Their initial 87Sr/86Sr ratios (0.7048-0.7052) and εNd(t) values (-21.9 to -17.6) well constrain the Sr-Nd isotopic compositions of the

lithospheric mantle source for the trachyte, better than those of whole-rock (0.7114 and -18.6, respectively). In contrast, apatites in the syenites crystallized from host melt throughout the whole history of the magma evolution. Their geochemical features and variable initial 87Sr/86Sr ratios (0.7084–0.7175) and εNd (t) values (-16.0 to -12.7) suggest that the syenites were formed by the cumulation of their parental magma, coupled with gradual mixed by felsic magma with a high initial 87Sr/86Sr ratio. However, a few and small-size apatite grains crystallized from the parental magma of the arfvedsonite granites and alkali rhyolites suggest that the in situ geochemistry of apatites is not feasible to constrain the petrogenetic process of the high-silica alkaline rocks. Combined with the whole-rock data, the geochemical features and Sr-Nd isotopic compositions of apatites indicate a crystal mush model to interpret the genetic link between syenites and arfvedsonite granites and alkali rhyolites. The early accumulations of mixing mafic and felsic magmas formed syenites at the margin, while the residual silicic melts solidified as arfvedsonite granites at the core. After the exposure of the intrusives rocks by rapid exhumation, the injection of high-temperature mantle-derived magma into the crystal mush promoted the extraction of the residual melt from the magma chamber. The mantle-derived magmas and residual melts directly erupted to the surface to form trachyte and rhyolite in the middle, eventually forming the alkaline ring complex.

Continental crustal growth processes recorded in the Gangdese Batholith, southern Tibet

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

The continental crust in the overriding plate of the India-Asia collision zone in southern Tibet is characterized by an overthickened layer of felsic composition with an underlying granulite-eclogite layer. A large data set indicates that this crust experienced magmatism from 245 to 10 Ma, as recorded by the Gangdese Batholith. Magmatism was punctuated by flare-ups at 185-170, 90-75, and 55-45 Ma caused by a combination of external and internal factors. The growth of this crust starts with a period dominated by fractional crystallization and the formation of voluminous (ultra)mafic arc cumulates in the lower crust during subduction, followed by their melting during late-subduction and collision, due to changes in convergence rate. This combined accumulation-melting process resulted in the vertical stratification and density sorting of the Gangdese crust. Comparisons with other similarly thickened collision zones suggests that this is a general process that leads to the stabilization of continental crust.

Contribution of alkaline magmatism to the petrogenesis of Triassic aluminous A-type granites from the Liaodong Peninsula, North China Carton

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Poster, Monday 11th and Tuesday 12th September, 17:00 - 19:00

Aluminous A-type granites are rarely associated with mantle-derived rocks. Their generation is usually related to the crustal melting and the mantle magma mainly serves as the heat source. However, some Triassic aluminous A-type granites that coexisted with the large mantle-derived alkaline complex and show close genetic link were recently found in the Saima-Bolinchuan area of Liaodong Peninsula, eastern China, which provides new insights into the petrogenesis of the aluminous A-type granites. Four small granitic stocks, including Yaopai, Xiaoshimen, Dashihumiao and Tianqiaogou were identified surrounding the Triassic Saima alkaline complex. They are mainly quartz monzonite and monzogranites and formed at 223-230 Ma, identical with the formation age of associated alkaline rocks (224-230 Ma). The granites are metaluminous but show high alkali contents at the SiO_2 content of 62.1-69.8 wt%. Their high Ga/Al ratios and high Nb, Zr, Ce and Y concentrations, in combination with the high bulk zirconium saturation

temperature (760-843℃), indicative of aluminum A-type granite affinity for these rocks. In-situ apatite Sr-Nd and zircon Hf isotopes of the granites as well as the bulk Sr-Nd-Hf isotopes are overlapped with the associated alkaline rocks though slightly less enriched, suggesting the ultimate origination of the granites from mantle sources similar to the alkaline rocks. Mineralogical and geochemical variations from the alkaline rocks to the A-type granitic rocks indicate that the fractional crystallization of syenitic melts parental to the associated Saima alkaline rocks, combined with the addition of crustal materials generated the granitic rocks showing aluminous A-type features. Our work reveals that the mantle can not only provide heat for the formation of aluminum A-type granites, but also be its main material provenance.

Theme 3 – Architecture of crustal magmatic systems and rate of magmatic processes

Thermal Histories of the Mount Whitney Intrusive Suite Recorded in Quartz

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Minerals in granitic rocks (s.l.) have the potential to record the chemical and thermal evolution of sub-volcanic and ore-forming magmatic systems. However, once granitic bodies cool below the solidus, their mineral assemblages are susceptible to post-magmatic hydrothermal and metamorphic alteration. Quartz trace element chemistry can help disentangle the magmatic and post-magmatic histories of granitic rocks. In particular, the solubility of Ti in quartz (with respect to $aTiO_2$, temperature and pressure) combined with the diffusivity of Ti in quartz are potentially powerful tools for investigating crystallization temperatures and cooling histories. In this study, quartz crystals from the Mount Whitney Intrusive Suite and Golden Bear Dike are studied with cathodoluminescence (CL) imaging, Ti-in-quartz thermobarometry, and Ti diffusion modeling to disentangle magmatic and post-magmatic features in quartz and place constraints on the cooling rates of granitic systems.

The Mount Whitney Intrusive Suite (MWIS) is one of several Late Cretaceous, compositionally-zoned plutonic suites along the spine of the Sierra Nevada Batholith in the western United States. Major units within the suite record zircon crystallization spanning from 90 to 83 Ma. In addition to the main plutonic body, the MWIS also hosts the petrologically-linked Golden Bear Dike (GBD), a ~83 Ma, 40 % crystalline, k-spar megacryst-bearing dike that extends eastward into the wall rock. Rapid quenching of the GBD relative to the main body of the MWIS provides a natural laboratory to investigate the effect of cooling rate on the preservation/alteration of granitic minerals.

Quartz phenocrysts in the Golden Bear Dike contain several common features. The cores of quartz phenocrysts typically contain clusters of multiple minerals (e.g., titanite, apatite, zircon, Fe-Ti oxides) in an altered groundmass. Quartz mantles and rims are characterized by oscillatory zoning in CL. Quartz crystals from the MWIS retain a more diverse and complex internal morphology consisting of: 1) massive, uniform zoning, 2) "wormy" solid-state metamorphic zoning, 3) low-Ti veining, and 4) zoning and core mineral clusters akin to quartz from the GBD.

The later group of MWIS quartz is a potential direct analog to quartz crystals in the GBD. Comparison of these crystal populations using Ti-in-quartz thermobarometry and diffusion modeling suggests crystallization 10s of degrees above the wet solidus and rapid cooling of the MWIS on the order of 100-300 °C/Myr. While these results are certainly not definitive, it is difficult to reconcile the observed diffusion profiles with the slower diffusivities of some experimental studies.

Magmatic emplacement mechanisms of the S-type Peninsula Granite, Sea Point contact, Saldania Belt, South Africa

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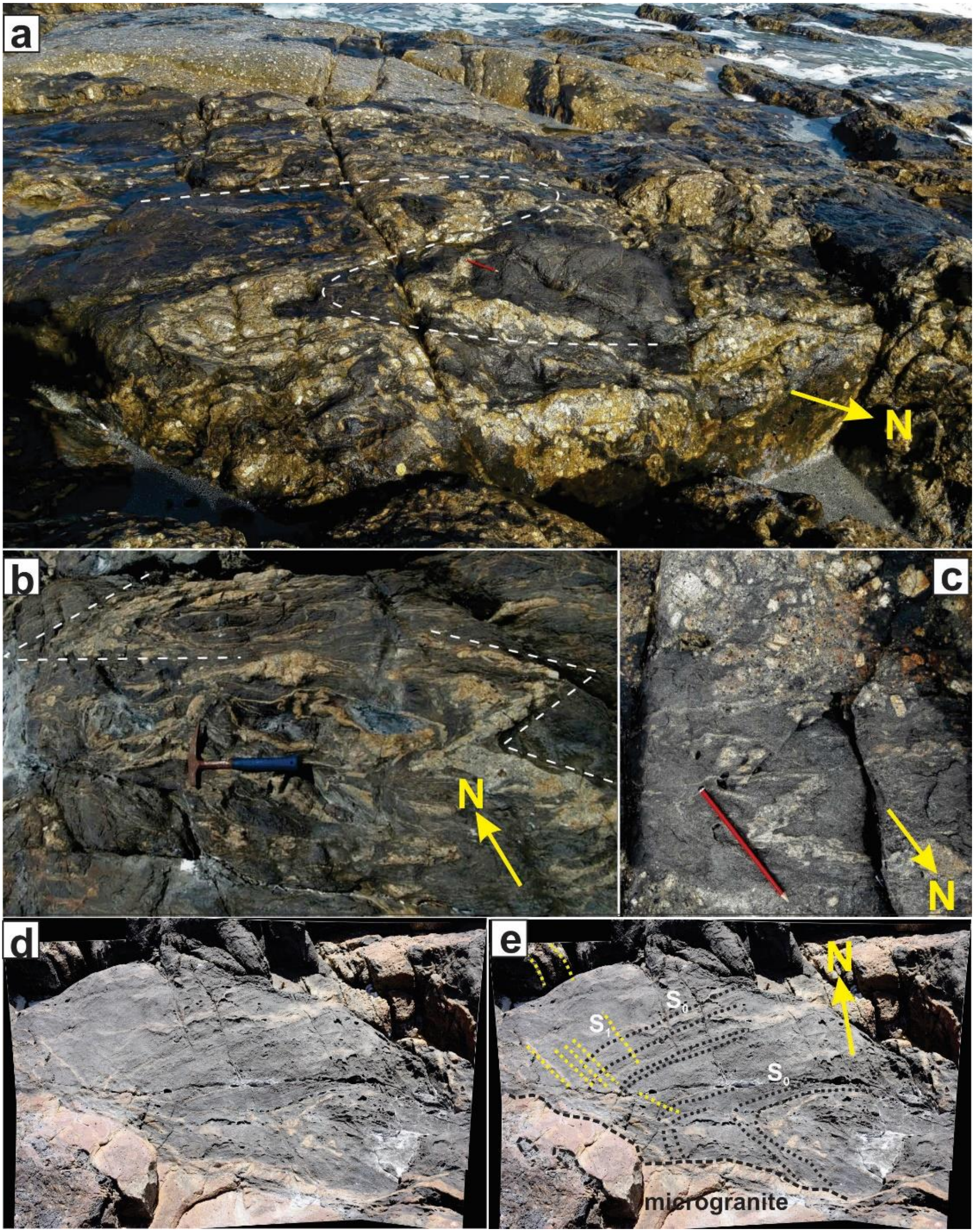
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

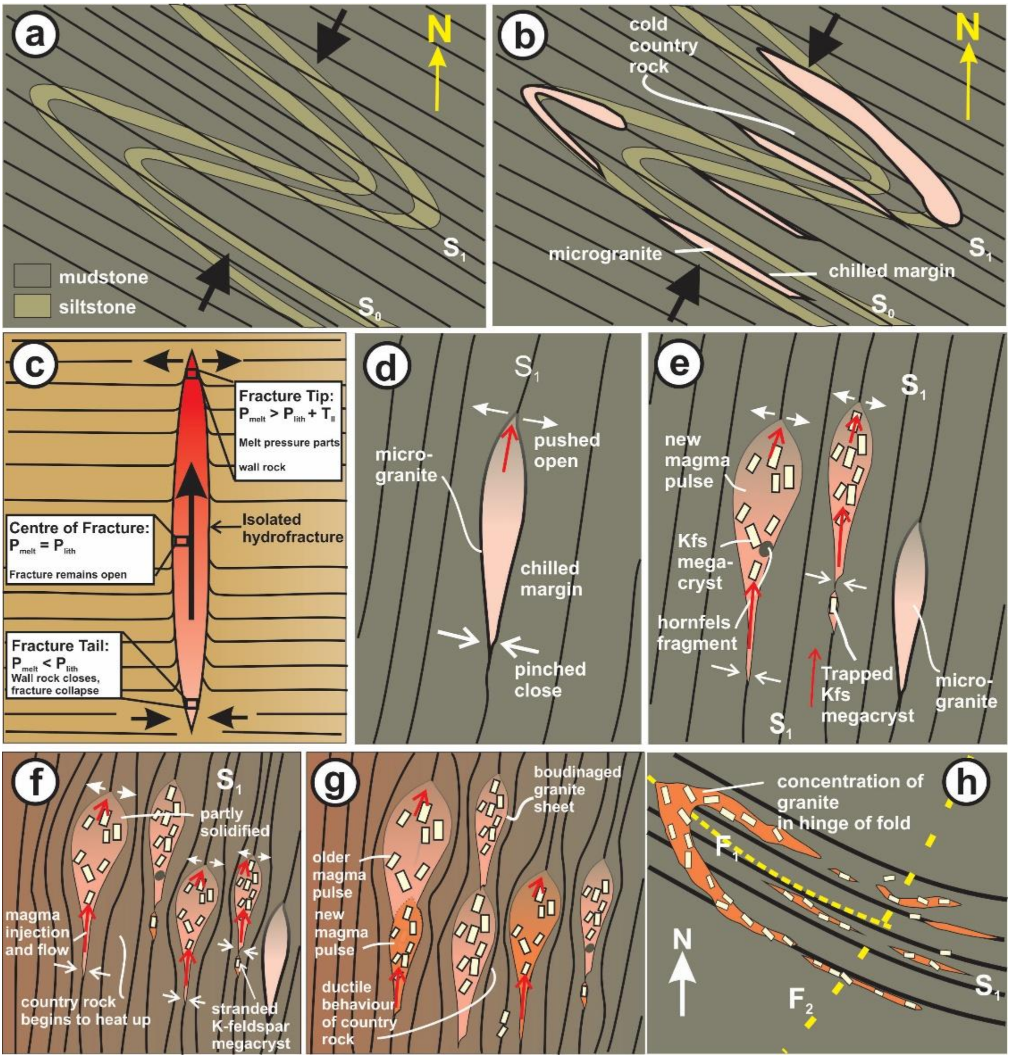
The Sea Point contact, Cape Town, South Africa exposes the intrusive contact between the Peninsula Granite of the Cape Granite Suite and the metasedimentary Malmesbury Group country rock. The main contact zone is marked by compositionally variable "hybrid" granite sheets that intruded concordant to the country rock structure that pass into the dominant voluminous coarse-grained porphyritic granite.

The hybrid granites were primarily emplaced as incrementally assembled, repeated pulses of steeply inclined granitic sheets approximately normal to, or at high angles to the regional NE-SW-directed D1 shortening. The pre-existing planar anisotropies (bedding planes and foliations, predominantly S1) in the country rock provided preferential pathways for magma emplacement and propagation during deformation. The tensile strength normal and parallel to the bedding and foliation anisotropy of the country rock was larger than the regional differential stress ($\sigma1 - \sigma3$, with $\sigma1 \geq \sigma2 \geq \sigma3$), allowing for magma emplacement relative to shortening.



Magma overpressure at the tip of the hydrofracture allowed upward magma propagation whereas lower magma pressure at the tail of the hydrofracture resulted in closure. This filter-pressing along a magma conduit which contained a variable crystal content left behind variable amounts of melt and crystals in the country rock due to magma through-flow. Magma was concentrated in the hinge zones of NW-SE-oriented F1 folds in the Malmesbury Group. Field and petrographic evidence suggest a late syn-tectonic timing for granite emplacement relative to the main D1 deformation phase. Shear sense indicators occur on horizontal surfaces, approximately perpendicular to the foliation plane. These occur as sigma and delta-type markers in country rock xenoliths and in tails associated with various entrapped K-feldspar megacrysts in the Malmesbury Group country rock. These suggest a degree of shearing and deformation during granite emplacement in addition to magma flow. A degree of ductile flow of the host rock to accommodate granite emplacement due to highly viscous magma flow is also evident.

Granitic intrusion involved a feedback mechanism whereby tensional stresses opened up space which allowed magma to intrude, which subsequently pushed aside the country rock to make space for itself particularly as the intruding magma pulses became more voluminous. Heating of the country rock during magma pulse intrusion resulted in sufficient heating to enable the country rock to behave plastically thus facilitating magma through-flow. Magma stoping, as evident from country rock xenoliths within various types of hybrid granite, is interpreted to have been a secondary emplacement process.



Magma defrosting and melt extraction, Ashland pluton, California and Oregon, USA

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Oral, Thursday 14th September, 11:00 - 11:15

Many granitic magmas spend much of their history as weakly mobile or locked mushes. Eruption of such magmas evidently requires heating--defrosting--which allows for extraction of melt-rich magmas or mobilization of the entire mush (monotonous dacite). The former type of defrosting implies formation of a conjugate, cumulate, plutonic part of the system. Petrographic and geochemical features of defrosting are well-described from eruptive rocks. Is there evidence for defrosting and potential melt loss, in plutons? We present such evidence from the Late Middle Jurassic Ashland pluton, which is exposed along the Oregon–California border.

The Ashland pluton is an eastward-tilted intrusive complex that consists in structural order (west to east) of diorite and gabbro, tonalite, quartz monzodiorite and granodiorite (QMD unit), and upper biotite granite. The mafic enclave-rich QMD unit displays crystal fragmentation, formation of mineral clusters, widespread resorption of hornblende, biotite, plagioclase, and titanite, and local concentrations of refractory accessory minerals, which were originally enclosed in resorbed phases. All these features are consistent with partial melting of a magmatic mush. Augite, hornblende, and plagioclase in the QMD unit are not in exchange equilibrium with a melt of bulk-rock composition. Moreover, calculated compositions of melt coexisting with augite are much more evolved than bulk rocks. These data indicate that the QMD unit lost a melt phase. This lost melt lies, at least in part, in the biotite granite unit, which intrudes and overlies the QMD. In the biotite granite, plagioclase core compositions are identical to plagioclase in the QMD, some plagioclase cores contain inclusions of deeply resorbed titanite, and alkali feldspar displays subhedral to anhedral cores in CL images. These features likely represent crystal cargo from the QMD source. Hornblende and biotite in the biotite granite are enriched in Ti and Nb, which indicates that biotite granite magmas did not evolve by fractional crystallization of QMD magmas. Instead, we interpret the enrichment to reflect high field strength element contributions from titanite during defrosting of QMD mush. The defrosted melt rose and crystallized to form the upper biotite granite unit. Interpretation of the QMD as a defrosted mush, and the biotite granite unit as the extracted melt is consistent with the cumulate compositions of most QMD samples.

Should I stay or should I blow? Emplacement and eruption of a shallow-crustal granitic magma reservoir – the Reyðarártindur granite pluton, Southeast Iceland

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Oral, Thursday 14th September, 12:15 - 12:30

Silicic magmas have a hard time erupting without a specific trigger, simply because of their high viscosity. In Iceland, the frequent association of silicic eruptive products with mafic magmas led to the hypothesis that mafic magma recharge is the main trigger for silicic magma eruption. Here, we present the first study of the Reyðarártindur granite pluton, Southeast Iceland, an example of shallow silicic magma emplacement and eruption without the involvement of mafic magma.

The Reyðarártindur pluton is a Miocene granitic pluton emplaced into mainly basaltic lavas at about 1-2 km depth. While the pluton floor is not exposed, glacial erosion produced natural sections through the uppermost 300 m of the pluton. These sections include spectacular exposures of the roof and wall contacts, as well as access to the upper part of the pluton interior.

Our detailed geological and structural mapping, paired with photogrammetry, allowed us to reconstruct the original pluton shape with a total estimated volume of least 2.5 km3 contained in a complex rhomboid with steep walls and a stepped, but dominantly flat roof. While the wall contacts truncate the basalt host rock at right angles, the roof is concordant. We interpret these observations to reflect initial magma emplacement at different depths, and pluton growth by piecemeal floor subsidence.

Rock sampling, textural, petrological, and geochemical analyses demonstrate that the bulk of the pluton is composed of the same granitic rock. The lowest exposures contain abundant enclaves of quartz monzonite and another granite, all sourced from the same underlying plumbing system. All three granitoids are also present in the base of two volcanic conduits that extend from the pluton roof into the overlying rocks. These conduits are associated with local pluton-roof subsidence and faulting dissimilar to the roof structures observed elsewhere. Within the conduits, tuffisites and magmatic breccias occur, and the rock is grading upwards into more fine-grained rock with textures typical of volcanic rocks. Based on these observations, we conclude that silicic magma recharge and mingling triggered eruptions from the Reyđarártindur magma reservoir.

Hence, Reyđarártindur is a striking example of the plutonic construction and the plutonic-volcanic connection that illustrates silicic magma emplacement and eruption without the involvement of mafic magma.

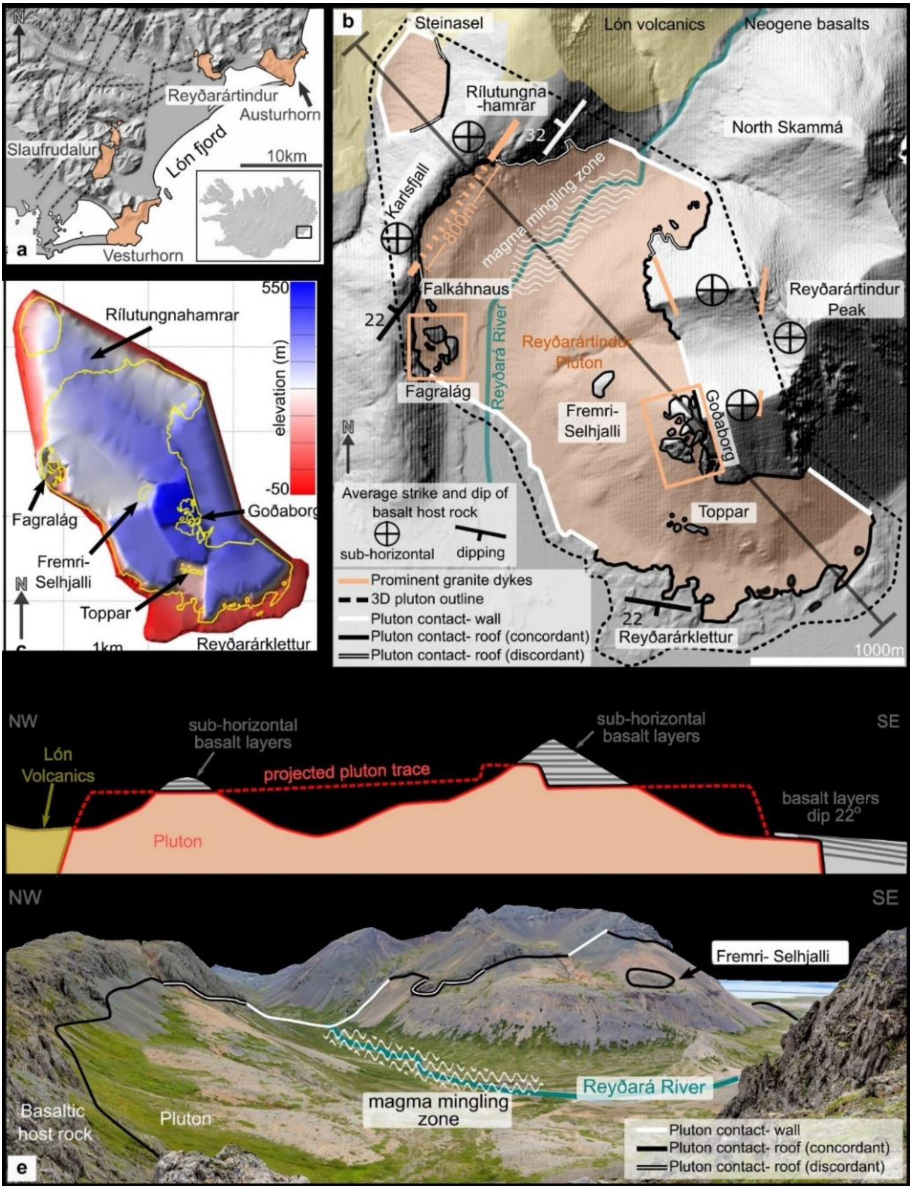

Figure 1. a) Locations of plutons in Southeast Iceland. b) Map of the Reyðarártindur pluton. c) 3D reconstruction of the pre-erosional pluton shape. d) Cross-section through the pluton. e) View across the main part of the pluton.

Modeling the rheology of crystal-bearing magmas

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Oral, Thursday 14th September, 12:00 - 12:15

We propose a two-phase flow model describing the rheology of crystal-bearing magmas that has the potential to represent a wide range of processes inferred to control the evolution of magmatic systems. Such processes include magma recharge and mixing, the temporary storage of crystal cargo, the extent and shape of the magmatic system itself, and the jamming of crystal-rich magmas that enables a mush to partake in volcanic eruption and/or cool down to form a plutonic body. We have shown over the years that Computational Fluid Dynamics coupled with Discrete Element Modeling (CDF-DEM) has the potential to represent the rheology crystal-bearing magmas. The scale of such simulation, however, is small (less than a cubic meter) compared to the cubic kilometer size of natural magmatic systems. The duration of the simulated processes (a few hours) is also regrettably short. As a result, CDF-DEM can only address a few of the key processes listed above (e.g., magma recharge and mixing). To scale up simulation time and size, we propose to define a two-phase flow rheology where the melt is treated as a fluid and the behavior of suspended crystals is averaged into a granular continuous phase. Such an approach has been used in the study of immersed granular systems and many

rheology relationships are available in the literature (e.g., mu(I)). Using CDF-DEM simulations as a baseline, we show that, unfortunately, the high viscosity in silicate liquids yields dynamical regimes that are not captured by these relationships. We thus used the same CDF-DEM outputs to define a new, two-phase flow rheology that accommodates a large range of crystal contents at high liquid viscosity, including the full jamming expected to occur in mushes. We then present a two-phase flow model based on this new rheology that has the potential to be scaled up to the size of natural magmatic systems.

High-resolution numerical modelling of rhyolite generation and transport induced by basalt emplacement into the crust beneath Long Valley, CA

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

We present a new high-resolution numerical model of the thermal and compositional evolution of the crustal column beneath Long Valley, California, a site of voluminous rhyolitic volcanism over the past 2.2 Myr, driven by the influx of basalt. This model incorporates a set of criteria for segregation of produced rhyolitic melts (i.e., partial melts of granitoid wall rock and late-stage interstitial melts from ≥80% crystallized basaltic sills), and their

emplacement higher in the crustal column, which significantly alters crustal-scale thermal and compositional profiles. The basaltic sills are randomly emplaced at a rate of 50 m/5 kyr within a climbing 2-km depth window (from 28-30 km to 18-20 km) into an initial 20°C/km geotherm. Segregation and dike transport of the rhyolite melt are facilitated by 100% melting and ascent of pre-existing, eutectic aplite dikes (ubiquitous in granitoids) of critical widths, which draws in partial melt from granitoid as well as late-stage interstitial melt from adjacent basaltic sills. Our results show that mobilized rhyolite melt is, on average, a mixture of ~40% partial melt of granitoid and ~60% interstitial melt from basaltic sills; its total thickness is ~25% of the cumulative thickness of emplaced basalt. Owing to lower (vs higher) Sr and Nd bulk partition coefficients for rhyolitic melt derived from basaltic sills (vs granitoid), >90% of the Sr and Nd in mobilized rhyolite melt is derived from basaltic sills. Thus, basalts emplaced into granitoid crust strongly control the isotopic signature of the produced, mixed rhyolites. Our model emplaces the newly formed rhyolites (~73 wt% SiO_2 on average) into the middle crust (~15-18 km), similar to the composition and depth of most of the granites exposed at Spirit Mountain batholith in the Colorado River extensional corridor, Nevada (Walker et al., 2007). The next stage in our modelling work is to explore the conditions for development of an upper high-SiO_2 (>76 wt%) leucogranite cap and lower quartz-monzonite zone (~63-68 wt% SiO_2), similar to the compositional gradient observed at the Spirit Mountain pluton; Walker et al., 2007). Tracking the thermal and compositional consequences of transporting two generations of segregated rhyolite melt, driven by the emplacement of basalt into the lower and middle crust, respectively, helps place constraints on the multi-stage processes that led to the formation of the Long Valley, CA high-SiO_2 rhyolites.

Temporal evolution of the chemical and thermal architecture of volcanic plumbing systems

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The determination of the chemistry of minerals erupted during the history of volcanoes provides information on the temporal evolution of the distribution and chemistry of magma stored within their plumbing systems. We use a combination of unsupervised and supervised machine learning to produce a petrologic image of magmatic systems both associated with plutonic and volcanic products.

The results show that while magmatic plumbing systems have specific characteristics, they tend to be ephemeral in their shallowest portions. At the same time, the thermobarometric record of volcanic eruptions is best explained by a sampling bias with the shallowest portions

of the plumbing system, containing eruptible magma, being preferentially sampled by eruptions. Moreover, most of the magmas are not saturated in H_2O-rich fluids in the deepest portion of the plumbing system. This favours decompression melting and a sparse record of the high-temperature-high-pressure structure of the plumbing system. While the results for some eruptions can be reconciled with a trigger by the injection of magma sourced from depth, other eruptions do not record any evidence of magma injection in the period immediately preceding an eruption.

The combination of thermobarometry and chemometry reveals the presence at shallow depth of chemically evolved magmas even in systems commonly erupting basaltic magmas. Finally, the comparison between recalculated melts and whole rock analyses of volcanic rocks highlights differences produced by the entrainment of antecrystals and/or the reaction between percolating melts and highly crystallised magmas residing at different depths within the crust.

Transtensional tectonic controls on post-Variscan magmatism and related ore formation in the Eastern Erzgebirge, Germany

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Eastern Erzgebirge region is exceptionally well endowed in magmatic-hydrothermal ore deposits, which are related to granitic magmatism following the Paleozoic Variscan Orogeny. In this contribution, we explore possible links between this magmatism and the Elbe Shear Zone (ESZ), a major trans-crustal geological structure that separates the Erzgebirge from the significantly less endowed Lausitz Block. This raises the question about the possible role of the ESZ in the evolution of the Eastern Erzgebirge mineral systems.

The ESZ is well known to be a zone of long-lived (and still ongoing) tectonic activity, with mostly dextral kinematics and a total of ~40–50 km offset. It has been subject to a complex interplay of late to post-Variscan tectonic, magmatic, and sedimentary processes. At least two distinct trans-tensional events can be distinguished, and attributed to dextral strike-slip activity on the ESZ. These are recorded by (1) the Meissen Massif, a composite intrusion that was emplaced at 330–320 Ma into a large dilatational jog, and (2) the Döhlen Basin, a pull-apart intramontane basin with abundant ignimbrite tuff units ranging in age from ~294–286 Ma.

These two ages bracket a potentially extensive period of activity on the ESZ, and indicate a spatio-temporal link between the ESZ and formation of the Tharandt and Altenberg-Teplice Calderas at ~315–310 Ma. The latter is well known to host a number of small granitic stocks endowed with significant Sn-Li-(W-Cu) mineralization. We suggest that the transtensional tectonics associated with dextral strike-slip on the Elbe shear zone is an important control on this mineralization, providing the large-scale crustal architecture that supported these significant plutonic and caldera systems. Specifically, we suggest that zones of strain-transfer between NW–SE striking dextral strike-slip faults localize felsic magmatism by (1) establishing favorable pathways to the lower crust through which melts can ascend and (2) accommodating growing plutons in the upper crust.

This contribution is a part of the "New Potential" project initiated by the State Geological Survey of Saxony, which deals with the exploration of new perspective areas in the Eastern Erzgebirge mountains.

Depth of emplacement of the Re di Castello intrusion (Adamello Batholith) constrained by contact metamorphism of pelitic country rocks

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Re di Castello is the earliest and southernmost unit of the composite Adamello batholith. It emplaced between 42 and 39 Ma. Its depth of emplacement is not well constrained.

We have studied the contact metamorphism of pelitic country rocks in two localities: the upper Caffaro Valley and the Borzago Valley, respectively in the southern and the northern sub-units of the Re di Castello.

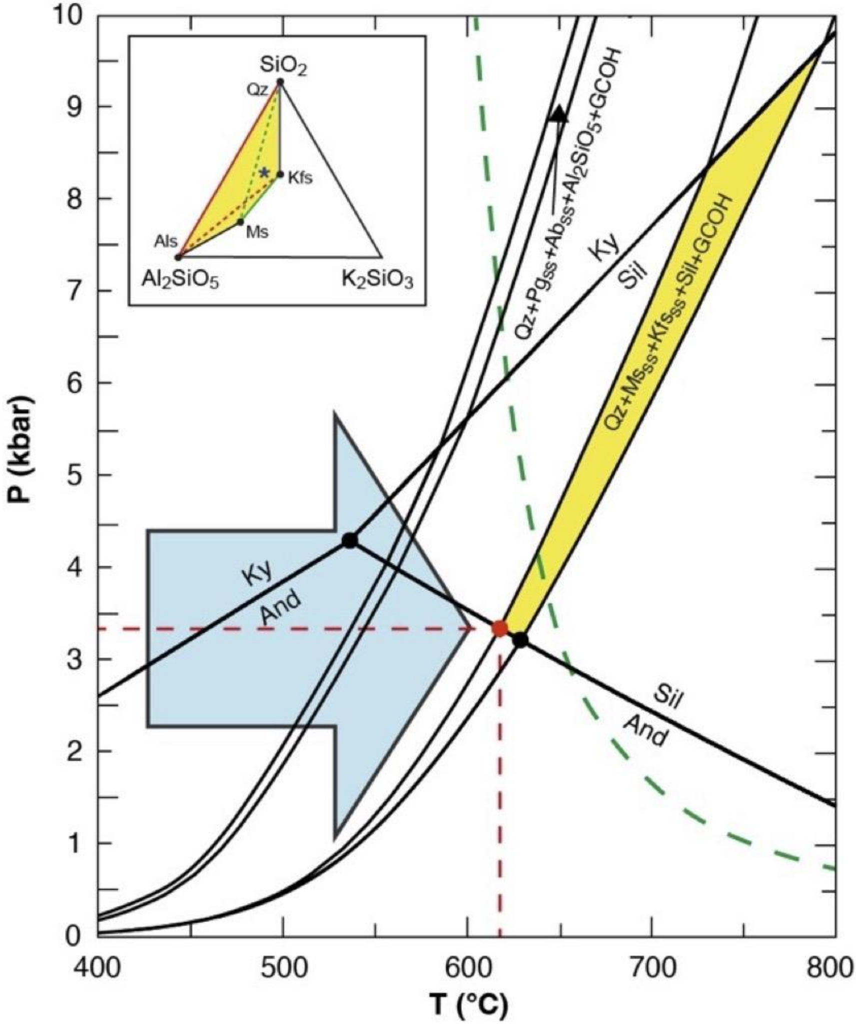
In the Caffaro Valley the country rocks are represented by the Triassic sedimentary Lozio Shale, a carbon-rich slate-siltstone which was intruded by quartz-dioritic magma.

Near the contact the hornfelses display the mineralogical assemblage Kfs-Crd-Bt-Ms-Pl-Qz-Gr, with rare fibrolitic sillimanite in only one sample. Andalusite was never observed throughout the aureole.

In the Borzago valley, contact metamorphism developed on already metamorphosed schists of the Variscan basement. The sequence of mineral assemblages progresses from And-Crd-bearing parageneses to the Sil-Crd-Bt-Kfs-Ms-Pl-Qz that characterizes peak conditions, at which incipient melting is also observed.

For samples at both localities, thermodynamic modelling in the TiNCKFMASH system failed at predicting a stability field for the sequences of mineral assemblages developed during contact metamorphism.

The P-T conditions at the thermal peak were thus constrained by an alternative bathograd-like approach, considering phase relationships in the simplified KNASH-C system. To form sillimanite only as product of the incomplete Ms-Qz breakdown - divariant for the presence of Na in Ms and Kfs and shifted to lower T due to the presence of graphite (in the Lozio Shale) - an isobaric path typical of contact metamophism must have crossed above the Msss-Qz-Kfsss-Sil-And-fluid invariant point. This constrains an emplacement pressure >3.3 kbar in the Caffaro Valley (Figure 1), and >3.1 kbar in the Borzago Valley. Concerning temperature, the same univariant point also constrains the minimum temperature in the Caffaro Valley as >615-620 °C, consistent with results of RSCM thermometry on graphite from the Lozio Shale. The evidence of incipient melting in the samples from the Borzago valley indicates higher temperatures, probably approaching 670°C.



Assuming an average crust density of 2.7 g cm^{-3}, the estimated pressures correspond to a minimum paleo-depth of emplacement of 11-12 km. These depths are somewhat greater than normally considered, and should be regarded as revised constraints on models of the emplacement dynamics of the Adamello batholith and on paleogeographic reconstructions of this part of the Southalpine domain.

Time scales of magma recharge for supereruptions

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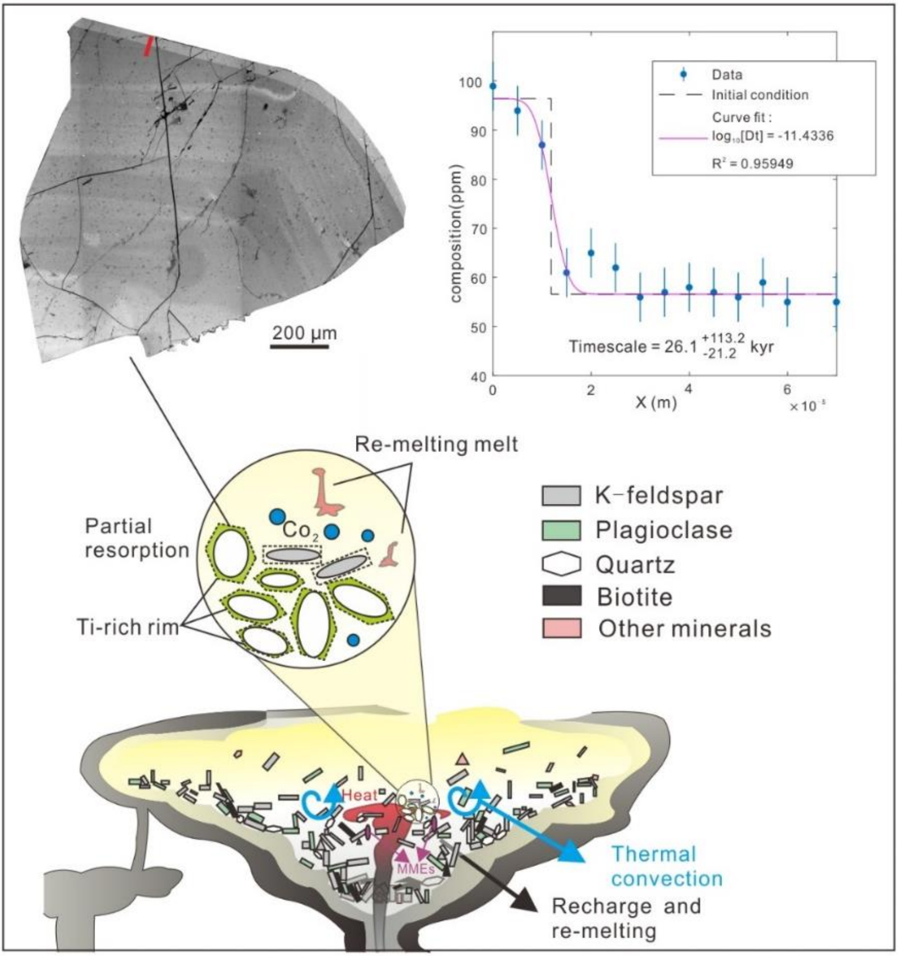
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Explosive “supereruption” generally refers to large-scale rhyolitic magma eruptions, which can lead to catastrophic climate change. As currently understood, the large-scale silicic magma eruption is related to crystal mush recharge via mafic magma periodical injection. Despite the importance of supereruption, the recharge duration of crystal mush before eruption remains enigmatic, and determining the eruptive melt volume produced by the recharge process is still challenging. Here, we present a study of the newly reported early Eocene Pangduo supereruption in southern Tibet to limit the timescale of pre-supereruption recharge and to unravel the effects of recharge duration and reheating area proportion on the eruptive melt volume. Cathodoluminescence (CL) and Micro X-ray fluorescence (μXRF) images reveal the development of a band with high Ti content in the outermost of some quartz grains, which represent later reheating events. The duration of the reheating event is limited by the quartz Ti diffusion on a scale of 10^4 to 10^5 years. The three-dimensional (3D) heat conduction model simulation results indicate that 10^4 to 10^5 years of

reheating can lead to a recharge, which potentially produces eruptive melts with volumes similar to those in the Pangduo basin. Our heat conduction model first proves that the recharge duration of 10^3–10^5 years and reheating area proportion of ~0.2 are the most likely conditions for general supereruptions. Our study, therefore, limits the supereruption formation conditions more properly, which shed new light on predicting the occurrence of future supereruption.



Small and nimble or big and mushy? On the nature of granitic magma plumbing systems in Victoria, SE Australia

Alexander Cruden*, David Moore, Roberto Weinberg

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Overview Keynote, Thursday 14th September, 08:30 - 09:15

Several paradigms have emerged over the past decade on the structure, kinematics and chemical evolution of crustal-scale granitic magma plumbing systems (GMPS). A common view of GMPS, based on crustal sections through continental magmatic arcs in the North American Cordillera and Himalaya, is that they comprise either vertically extensive, closely spaced or cross cutting plutons (Fig. 1C) or an interconnected network of large magma mush bodies (Fig. 1B). In both cases the mid to lower crust comprises >50% to ~100% intrusive igneous rock and mid- to upper crustal magma bodies are envisioned to feed large silicic caldera complexes (Fig. 1B) or arc volcanoes (Fig. 1C). Such GMPS could be viewed as large and mushy with long magma ascent and pluton building timescales, which is supported in some cases by protracted U-Pb zircon geochronology systematics within intrusions.

An alternative view, informed by field and geophysical studies of plutons in orogenic belts (e.g., Precambrian, Canadian and Baltic Shields; Paleozoic, Variscan, Lachlan and Appalachian orogens) and the South American Cordillera, is that plutons occur in interconnected networks of incrementally emplaced tabular intrusions (Fig. 1A). These networks can also feed volcanoes and calderas at the surface but the total volume of igneous intrusions in the upper to lower crust may be significantly less than 50%. Magma ascent and emplacement in such GMPS can be viewed as fast and nimble, with strong links to the kinematics of deformation in the evolving arc or orogen. U-Pb zircon geochronology from plutons in these settings also supports the notion of incremental assembly by small, fast moving magma batches, over short timescales.

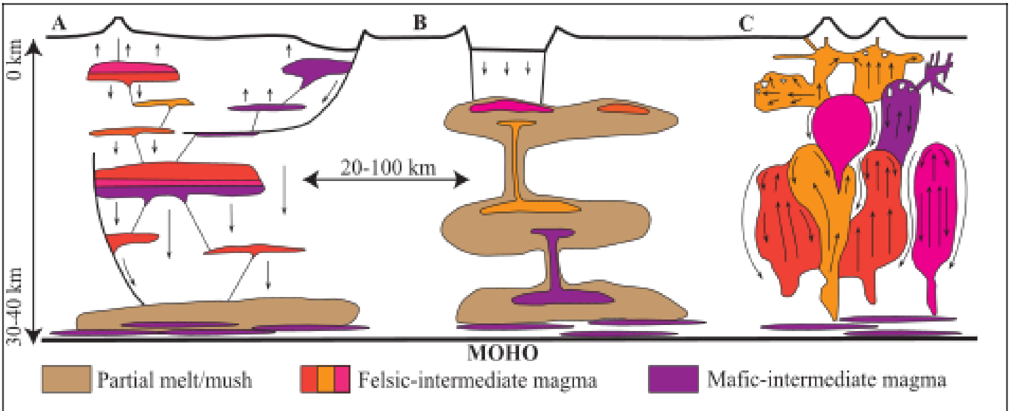

Figure 1. Spectrum of granite magma plumbing systems (GMPS). (A) Channelised ascent pathways and tabular intrusions. (B) Magma mush column. (C) Diapirism and downward flow. See Cruden & Weinberg (2018 In: Burkhardt, S. (Ed), Volcanic and Igneous Plumbing Systems, Elsevier) for further discussion and citations.

In this presentation we will review the evidence for and against these competing hypotheses for GMPS, with a particular focus on Devonian granite plutons and batholiths in the Lachlan Fold Belt of Victoria, SE Australia, birthplace of the I- and S-type granite classification scheme. The map patterns, contact relationships, internal structure and cross-sectional geometry of selected Victorian granites will be highlighted based on field observations, potential field geophysics data and modelling, and seismic reflection surveys. At least in the Victorian examples, GMPS of the Lachlan Fold Belt appear to be of the fast and nimble type, with little evidence for large crystallised magma bodies in the middle and lower crust.

Long-standing trans-crustal magma reservoir beneath the long-dormant Ciomadul volcano, Romania

Barbara Cserép*, Réka Lukács, Kata Molnár, Máté Szemerédi, Saskia Erdmann, Ioan Seghedi, Olivier Bachmann, Emese Oelberg-Pánczél, Boglárka-Mercédesz Kis, Szabolcs Harangi

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Ciomadul is a typical long-dormant dacitic volcano, where active eruptive phases occurred after 10’s to 100 kyr quiescence. Volcanism started with sporadic lava dome extrusions (950–350 ka), followed by the development of the Ciomadul volcanic complex since 160 ka. Although the last eruption occurred 30 ka, geophysical results suggest a subvolcanic melt-bearing magma reservoir supported also by anomalous CO_2 emission with

magmatic He-isotope values. Petrological observations with zircon and amphibole data imply a multilevel trans-crustal magma reservoir with a long-standing upper crustal mush body of intermediate to silicic composition underlain by more mafic magmas.

Felsic crystal clots (FCC) with mineral phases akin to the macrocryst assemblage are common mostly in the lava dome rocks. FCCs usually contain inter-crystal rhyolitic glass, suggesting that they represent near-solidus mush fragments. This is corroborated by plagioclase-amphibole thermometry, recording significant crystallization at low temperature (<750 °C). In contrast, mafic crystal clots indicate a deeper, presumably lower crustal basaltic to andesitic magma accumulation. Notably, distinct recharge magmas characterized the 160–95 ka lava dome and the 56–30 ka dominantly explosive eruption phases, respectively.

Zircon U-Th-Pb dating indicates prolonged and continuous existence of a relatively cold (700–800 °C), slightly oxidized (0.8–1.6 ΔNNO) felsic magma reservoir for the last 1.5 Myr. Zircon crystallization temperature decreases with time and there are notably fewer zircon with <100 ka dates. Results of thermal modelling and estimation of the present geothermal gradient suggest residual magma storage at >700 °C at 8–12 km depth.

Amphibole is ubiquitous in Ciomadul's erupted volcanic products. Significant amphibole compositional variation is observed within units, single samples, but also within single crystals. Based on the amphibole major and trace element character, distinct magmatic environments are defined. Among them, the low-Al and low-Mg amphibole population indicates a low-T magmatic environment, i.e. crystallization in a shallow crustal felsic crystal mush, which is always represented in the volcanic products. High-Mg amphibole with distinct Al contents, carried by various recharge magmas, highlight that magma recharge played a role in the reactivation of the physically uneruptible upper crustal mush body. The dacite crystal assemblage and its chemical compositions are consistent with crystallization from a wet and oxidized magma, distinct from the volcanism of the East Carpathians that occurred before 1 Ma. This change in magma composition can be related to the present active geodynamic setting, i.e. dehydration and wet melting of the descending slab beneath the Vrancea zone.

The structure and evolution of a lithospheric-scale magma system using geologically-informed seismic images

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Junior Keynote, Thursday 14th September, 10:30 - 11:00

Our understanding of magmatic systems has undergone a revolution in the past decade thanks to improvements in geochemical, petrologic, and geophysical methods. Most now view magmatic system architecture as transcrustal “mushy” magmatic systems thanks to geochemical and petrologic studies that indicate magma storage and differentiation takes place over a range of depths throughout the crust. However, reconciling "big red blobs" common in geophysical images with these transcrustal systems can still be challenging due to shortcomings in our understanding of how geophysical measurements relate to in-situ spatial distributions of melt. For instance, seismic properties are non-unique with respect to composition and melt percentage, and must be integrated with geochemical observations to better understand the architecture and chemical evolution of magmatic systems. The Puna Plateau in the Central Andes of South America represents a locality where 1) the tectonic history allows for along-strike variations in the margin to be related to the evolution of a magmatic system, and 2) extensive geochemical and seismic data can be combined to investigate the role of depth-dependent processes in generating particularly large transcrustal magmatic systems. We find that as the Puna magmatic system moves from nascent to mature, inferred midcrustal magma reservoirs become slower, shallower, and larger in their subsurface seismic signature, and corresponds to an increase in eruptive products. We then investigate the southernmost portion of this magmatic system in detail, as diverse compositional suites of eruptive products (basalt-to-dacite) allow us to interpret our seismic images in the context of geochemical evidence for magma differentiation. Near the base of the crust (>40 km), we observe shear-wave velocities that are anomalously slow compared to what is expected (<4.0 km/s) and geochemical signatures indicate fractional crystallization and crustal assimilation in the garnet stability field, whereas in the mid-crust (~20 km), shear-wave velocities necessitate the presence of melt (~2.7 km/s) and europium (Eu) anomalies indicate low-pressure differentiation. Our seismic results provide spatiotemporal insight into the evolution of silicic magmatic systems that can be reconciled with the geochemical trends and the petrological features of exposed arcs, and provide context through which to interpret seismic images of other magmatic systems.

Investigating the petrologic links of the Jackass Lakes volcanic-porphyry-plutonic complex, Sierra Nevada batholith

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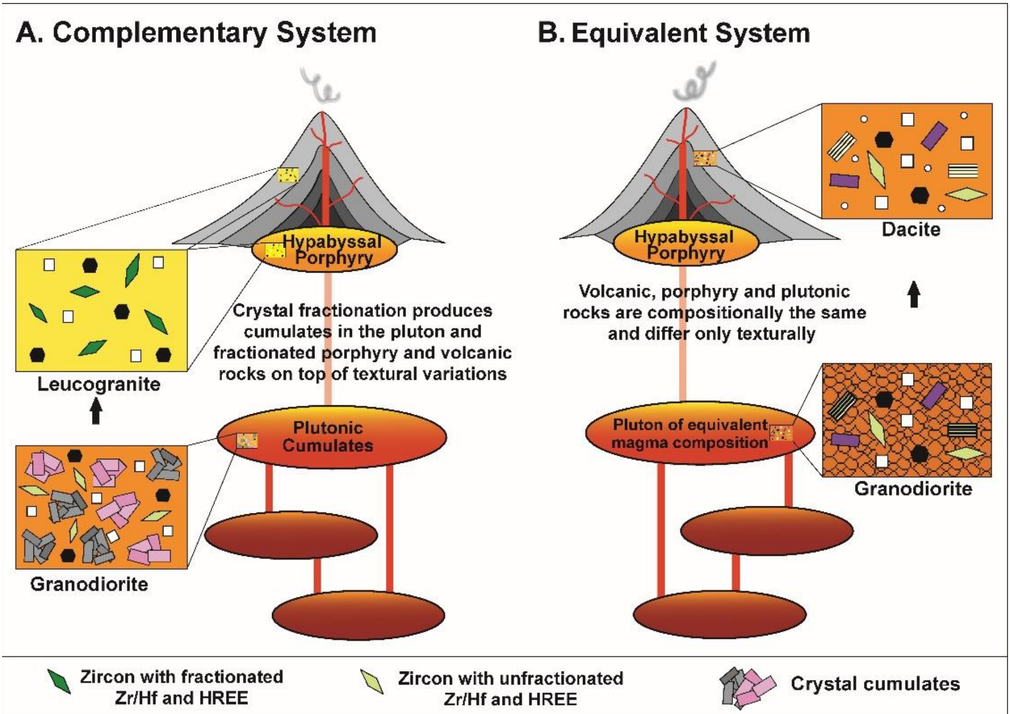
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The 99-97 Ma Jackass Lakes pluton (JLP) in the central Sierra Nevada batholith is a well-exposed 175 km2 resurgent pluton of granodiorite (Kj) and minor diorite that intruded into dacitic and rhyolitic volcanic ejecta (Km) and the Post Peak subvolcanic porphyry (Kpp) of the 101-97 Ma Merced Peak Caldera sequence. U-Pb zircon ages by previous studies and ages attained in this study show that all three units are coeval within uncertainty (Km: 97.97 ± 0.50 Ma, Kpp: 99.02 ± 0.56 Ma and 97.86 ± 0.56 Ma, Kj: 98.09 ± 0.56 Ma and 97.55 ± 0.54 Ma). This timing

relationship is essential to determine the petrologic connection of the volcanic-porphyry-plutonic units.

We are testing the following hypotheses: 1) the JLP granodiorites are compositionally complementary to the more felsic Kpp leucogranite and Km meta-rhyolites that formed from melt-extraction from the magma reservoir leaving behind crystal cumulates preserved in the plutonic rocks. Alternatively, 2) all three units are compositionally the same (equivalent).



Mapping of ~32.5 km^2 of the north- and west-central JLP at 1:10,000 scale included the main porphyritic hornblende-bearing biotite granodiorite (Kj), the equigranular hornblende biotite granodiorite (Kja, Anne Lake phase), the Kpp biotite leucogranite, and the dacitic to rhyolitic, lithic-bearing crystal tuff (Km). The mapping revealed new granodiorite phases of the JLP that vary in volume % mafic minerals, grain size, and texture (granodiorites of Rutherford Lake and Fernandez Pass). The nature of contacts between JLP phases varies from sharp to gradational over ~30 ft. Stoped blocks of Kj are found in the minor, younger granodiorite phases. Mafic enclave swarms and stoped blocks of Km and Kpp are found exclusively in the Kj.

Hafnium isotope data for the plutonic, porphyry, and volcanic rock zircons range between εHf = +5 to εHf = -5 in all units, suggesting they share a similar source. Petrographic and XRF bulk rock element analyses show support for complementary compositions for Kj and Kpp units, which are also supported by crystal accumulation of plagioclase crystals seen in thin section. Melt extraction is inferred from Kj and Kpp distributions in Ba and Zr versus SiO_2 plots. The Kj and Kpp "unmix" from the linear trend at 68 wt. % SiO_2, yielding a magma crystallinity that likely promoted crystal-melt separation. Volcanic samples also show equivalent rock compositions with some granodiorites, indicating complex volcanic-plutonic relationships. In addition, the plutonic units indicate small, heterogeneous magmas forming small irregular plutonics with boundaries.

Plutonic formation through sills stacking and amalgamation: The case of Beauvoir rare-metal granite

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Constraining the assembly and evolution of granitic intrusions and the kinematics associated with their magmatic differentiation remain a major objective in igneous petrology. To progress on those issues, we took advantage of a 1km long drilled core of the Echassières-Beauvoir granite, a rare metal granite intrusion from the French Massif Central, allowing a high resolution sampling of a fully recovered plutonic body. Based on structural data, and high-resolution major and trace element composition of the mineral phases (in-situ measurements and chemical map) associated with cathodoluminescence imaging, we provide constraints on the differentiation processes and its dynamics during the construction of the intrusion. Mostly based on mineral composition and crystal morphologies, we show that the granite formed via the stacking of deca- to hectometric crystal-poor magma sills, corresponding to the different sub-units of the Beauvoir granite. Furthermore, the detailed study of sill boundaries provides a dynamic record of the pluton assembly: although globally

constructed from bottom to top, sill emplacement can also occur through off-sequence intrusion within partially crystallized mushy sub-units.

Once intruded these sills crystallize an assemblage of quartz-topaz-mica and alkali-feldspar, recording differentiation trends from bottom to the top of each sub-units. Differentiation leads to the formation of a crystal-rich mush and associated interstitial residual melts enriched in incompatible elements (e.g., Li, F, P). Textural and mineralogical evidences suggest efficient extraction of these residual melts from the quartz-rich mush to form albite-rich segregates. Locally, these segregates are found as intrusive in overlying subsequently intruded sill, thus representing (less evolved-) magmas injected by residual melts. They can also be observed as fragmented and dismembered mm to cm albite-rich domains, recording mixing features between the two magmas. Ultimately, the enriched residual liquids are then collected at the top of the plutonic body, forming the evolved unit of the Beauvoir granite (≈130m). This process of evolved interstitial melt extraction leading to an accumulation of non-viscous evolved melt in the upper-part of magmatic reservoir, could then be mobilized as erupted silica-rich magma, potentially corresponding to rhyolitic intruding the surrounding host-rocks. This study eventually provides fundamental constraints on the processes leading to the construction and enrichment in rare metal (e.g., Li) granite bodies.

Cumulate formation and melt extraction from mush-dominated magma reservoirs: the Melt Flush process

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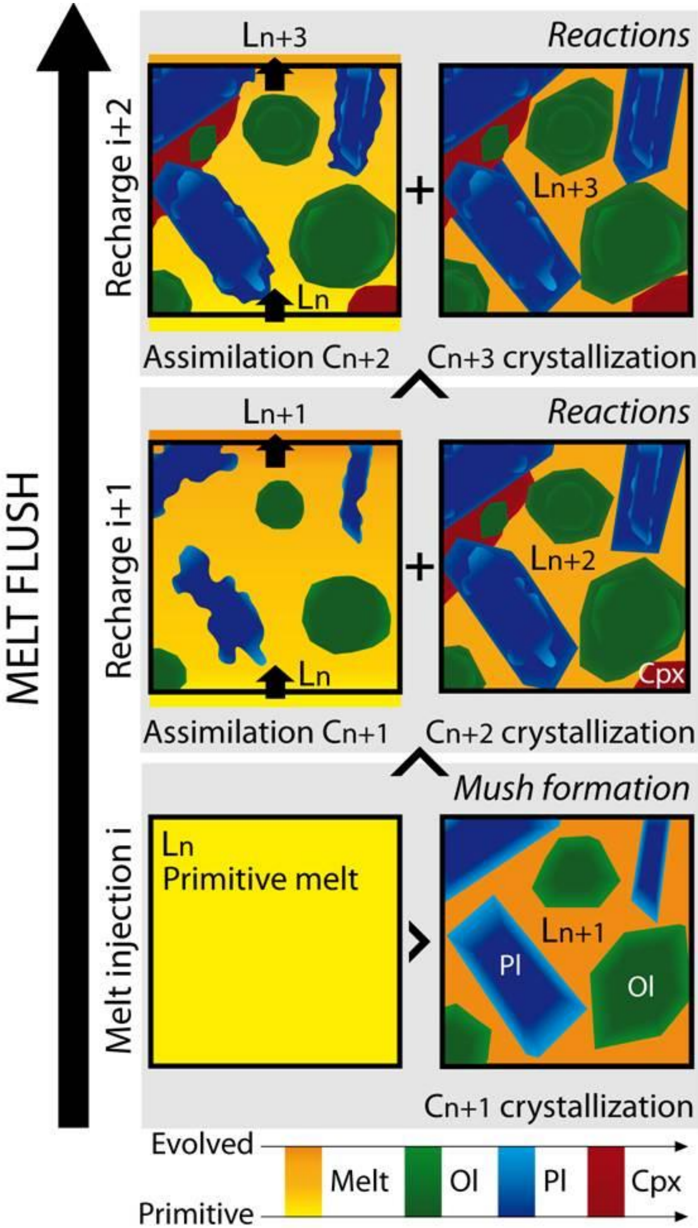
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

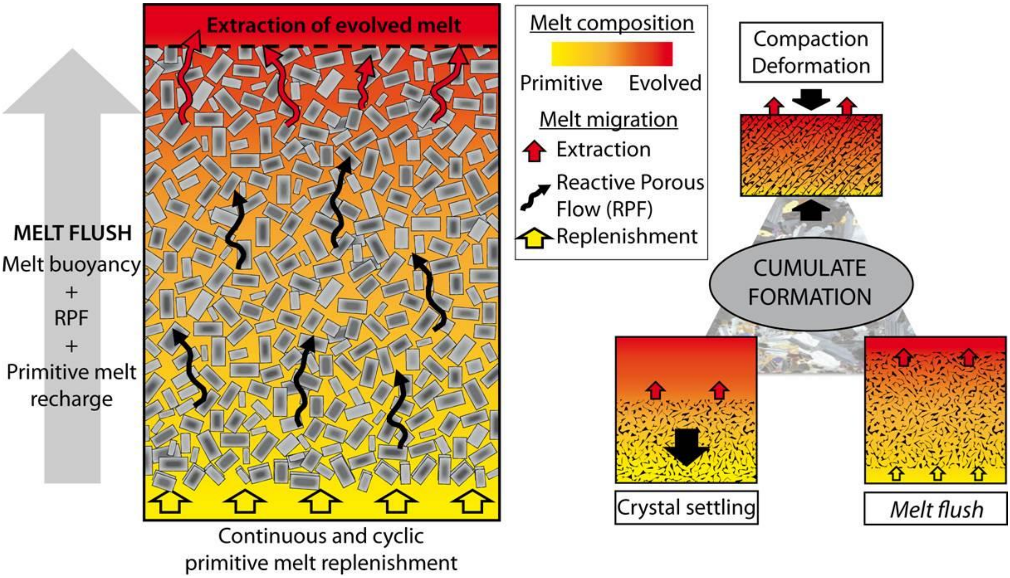
Volcanism is the surface expression of extensive magmatic systems, with their intrusive counterpart representing ~80% of the total magma budget. Our knowledge of igneous processes therefore largely relies on our understanding of deep plutonic processes. In continental or oceanic environments, most of the intrusive igneous rocks bear geochemical cumulate signatures (e.g., depletion in incompatible elements and enrichment in compatible ones) that are commonly explained by mineral-melt segregation during differentiation. Deformation-assisted compaction aided by melt buoyancy is usually referred to as the main process involved in melt extraction. However, buoyancy alone is not sufficient, and numerous of cumulative rocks are lacking any compaction evidence, opening the potential for involving other processes. In addition, our view of magmatic systems has shifted in the last decades from large melt-rich bodies to crystal-rich magma reservoirs. This paradigm shift challenges some of the long-established first-order igneous concepts like the idea that melt differentiation at depth is mainly governed by

fractional crystallization; alternatively, the presence of mush potentially favors additional processes such as melt-mush reactions.

We propose a novel igneous process for the formation of igneous cumulates, consistent with the mushy nature of several igneous reservoirs, their continuous/cyclic replenishment by primitive melts, and the widespread occurrence of reactive porous flow (RPF) during magma differentiation identified in a growing number of magmatic systems. The "melt flush" process relies on melt-mush reactions between the primitive recharge melt(s) and crystal mush. Replacement of the more evolved interstitial melt by the primitive recharge melt leading to reactions (dissolution+crystallization), and concomitant extraction of the more evolved melt from the cumulate by buoyancy participate in the acquisition of the final cumulate signature.

This process relying on oceanic igneous systems considers for the first time melt inputs and not only melt extraction, and matches the petrographic (e.g., mineral dissolution evidence) and geochemical constraints (trace element signatures) brought by natural samples. The first of that kind first-order thermodynamic models show that one-step equilibration of primitive melts with primitive to moderately differentiated mush crystals triggers mineral assimilation. Together with the constraints established from the natural rock record, it strengthens the idea that RPF is a potential key process for magma differentiation in magma reservoirs at different evolution stages. The proposed melt flush process eventually adds to other processes involved in cumulate formation like magma compaction or crystal settling, and is likely to apply to any other magmatic system from various settings sharing similar reservoir characteristics.





Fingerprinting microstructural evidence of disequilibrium crystal growth in plutonic settings

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Dendritic crystals grow from strongly supersaturated melts, recording processes that occur when magmatic environments are far from thermodynamic equilibrium. While dendrites are relatively common in volcanic rocks that have undergone rapid ascent and cooling, they are rare in plutonic rocks, perhaps because conditions at depth are generally more quiescent. However, there may

also be an element of preservation bias whereby initially dendritic crystals that experience prolonged magma storage may develop euhedral overgrowths or undergo textural re-equilibration that masks their dendritic heritage. In recent years, studies have suggested that common igneous microstructures such as monomineralic clusters and complex zoning morphologies may result from the modification of dendrites. To test this hypothesis, and develop a better understanding of the prevalence of extreme plutonic disequilibrium, a thorough knowledge of dendrite morphologies and characteristics in common rock-forming minerals is required.

We present a detailed characterisation of feldspar dendrites from silicic plutons, using orbicular and comb layered samples from a variety of localities, including the Karamea Granite in New Zealand. We use electron backscatter diffraction (EBSD) to describe the structure of the dendrites, and cathodoluminescence mapping, energy dispersive X-ray spectroscopy (EDS), electron probe microanalysis and optical microscopy to explore the formation of feldspar dendrites and their subsequent modification during cooling.

We find that feldspar dendrites exhibit a strong preference for growing epitaxially on pre-existing feldspar grains. Where the starting material is a suspended seed crystal, dendrites inherit the crystallographic orientation of the seed and grow radially outwards from the substrate into free space, irrespective of crystallographic orientation. This behaviour results in elongation along irrational crystallographic directions. In contrast, where the starting material is a fine-grained layer of seed crystals, certain growth directions are favoured by competitive growth and become more prevalent as crystallisation progresses, producing a crystallographic preferred orientation.

EBSD analysis also enables quantification of the crystal lattice curvature caused by the accumulation of dislocations during dendritic growth. The analysed plutonic plagioclase dendrites curve at a few degrees per millimetre of growth, and most of this rotation is accommodated along subgrain boundaries. The subgrain boundaries have systematic orientations and misorientation axes, and we find that these subgrains are present even in samples that display evidence of textural re-equilibration, suggesting that they may be a durable indicator of dendritic heritage. In summary, EBSD reveals a distinctive set of quantifiable microstructural characteristics that archive periods of significant disequilibrium in the plutonic record.

Plutonic perspectives on the rhyolite factory

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Magmatic systems feed eruptions to the surface; lead to the formation of ore deposits; provide energy for geothermal systems; and are key to Earth's differentiation. While it is commonly accepted that silicic magmatic systems span much of the crust, little direct evidence is available for their vertical continuity (or lack thereof), or for the distribution of melt within them.

We focus on Miocene plutonic and volcanic units exposed in the Colorado Extensional Corridor, SW USA (see CF Miller et al., this meeting). Plutonic units (Searchlight Pluton–SLP, Aztec Wash Pluton–AWP, and Spirit Mountain Batholith–SMB) consist primarily of coarse-grained granitoids rich in feldspar that can be credibly considered cumulates. Marginal facies and fine-grained dikes and sills are interpreted to record melt compositions that fed the plutons. Leucogranite dikes and roof units were extracted from the crystallizing plutons. The nearby Upper Highland Range Volcanics record compositions extracted from the SLP system.

We use whole-rock compositions to calculate extraction pressures, and glass compositions in volcanic rocks to calculate pre-eruptive storage pressures using rhyolite-MELTS. We seek pressures consistent with assemblages containing quartz+2 feldspars±magnetite±ilmenite (Q2F or Q2FMI assemblages). We use the calculated pressures to assess the distribution of magma in silicic magmatic crustal columns.

The dataset reveals 3 main clusters of compositions and pressures: 72-74.5 wt% SiO_2, 440-370 MPa (Q2F extraction); 76-77 wt% SiO_2, 250-190 MPa (Q2FMI extraction and pre-eruptive storage); 77.5-78 wt% SiO_2, 170-120 MPa (Q2FMI extraction and pre-eruptive storage). Compositions attributed to cumulates (based on texture, major and trace-element compositions) do not yield extraction pressures, suggesting that rhyolite-MELTS can distinguish magmatic from cumulatic compositions.

Our data show that magma distribution spanned from the middle crust to the surface, with well-defined gaps in pressure between the three groups. Magma mushes were located in the middle crust (~400 MPa, ~15 km depth), from which magmas that fed the shallow plutonic units were derived – there is no exposed record of these magma mushes, and they are inferred from extraction pressures for the less evolved fine-grained rocks. We infer two sets of shallower mush bodies that fed eruptions to the surface. The leucogranite roof zones represent bodies of eruptible magma that failed to erupt and instead solidified in the subsurface. Magma distribution is vertically discretized, rather than continuous as shown in most models – there are specific horizons within the crust where magma accumulation is favored, while much of the crust remains melt-free.

Timescale of pervasive melt migration in the continental crust

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Movement of a large volume of granitic melt is an important factor in the compositional differentiation of the continental crust and the presence of melt in rocks profoundly influences their rheology. Different mechanisms controlling melt migration through crust were proposed. We suggest that pervasive melt flow could be possibly one of them. In such scenario, melt driven by deformation passes pervasively along grain boundaries through the whole rock volume. And the term pervasive melt flow is used for grain-scale, diffuse, porous and reactive flow of felsic silicate melt through rocks. Through-flow of melt destroys pre-existing fabrics and the original chemical and isotopic nature of the protolith. Melt segregation is inefficient and protolith become isotropic granite-like, with partly preserved relics of the original, without ever containing more than a few melt percent at any time.

In order to decipher duration of pervasive melt migration we used precise U-Pb monazite ID-TIMS (isotope dilution thermal ionization mass spectrometry) and U-Pb monazite Laser Ablation Split Stream (LASS) geochronology in combination with monazite chemistry as well as U-Pb zircon SHRIMP geochronology. Monazite reveal continuous chemical equilibration with passing melt. They are getting progressively enriched in HREE and depleted in Eu. Monazites in the least affected rock preserve original magmatic zoning in Th and U, in contrast to more with melt equilibrated rock types, where this zoning is lost. Data for each migmatite type reveal similar date spread for both cores and the Y-rich well defined rims of single monazite grains, indicating a disconnect between U-Pb dates and chemical zoning. There is also no correlation between U-Pb ages and Yb/Gd ratio. This suggest perturbance of the isotopic system. We interpret these random distribution within-grain date variations as a result of dissolution-reprecipitation reactions between monazite grains and melt. During the coupled dissolution-reprecipitation radiogenic Pb was redistributed within the grain. This is supported by dissolution of apatite into silicate melts that stabilizes monazite during migmatitization, preventing their dissolution but not reaction with passing melt. Redistribution of radiogenic Pb resulted in meaningless individual ages from different migmatite types, but gave overall duration of the thermal event – pervasive melt flow. Duration of pervasive melt flow was dated 8-10myr. This suggest that porous flow of silicate melts in continental crust is a process which can operate over a long time and impacts on the rheology of the crust during orogeny.

Using microstructural analysis to decode the history of plutonic rocks

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Overview Keynote, Thursday 14th September, 09:15 - 10:00

The detailed microstructure of materials - in terms of e.g. grain size, grain shape and fabrics – exerts a fundamental control on the way they behave. Consequently, there has been sustained and concerted effort in the field of Materials Science to understand the physical, chemical and thermodynamic controls on microstructure, to enable the creation of materials with the desired physical properties. This well-developed field of enquiry can be approached from the opposite direction, using the knowledge developed by the Materials Science community to permit the control of microstructures to, instead, decode what controls were exerted on the rocks we are interested in. This approach is commonplace in some fields of Earth Sciences, such as structural geology, but under-used in petrology, despite its potential to obtain otherwise inaccessible information.

A critical first step in the microstructural examination of plutonic rocks is an assessment of the extent to which they have been modified following solidification. Some authors assert that all primary microstructures have been erased during slow cooling, meaning that plutonic rocks are essentially metamorphic in character. However, the three processes leading to recrystallisation and overprinting of primary microstructures – metasomatism (chemical reactions driven by mass transport via fluids), deformation and textural equilibration – each leave a characteristic signature, permitting assessment of both the mechanism, and the extent, of change. An assessment of a wide range of plutonic rocks shows that, in general, any overprinting of primary microstructures is minor.

Perhaps the most fundamental use of microstructures is to constrain how any given sample of igneous rock was constructed – are we looking at something which grew in situ, forming an inwards-propagating solidification front, or did the crystals accumulate to form our sample after having been transported from their initial site of nucleation and growth by some fluid dynamical process? These two mechanisms leave clearly distinct signatures in the extent of grain alignment, the orientations of grain boundaries relative to crystallographic orientations and the extent to which grains enclose others – a perhaps less reliable additional diagnostic is the distribution of grain sizes. Microstructural observations thus provide supplementary evidence to support field-based deductions about the source of modal variations such as layering, but can also be used to make inferences about the presence of large crystal-free bodies of magma using samples with no field context, such as enclaves and xenoliths (or even meteorites!).

A rich source of information is provided by the way the shape of plagioclase feldspar grains growing in a liquid-rich environment is controlled by cooling rate, via the changing kinetics of attachment of atoms to the various growth faces. The average aspect ratio of randomly oriented plagioclase grains intersected by the plane of a thin section varies smoothly across simple tabular bodies, recording not only the rate of heat loss following emplacement, but also magma flow through the body as it inflated. The cooling rate control of plagioclase grain shape is also recorded in the geometry of three-grain junctions involving two grains of plagioclase and one of a mafic mineral such as pyroxene and olivine: departures from expected values can be used to constrain the extent of subsolidus microstructural evolution driven by textural equilibration in very slowly-cooled bodies.

Microstructures can be used to detect whether the magma convected during solidification – a further indication of the presence of large bodies of essentially crystal-free magma. The creation of crystal clusters by synneusis is facilitated by convection, and the length of time these clusters were suspended by vigorous convective currents is recorded by the extent to which individual grains continued to grow following aggregation. The spatial distribution of clusters is also indicative of convection, with large clusters of dense minerals far from the intrusion floor recording delayed settling due to prolonged suspension. Further evidence of crystal growth predominantly as individual grains or clusters suspended in a convecting magma is provided by those intrusions in which the plagioclase grain shape is spatially invariant, due to growth rates being averaged out by crystal mobility.

A final topic of great interest to igneous petrologists is the highly contentious question of the process(es) by which large volumes of essentially crystal-free magma are extracted from deep-seated mush zones. That microstructures are not generally considered as an important source of evidence is illustrated by the alacrity with which geologists turn to gravitationally-driven compaction as the prime mechanism for liquid extraction, almost entirely on the basis of numerical modelling. Despite the certainty that viscous compaction would leave a discernible microstructural imprint, little observational evidence has been presented in support of this mechanism.

The detailed understanding of microstructures developed by materials scientists has enormous potential for igneous petrology. Reading the rocks, both in the field and down the microscope, in combination with careful geochemical analysis, is a powerful approach that has not yet fulfilled its potential.

K-feldspar megacrysts coffins testify intra-chamber convective mixing

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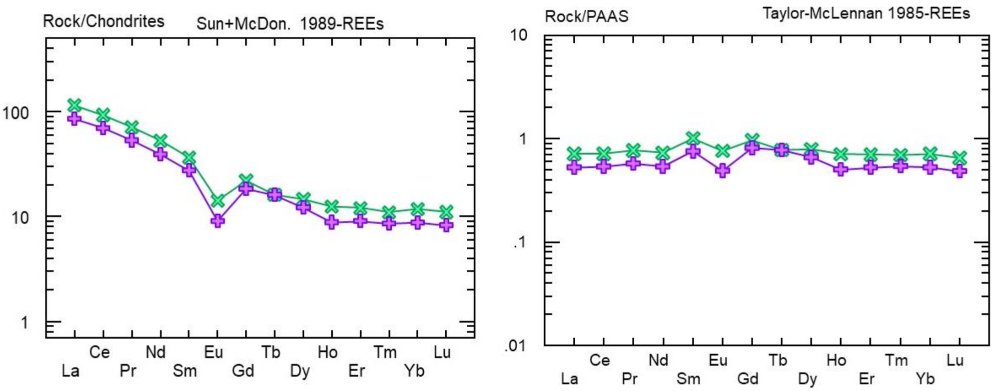
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

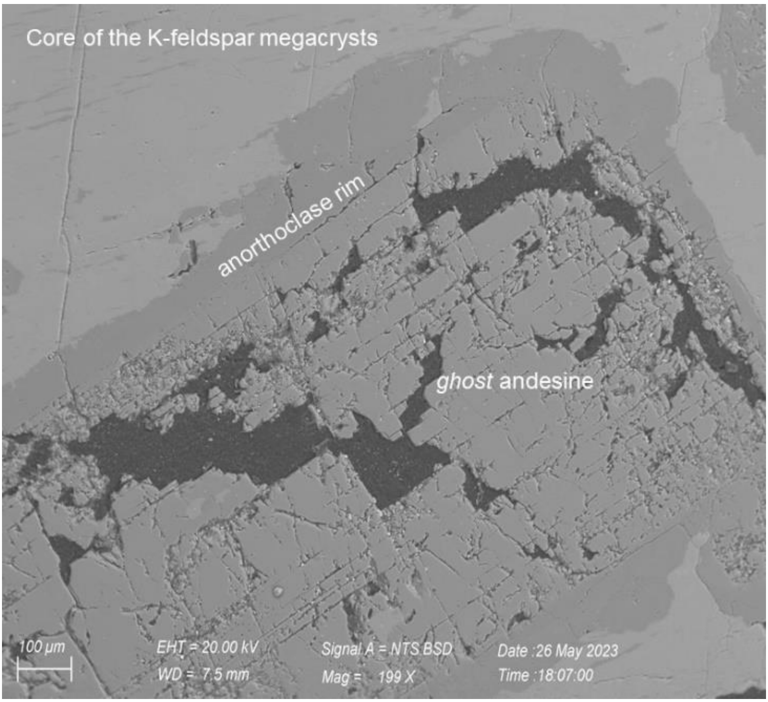
The origin and significance of K-feldspar megacrysts, a common feature of most granites, is still controversial. Throughout the years, two opposite mechanisms with markedly different petrological implications have been invoked: i) late growth by sub-solidus textural coarsening, or ii) early crystallization in the presence of abundant sialic melt. Recent studies support model 2, provided that slow nucleation of K-feldspar get along with high diffusion rates. This implies that crystallization likely occurs early during the cooling-solidification history of the magma, particularly in Ba-rich melts. For this reason, the recent research on megacrysts is opening new perspectives on the rheology and chemo-mechanical behaviour of crystal mushes. The Castellaccio Pluton, Asinara Island (NW Sardinia, Italy), is a small Variscan pluton (~ 320 Ma) that contains abundant K-feldspar megacrysts in two out of five textural facies. K-feldspar megacrysts appear as idiomorphic crystals up to 20 cm in size, which can be dispersed in a medium grained matrix or localized

forming cumulitic domains. The bulk chemistry of the five textural facies is almost indistinguishable, and fall into the field of sub-alkaline granites, with alkalic-calcic affinity, peraluminous and silica saturated, with no ferroan or magnesian tendency. Bulk-rock REE, normalized to chondrite, results in a wing-shaped pattern with pronounced Eu anomaly, while the PAAS normalization produces a nearly unfractionated pattern, except for a slight negative Eu anomaly.



Average Bulk REE patterns normalized to the chondrites (left) and PAAS (right) of the two K-feldspar megacrysts bearing facies of the Castellaccio Pluton.

In thin sections, the megacrysts are poikilitic showing a plethora of plagioclase, biotite, titanite, apatite, ilmenite, zircon, and monazite inclusions. Petrographic observation and EDX elemental quant map allow to recognize the main equilibrium phases: (i) ghost andesine An_{32}-Ab_{67}-Or_1; ii) anorthoclase rim Ab_{87}-An_2-Or_{11} (iii) K-feldspar megacryst. The ghost andesine sometime preserves a relict euhedral habit despite the heavy physical and chemical deconstruction, which favoured the growth of surrounding anorthoclase rim. The anorthoclase rim has the typical features of a reaction rim. The K-feldspar megacryst is Na-rich (up to 4 wt.%) at the contact with the anorthoclase rim and Na-poor (0.2-0.4 wt.%) away from it. It is worth saying that the K-feldspar Ba content ranges from 0.01 up to 1.95 wt.% and follow exactly the opposite trend of Na. Combining fieldwork, petrography and mineral chemistry, an evolution model could be proposed: a) early crystallization of ghost andesine + biotite, b) convective mixing due to Rayleigh-Taylor instability of the crystallization front, c) reaction of ghost andesine with a K-rich evolved melt forming the anorthoclase rim and, finally, d) growth of K-feldspar megacryst coffins.



Numerical model of multi-phase porous, mush, and suspension flows in magmatic systems

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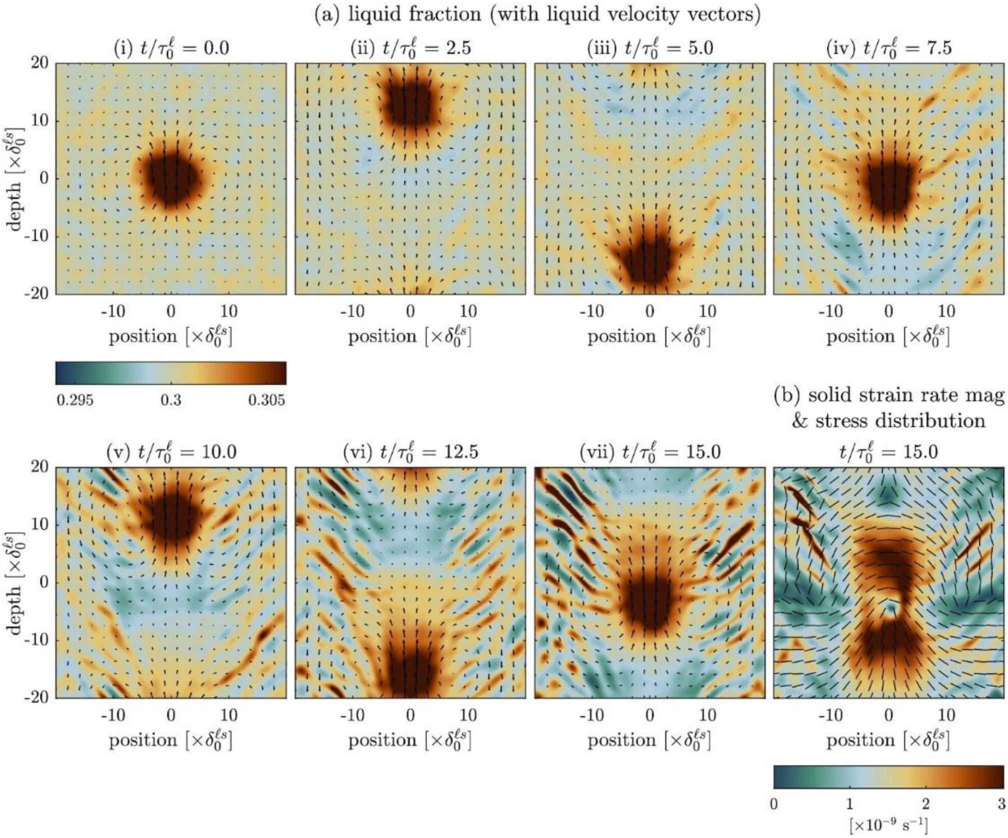
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Magmatic systems in the Earth's mantle and crust can range from melt-poor partially molten rock to trans-crustal magma mushes with ephemeral lenses of melt-rich suspensions. Most process- based models of magmatic systems, however, are limited to two-phase porous flow at low melt fractions (<20%) or suspension flow at high melt fractions (>60%). A lack of formal extensions to intermediate phase fractions has long hindered investigations into the dynamics of mush flows. To address this knowledge gap and unify two-phase magma flow models, we present a two- dimensional system-scale numerical model of the fluid mechanics of an n-phase system valid at all phase fractions. The numerical implementation uses a finite-difference staggered-grid approach with a dampened pseudo-transient iterative algorithm and is verified using the Method of Manufactured Solutions. Numerical experiments replicate known limits of two-phase flow including rank-ordered porosity wave trains in 1D and porosity wave breakup in 2D in the porous flow regime, as well as particle concentration waves in 1D and mixture convection in 2D in the suspension flow regime. In the

mush regime, numerical experiments show strong liquid localisation into pockets and stress-aligned bands. A tentative application to a three-phase, solid- liquid-vapour system demonstrates the broad utility of the n-phase general model and its numerical implementation. The model code is available open source at github.com/kellertobs/pantarhei.



Melt-assisted km-scale deformation localization: a late-Variscan magmatic strike-slip shear zone in southern Corsica

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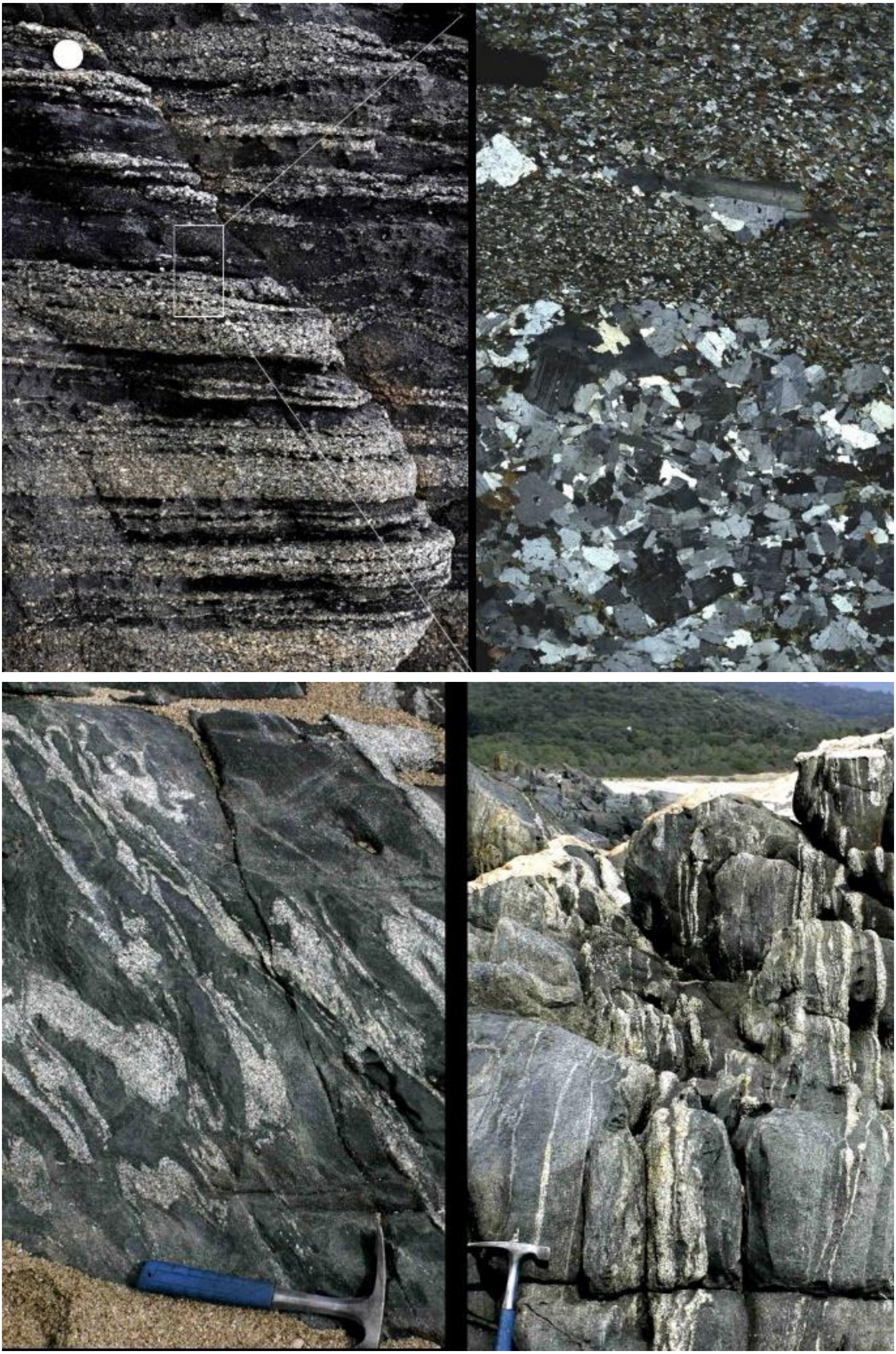
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Large-scale magmatic flow patterns are developed in the Variscan Batholith of Corsica. They are mostly represented by the alignment of mm-cm sized euhedral feldspar crystals. The steep magmatic foliation trends generally N-S in the northern part of the island, swings to approximately NW-SE orientation in the central part and, towards the south, again to N-S orientation and then back NW-SE. Locally, W-E orientations may occur. This pattern is intensified by magmatic layering, mainly km-long lenses and layers of mafic and intermediate intrusions into the granitoids. Fabrics on the macro- to micro-scale indicate magma mingling and mixing. This reflects the complex intrusion history and the compositional variability of the Corsica Batholith on various scales.

North of the Golfe de Valinco, in the south of Corsica, a W-E trending magmatic layering in mingled dioritic, tonalitic, and granitic magmas forms a steep, sinistral, at least several km wide, magmatic shear zone. The flow foliation is represented by the alignment of platy feldspar crystals, as well as amphibole and biotite. Characteristic magmatic structures include multiple mm to cm layering, monoclinic folding with flat faces of amphibole and biotite grains aligned in the axial planes, boudinage, melt-injected micro shear zones, and fragmenting and back-veining of dioritic enclaves. The intensity of grain alignment roughly correlates with the thickness of layers. It is low in thick and short boudins and high in cm-thin and cm-m long layers. Locally, feldspar crystals are recrystallized to a few, up to 1 mm large, polygonal grains, and quartz commonly shows chessboard subgrain patterns. No further indications of solid-state deformation are present.

Field observations, as well as pattern quantification on variably oriented rock surfaces, indicate variations of crystal alignment and fabric anisotropy in cm- to more than 100 m thick bands parallel to the W-E oriented layering, and various stages of melt-present fragmentation. These variations are interpreted as variations of flow intensity and strain-rate. The observations on the macro to micro-scale point to repeated injections of mafic to felsic magma and crystallization in the presence of a regional stress field. The resulting km-scale sinistral, sub-horizontal, synmagmatic shear zone reflects large-scale movements during late-Variscan crustal reorganization and represents an excellent example of localization of deformation into magma-enriched parts of the continental crust.



The high-SiO_2 rhyolite (HSR) dike swarm of Benton Range, CA: an example of similar HSR cold storage in dikes beneath the Long Valley volcanic field?

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The high-SiO_2 rhyolite (HSR) dike swarm (~28 x ~7 km) of the Benton Range in eastern California is among the few documented localities where near-eutectic HSRs are preserved in wide dikes (~3-17 m) that exceed critical widths (e.g., Petford et al., 1993). Individual dikes can be traced for ≤ 4 km and are broadly oriented N-S. The dikes have crosscutting relationships with dated granitoids, including two-mica granites (Renne and Turrin, 1987), which constrain their age between ~200-165 Ma (an era of diminished Sierra magmatism; Paterson et al., 2012). The exposed Benton HSR dike swarm is surrounded by volcanic deposits from the much younger Long Valley volcanic field, including the Bishop Tuff and Glass Mountain rhyolites. Although the trace-element compositions of the Benton HSR dikes preclude any direct genetic relationship with the Long Valley HSRs, their major element compositions and mineral assemblages are strikingly similar. The Benton HSR dikes contain large porphyritic crystals of quartz, K-feldspar, plagioclase and biotite, often in a fine-grained matrix that is more reminiscent of volcanic than plutonic

rocks. Quartz often displays rapid-growth textures (e.g., hopper cavities and faceted protuberances) and granophyric intergrowths of quartz and feldspar are common. Accessory phases include Fe-Ti oxides, zircon, apatite, and allanite. The latter indicates crystallization temperatures ≤780°C (Vasquez et al., 2004), which is consistent with application of a new Ti-based quartz-melt thermometer (Lange et al., 2022) that gives temperatures from ~720-780°C. Microprobe analyses reveal unaltered zones of plagioclase that preserve their original magmatic compositions. Application of the plagioclase-liquid hygrometer (Waters and Lange, 2015) leads to an average melt water content of ~6.4 (± 0.4) wt%. With temperatures and water contents known, the average density (~2.2 g/cm3) and viscosity (~4.9 log10 Pa-s) of the Benton Range HSRs during transit was calculated. Since most of the dikes range from ~3-9 m width, resulting velocities are ~4-34 km/day. The occurrence of the Benton HSR dike swarm raises the possibility that a similar swarm of critical-width HSR dikes could have existed beneath the Plio-Quaternary Long Valley volcanic field during periods of cold storage. Whole-sale remelting of the near-eutectic HSR dikes could have occurred due to the influx of hot (>700°C), hydrous fluids from degassed basalts at depth. Episodic remelting of HSR dikes could explain eruption ages up to 360 kyrs after Rb/Sr isochron ages recorded in the Glass Mountain rhyolites (e.g., Davies et al., 1994; Gordon et al., 2023).

Mushy magma strain archives in enclaves: do enclave morphologies provide a true picture of strain partitioning during magma transport?

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Studies of pluton construction, tectonomagmatic interactions and crystallisation processes, are dependent on their archiving of palaeostress. Strain partitioning is reliant on a magma's effective viscosity, a function of melt composition, crystal percentage and shape. As magma crystallises, rheological lock up occurs when crystal content reaches ≈55%, transitioning to a crystal-rich mush. This mush progresses into a rigid sponge with interstitial melt, until fully crystallised. Contrasting rheological conditions within crystal mushes are of particular importance to textural development in intrusions, altering the mechanics and distribution of strain archiving. Testing the role of rheological state in fabric development is easiest at magma mingling zones. Enclaves represent well-studied features of magma mingling, being small volumes of relatively low viscosity melt within a more viscous granitoid host mushy magma. The shape, axial alignment and petrofabrics of enclaves have been interpreted to represent strain archives of processes not documented elsewhere in the pluton.

Variation in enclave strain archives relative to the host intrusion have been interpreted to reflect changing rheological conditions, with the compositional contrast of both magmas producing an ever-increasing rheology contrast throughout the cooling of an intrusion. Enclaves of a suitably low rheological contrast to the host will deform contemporaneously producing the same mineral alignment and long-axis orientation. Conversely, enclaves with too large a rheological contrast are expected to have a long-axis orientation and mineral fabric misaligned to the surrounding host intrusion. Therefore, enclaves with different orientations should archive contrasting palaeostress records, with the morphology and mineral fabrics of the enclave related to its rheology during transport through the surrounding melt. In this study we test these assumptions.

To assess strain archives in enclaves, we performed a quantitative analysis of mineral fabric development within two enclaves with different alignments compared to the silicate petrofabric of the Fanad Pluton, Ireland. High-resolution grid sampling of both enclaves and the surrounding host allowed generation of magnetic and petrographic data, which were used to investigate the influence of rheological differences between the enclaves and the host during strain partitioning. Fabrics from anisotropy of magnetic susceptibility and magnetic remanence in both enclaves align with the magnetic and petrofabric of the host, implying strain archive cohesion between both magmas independent of the rheology contrasts. These fabrics were verified by measuring crystallographic preferred orientation of major silicate phases in both lithologies. The study highlights the need to critically reappraise the role of enclaves as recorders of strain within magmatic systems.

Giant reservoirs with >380,000 km^3 of magma in the ancient Earth's crust: a case study from the Bushveld Complex in South Africa

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

For over a century, the classic paradigm of volcanology and igneous petrology has been premised upon the existence of magma chambers, filled by crystal-free melt, forming 'big tanks'. Such magma chambers gradually lose heat and crystallize from all margins inwards and occasionally supply overlying volcanoes with magma that erupts onto the Earth's surface. This founding concept has been recently challenged on the basis of observations and evidence from various disciplines (Cashman et al. 2017). There are, however, some observations from magmatic complexes that conflict with this emerging paradigm. Here we present one well-constrained example from the Bushveld Complex in

South Africa, indicating that its magma chamber appears to have contained, during one stage of its evolution, an enormous volume of resident melt that slowly crystallized from the base upwards to produce a continuous sequence of chemically stratified cumulate rocks (Latypov et al. 2022a). In the south-eastern part of the complex, the magmatic layering of the Main Zone continuously drapes across a ~4-km-high sloping step in the chamber floor. Such deposition of magmatic layering implies that the resident melt column was thicker than the stepped relief of the chamber floor. Prolonged internal differentiation within this thick magma column is further supported by evolutionary trends in crystallization sequence and mineral compositions through the sequence. The resident melt column in the Bushveld chamber during the formation of the Main Zone is estimated at >5-km in thickness and >380,000 km^3 in volume (Latypov et al. 2022a). This volume is several orders of magnitude larger than the largest ignimbrite/tuff super-eruptions in Earth's history (e.g., Bishop tuff – 600 km^3 and Youngest Toba eruption – up to 13,200 km^3) and is only comparable to estimates of some of Earth's large igneous provinces, such as the Karoo (367,000 km^3) and Afar (350,000 km^3). This suggests that super-large, entirely molten, and long-lived magma chambers occur, at least occasionally, in the geological history of our planet. Therefore, the classical view of magma chambers as 'big magma tanks' remains a viable research concept for some of Earth's magmatic provinces (Latypov et al. 2022a, b).

Cashman, K. V. et al. Science 355, eaag3055 (2017).

Latypov, R. M. et al. Scientific Reports 12, 15651 (2022a).

Latypov, R. M. et al. Scientific Reports 12, 4092 (2022b).

Direct field evidence for polybaric fractional crystallization

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The transcrustal mush paradigm has been proposed to explain how primitive basaltic melts, in equilibrium with the mantle, differentiated into a felsic composition comparable to the bulk continental crust. Continuous compositional stratification from the lower to upper crust formed by polybaric fractional crystallization is expected in this paradigm. However, the exposed arc crustal sections show magma differentiation dominantly occurs isobaric in the lower crust and lack clear compositional stratification in the middle-upper crust. To address this challenge, it is critical to investigate a crustal section built by contemporaneously and genetically related intrusive rocks in the field. This study reports a new continental arc crustal section represented by the Kinsman suite, in the NE Appalachian orogen (New Hampshire, USA), whose

emplacement depth varies from ~1 to 9 kbar (~4–36 km). The Kinsman suite is mainly composed of peraluminous granitoids that show continuous geochemical stratification in both major and trace elements over depths. As pressure decreases, the Kinsman granitoids show higher SiO_2 and Rb and lower MgO, FeOtotal, Al_2O_3, CaO, Sr, Ba, and Sc contents. Such a compositional stratification with limited zircon εHf(t) variations (-5.2 to +3.7) lend direct evidence to the polybaric mush model. This study suggests that polybaric fractional crystallization is a vital mechanism that drives arc crustal differentiation.

Porous melt flow in felsic continental crust -- numerical models

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Grain-scale porous flow is usually considered as the first stage of melt transport prior to melt segregation into meso- to macro-scale conduits, such as networks of leucosomes or dykes. However, there is growing evidence that grain-scale porous melt flow can explain formation of some metaigneous migmatites, namely in the Bohemian Massif (Czech Republic), Vosges (France) and Fiordland (New Zealand). We focus on the example from the Bohemian Massif: in these migmatites, veins are lacking, leucosomes are rare and relics of melt are spread along grain boundaries. Textural, geochemical and compositional variations in these rocks show that they formed due to equilibration with melt coming from an external source that was chemically similar to the host rock. Geochronological data further suggest that in these rocks, porous melt flow operated for millions of years.

The question arises, under what circumstances this style of melt transport can operate and what consequences it has on the crustal composition, thermal state and deformation. We address this question by means of numerical modeling using the code ASPECT (aspect.geodynamics.org). Our models are two-dimensional, thermo-mechanical and mimic evolution of material consisting of two phases - solid rock and melt. The rock matrix is porous and the system of melt-filled pores is described by its permeability. The model domain represents a cross section through a thick and hot continental crust. Our results suggest that in such a crust, melt can slowly migrate through pores with a characteristic spacing of one millimeter or larger. In spite of its low velocity (millimeters to centimeters per year), it can gradually create large partially-molten zones in the middle-lower crust. The typical melt fraction in these zones is ~10-20%. Regions with a higher melt fraction, resembling magmatic bodies, form on top of the partially-molten zones, but they are only transient and volumetrically small. Compositionally enriched middle crust and depleted lower crust develop, and the enriched middle crust shows km-scale compositional variations. The changes of the composition due to melt migration provide a feedback mechanism causing the decrease of the solidus temperature and growth of the partially molten zone. The style of model evolution depends on the model parameters, namely the permeability, viscosity of the solid rock and thermal conditions. Depending on these parameters, the models show melt-enhanced convection, formation of a partially-molten diapir and/or porosity waves.

Melt percolation through and extraction from the Balmuccia mantle body (European Southern Alps): the root of the Sesia Magmatic System?

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Understanding melt migration and extraction through and from the lithospheric mantle domains of trans-lithospheric magmatic systems is key to deciphering the early-stage processes that govern the magmatic evolution of such large-scale systems and ultimately to understand where the new continental crust arises from. However, the investigation of the deepest part of the magmatic column is limited by the scarcity of suitable locations where the crust-mantle transition is accessible.

The Ivrea Zone exposes the lower crustal section of the Sesia Magmatic System, a post-collisional trans-lithospheric magmatic system of Permian age emplaced into the high-grade basement of the European Southern Alps. The lower crustal configuration is characterized by large volumes of Permian layered gabbros, which enclose several mantle peridotite lenses, the Balmuccia body being the most famous. The latter is composed of peridotites and contains different types of pyroxenite and gabbroic dykes, testifying to abundant melt percolation. Classically, it was interpreted as the result of the pre-Permian tectonic emplacement of mantle slices into the basement. No genetic relationship with the host gabbroic rocks has been inferred. However, structural continuity between the fabric and dykes in the peridotites, and the layering in the host gabbros coupled with the discordant nature of their contacts suggest a primary magmatic relationship. This interpretation is corroborated by recent seismic studies which indicate that the Balmuccia body represents the shallow expression of the Ivrea Geophysical Body, the interface between the peridotites and the surrounding gabbros possibly corresponding to the Permian fossil crust-mantle transition.

Combining field observations, petrological, geochemical, and isotopic investigations across the Balmuccia body and surrounding gabbros, this study aims at exploring the significance of the percolated mantle domains, the mechanisms controlling the different types of melt flow, and understanding whether the percolated mantle domains exemplify the trails of the Permian melts which fed the Sesia Magmatic System.

Preliminary data suggest that reactive porous flow through the lithosphere refertilized the peridotites, whereas reactive channeled flow and dyking produced the pyroxenite and gabbroic dykes, the mechanisms of melt migration being rheology-controlled. Moreover, geochemical and isotopic affinities between dykes in the peridotites and host gabbros, indicate their genetic relationship. In this scenario, the percolated mantle domains reflect the lithospheric mantle roots of the Sesia Magmatic System, where the interaction of the uprising melts with the mantle accounted for the early-stage Permian magmatic evolution, and the extraction of mafic melts produced voluminous mafic underplating in the lower crust.

Crustal architecture and evolution revealed by xenoliths from Lesser Antilles

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Xenoliths provide small windows into processes occurring at great depth in the Earth's interior, which we are not able to observe directly. Crustal xenoliths from active arcs are particularly interesting as they provide as with almost in situ information on crustal structure. If we have end members xenoliths, igneous to meta-igneous for example, from a single volcano we can gain a better understanding of crust growth processes and magmatic architecture.

The Lesser Antilles volcanic arc is known for its unusually abundant plutonic xenoliths. Xenoliths from Petit St. Vincent (Grenadines archipelago) are particularly interesting because of their textural and petrogenetic range. We combined petrographic observations, electron backscatter diffraction (EBSD) analysis, major and trace element chemistry of xenoliths and lavas and geochemical and thermal modelling to explore the construction of arc crust beneath Petit St. Vincent and redistribution of fluid-mobile elements. Petit St. Vincent xenoliths are dominated by calcic plagioclase, clinopyroxene and amphibole, and can be divided into two main categories, igneous and meta-igneous. Igneous xenoliths typically have cumulate textures; meta-igneous xenoliths range texturally from those that preserve vestiges of primary magmatic fabrics to intensely deformed varieties characterised by grain-size reduction and foliation development.

Meta-igneous xenoliths also contain the most calcic plagioclase ($An_{98–100}$). The presence of both meta-igneous and igneous xenoliths provides evidence for reworking of older arc crust and antecedent igneous intrusions. The latter have a protolith composition similar to high-MgO, low-Sr picrites and high-Ca, high-Sr ankaramites from the neighbouring islands of Petite Martinique and Grenada. The meta-igneous xenoliths derive from older, mafic arc crust present at the onset of subduction. Trace element chemistry and EBSD analyses of meta-igneous xenoliths are consistent with a complex history of re-melting and deformation mediated by chlorine-bearing H_2O rich fluids (including melts). Thermal modelling supports crustal reworking through repeated magma intrusions and indicates that the observed thermal structure and thickness of crust beneath Petit St. Vincent could have developed on a timescale of approximately 4 million years at rates compatible with the regional arc magma flux. Based on evidence from thermodynamic models and exhumed ancient arc crust sections, Collins et al. (Nature Geoscience, 13, 331–338, 2020) have proposed that water-fluxed melting may be an important aspect of deep arc crust sections world-wide. Textures and mineralogy of xenoliths from Petit St. Vincent, including their characteristic high-An plagioclase, testify to such a process beneath an active, intra-oceanic arc.

Ascent of volatile-rich felsic magma in dikes and formation of crystal magma chambers

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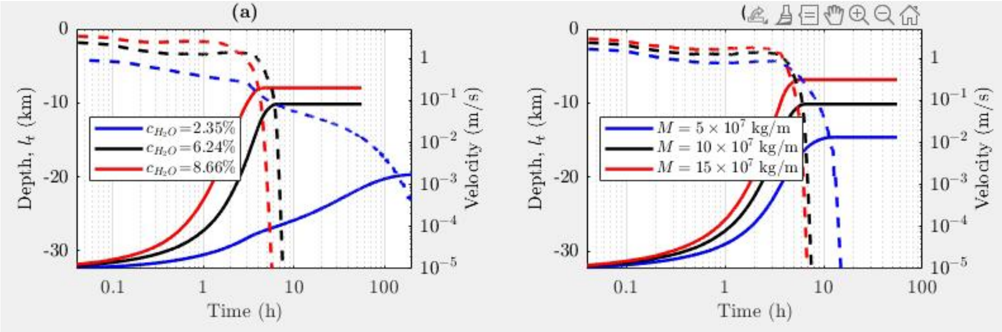
Oral, Thursday 14th September, 16:30 - 16:45

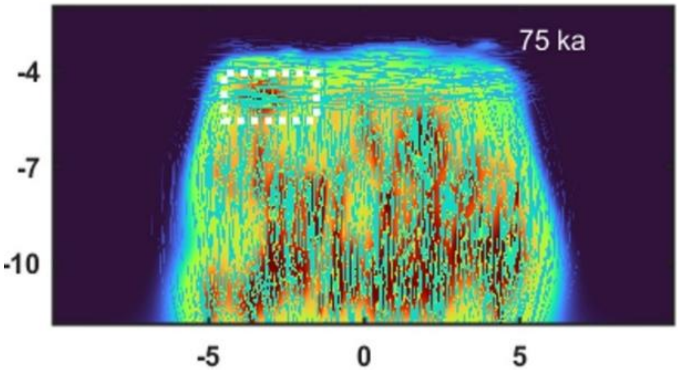
Magma ascending in dikes undergoes complicated physical and chemical transformations as it propagates through the Earth's crust. Our study introduces a mathematical model that accounts for the presence of multiple volatile species (H_2O and CO_2) in silicic magma, bubble growth, heat transfer, crystallization, and latent heat release. The model's outcomes indicate rapid ascent times (hours to days) from a deep source, and a significant increase in viscosity near the surface due to cooling and degassing induces crystallization, resulting in the dike stagnation and solidification. Faster dike propagation and shallower stopping depth are influenced by higher initial water content, temperature, and a greater mass of buoyant magma within the dike. Simulations suggest a plausible mechanism for the transportation of deep volatiles to shallow intrusions associated with porphyry ore deposits.

Repetitive dike injection is studied by means a two-dimensional thermo-elastic model that investigates the formation of a magma body in a granitic crust through the injection of rhyolitic or basaltic dikes and sills. By utilizing elastic analytical solutions, the displacement of rocks resulting from magma intrusion and evacuation during volcanic eruptions are calculated. The melting and crystallization behavior of magma and rocks is governed by phase diagrams. Through the computation of temperature histories, we can predict the crystallization and dissolution of zircon crystals and determine their ages.

The incremental injection of dikes leads to the formation of magma batches with diverse shapes, interconnected horizontally and vertically. Melt production strongly depends on the rate of magma influx, the width of the injection area, and the frequency of eruptions. High rates of injection can generate large magma reservoirs capable of significant eruptions, while repeated eruptions cause the shrinkage of magma bodies. Intense heat input results in the alteration of old cores of zircon crystals in the host rocks. Peripheral magmatic zircons form rapidly due to the quick cooling of intruded dikes, whereas central crystals can experience growth over hundreds of thousands of years.

The model applied to Elbrus volcano allowed reconstruction of the evolution of its plumbing system during 600 ka of activity. Presence of a wide range of zircon ages together with large erupted volume can occur in a narrow range of governing parameters.


(a)
Depth, l_t (km)
Velocity (m/s)
Time (h)
c_{H_2O}=2.35%
c_{H_2O}=6.24%
c_{H_2O}=8.66%
$M = 5 \times 10^7$ kg/m
$M = 10 \times 10^7$ kg/m
$M = 15 \times 10^7$ kg/m


75 ka
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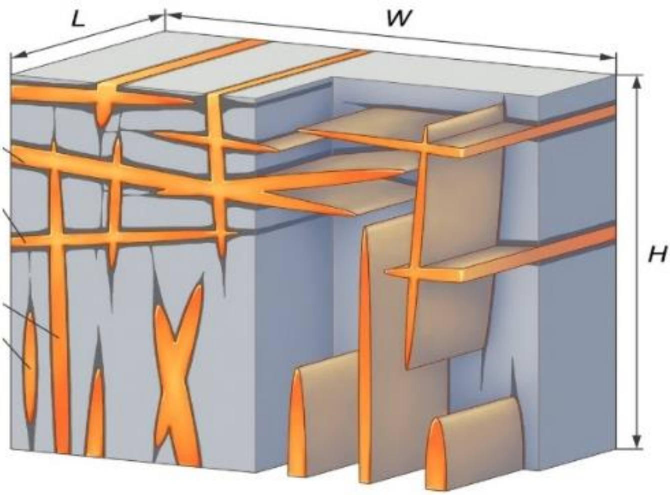
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Magma processes in the Tuolumne intrusive complex, Kuna Crest lobe, and the Jackass Lakes pluton, Sierra Nevada batholith, CA: Size, longevity, and magma focusing matter

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Arc magma plumbing systems may develop thick magma columns as they mature. Magmas may stall at different crustal levels to form varying size magma storage sites that are active up to a few myr. The 1,100 km^2, 95-85 Ma Tuolumne intrusive complex (TIC) represents such a site. It is composed of four nested, extensive granodiorite units of irregular shape that are largely separated by gradational contacts and wide hybrid zones. Local sharp contacts often coincide with structural truncations and age gaps consistent with magmatic erosion. Mineral and whole rock geochemistry and geochronology indicate that magma mixing, recycling of older magma into younger, and melt loss were important. However, TIC initiation was distinct, which is preserved in a < 1 km wide sheeted complex that lines the 95-93 Ma, 70-80 km2 Kuna Crest lobe (KCL). It is composed of cm-m thin gabbroic to granodioritic sheets that did not interact. They crystallized within <<500ka, indicating more punctuated, low volume, and compositionally heterogeneous magma pulses before they increasingly amalgamated to form bigger magma bodies, first in the KCL interior, later in the TIC interior. How long-lived and prevalent were sheeting and magma-magma interactions before 95 Ma? Did large-scale magma mixing, homogenization, and erosion (MHE) occur outside the magma focusing zone?

The ~175 km^2, 98-97 Ma Jackass Lakes pluton (JLP) south of the TIC is about one sixth of the TIC size and longevity and twice as large as the KCL but same longevity. It is trapezoidal in shape and is interpreted to be sheeted. It is composed of the main porphyritic JLP granodiorite (Kj) that was injected by younger, irregular shaped, more mafic granodiorites. LA-ICPMS U-Pb zircon ages indicate all granodiorites are approximately contemporaneous. In the NW JLP, the younger granodiorites and diorites grade into one another indicating magma interconnectivity and hybridization along contacts only, while they are reportedly discreet sheets in the SE. Whole rock element geochemistry and petrography indicate crystal accumulation/melt loss from the Kj only, which is preserved as leucogranite porphyry and felsic volcanics. Hf isotope ratios of zircon from the JLP granodiorites indicate the same range as the entire TIC. Hf isotope homogeneity in the KCL and heterogeneity in the JLP, and lithologic heterogeneity in both likely represent original magma pulses while major MHE processes like in the TIC failed due to faster cooling and location outside a regional magma focusing zone. Melt loss, however, occurred in all plutons.

Mid to upper crustal formation, evolution, transport, emplacement, and eruption of silicic magma within a transcrustal magmatic system: Miocene Colorado River Extensional Corridor, Nevada, USA

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

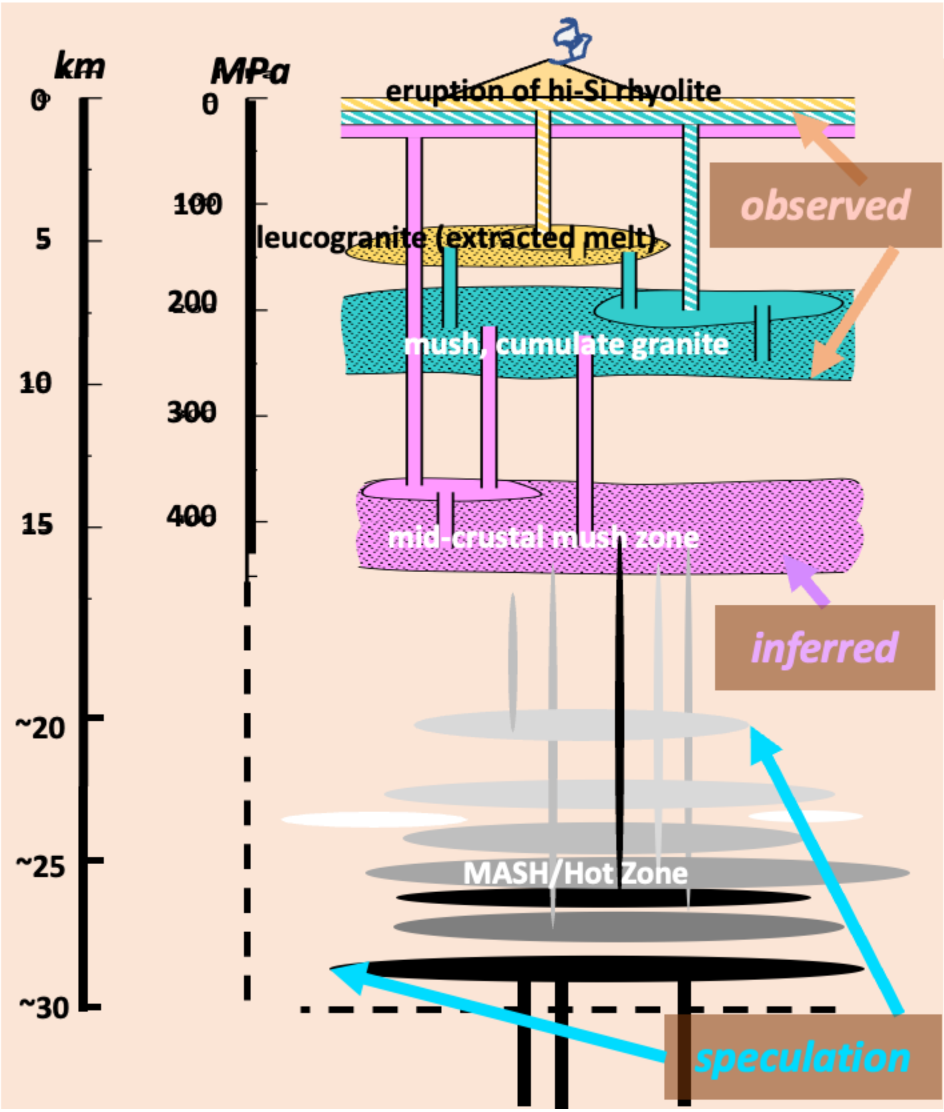
Transcrustal magmatic systems are now widely proposed: magmatism initiating in the mantle propagates upward through the crust, yielding a mushy, compositionally diverse column with transient melt-rich lenses, some of which erupt. However, details of how such systems work remain hazy – in dispute and/or highly variable. We investigate the silicic magma that constructed plutons and erupted during the Miocene in the Colorado River Extensional Corridor (CREC). These granites and rhyolites, exposed to paleodepths of as much as ~13 km in steep tilt blocks, provide insights into where and how silicic magmas were generated, modified, and transported in the upper part of this system.

Silicic rocks dominate either all or the younger parts of the CREC plutons, and the younger portion of the coeval volcanic sequence. Slightly older intermediate rocks are abundant in volcanic sections (trachyandesite-trachydacite) and locally in plutons (quartz monzonite).

Sparse to abundant mafic magma (basaltic trachyandesite) mingled with and postdated granite and rhyolite. Isotopic data (Nd, Sr, Hf, O) suggest that mafic magma was derived from ancient, enriched lithospheric mantle and demonstrate that both intermediate and silicic magmas were hybrids that included large Proterozoic crustal components.

Most of the granite is coarse grained and reveals evidence for crystal accumulation and/or melt extraction. We focus here on the fine-grained rocks (low-silica granite dikes, sills, quenched margins) that appear to document compositions of crystal-poor magmas that fed the plutons. Their uniform compositions (73+1 wt% SiO_2) are consistent with being parental to the cumulates and extracted melts that formed CREC granites and rhyolites, and these putative feeders are isotopically indistinguishable from other granites and rhyolites. We infer that crust-mantle hybridization to form CREC silicic magmas occurred beneath the deepest exposed level of crust, and that evident compositional variation is mostly a consequence of closed-system fractional crystallization.

Rhyolite-MELTS barometry indicates that the crystal-poor magmas parental to CREC granites and rhyolites were extracted from qtz+feldspar-bearing mush at ~400 MPa (~15 km)(Gualda et al, this meeting). Barometry reveals that common leucogranites and erupted rhyolites (76-78% SiO_2) represent melt extracted from mush within the plutons at ~4-8 km depth. The CREC transcrustal system appears to have included a lower crustal “hot zone” where mantle-derived magma interacted with ancient crust to form an intermediate hybrid; a mid-crustal mush zone where interstitial silicic melt formed and was extracted; and upper crustal lenses where the extracted granitic melt formed cumulates and fractionated, eruptible melts.



Deformed or undeformed: A petrostructural reckoning of the Regional Deformation in the Archean Bundelkhand Granitoids

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Bundelkhand Craton covers an area of over 29,000 km^2 in the North Central Peninsular India and displays a wide variety of rock types, in which the Bundelkhand granitoids cover ~90% of the surface area of the craton. The granitoids are believed to be formed as a result of partial melting of the Bundelkhand TTG gneisses and were emplaced syntectonically ~2.6 Ga. These granitoids range from syeno-monzo-granites, granodiorites to diorites. These Archean granitoids host a variety of structural features ranging from primary magmatic foliations and lineations to brittle fracture and ductile shear zones. Although, most outcrops of these granitoids show no pervasive deformational feature in the field or in hand-specimen, and hence often misinterpreted as undeformed in nature, we state otherwise. Anisotropy of Magnetic Susceptibility (AMS) studies were performed on these virtually undeformed granitoid samples from 150 locations encompassing the craton, to determine their hidden (magnetic) fabrics. As determined from AMS study, the degree of anisotropy (Pj) for the samples range from 1.015 to 1.387. In the samples which show Pj<1.1

the mineralogy of the rock controls the degree of anisotropy and where the Pj>1.1, the same is controlled by deformation. Out of these granitoids, ~75% of the samples show Pj values <1.1, however. in microscale, solid state deformational features prevail. This may be attributed to the process of static recrystallization of the quartz grains due to the formational temperature of the granitoid pluton and low degree of stain accumulated due to the magma mush or cooling pluton. Alternatively, the remaining samples show even higher order deformational features which brings us to the inference that Pj values are not always a reliable factor for interpretation of deformational control in granitoids. The values of shape parameter (T) in the samples range from -0.699 to 0.797 and show uniform distribution suggesting the prevalence of both flattening and constrictional deformation regimes during the emplacement. Moreover, microstructural studies suggest that these granitoids are not strictly undeformed as various static and dynamic recrystallization features are displayed by quartz, feldspar, etc. The spatial disposition of the magnetic fabrics suggests the presence of a few micro-plutons in the craton which are possibly younger emplacements than the rest of the Bundelkhand granitoids. Also, from the inter-relationships of the magnetic fabrics we reckon that there have been more than one phases of deformation in the craton.

Timescales in felsic igneous rocks: constraints from element diffusion in garnet and quartz

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Diffusion of elements in minerals such as garnet and quartz may provide important insights into a variety of processes that operate at different timescales in felsic volcanic and plutonic rocks. Whether or not laboratory experiments can simply be applied to natural rock systems remains a matter of debate. This is because most diffusion experiments are done at 1atm anhydrous with or without controlled activities of the diffusing species of interest, while natural processes in magma reservoirs occur at higher pressures and dominantly under hydrous conditions. We provide examples on the importance of Ti diffusion in quartz and major and trace element diffusion in garnet.

The 1st exemple adresses Ti diffusion in quartz (e.g. Jollands et al. 2020). Ti diffusion in quartz is widely debated, mainly because of the ~3 orders of magnitude difference in experimentally determined Ti diffusion coefficients. Fast Ti diffusion in quartz would provide opportunities for understanding short time scale processes relevant for high silica volcanic rocks, while slow diffusion in quartz is more relevant for the assembly of felsic plutonic systems. We discuss various geological and experimental constraints to address these issues and the usefulness of applying Ti diffusion in quartz to felsic rocks.

The 2nd example uses results from garnets from mid-crustal plutonic rocks from the Ivrea-Zone (N-Italy), which contain metapelitic enclaves and composite metamorphic-magmatic xeno-phenocryst garnet. To quantify the duration of magmatic overgrowth, we have numerically modelled Cr, Y, REEs and Hf trace element diffusion, as well as multicomponent major divalent cation diffusion within garnet using available experimental diffusion data and Cr diffusion data retrieved from natural garnets. All modelled diffusants conform to a single temperature-time path, in which the temperatures associated with magmatic overgrowths persisted for 5.4 and 6.3 kyr (Devoir et al. 2021).

Appinite complexes, granitoid batholiths and crustal growth: a conceptual model

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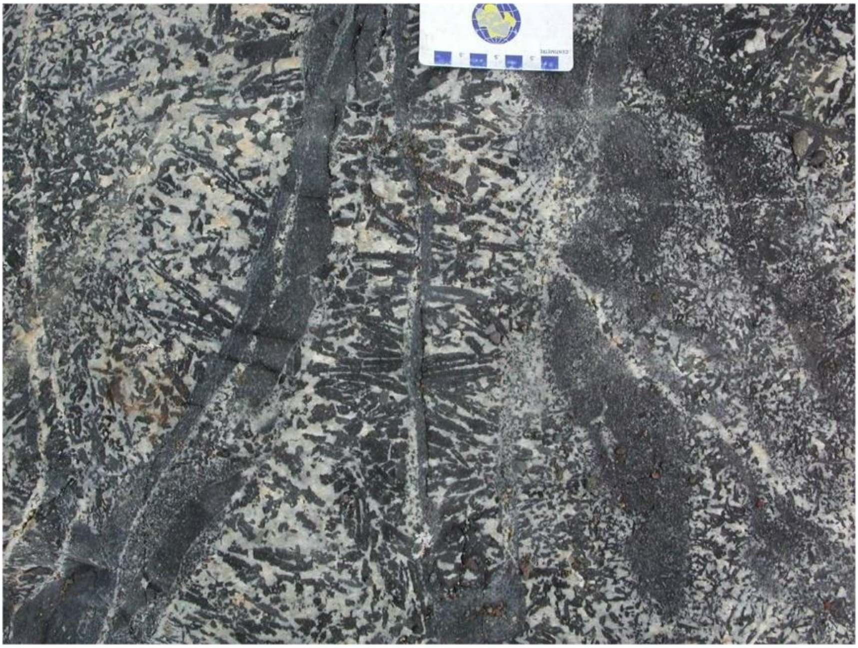
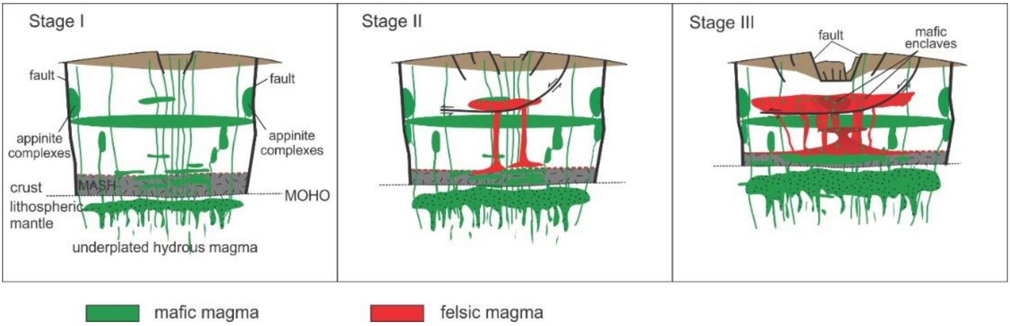
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Appinites are a suite of plutonic rocks, ranging from ultramafic to felsic in composition, that are characterized by idiomorphic hornblende as the dominant mafic mineral in all lithologies and by spectacularly diverse textures, including planar and linear magmatic fabrics, mafic pegmatites and widespread evidence of mingling between mafic and felsic compositions.



These features suggest crystallization from anomalously water-rich magma which, according to limited isotopic studies, has both mantle and meteoric components. Appinites typically occur as small (~2 km diameter) complexes emplaced along the periphery of granitoid plutons and commonly adjacent to major deep crustal faults, which they preferentially exploit during their ascent. Several studies emphasize the relationship between intrusion of appinites, granitoid plutonism and termination of subduction. However, recent geochronological data suggest a more long-lived genetic relationship between appinites and granitoid magma generation and subduction. Appinites may represent aliquots of hydrous basaltic magma derived from variably fractionated mafic underplates that were originally emplaced during protracted subduction adjacent to the MOHO, triggering generation of voluminous granitoid magmas by partial melting in the overlying MASH zone. The hydrous mafic magmas from this underplate may have ascended, accumulated, and differentiated at mid-to-upper crustal levels (ca. 3-6 kbar, 15 km depth) and crystallized under water-saturated conditions. The granitoid magmas were emplaced in pulses when transient stresses activated favourably oriented structures which became conduits for magma transport. The ascent of late mafic magmas, however, is impeded by the rheological barriers created by the structurally overlying granitoid magma bodies. Magmas that form appinite complexes evaded those rheological barriers because they preferentially exploited the deep crustal faults that bounded the plutonic system. In this scenario, appinite complexes may be a direct connection to the mafic underplate and so its most mafic components may provide insights into processes that generate granitoid batholiths and, more generally, into crustal growth in arc systems.

Murphy, J.B., Collins, W.J., Archibald, D.B. 2022.Appinite complexes, granitoid batholiths and crustal growth: a conceptual model. Geoscience Canada, 49, 237-249. https://doi.org/10.12789/geocanj.2022.49



Crystallization and residence of high-silica rhyolite in the Searchlight magmatic system (Nevada, USA)

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Oral, Thursday 14th September, 16:15 - 16:30

The Searchlight pluton (SLP) and overlying Highland Range volcanics (HRV) comprise the Miocene Searchlight magmatic system (Nevada, USA). Extension has tilted the section up to 90°, exposing ~15 km from the volcanics through the pluton. The SLP includes a lower quartz monzonite unit, a middle granite to leucogranite unit, and an upper quartz monzonite to granite unit. Geochronology indicates the pluton was built incrementally over 1.5-2 Myr. The HRV is composed of trachyandesite/trachydacite lavas overlain by predominantly high-silica rhyolite lavas and tuffs. Bulk rock geochemistry and geothermobarometry of the middle SLP and HRV rhyolites broadly overlap, and geochronology suggests the units were contemporaneous. These observations suggest the middle SLP and upper HRV magmas were genetically related, making the Searchlight magmatic system ideal for investigating the generation and crystallization of silicic magmas.

We assess crystallization timescales of the HRV rhyolites using diffusion chronometry. The rhyolites are crystal-poor and dominated by quartz, sanidine, and plagioclase. Feldspars are unzoned in major elements, and modeling suggests quartz and sanidine co-crystallized shortly before the onset of plagioclase crystallization. These observations suggest crystallization largely at the minimum. Quartz zoning in panchromatic cathodoluminescence (CL) images predominantly correlates with Ti-associated wavelengths in hyperspectral CL, and we use grayscale intensity profiles from CL images to assess Ti-in-quartz diffusion times.

We identify three timescales: long timescales from discontinuous, diffusely zoned cores that are likely xenocrystic; intermediate timescales from non-diffuse cores; and short timescales from interior/rim zones. Estimating absolute times is complicated by experiments suggesting Ti-in-quartz diffusivities (DTi,qtz) between 10^{-22} and 10^{-26} m^2/s at 750 °C. This produces time estimates from non-diffuse core boundaries, which we interpret as phenocrystic, ranging from decades to >1 My. We further constrain these timescales by leveraging zircon geochronology and the relationship between the middle SLP and upper HRV: only results using DTi,qtz= 10^{-22} m^2/s are permitted by the <150 kyr of estimated zircon crystallization in the middle SLP. Furthermore, only quartz growth rates calculated using times estimated with DTi,qtz= 10^{-22} m²/s are consistent with other published quartz growth rates; rates calculated with DTi,qtz= 10^{-25} or 10^{-26} m²/s are as slow as published zircon growth rates.

We interpret our results to indicate quartz in the HRV rhyolites crystallized over decadal to centennial timescales at ~10^{-13} m/s but note that more work is needed to understand the discrepancy in DTi,qtz. Investigations of trace element zoning in HRV feldspars and Ti diffusion in middle SLP quartz is underway.

Magmatic evolution of a high-silica subvolcanic magma reservoir: evidences from the Early-Miocene batholith of central Chile (33-34°S)

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Oral, Thursday 14th September, 16:00 - 16:15

Silicic plutons provide an opportunity to access the processes that govern the magma emplacement and compositional differentiation in the Earth's crust. Over the last few years, there has been special interest on the genetic relationship between plutonic and volcanic rocks, with intense debate on the ability of upper crustal magma reservoirs to produce high-silica magmas and feed rhyolitic volcanism. In this regard, a comprehensive study of granitic plutons from unexplored naturales cases can illuminate the evolution of crustal magmatic reservoirs.

Based on petrological, geochronological, and magnetic fabric data, we present the case of the Early-Miocene batholith in central Chile, emplaced at shallow depths (~5 km), which may preserve the remnants of a fossil subvolcanic system. The batholith is composed of two main intrusions: the vertically zoned La Obra pluton composed of granitic/granodioritic layers with subordinate intermediate domains; and the high-silica granitic Cerro Blanco pluton, nearly homogeneous, with abundant leucogranitic dykes. Quartz-dioritic satellite stocks are observed around the main bodies.

We interpret the batholith as the crystallized remnants of a magmatic system formed by the injection of multiple pulses of magma of different compositions that cooled over a time span of ~1.4 Ma (U-Pb ages ranges 19.9-21.4 Ma), with younger ages recorded in the inner zone. A first stage was dominated by sheet-like intrusions of intermediate magma, now preserved at the margins of the main plutons and the satellite stocks. In a second stage, both felsic and intermediate pulses intruded along horizontal plains throughout the whole plutonic system, as indicated by the subhorizontal magnetic lineations and similar ages recorded at the margins. The late cooling stage was dominated high-silica granitic magmas in the inner parts of the system, probably representing silicic melts distributed in sheet-like concentration zones.

The steep magnetic lineation recorded in the Cerro Blanco pluton is interpreted as the result of magma evacuation channels feeding the shallow magmatic systems. This is also suggested by the abundance of porphyritic rhyolitic dikes intruding both the granite and the host rocks. We propose that the Cerro Blanco pluton was able to feed the explosive volcanic events recorded in the surrounding Miocene rocks, as evidenced by the high-silica tuffs similar in age to the plutonic suite. Although additional analyses are required to confirm the genetic relationship between the plutonic and volcanic rocks, the La Obra–Cerro Blanco system represents a potential case study to address the processes connecting the plutonic and volcanic environment.

Petrologic evidence for melt extraction and crystal accumulation under a large, silicic caldera (Sesia Magmatic System, Italy)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Understanding the physical evolution of shallow magma bodies in the Earth's upper crust is crucial to the development of reliable monitoring and forewarning systems in active volcanic areas. However, the mechanisms controlling the storage and rapid extraction of volatile-rich magmas from shallow crustal levels, which ultimately led to violent expulsion of large volumes of magmas during climactic eruptions, are still to be fully unravelled.

The Sesia Valley of southern Alps (Italy) hosts a virtually complete section of continental crust, which contains the remnants of a Permian (~283 Ma) caldera plumbing system that produced, during its lifetime, at least a catastrophic eruption (>500 km^3 rhyolitic material). In this crustal section, three granitoid intrusions, the Valle Mosso, Alzo-Roccapietra and Baveno plutons compose the upper- crustal portion of the plumbing system. These three bodies were originally part of a single, larger intrusion, dismembered by extensional (Jurassic) and Alpine tectonics and are now arranged in tilted blocks along a North-South trend, with the Alzo-Roccapietra pluton corresponding to the central pivot. This composite intrusion consists of two thick (~2 km across) granitoid units, outcropping from West to East as: (1) a porphyritic quartz-monzonite (~68 wt % SiO_2) and (2) an equigranular monzogranite (~73 wt % SiO_2) bodies that show cryptic contacts.

The porphyritic quartz-monzonite unit displays preferred orientation of touching plagioclase and orthoclase phenocrysts parallel to the migmatitic foliation of the metamorphic host-rock, a feature that is commonly interpreted as indicative of crystal accumulation and migration of residual melt in silicic intrusions. To test weather melt extraction is a process capable of generating the textural and compositional variability observed across the Roccapietra intrusion, we tracked via rhyolite-MELTS thermodynamic modelling, the evolution of the latent heat budget during crystallization of a hydrous (4% H_2O) rhyolitic melt. Results show that the Roccapietra parental silicic magma spent a relatively longer time at a temperature interval between 730 and 710 °C, corresponding to a range crystal fraction of 0.4-0.7, favourable to a process of extraction of a residual melt from an interlocked crystal framework.

Overall, textural, petrologic and thermodynamic evidence of melt extraction in an upper crustal intrusion with direct links to a large caldera complex highlight the importance of granitic studies in deciphering mechanisms and timescales of crystal-melt segregation processes that precede volcanic eruptions.

Tracking crustal contamination in arc batholiths: the Adamello case study

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Oral, Thursday 14th September, 15:45 - 16:00

The build-up of magmatic systems in continental arcs is accompanied by interactions between magma and various crustal reservoirs, modulating the geochemical and isotopic composition of the newly formed crust. To gain new insights into such interaction processes, we examined bulk Sr-Nd and in-situ plagioclase Sr isotopic data in samples previously characterised by U-Pb dating on zircon (LA-ICP-MS and CA-ID-TIMS) and εHf (Schoene et al., 2012; Broderick et al., 2015; Schaltegger et al., 2019) in the 42-30 Ma Adamello batholith (Northern Italy), the largest Tertiary magmatic complex in the Alps. We measured the Sr isotope compositions of plagioclase in-situ (LA-MC-ICP-MS) in samples from the first 1 Myr of magmatic activity (Schoene et al., 2012; Broderick et al., 2015) and bulk-sample Sr-Nd isotopic ratios (TIMS) in samples covering the 12 Myr of igneous crystallization of the batholith (Schaltegger et al., 2019).

We performed Sr-Nd isotope binary mixing models between mantle-derived magma and a metapelitic contaminant representative of the Southern Alpine Basement. This model shows that the isotopic evolution of the Adamello batholith can be explained by increasing metapelitic contamination over time, which is consistent with previous studies (Del Moro et al., 1979; Schaltegger et al., 2019). We identify a decrease in contamination at the end of the batholith lifetime, which was previously not possible by in-situ zircon Hf isotope analysis.

Our in-situ Sr isotope data in plagioclase from felsic units show similar 87Sr/86Sr ratios for anorthite contents ranging from 20 to 90, indicating that crustal contamination precedeed significant differentiation. This is further substantiated by compiled bulk rock SiO2-87Sr/86Sr data supporting the hypothesis that there is no statistically significant increase in Sr isotopes, (i.e., a crustal contamination proxy) with increasing differentiation. This indicates that crustal contamination predominantly occurs below the emplacement level of Adamello magmas consistent with enthalpic constraints (e.g., Thompson et al., 2002).

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Magma Batch Emplacement – Insights from the Slaufrudalur pluton, SE Iceland

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Granitic plutons are formed by the amalgamation of smaller magma batches. The shape and volume of the batches influence the internal architecture of igneous intrusions and thus magma transport (Annen et al., 2015). The intrusion of magma batches into plutons has mostly been analyzed by numerical modelling and must be further constrained by field studies.

We focus on the Slaufrudalur pluton of southeastern Iceland to investigate magma batch emplacement and incremental growth of igneous intrusions. The Slaufrudalur pluton is the largest exposed granitic intrusion in the Neogene basaltic lava pile of Iceland, shows bulk volume of 8-10 km^3 and was assembled by cauldron subsidence (Burchardt et al., 2012).

We carried out mapping in the pluton, AMS sampling (anisotropy of magnetic susceptibility), photogrammetry and 3D reconstruction of a prominently exposed magma batch unit with laterally continuous bottom and top contacts. The magma batch unit is a stratigraphic marker that may be represented by a plane (Solberg, 2022) with N34°E strike, shows average volume of 0.15 km^3 and may be quantified in terms of average magnetic fabric with implications for magma flow kinematics and contact relationships with subsequent batches. The pluton as a whole is horizontally layered, except near the walls. Moreover, we identified a potential feeder in the southwest, internal syn-magmatic deformation, mingling and mixing mostly towards the northeast, as well as host rock deformation and alteration along the wall fault and wall-roof transition in the northeast.

We suggest the following: (1) the magma batch unit spread horizontally from a feeder zone in the southwest, (2) mingling with subsequent units increased towards the northeast with distance from the feeder, (3) roof-wall deformation reflects the interplay between buildup of internal overpressure and cauldron subsidence during magma batch emplacement, and lastly (4) wall zones served as feeders and accommodated vertical pluton growth, resulting in the host rock deformation and alteration. The Slaufrudalur pluton offers prime examples of features associated with magma batch emplacement.

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Burchardt, S., Tanner, D., and Krumbholz, M. 2012. The Slaufrudalur pluton, SE Iceland: An example of shallow magma emplacement by coupled cauldron subsidence and magmatic stoping. GSA Bulletin, 10.1130/B30430.1.

Solberg, M. 2022. Correlation of magma intrusions in the Slaufrudalur pluton with 3D modeling and photogrammetry. BSc Dissertation, Uppsala University.

An integrated AMS and EBSD approach to unravel the architecture of post-collisional granitoid complexes: insights on the tectonic evolution of the late Variscan Serre Batholith

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Serre Batholith is a c. 13-km thick composite late Variscan batholith (c. 1200 km²), constituting the intermediate portion of a nearly complete and uninterrupted section of continental crust exposed in central Calabria. The construction of the batholith began with the emplacement of strongly to moderately foliated deep-seated quartz-diorites and tonalites (c. 297 Ma) at c. 20 km depth, followed upward by weakly to non-foliated strongly peraluminous porphyritic to equigranular granodiorites and granites (c. 295 Ma) and, finally, by shallow-seated non-foliated weakly peraluminous granodiorites (c. 292 Ma) at c. 6 km depth (Caggianelli et al., 2000; Fiannacca et al., 2015, 2017). Its building and structural evolution could be related to deep-seated strike slip shear zone dynamics following the crustal thickening linked to the final amalgamation of Pangea. Microstructures reveal deformation from submagmatic to low-temperature solid state conditions for all the granitoids, suggesting that a tectonic stress was indeed

active before the complete crystallization of the different magmatic bodies and continued long after their solidification. Anisotropy of Magnetic Susceptibility (AMS) analysis was performed on oriented samples collected from 154 sites distributed throughout the Serre Massif, where all the granitoid units are exposed with continuity. The mean strike of the magnetic foliation is recorded NE-SW. Magnetic foliations agree with the main foliation of the upper crustal metamorphic host rocks showing a dominant NW-SE compression direction. Degree of magnetic anisotropy increases towards north-east and south-west of the study area, highlighting possible higher strain zones or, alternatively, a superposed deformation event. Quartz CPO data for 8 granitoid samples from the different crustal levels indicate deformation dominated by the activation of rhomb (a) slip and, in some cases, a combination of basal (a) and rhomb (a) slip, indicative of dominant medium to low-temperature deformation. The asymmetry of quartz CPO indicates top-to-west sense of shear in the samples from the lowermost levels and top-to-east sense of movement for the deep-intermediate rocks. Symmetrical and very scattered data do not convey any clear information on deformation for the intermediate-shallow granitoids. On the whole, Electron Backscatter Diffraction (EBSD) data would point to synkinematic intrusion for the deep to intermediate granitoids. For the upper magmatic levels, a possible late to post kinematic scenario might be implied. All the obtained evidence will help clarify the relationships between emplacement, dynamics and structural evolution of the Serre Batholith granitoids, contributing, ultimately, to the general understanding of build-up mechanisms of post-collisional batholiths.

Buoyant magma ascent triggered by gravitational instabilities

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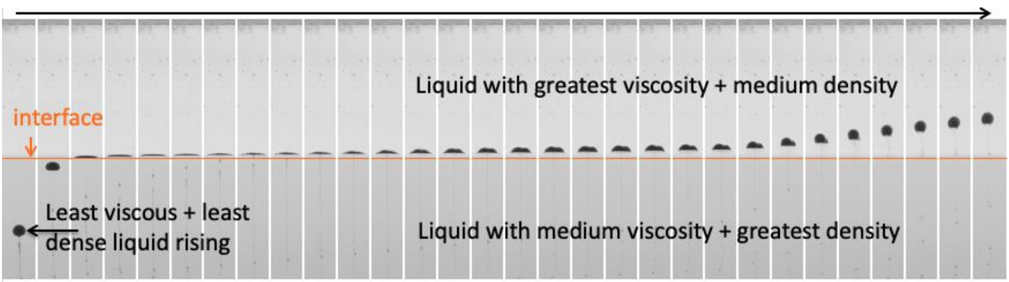
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Felsic magmas can be transported through the crust under a range of conditions and timescales via dikes, diapirs and percolative flow. Melt-rich lenses, formed by reactive flow and compaction or by direct intrusion, may be a common feature in mush-dominated magmatic systems. Such lenses, particularly if comprised of wet, felsic magma, can be less dense than the overlying mush, such that gravitational instabilities may develop, causing the melt-rich layer to locally thicken and protrude upwards. This may eventually initiate dike propagation with potential for rapid magma ascent, or else form a neck that narrows until a blob of melt detaches and rises with viscous deformation of the surrounding mush. The dynamics of these instabilities have implications for the volumes, frequencies and rates of magma transfers through the crust. Previous analogue experiments showed that, due to the much higher viscosity of mush than melt, the wavelength of the instability is the diameter of the melt-rich lens and that the wider the lens and the less viscous the mush, the faster the instability grows. However, that work only established the growth rate of the instability in the initial stage when the amplitude of the instability is much smaller than the lens diameter and grows (thickens) exponentially. Here we extend the analysis to longer durations to determine how long the amplitude grows exponentially, the evolution of the geometry of the non-linear instability, and implications for timescales of magma ascent. Complementary experiments with discrete layers of analogue mush, indicate that a diapir rising steadily though uniform mush will decelerate and spread laterally when it reaches mush with a higher viscosity, forming a temporary melt lens until gravitational instability causes it to locally thicken sufficiently to protrude into the overlying layer and continue its rise through the more viscous layer.



Building a trans-crustal magmatic system – the study of the 4th dimension

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Overview Keynote, Thursday 14th September, 14:00 - 14:45

Crustal magmatic systems that span the entire depth range from the lithospheric mantle and lower crust, through middle crust and up to the paleo-surface, are forming in continental arcs as well as during continent-continent collisions. I exclude here mafic magmatic systems related to Large Igneous Provinces. To understand the timescales of the evolution of a magmatic system, we wish to reconstruct (i) the total duration of magma emplacement, (ii) magma emplacement rates, (iii) the tempo of magmatism, i.e., distinguish between continuous and pulsed magma supply, and (iv) the evolution of the magma sources through time. We have access to this information mainly through the U/Pb age and the Hf isotope composition of zircon from any magmatic rock with a crystallization age of >~500 ky.

This contribution will review the existing analytical and conceptual approaches to interpret U-Pb geochronology datasets of magmatic zircon and how they shape our understanding of magmatic evolution in crustal settings. However, we also need to explore the pitfalls of these concepts, identifying sources of analytical and interpretation error and how these errors can directly impact on our scientific conclusion.

Which analytical techniques are sufficiently precise and accurate to reconstruct the timescales of magmatic processes?

Processes in magmatic systems occur at the 10 ky to 1 my time scale. The selected dating method therefore needs to be capable of resolving this time. When considering some of the external sources of error (secondary standard variance, matrix-dependent inaccuracy) the uncertainty of LA-ICP-MS U/Pb dates (or SIMS dates) is at least 2% of the $^{206}Pb/^{238}U$ date. Furthermore, they suffer from radiation-damage related Pb loss since the analyzed, untreated zircon material is known to yield ages that are too young. Therefore, only CA-ID-TIMS U-Pb dates offer the necessary temporal resolution in rocks older than 500 ky, in-situ U-Pb dates with correctly assessed uncertainties are only useful for the reconstruction of protracted batholith construction over millions of years. Successful application of ^{40}Ar-^{39}Ar dating is restricted to very young high-silica volcanic rocks via single sanidine total fusion dating.

How do complex high-precision (CA-ID-TIMS) U-Pb data sets reflect processes in magmatic systems:

Such dates from chemically abraded zircon are sufficiently precise and accurate to resolve protracted zircon growth (~0.02% of a $^{206}Pb/^{238}U$ date) and to interrogate the duration and rates of magma chamber processes. An ID-TIMS date of an entire zircon represents the volumetrically weighted mean age of all growth zones, visible through the concentric oscillatory zoning in CL or BSE images, and commonly interrupted by numerous resorption surfaces. The more internal growth layers reflect older growth, either previously crystallized zircon gets transported to shallower levels, or they reflect the onset of zircon saturation at deeper levels of the magmatic system. Marginal zones may reflect autocrystic growth in the last melt possible represented by the matrix of our igneous rock sample. Youngest zircon dates of several 100 ky in historical volcanic rocks (such as Mount St. Helens or Toba) demonstrate that there is no guarantee that any zircon has been formed in this last melt. Therefore, only unambiguous field relations can help tell us more about what story the zircon is telling us. Different grains from the same hand sample may record different timescales of crystallization because they nucleate and grow at different times. Furthermore, variable eHf values from individual zircon crystals demonstrate that individual crystals formed within different magmas at different times.

We therefore need to draw a dynamic picture of magmatic plumbing systems with coexisting ephemeral portions of high and low proportions of liquid. Parts of the system undergo >50% solidification, where zircon gets caught in the crystal framework, and possibly recycled upon later rejuvenation of the system, reflected by repeated resorption stages visible in CL images.

Recent work has also shown that a spectrum of single zircon dates from an igneous rock needs thorough evaluation before implying the total lifetime of a magmatic system. Beside the presence of antecrystic and autocrystic zircon, we also may be facing minor volumes of (cryptic) xenocrystic cores, increasing the total grain age. Furthermore, analytical effects may bias the $^{206}Pb/^{238}U$ date due to variable radiogenic/common Pb ratios or Th/U ratios of the grains. The combination of these effects may lead to an apparent zircon continuum over several 100 ky, obfuscating (i) shorter timescales of magma presence, or (ii) the pulsed character of a magmatic system. Such mixed zircon populations therefore do not satisfy zircon growth models that are based on continuous zircon growth in a closed system.

Immobile trace elements tracking interstitial crystallisation of a silicic crystal mush

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

In recent decades there has been a paradigm shift in our understanding of subvolcanic magma storage, away from a melt-dominated model and towards a magma reservoir comprising small melt-rich lenses distributed throughout a crystal mush. Large plutonic bodies are thought to be the solidified remains of these magma reservoirs and can provide insight into the structure and processes occurring in the crystal mush. Of particular interest is understanding how a mechanically solid crystal mush can be remobilised or have large volumes of melt extracted to feed large volcanic eruptions. The eruptibility and mobility of a crystal mush is dependent on the abundance and distribution of residual melt, so key to understanding melt extraction is understanding how porosity has decreased following emplacement into the crust. We examine these problems using samples from the Adamello Batholith, Italy, through in situ trace element work in interstitial phases.

Trace element profiles in zoned plagioclase rims are consistent with approximately 50% in situ fractional crystallisation of an interstitial mineral assemblage dominated by k-feldspar, quartz and magnetite with accompanying biotite, amphibole, apatite, sphene, zircon and epidote. After this plagioclase stops crystallising and k-feldspar, quartz and accessory phases dominate the crystallising assemblage.

These data will be complemented by in situ trace element analysis of other interstitial phases. The same method will be applied to variably sheared samples from the Re di Castello pluton, Adamello Batholith, to model the progressive decrease in porosity of the crystallising mush and the influence of mechanical strain in assisting melt extraction.

Understanding how the structure of the mush developed from emplacement to rheological lock up through to complete solidification will aid in our understanding of mobility and eruptibility of a mush. This can be applied to our understanding of magma reservoir dynamics and how magma accumulates before large explosive silicic eruptions.

The Generation and Extraction of Arc Andesites and Dacites from a Lower-Crustal Mush Zone, Fiordland, New Zealand

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Oral, Thursday 14th September, 11:15 - 11:30

The lower crust of continental arcs is commonly considered to be the engine room for continental crust creation; however, there is strong disagreement about how melts diversify at the base of the crust and how they are extracted. We investigate this problem by examining the roots of the Mesozoic Median batholith exposed in Fiordland, New Zealand. Lower-crustal batholithic rocks were emplaced at ca. 30-50 km depth during a brief magmatic surge from 128 to 115 Ma. In western Fiordland near Doubtful Sound, we identify three vertically stratified zones in a well-preserved lower crustal pluton termed the Misty pluton. These zones include: 1) a basal ultramafic complex, 2) a middle zone of hornblende and pyroxene diorites, and 3) an upper zone of hornblende diorites and felsic dikes. In the basal zone, field relationships show mutually intrusive relationships between hornblende peridotite, hornblendite and diorite indicating that these bodies were comagmatic. In the middle zone, hornblende and pyroxene diorites are intruded by syn-magmatic ultramafic hornblendite sheets and dikes. Leucocratic segregations are concentrated

near hornblendite injections and are sometimes associated with peritectic garnets. Abundant, mm-scale veins of segregated leucocratic veins emminate from the diorites. In the upper zone, these leucocratic veins coalesce into granitic dikes. These dikes are compositionally similar to upper- to middle-crustal batholithic rocks in central and eastern Fiordland.

Bulk-rock geochemistry reveals that lower-crustal diorites have characteristics of high-Sr/Y plutons (Sr/Y >50, Na_2O >3.5 wt%, Sr >1000 ppm, and Y <20 ppm), features that have been previously interpreted to indicate the presence of garnet as a residual or fractionating phase. However, garnet is absent in diorites, and igneous clinopyroxenes and amphiboles have low Sr (<200 ppm), high Y (25–130 ppm), and low molar Mg# [100 × Mg/(Mg + Fe)] values (50–70). Chondrite-normalized rare-earth-element patterns also show little to no evidence for involvement of garnet. Fe-Mg partitioning relationships indicate that amphiboles and clinopyroxenes are not in equilibrium with their encompassing bulk rocks but could have been in equilibrium with fractionated andesitic to dacitic melts determined from chemometry of coexisting igneous hornblendes. These data indicate that high-Sr/Y bulk rocks represent lower-crustal cumulates formed by plagioclase + amphibole + clinopyroxene accumulation and interstitial melt loss from crystal-rich mush zones. We speculate that hornblendite intrusions in the lower crust played a critical role in destabilizing and remobilizing the diorite mush and facilitated melt extraction via diking from the lower crust.

Lower crustal gabbros vs upper crustal granites: which way of happiness? A case study from the Sesia Magmatic System (European Southern Alps)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Trans-lithospheric magmatic systems are the major producers of new felsic crust. Their magmatic columns are characterized by gabbroic rocks in the lower crust, intermediate rocks in the middle crust and more evolved granites at shallower crustal levels. Chemically, granites can form either by differentiation of mantle-derived melts in a closed-system, or through the interaction between mantle-melts and crustal material in an open system. Physically, melt extraction and migration from the lower to the upper crust is inferred to occur as an intra-mush process or in more discrete extraction channels connecting the different magmatic reservoirs. Deciphering the mechanisms of evolution and maturation of such systems is crucial to understand large scale magmatic processes and crustal evolution.

The Sesia Magmatic System almost completely exposes a post-collisional magmatic system of Permian age intruded in the high-grade metamorphic basement of the Ivrea Zone and Serie dei Laghi (European Southern

Alps). It is well established that large volumes of gabbro were emplaced at the base of the continental crust, interacted with high-grade crustal material and evolved to produce granitic bodies and rhyolitic magmas in the middle and upper crust. Less understood are the mechanisms of hybridization and extraction. In particular, it is not clear yet: i) at which stage(s) of the magmatic evolution mantle-derived melts interacted with crustal material, ii) which kind(s) of crustal material was involved, iii) how magma hybridization affected the chemical and isotopic evolution of the magmatic system, iv) in which structures melt was extracted towards shallower crustal levels.

We present new structural, petrological, geochemical and isotopic data from a cross-section along the Sessera Valley. Three main units are exposed: layered amphibole-gabbronorites, an opx-dominated series ranging from norite to opx-bearing granites (charnockites), and migmatitic paragneisses, with the opx-dominated rocks and paragneisses occurring in spatial association as elongated bodies within the amphibole-gabbronorites. Layering, foliations and lithological contacts are steeply-dipping and strike NW-SE, the stretching lineations deeply plunge towards NW. Contacts between amphibole-gabbronorite and opx-dominated rocks, and within the opx-dominated series are diffuse, testifying for their magmatic nature. The rocks of the opx-dominated series show a continuous chemical trend filling the compositional gap between gabbros and granites, their compositions resulting from the interaction between gabbroic rocks and pelitic material. We propose that the opx-dominated series represents discrete, pipe-like structures where hybrid melts resulting from the interaction of gabbros and metapelites were extracted from the lower crust and fed the granites in the upper crust.

The effects of grain-scale melt migration process on metagranite at eclogite facies, the Snieznik dome, Bohemian Massif

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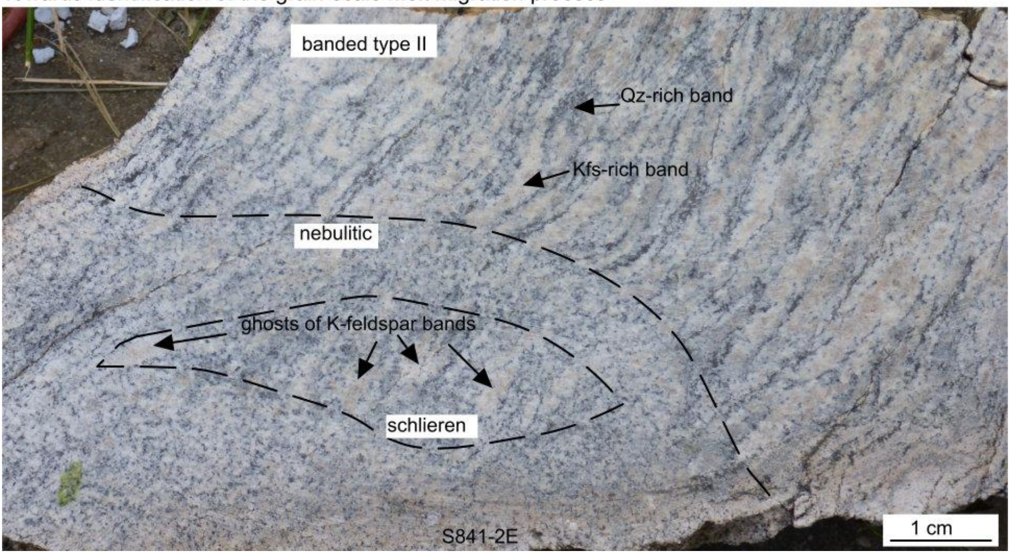
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Augen to banded metagranite from the Snieznik dome have been modified locally to have stromatic, schlieren, nebulitic and granite-looking textures typical of migmatites. Former presence, and increasing role of melt in transformation towards nebulite is inferred from interstitial phases along grain boundaries in the dynamically recrystallized monomineralic feldspar and quartz aggregates, and from textures of fine-grained plagioclase and quartz replacing K-feldspar. These features are interpreted as resulting from dissolution-reprecipitation along grain boundaries due to grain-scale melt migration, being pervasive at the grain-scale, but localized at hand-specimen to outcrop scales. The new minerals crystallized from melt are in textural equilibrium with phengite. All the rock types have the same mineral assemblage of Grt−Ph−Bt−Ttn−Kfs−Pl−Qz±Rt±Ilm, with similar garnet, phengite and biotite composition, leading to modelled equilibration conditions of 15−17 kbar and 690–740 °C. Because the mineral compositions in the assemblage of interest are independent of the amount of melt, the modelling did not allow to estimate melt quantities in individual rock types. However, migmatite textures suggest that increasing degree of melt-rock interaction occurred from the banded to the schlieren and nebulitic types. The initiation of melt migration is related to gently dipping structures related to continental subduction to eclogite-facies conditions, and more pronounced melt migration is related with vertical fabrics leading to exhumation of the continental subduction wedge from eclogite-facies to mid-crustal conditions.

The effects of melt migration had impact on partial recrystallization of zircon. Zircon in augen to banded types shows oscillatory zoning and gives Cambro-Ordovician age of the protolith. In schlieren to nebulite types, zircon shows domains of blurred oscillatory zoning to structure-less textures. These metamorphic domains are located along grain boundaries, form embayments, form straight or curved linear structures cutting through the oscillatory zoned domains, or are affecting the whole grains. The domains with sharp oscillatory zoning tend to give Cambro-Oridovician ages, while the metamorphic domains tend to give Carboniferous age. Zircon shows numerous apparent “inclusions” of phengite, K-feldspar, quartz, plagioclase, rare garnet, rutile and biotite. However, the “inclusions” of phengite, garnet and rutile are located in the metamorphic domains of the zircon grains. In places, the inclusions are aligned, and these structures are interpreted as former cracks, along which the metamorphic phases crystallized and zircon (re)crystallized. As the assemblage of phengite-garnet-rutile is compatible with previously inferred eclogite-facies conditions, we interpret the Carboniferous zircon (re)crystallization as dating the eclogite-facies grain-scale melt migration process.

Towards identification of the grain-scale melt migration process



Application of the melt inclusion in zircon geobarometry to the Miocene Kaikomagatake granitoid pluton, Izu collision zone, central Japan: comparison with the Al-in-hornblende geobarometry

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The crystallization pressures of granitic magmas are fundamental to unravel the tectonic evolution of orogenic belts. Recently, Taniwaki et al. (in press, Lithos) proposed a new approach to estimate crystallization pressures of granitoid magmas using melt inclusions in zircon, a ubiquitous accessory mineral in granitoids. In this study, we apply the melt inclusion in zircon geobarometry to the Miocene Kaikomagatake granitoid pluton, central Japan, which emplacement pressure of 240–220 MPa has been estimated based on the Al-in-hornblende geobarometry (Watanabe et al., 2020, JMPS).

Homogenization experiments of polymineralic inclusions in zircon extracted from a hornblende-biotite-bearing granodiorite sample in the Kaikomagatake pluton have been conducted using a piston-cylinder high-pressure–high-temperature apparatus. Major element analyses of the homogenized (former) melt inclusions are carried out using a SEM-EDS after the homogenization experiments. We further estimate H_2O contents of the melt inclusions from excess oxygen (difference between concentration of oxygen measured by EDS and the stoichiometric amount of oxygen of the major element oxides) assuming that the excess oxygen consists of H_2O.

The melt inclusion compositions (n = 8) are granitic and their SiO_2 contents are 70–83 wt %. Of the eight melt inclusion compositions run with the rhyolite-MELTS geobarometer (Gualda et al., 2012, CMP), four simulations have yielded pressure estimates of 174, 124, 53 and 52 MPa, considerably lower than those resulted from Al-in-hornblende geobarometry for the pluton (240–220 MPa). On the other hand, the DERP geobarometer (Wilke et al., 2017, JPet) applied to same four melt inclusions have yielded pressures of 529, 265, 166 and 263 MPa, broadly comparable to the results of Al-in-hornblende geobarometry except for one estimate with the highest pressure of 529 MPa. The estimated H_2O contents of the same four melt inclusions are 6.1, 6.9, 6.9 and 10.1 wt %, providing the minimum pressure estimates of ~200–250 MPa (6–7 wt % H_2O) and ~500 MPa (10 wt % H_2O) based on the water solubility in granitic melts (Holtz et al., 1995, AM). The minimum pressure estimates are consistent to the results of Al-in-hornblende geobarometry except for one estimate with the highest H_2O content. Despite technical difficulty in analysis of small melt inclusions and the fact that the melt inclusion compositions can be modified from initial melt compositions in many ways, these data presented here collectively suggest that the melt inclusion in zircon geobarometry can provide an alternative constraint on crystallization pressures of granitoid magmas.

The role of latent heat buffering in the generation of high-silica rhyolites

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Oral, Thursday 14th September, 11:30 - 11:45

In silicic magmatic systems, the physical process of crystal-melt separation is responsible for the accumulation of large volumes (>100 km^3) of eruptible rhyolitic melt in the shallow crust. Granitic intrusions, although providing a terminal, time-integrated image of melt segregation processes, provide an unmatched record of the physical properties controlling mechanisms and rates of interstitial melt extraction from a crystal-rich source. We applied mass balance calculations and phase equilibria-based thermodynamic modeling (rhyolite-MELTS) to an extensive bulk-rock geochemistry dataset (>150 samples) collected in a Permian upper-crustal granitoid intrusion (Valle Mosso pluton) of the Italian Southern Alps. Textural and geochemical evidence indicate that this intrusion constituted a single, zoned magma body, with a crystal-rich base and a thick (~2 km), high-silica cap (up to 77 wt% SiO_2). Compositions and physical characteristics (e.g. temperature, viscosity) of

frozen, high-SiO_2 residual melts are compatible with different degrees of crystallization of a hydrous parental granitic magma (2-5 wt% initial H_2O). The large compositional variability of cumulate materials, when analyzed through mass balance modeling, suggests variable degrees of melt extraction efficiency and corresponding terminal porosities. Specifically, the markedly bimodal distribution of porosity values indicates that at least two distinct melt segregation mechanisms were operating in this system, which produced both high (φ=0.65-0.45) and low terminal porosities (φ=0.45-0.25) in the cumulate materials. Modeling of latent heat budget shows that coexistence of two distinct cumulate products can be explained by melt segregation processes taking place at different depths across a thick, interconnected magmatic reservoir with initially homogenous water content. Deep in the mush column, low water activities ($aH_2O<0.5$) promoted thermal buffering of cooling magma at high crystallinities, enabling residual melt extraction by percolation through a crystalline framework accompanied by crystal repacking. Instead, at shallower depths, higher water activities ($aH_2O>0.5$) ensured prolonged magma residence at porosities that allowed crystal melt separation via hindered settling. Distinct melt extraction processes acting synchronously but at different depths in a vertically extensive mush column can account for the large volume (~100 km^3) of residual, haplogranitic melt mobilized during the relatively short lifespan of the Valle Mosso magma body (~10^5 year).

The role of dike transport during differentiation and segregation of a 2-km high-SiO_2 (>76 wt%) leucogranite cap in the zoned Spirit Mountain granite, southern Nevada

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

High-SiO2 (≥76 wt%) rhyolite (HSR), often characterized by low Sr contents (<20 ppm), only erupts in abundance in regions of continental lithospheric extension. In contrast, HSR rarely erupts in volume at subduction zones and is generally restricted to thin (<20 cm) aplite dikes within arc granitoids. Among the few granitoid exposures that showcase the efficient and massive accumulation of HSR leucogranite are the bimodal (granite-diorite) Miocene intrusions of the Colorado River extensional corridor in Southern Nevada (e.g., Miller et al., 2011), most notably the Spirit Mountain granite. The pioneering work of Walker et al. (2007), via field mapping, elemental analyses, and zircon geochronology, shows that the ~7 km thick (x ~25 km wide) Spirit Mountain granite was assembled through emplacement of stacked sheets of low-SiO2 rhyolite over a ~2 Myr time span (~17.4-15.3 Ma). Internal differentiation mechanisms formed a ~2 km cap of HSR leucogranite on top of a ~5 km thick granitoid that zones from a coarse granite down to quartz monzonite, which additionally contains fine-

grained dioritic enclaves. Previous studies (e.g., Walker et al., 2007; Miller et al., 2011) focused on the role of compaction within a crystal-rich mush to drive segregation of interstitial melts from the granitic intrusions, leading to the leucogranite cap and the quartz monzonite (cumulate) base. In this study, we test a modification of this model to explain the efficient segregation and accumulation of a 2 km thick HSR cap in the Spirit Mountain granite, which is strikingly absent in arc granitoids. Here, we examine whether differentiation occurred through episodic partial melting driven by the influx of hot (>700°C) H2O-rich fluid from degassed basaltic intrusions at the base of the Spirit Mountain granite. We further explore the role of pre-existing aplite dikes, which form during late stages of granitoid solidification, during partial melting. These eutectic aplite dikes would melt completely, and their ascent would draw in partial melt from the surrounding granite. To test this hypothesis, we analyzed ~40 samples along a 7-km vertical transect through the Spirit Mountain granite, including ~13 pairs of aplite dikes (10-120 cm width) and their adjacent host rocks. We show that the molten aplite HSR dikes with critical widths of 10-100 cm could ascend, without freezing, through several km of sub-solidus granite that is ~550-650°C (Petford et al., 1993). We propose that this mechanism played a key role throughout the 2 Myr assembly of the Spirit Mountain granite.

Melt extraction by impingement of a large felsic enclave in a granitic body: Evidence from Aztec Wash Pluton (Nevada, USA)

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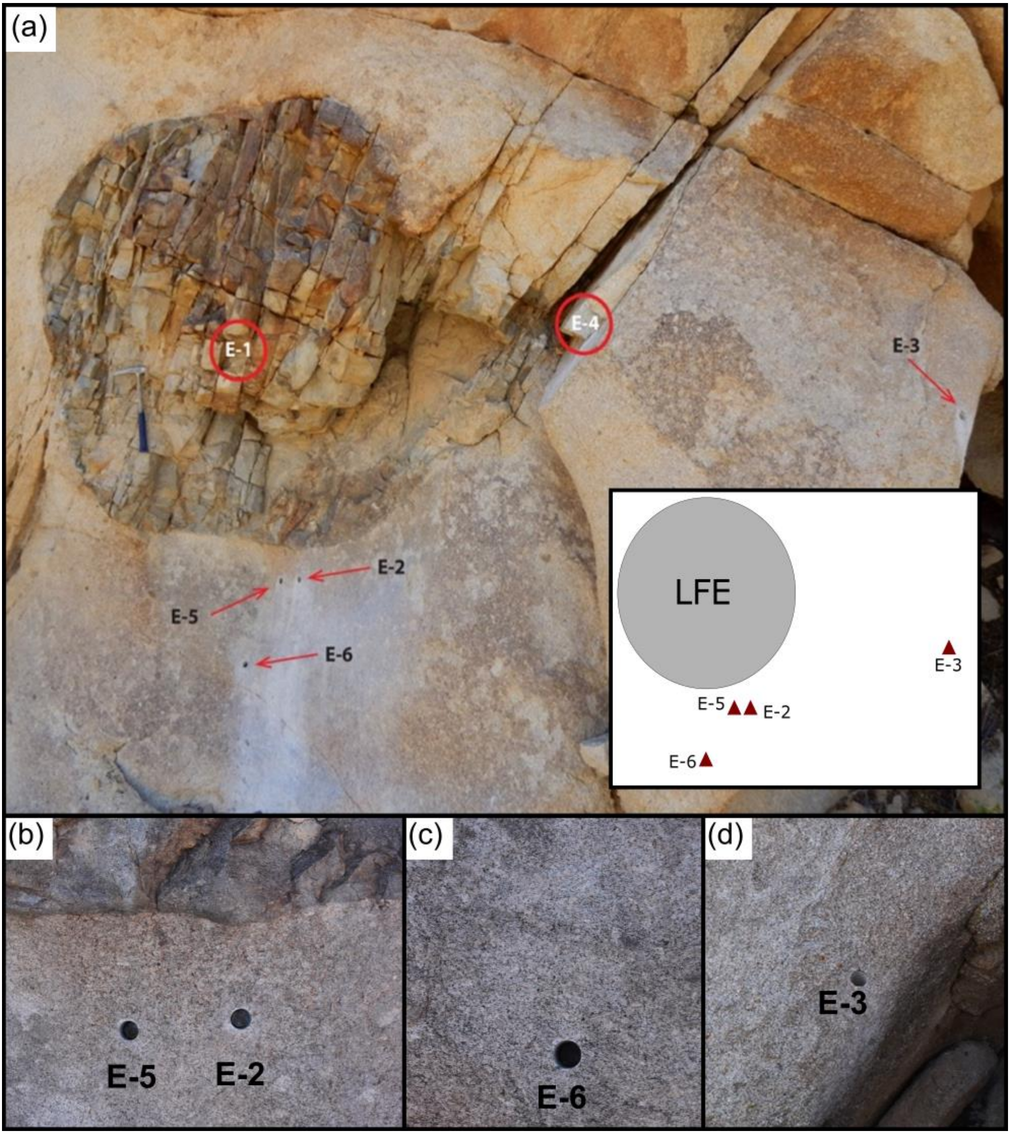
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Compaction and melt extraction are key processes in the generation of eruptible magma bodies. Analyzing magmatic fabrics in the Aztec Wash Pluton (15.7 Ma, NV, USA) illuminates magma dynamics during the emplacement of a large (2 m diameter) felsic enclave (LFE) in a silicic magma body. The LFE is an ellipsoidal microgranite mass inferred to have been solid or nearly so when it was enclosed within host granite. We infer that it settled at the upper boundary of a crystal-rich zone of the magma body at the time of impingement. Textural and compositional analysis by Scanning Electron Microscope (SEM) allows visualization of deformation of crystal-rich magma mush. Four thin sections sampled from the granite surrounding the LFE (three 0.25-0.5 m underneath, one 2.5 m to the side – far field) show a change in the strength of magmatic foliation (revealed primarily by alkali feldspar) around the enclave. Backscattered Electron (BSE) imaging, Energy Dispersive Spectrometry (EDS), and Electron Backscatter Diffraction (EBSD) techniques show key textural and compositional differences between the samples located underneath the LFE and the sample

from the far-field granite. BSE images show multiple instances of broken feldspar grains underneath the enclave. Alkali feldspar crystals beneath the enclave have well-defined euhedral rims, while alkali feldspar grains in the far-field sample have irregular overgrowths. These textures suggest that melt extraction occurred beneath the enclave but not in the far field. In addition, whole-rock geochemical analysis of all four samples shows that the far-field sample (72.1% SiO_2, 750 ppm Ba, 330 ppm Sr) is more evolved than the three samples underneath the enclave (69.6-70.0% SiO_2, 1100-1170 ppm Ba, 400-430 ppm Sr). Compositions of Aztec Wash samples from this and other portions of Aztec Wash pluton interpreted to represent cumulate mushes are very similar but fall between these values (70.3-71.7% SiO2, 830-1070 ppm Ba, 300-380 ppm Sr; Harper et al. 2004). The samples collected underneath the enclave thus represent the least evolved low-SiO_2 granite (cumulate) identified within the Aztec Wash Pluton. This suggests that mush was deformed during the emplacement of the LFE, reorienting alkali feldspars and expelling melt. Impingement of the LFE led to melt extraction, which caused the differences in rim textures. Analysis of textural and compositional differences between the irregular rims and the euhedral rims to constrain melt extraction is ongoing.


(a)
E-1
E-4
E-3
E-2
E-5
E-6
LFE
E-3
E-5
E-2
E-6
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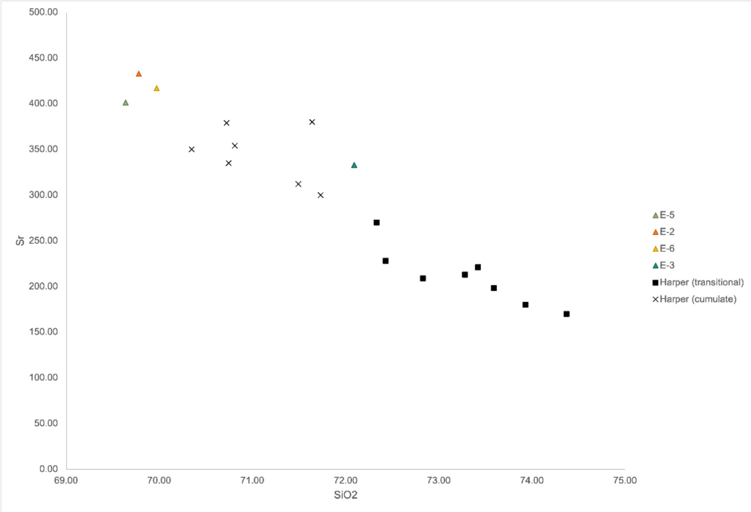
E-6
(d)
E-3



Crystal growth versus diffusional re-equilibration in k-feldspar

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Diffusion and crystal growth are keys to understand magma dynamics, and thus the evolution of igneous systems (e.g., [1], [2]). As k-feldspar is a major mineral in felsic plutonic rocks, investigating k-feldspar provides valuable information on magma dynamics. K-feldspar has been widely used to determine timescales of crystal growth or residence times for volcanic and plutonic systems (e.g., [3], [4]).

As chemical zoning (e.g., Ba zoning) is commonly observed in k-feldspar megacrysts, this makes them good targets for studying and developing methods to distinguish crystal growth from diffusional re-equilibration. Therefore, our study focuses on the investigation of trace element chemistry and zoning patterns (EPMA and LA-ICP-MS) of k-feldspar megacrysts from two granitoid batholiths (Bergell, Switzerland; Sardinia, Italy) to unravel the growth and/or diffusion patterns. Results from the different samples show Ba zoning preserved despite perthite exsolutions (Bergell), with an average of 7 to 10 zones of random spacing and thickness per crystal. Petrography and EPMA data highlight three different features. (1) Sawtooth chemical profiles encompassing textural growth patterns combined with Ba zoning and a more evolved composition towards the borders correlated with the zones of higher Ba composition. (2) Sawtooth and relaxed step-function profiles (potentially related to diffusion) when megacrysts display textural growth patterns associated to Ba zoning (Bergell). (3) No obvious zoning on high-resolution maps but relaxed step-function profiles within single crystals (Sardinia). (1) and (2) could be observed within a single rock sample. In addition, various inclusions are related to Ba zoning (zoned plagioclase, biotite, quartz - Bergell), located on and parallel to the zoning planes. Inclusions from Sardinia samples (mostly zoned plagioclase and biotite) are randomly distributed. Ultimately, we aim to quantify k-feldspar growth times by coupled-growth and diffusion and comparing the results to absolute growth times derived from U-Pb dating of zircons (e.g., [1]).

[1] Costa (2021) Annual Review of Earth and Planetary Sciences, 49, 231-252.

[2] Costa, Shea & Ubide (2020) Nature Reviews Earth & Environment, 1(4), 201-214.

[3] Moore & Sisson (2008) Geosphere

Modeling magma chamber growth and eruption; key processes and recent model developments

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Oral, Thursday 14th September, 16:45 - 17:00

The growth of silicic magma reservoirs in the crust directly influences volcanic hazards, hydrothermal and ore-forming processes, and the thermochemical evolution of the crust, yet the conditions and timescales that lead to the accumulation of appreciable amounts (~10-100+ km3) of eruptible silicic magma remain poorly understood. Numerical magma reservoir models have the potential to test hypotheses about the physical mechanisms and conditions that lead to the growth and eruption of silicic magmas and to unify diverse datasets (geochemical and geophysical) to understand the evolution of specific magmatic systems. Many magma reservoir modeling efforts designed to track the long-term growth of magma bodies have focused on the role of thermal processes in generating and sustaining high melt fraction magmas (e.g., Annen 2009; Gelman et al. 2013). However, purely thermal models fail to capture potentially important feedbacks with the mechanical evolution of the magma, such as the influence of pressure evolution on phase changes and the influence of eruptions on the mass and energy budget of a magma body. Similarly, most magma chamber models used for interpretation of geodetic data are purely mechanical and therefore fail to capture the effects of magmatic processes (e.g., phase change) that could influence the mechanical response of a chamber to recharge and eruptions. The thermo-mechanical magma chamber model of Degruyter and Huber (2014) (hereafter referred to as DH14) is uniquely poised to address questions about the growth, longevity, and eruptibility of silicic magma bodies in the crust because it includes full coupling between thermal and mechanical processes. The simplified framework of the box model permits fast computation to test how magma recharge and crustal conditions influence the growth and eruption of magma chambers across a wide parameter space. Here we review recent developments to the DH14 model and show how the model is applied to understand magma chamber growth and eruption. We focus on the special role that volatiles (including H_2O and CO_2) and magma composition (mafic vs silicic) play in the response of a magma chamber to recharge and eruptions and to the balance of mass added and erupted over time.

Dynamics and rates of mush growth and disaggregation across magmatic systems: A mineral perspective

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Junior Keynote, Thursday 14th September, 14:45 - 15:15

The new paradigm of crustal magma storage considers predominantly solid, crystal-rich mushes with transient, potentially eruptible melt pockets. In this context, crystals take a leading role as archives of magmatic processes and associated timescales (Fig. 1). Textural and compositional variations across crystal stratigraphies record the history of magmatic processes as minerals grow. The diffusive relaxation of compositional steps between crystal zones provides a measure of the time the crystal spent at magmatic temperatures, which can be orders of magnitude shorter than U-series crystal ages. This information has built a new understanding of trans-crustal mush systems grown over protracted timescales, yet unlocked and erupted geologically instantaneously.

Outstanding challenges include a better understanding of the processes each mineral type records and preserves against diffusion, as well as the uncertainties surrounding diffusion timescales. This keynote will review our understanding of mush growth and disaggregation across magmatic compositions and settings, from plutonic to volcanic systems, considering recent advances in high-resolution geochemical approaches informing the mineral perspective.

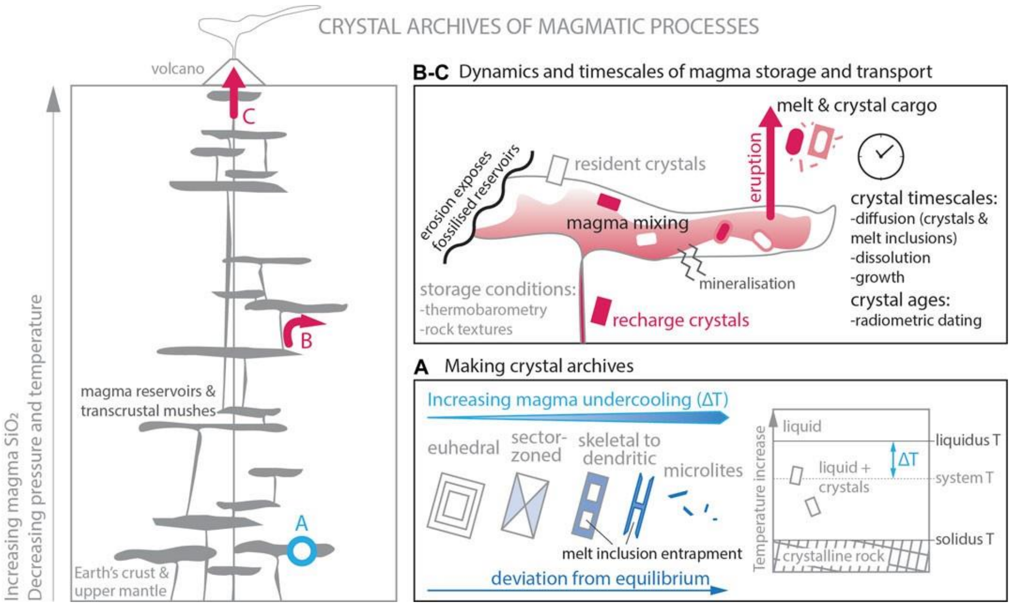

Figure 1. The crystal-eye on magma plumbing systems (from Ubide et al., 2021 Front Earth Sci).

From olivine and pyroxene in mafic magmas to quartz and zircon in silicic melts, diffusion chronometry exploits the extent of re-equilibration of chemical heterogenies to calculate the time a given crystal spent at magmatic temperatures; data from mafic to silicic systems suggests magmatic timescales typically increase with melt evolution (Fig. 2). Diffusion chronometry requires experimental determination of diffusion coefficients and their variation with temperature, as well as estimates of the temperature of crystallisation of the target mineral. Additionally, diffusion can be dependent upon parameters

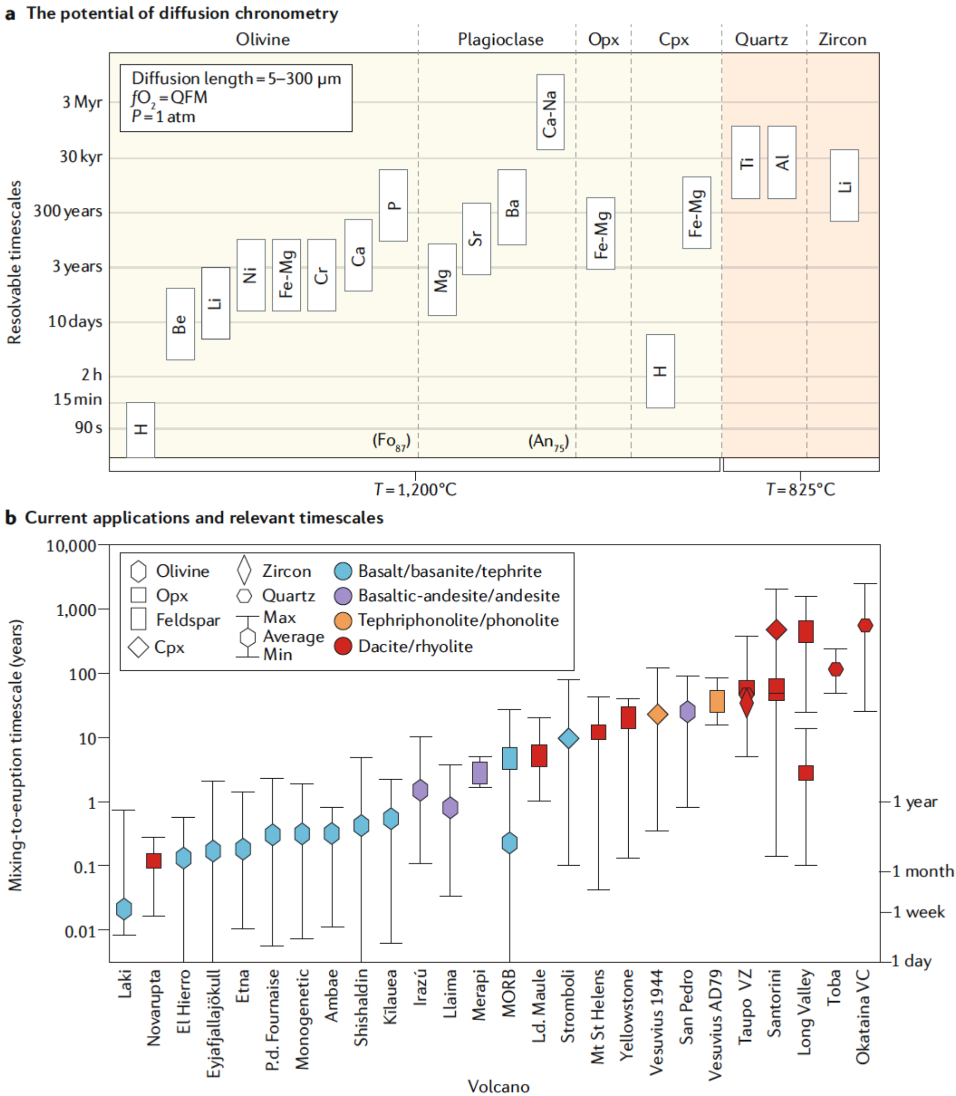

Figure 2. The potential and current applications of diffusion chronometry in minerals from mafic to silicic magmas (from Costa, Shea, Ubide, 2020 Nature Rev Earth & Environ).

such as chemical composition and crystallographic orientation. Improved constraints on diffusion coefficients and mineral thermometry will reduce uncertainties in timescale estimates, while developments in high-resolution geochemical analysis from electron microscopy to laser ablation mass spectrometry and secondary ion mass spectrometry can assist in improving the resolution of diffusion profiles for a range of major and trace elements as well as isotope systems.

Plutonic crystals pose major challenges for the preservation of mineral zoning patterns relative to volcanic phenocrysts, where chemical diffusion ceases upon eruption and rapid cooling, preserving magmatic zonation. For example, pyroxene crystal rims can record eruption triggering mechanisms in mafic volcanic rocks. In addition, slow diffusing trace elements like chromium and zirconium can hold information on earlier, extended magmatic histories at depth. In plutonic crystals, compositional zoning is typically limited to chemical species with very slow diffusion. These inferences have been enabled by recent developments in high-resolution geochemistry, including trace element mapping with laser ablation mass spectrometry and X-ray fluorescence synchrotron microscopy.

High-resolution geochemical imaging has also unveiled previously underappreciated effects of kinetic partitioning of trace elements in crystals formed at enhanced growth rates. Dynamic processes such as magma mixing, convection, ascent, and degassing can lead to mild increases in the degree of magma undercooling that lead to the formation of minerals with sector zoning (Fig. 1A). Sector-zoned crystals have distinct chemical compositions in sectors grown simultaneously along different crystallographic orientations. Two dimensional sections of sector-zoned crystals, for instance in resin mounts or thin sections, can expose sectors in different geometries, some of which can be easily mistaken as core to rim zoning. Misidentification of sector zoning can lead to misinterpretations of magmatic histories, and their timescales. Fortuitously, the correct interpretation of sector zoning itself can help establish the pathways and rates of magma transport and storage, eruption triggering in active volcanoes, or serve as prospectivity indicators for magmatic mineralisation in igneous cumulates.

Sector zoning has also been observed in zircon, a versatile mineral clock with elemental and isotope compositions archiving magmatic processes and timescales. Sector-zoned zircons can show strong compositional contrasts between sectors grown along and perpendicular to the c-crystallographic axis, complicating the assessment of zoning patterns and their implications for magma reservoir growth and the development of mineralisation vectors in detrital samples. Importantly, sector zoning can affect zircon standards commonly used as reference materials in laser ablation mass spectrometry. Advances in split-stream laser ablation quadrupole mass spectrometry provide improved spatial resolution to assess the impact of sector zoning on a large range of trace elements in zircon reference materials.

The exploration of isotope zoning brings an exciting perspective to the understanding of magmatic processes and timescales, provided diffusion mechanisms are adequately understood for the species in hand. Radiogenic isotope ratios can now be measured in situ with improved resolution and precision. For example, optimised $^{87}Sr/^{86}Sr$ analysis in plagioclase via laser ablation multi collector mass spectrometry makes it possible to track consanguinity of melts from which individual plagioclase zones grew. For the broad range of magma compositions and tectonic settings where plagioclase is stable, this new capability facilitates the reconstruction of mush systems and their evolution across space and time.

How to minimize eruptions and form ore deposits: constraints from numerical modelling

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Large magma reservoirs can reside in the upper crust for long periods of time (>0.5 My), as attested by the zircon record from super-eruptions. However, the mechanisms controlling the formation and growth of such large magma bodies are not fully understood. Similarly, mass balance calculations suggest supergiant porphyry copper systems (>10 Mt of contained Cu) are fueled by large volumes of magma (>1000's km^3) which are assembled at magmatic injection rates comparable with those of super-eruptions. Despite the occurrence of porphyry copper systems in volcanic arc settings, eruptions are considered to hinder the formation of these deposits since volatiles and metals are lost during eruptive events. Therefore, constraining the conditions that hinder eruptive events and allow for long lived hydrothermal activity can provide better understanding of the distinct evolutionary paths of upper crustal arc magmatic(-hydrothermal) systems (eruption, mineralization or plutonism).

We investigate different conditions of magma reservoir assembly using a modified version of the thermo-mechanical box model of magma chamber evolution and eruption frequency developed by Degruyter and Huber (2014) and Townsend et al. (2019). The model incorporates a new crystal fraction curve, calibrated with the experimental data from Marxer and Ulmer (2019) for intermediate calc-alkaline rocks. First, we model chambers of 10, 100 and 1000 km^3 and investigate how the number of eruptions, the volcanic/plutonic ratio and position in the regime diagram of Degruyter and Huber (2014) is affected by modifying: (i) depth of emplacement; (ii) bulk water content of the magma; (iii) magma injection rates; and (iv) the background temperature of the crust.

Preliminary results show that, in general, larger chambers tend to erupt less, compared to smaller ones. For the same magma reservoir volume, the position in the regime diagram is most strongly affected by the injection rates and background crustal temperature. The depth of emplacement and bulk water content can affect the number of eruptions and the plutonic/volcanic ratios, but their effect is minimized in conditions of hot background crust and very slow injection rates. Further work will investigate the evolution of several potential magma reservoirs compatible with well-studied porphyry copper systems such as the Chuquicamata district and explore scenarios where eruptive events are minimized.

A machine learning model to determine pressure and temperature of crustal magmas

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Oral, Thursday 14th September, 11:45 - 12:00

Regression models are widely used in igneous petrology to predict the pressures, temperatures, and water contents of magmas. However, large uncertainties on pressure determinations hinder our ability to understand the structure of crustal magmatic systems. We utilized machine learning on a large experimental database to develop new regression models that predict P-T of magmas based on either melt composition or melt chemistry plus associated mineral assemblage. Our method can be applied across the igneous spectrum from basalt to rhyolite, crustal pressures between 0.2 and 15

kbar, temperatures of 675-1425°C, and H_2O contents of up to 15 wt%. Testing and optimisation of the model shows that pressures can be accurately recovered with root-mean-square-error (RMSE) of 1.5 and 1.3 kbar for the melt-only and melt-phase assemblage models, respectively. The errors on temperature estimates are 27-33°C. These results demonstrate that melt chemistry is a reliable recorder of magmatic variables over a wide range of conditions. Using principal component analysis, we show that this finding is consistent with fairly low thermodynamic variance of natural magma compositions despite their relatively large number of constituent oxide components.

We applied our model to two contrasting case studies with well-constrained geophysical tomography: The Altiplano-Puna Volcanic Complex (APVC) in Chile and the Askja caldera in Iceland. Glasses and phase assemblages of three large magnitude eruptions from the APVC (Atana, Toconao, Purico ignimbrites) yield magma storage pressures and temperatures of 1.7-2.4 kbar and 726-789°C, in excellent agreement with previous thermobarometry. Although these pressures are shallower compared to the present day Altiplano-Puna Magma Body (APMB), the largest imaged magma reservoir on Earth, bulk-rhyolite compositions indicate source depth equivalent to the present day APMB. We suggest that extraction of rhyolite melts from the APMB mush, followed by re-equilibration at shallower depths, preceded each eruption. For historical eruptions from the Askja caldera, our magma reservoir depth estimates match the location of wave speed anomalies mapped by seismic tomography. Our analysis also indicates that Vp/Vs anomalies at 5-10 km depth correspond to hot (~1000°C) rhyolite source regions, while basaltic magmas (~1150°C) have been stored at 15 km depth under the caldera. These examples illustrate how our model can be used to link petrology and geophysics to better understand the architecture of volcanic feeding systems.

Duration of magma recharge and mush reactivation: Insight from the quartz phenocrysts in Xiangshan caldera, SE China

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Melt-rich rhyolite and crystal-rich accumulation can be produced through the crystal-melt separation process of crystal-rich mush. However, crystal-rich volcanic rocks are generally thought to be formed by the eruption of crystal-rich mush after its reactivation. Quartz is a common mineral in rhyolitic rocks which can record the temperature of magma and the duration of magma recharge. Therefore, the study of quartz phenocrysts from crystal-rich rhyolitic rocks will contribute to further understanding the process and timescale of magma

recharges and reactivation and remobilization of the immobile mush.

The crystal-rich rhyolitic porphyritic lava is widely exposed in Cretaceous calderas in the southeast China. However, the petrogenesis of crystal-rich porphyritic lava still remains controversial. Xiangshan caldera is a uranium mineralization related volcanic-plutonic complex, which is composed of first subcycle rhyodacite and second subcycle tuff, crystal-rich rhyolitic porphyritic lava, granite porphyry and quartz monzonitite porphyry. All the volcanic and plutonic rocks have consistent zircon U-Pb ages (135~133 Ma). The Sr-Nd-Hf-O isotopic composition and whole rock trace elements indicate that they may be derived from the same magma reservoir. The cathodoluminescence (CL) brightness is strongly correlated with Ti concentration in quartz. The CL of selected quartz grains from crystal-rich rhyolitic porphyritic lava and granite porphyry show brightness zoned mantles (Ti=19 to 77 ppm) and bright rims (high-Ti; >70 ppm). Some grains have dark cores (low-Ti; <9 ppm). The repeated rise of CL brightness and Ti contents in the mantle of quartz phenocrysts recorded the rise of temperature and/or the injection of more primitive magma, indicating several times of magma recharge in the magma reservoir. Both crystal-rich rhyolitic porphyritic lava and granite porphyry are product of mush reactivation and remobilization. The rhyolitic porphyritic lava migrated upward from the magma reservoir and blocked the magma channel, so the granite porphyry failed to erupt out of the surface, it froze and intruded near the surface. The timescale of Ti diffusion in the compositional zoned mantle of quartz documented that the reactivation and remobilization of the immobile mush is probably an ephemeral activity occurred in several 10^3 years up to 1.6×10^4 years that including several times of magmatic recharge. The zoned quartz mantle indicates that magma recharge of different scales happened at least 7 times and every recharge lasted for 17 to more than 11000 years.

Origin of crystals in mafic to intermediate magmas from circum-Pacific continental arcs: transcrustal magmatic systems versus transcrustal plutonic systems

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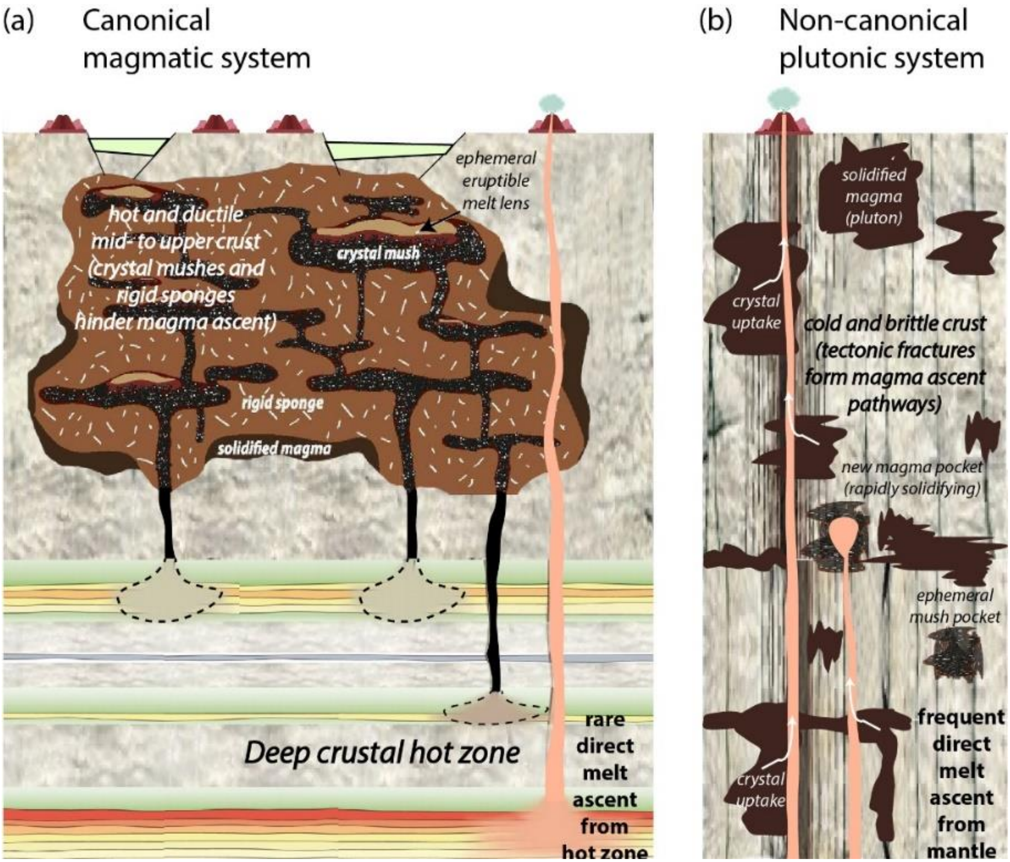
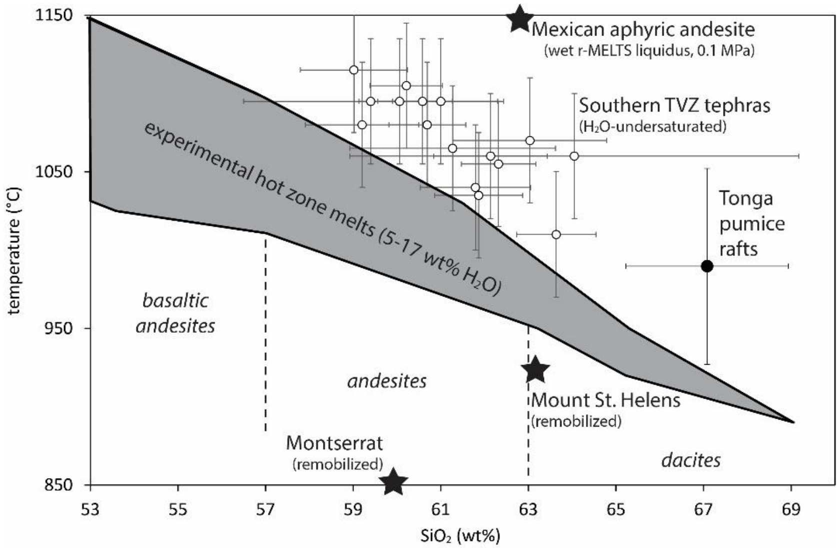
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Complex zoning in crystals is characteristic for arc magmas and occurs in response to closed-system changes in magmatic P-T-fO_2 conditions and open system processes such as magma mixing and degassing or regassing. However, over which time frame do such changes occur? Do zoning patterns record changes occurring during the polybaric ascent of magmas that carry the crystals, or alternatively indicate the uptake of antecrysts that experienced long periods of cold storage in plutonic precursors? A priori, these scenarios are

endmember models, with the former transcrustal magmatic systems, where the crystals record the changing conditions during magma ascent, traditionally preferred over the latter, which we here term transcrustal plutonic systems, where aphyric parental melts acquire their entirely antecrystic crystal cargo during ascent from plutonic protoliths, and where only crystal rims may be related to the host magma. We discuss the evidence for dominantly plutonic antecrystic cargo in some continental arc magmas, identified by considering mineral phase proportions and evidence for hydrothermally altered cargo picked up by fresh melts. We then turn to two-pyroxene thermobarometry and review the evidence for plutonic antecryst dominance revealed by this method in SW Japan and the southern Taupo Volcanic Zone. We provide additional data from the Andes, the Cascades, and northern Taiwan, corroborating that the uptake of crystals by aphyric to scarcely phyric melts is prevalent in continental arc magmatic systems. Thus, in many cases transcrustal plutonic systems seem to dominate, implying that a significant proportion of parental melts of continental arc magmas are felsic, too hot to carry crystals, and typically too hot and not hydrous enough to be generated by differentiation in frequently postulated lower crustal hot zones, as we will demonstrate. Our data indicate that in continental subduction zones, the mantle wedge is the source of a diversity of melt compositions, irrespective of the age and temperature of the subducting slab. We discuss the implications of the prevalence of non-canonical transcrustal plutonic systems for the thermal structure of the crust, magma ascent processes,

volcano monitoring, economic geology, as well as the evolution of continental crustal growth and recycling through time.





The Obscuring Effect of Magma Recharge on The Connection of Volcanic-Plutonic Rocks

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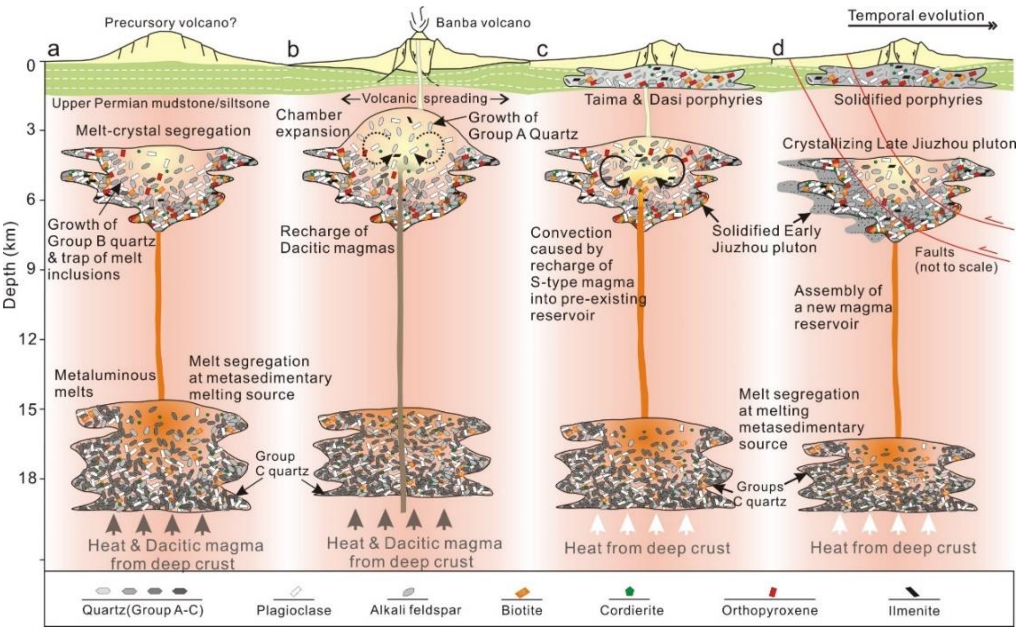
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The current debate on volcanic-plutonic connection is centered on whether efficient liquid-crystal segregation dominates the evolution of a mushy reservoir to produce evolved, crystal-poor rhyolite and cumulate leftover. However, magma recharge may remarkably influence the evolution of a mushy reservoir and obscure the evidence of liquid-crystal segregation. This complexity poses a challenge to exploring the connection of volcanic-plutonic rocks. This study investigates the Qinzhou Bay granitic

complex (~250-248 Ma) from South China, which contains crystal-poor (<19 vol%) peraluminous rhyolites and subsequent crystal-rich (28-54 vol%) porphyries. We present textural analyses, mineral and melt inclusion compositions, thermobarometry (the combination of Ti-in-zircon thermometer and Ti-in-quartz thermobarometer), and thermodynamic modeling to examine and explore the relationship between volcanic and plutonic units.

For the rhyolite unit, thermobarometric results reveal a polybaric storage system consisting of middle (>600±80 MPa) and upper (~150±40 MPa to ~60±20 MPa) crustal reservoirs. Variations in quartz Fe content and chlorine-rich, metaluminous melt inclusions suggest that magma hybridization with less evolved magmas occurred at both crustal levels. In particular, the elevated Fe contents in the quartz population that crystallizes at the shallowest level (~60±20 MPa) suggest that recharge magmas were directly injected into a less viscous melt-rich zone at the top of the rheologically zoned upper crustal reservoir. This explanation is also supported by the deviation of the whole-rock composition from the liquid evolution trend recorded in melt inclusions. Thermodynamic modeling and mass balance calculation suggest that the whole-rock composition of the rhyolite could be reproduced by mixing between regionally exposed dacites and segregated melts at crystallinities of 50-60% (the parental magma represented by the least evolved melt inclusion). For the porphyry unit, thermobarometric results reveal magma storage at middle (>450-550±40 MPa) and upper (110-140±20 MPa) crustal levels. The small-scale oscillatory zonation of plagioclase and the presence of microgranular enclaves in the porphyries suggest a recharge event of metasediment-sourced magmas, triggering reactivation and convection of the reservoir.

Because of the similar storage pressures, the porphyries may represent rejuvenated cumulates of rhyolitic magmas, whereas the texture and geochemistry of the cumulate-liquid pair were modified, a key factor rendering a cryptic connection between the rhyolite and porphyry. Our study highlights that whole-rock composition may record blended information of complex processes, and caution should be taken when whole-rock composition is used to extract information of a single process. Big data analysis on the basis of geochemistry should be conducted with caution to avoid biased understanding.



Theme 4 – Fluids in and around granites

Hydrocarbon-bearing fluid inclusions constrain fluid evolution and exhumation of mantle-hosted granitoids from the Samail ophiolite

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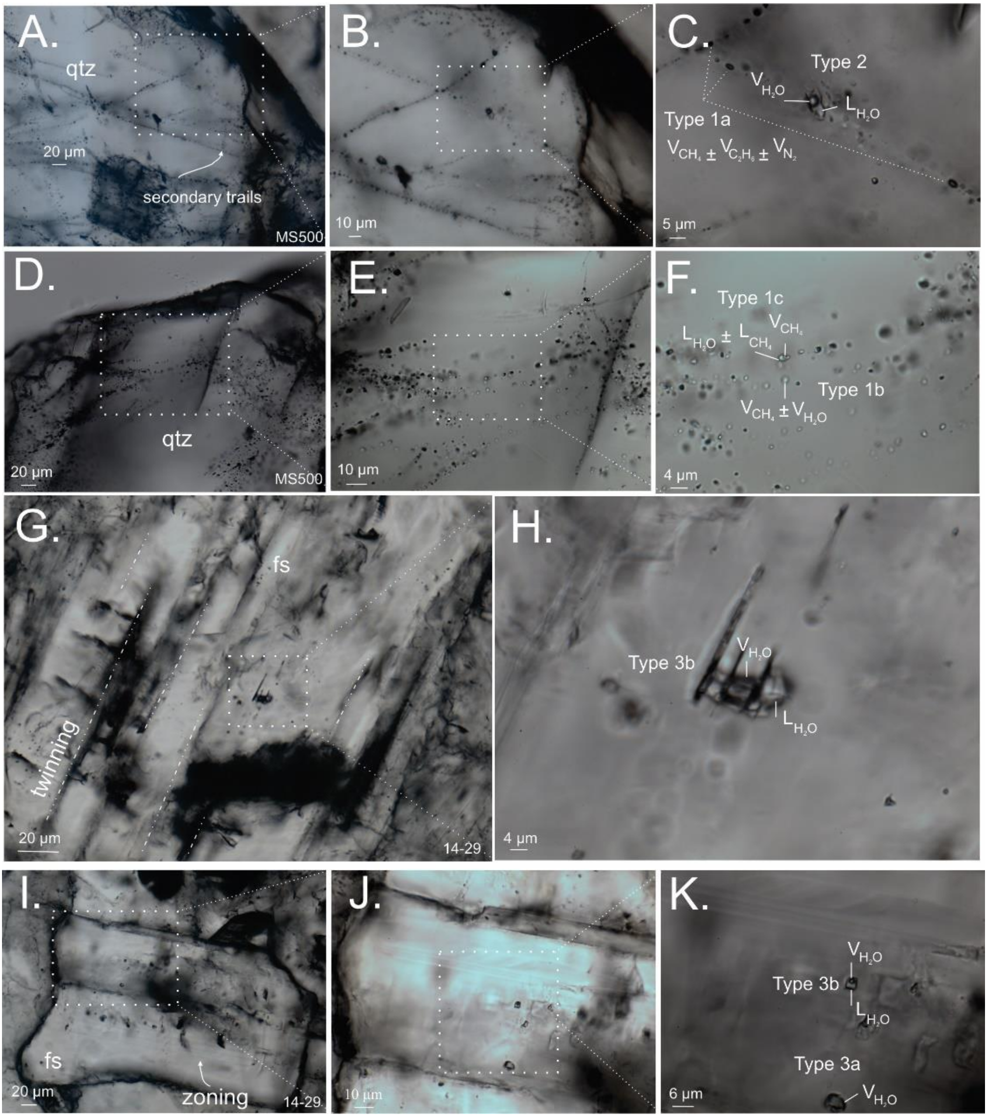
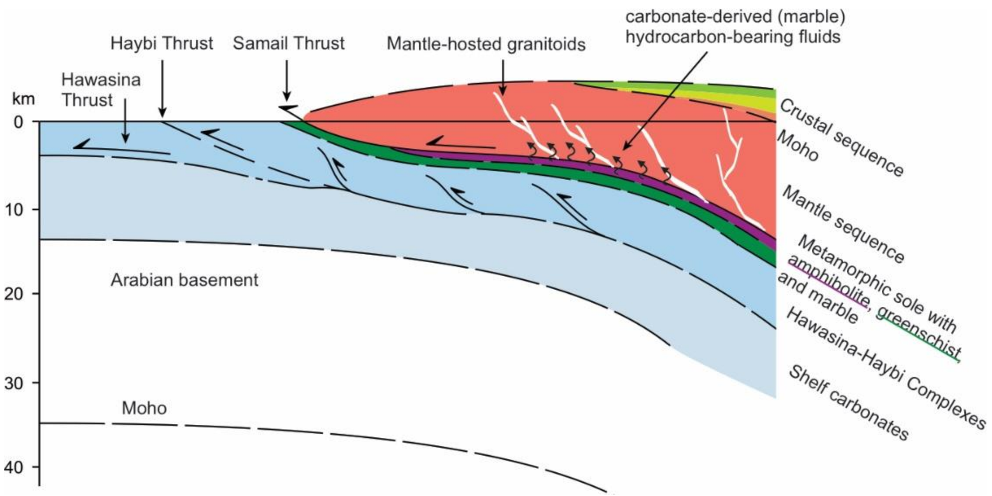
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Fluid inclusions in quartz can contain measurable volatile species, mainly H_2O and CO_2. This characteristic has been used to constrain the fluid evolution of igneous rocks. Although the mechanisms of carbon transfer through subduction are well-understood, decarbonisation and movement of hydrocarbon-bearing fluids during obduction and exhumation processes still requires further investigation. The Samail ophiolite in Oman and United Arab Emirates (UAE) is a well-studied section of subaerial oceanic crust. It consists of Late Cretaceous oceanic crust and underlying mantle obducted onto the Paleozoic-Mesozoic passive margin of the Arabian plate, interpreted to be a supra-subduction zone (SSZ) ophiolite. The peridotite-hosted granitoids in the uppermost mantle are interpreted to have formed by the melting of metasedimentary and amphibolite rocks from subducted oceanic lithosphere, provide insights into the

mass/fluid transfer from the metamorphic sole at the base of the ophiolite.



We analyzed carbon isotopes of fluid inclusions in quartz integrated with fluid inclusion petrography and Raman microspectroscopy from eleven samples of the peraluminous peridotite-hosted granitoids the Samail ophiolite. The strongly negative C isotope signal (average of -26.9‰) is derived from CH_4-bearing secondary fluid inclusions trapped in quartz interpreted to be derived from the metamorphosed carbonate rocks in the metamorphic sole and percolated into the mantle-section during the final stages of ophiolite obduction. Recognizing late-stage hydrocarbon-bearing fluid inclusions in the Samail mantle-hosted granitoids provides valuable insights into the fluid evolution of ophiolite systems where the metamorphic sole is not exposed and thus establishing a connection between fluids derived from the sole that migrate from the sole into the ophiolite.



The impact of H_2O and heat pulses in the stabilization of crustal mush columns

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

We use 1D numerical models to investigate the impact of H_2O-fluxed melting on the thermal structure of the crust and the stabilization of crustal magmatic mush columns. There have been suggestions that melt in the crust is mostly stored in such columns and that they reflect the mature state of hot, magmatic crustal regions. However, the thermal stabilization of such columns is difficult to achieve because of the very large heat influx from the mantle required to balance the heat loss to the surface of the Earth.

We modeled the impact of the passage of H_2O pulses with or without an accompanying heat wave. Although above the water-saturated solidus, the modeled crust is initially solid because no H_2O is present. The rapid but limited influx of H_2O causes melting and a sharp decrease in temperature due to the consumption of latent heat. This drop in temperature forces an influx of heat from the surroundings towards the anatectic region, leading to further melting as the temperature increases towards the steady-state geotherm. Counteracting this increase in melt fraction, H_2O diffuses towards lower temperature crust, expanding the anatectic region but

decreasing the overall melt fraction. The net effect of this low-temperature anatexis is to cause a decrease in heat flow through the crust because of thermal buffering caused by melting. With time, the steady-state heat flow and geothermal gradient return to values pre-dating anatexis, but at this point the crust stores significant amounts of energy, which is slowly released as H_2O diffuses out of the system and melt crystallizes.

Thus, H_2O-fluxed melting of hot crust can assist in the stabilization of mushes by lowering the solidus, buffering the temperatures, and storing energy in the crust for longer and at lower temperatures when compared to dehydration melting. This implies that in crustal arcs affected by intermittent heat-H_2O pulses related to the underplating of mantle-derived basalt, there is an increased chance of interaction between successive pulses. This interaction magnifies the impact of each incoming pulse, producing more melt over wider regions, storing more energy and increasing the likelihood of developing a crustal mush column.

Ore forming fluid of the Malanjkhand copper deposit, Central India: Evidence from Fluid inclusions and Raman Spectroscopy

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Malanjkhand copper deposit is located to the south of the Central Indian Tectonic zone (CITZ), forming an integral part of the Bastar Craton. It is the most significant and giant copper deposit in Peninsular India, and is considered to be of magmatic-hydrothermal origin. The ore mineralization is associated with reef quartz, quartz veins and also as disseminated ore in the granite. Both mineralized and unmineralized quartz reefs and granites are present. The ore petrography and micro-Raman spectroscopy of mineralized samples confirm the presence of various ore minerals; sphalerite globules in the chalcopyrite matrix provide Raman band at 356.84cm-1, Raman band of pyrite is obtained at 377.05cm-1. Chalcopyrite is the most dominant among all ore minerals and its Raman band is obtained at 293.26cm-1. Similarly, other minerals like malachite, marcasite, bournonite, cassiterite, molybdenite, wavellite, magnetite, hematite and sphalerite are confirmed by the obtained Raman bands.

Detailed fluid inclusion petrography was carried out on both mineralized and unmineralized quartz reefs and granitoids from this deposit. The fluid types of both

mineralized and unmineralized samples were matched in general, but variations are noticed in the abundance of inclusion types and their microthermometry records. Biphase aqueous inclusions, most abundant in mineralized granite and mineralized veins, are low-saline aqueous fluids. Whereas polyphase inclusions are more common in unmineralized samples. Although they generally consist of generally a halite daughter crystal but sylvite and anhydrite are also seen in some of them. The mineralized samples, sometimes consist of an opaque mineral. Primary H2O-CO2 inclusions are present in mineralized granite. The micro-Raman spectroscopy confirms that the gas bubble in aqueous carbonic inclusions is CO2, while dissolved CH4 is also detected in a few of them. Monophase aqueous inclusions are commonly present in healed planes and are late-stage fluids. They do not show any nucleation of the bubble, hence they are not metastable fluids. The microthermometry data suggest medium to high temperature (170 - 381oC) conditions during fluid inclusion entrapment in mineralized granite; these were between 209 to 352 oC in mineralized quartz veins, whereas in unmineralized granite it was from 169 to 273 oC and in unmineralized quartz veins from 133 to 182 oC. The salinity of such fluids in mineralized quartz is lower (<5 wt.% NaCl eq.) than barren quartz (2-13 wt.% NaCl eq.), which is possible during cooling of hydrothermal fluid with an increase in salinity at later stages when the mineral formation was finished. The density of the carbonic fluid is higher in mineralized granite than in barren samples. There are a few polyphase inclusions which are not homogenized and were busted, suggesting that fluid immiscibility existed at the initial stage. It is overall attributed that (i) the mineralized quartz was formed from low CO2-bearing H2O rich hydrothermal solutions with low salinity, (ii) an immiscibility between high saline fluid and carbonic fluid is invoked in mineralized granite, The envisaged immiscibility between aqueous and carbonic fluids at the initial stage probably favoured the ore deposition.

This study reveals that the ore-forming fluid was not simple but was a complex solution. The above observations suggested that the ore deposition precipitated through low to medium temperature fluids having low to medium salinity. The significance of the findings is that the observed temperature and salinity range for Malanjkhand Cu deposit correlates very well with some of the major porphyry Cu deposits of the world and should be assigned as Porphyry Cu-deposit.

A cannibalistic origin for rare-metal granites? Insights from the Velay anatectic dome (Variscan French Massif Central)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Major lithium deposits are related to peraluminous magmatism in collisional orogens but crustal melting conditions and protolith compositions for the genesis of rare-metal (Li-Sn-Ta-Cs-Be-F) granites remain controversial. Analyses of silicate minerals from metasedimentary rocks and orthogneisses as well as related granites from the Variscan Velay anatectic dome were coupled to geochemical modeling to assess the Li and F partitioning upon partial melting. The Li concentrations of biotite and cordierite from anatectic metapelites decrease from ~700 to 825°C, reflecting its incompatible behavior and the Li depletion of the melt during biotite breakdown. In contrast, F concentrations in biotite correlate positively with temperature, indicating that Li and F are decoupled during metapelite melting; Li-richest melts (~200-400 ppm) are produced below 750°C whereas F-richest ones (~0.2-0.4 wt%) are produced above 825°C near the biotite-out isograd. Therefore, metapelite melting is not amenable to generate F-Li-rich

rare-metal granites but produce melts akin to those in equilibrium with biotite from cordierite-bearing granites. In contrast, silicate melts in equilibrium with biotite from anatectic peraluminous orthogneisses show higher Li concentrations similar to the melts equilibrated with biotite from muscovite-bearing granites. Muscovite and biotite breakdown in orthogneiss occurs within a narrow temperature range (690-730°C) allowing the production of melts concomitantly enriched in F (0.3-1 wt%) and Li (~600-1350 ppm), which, following 80–90 wt% fractional crystallization, generate rare-metal granitic melts (~10000 ppm Li; ~2 wt% F). This study suggests that peraluminous granite re-melting ("cannibalism"), followed by magmatic differentiation, is a viable mechanism to form rare-metal granites.

Magmatic and post-magmatic processes in Homolka-type granites (Eisgarn Pluton, Moldanubikum)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The South Bohemian Batholith (SBB) is a complex body built by many intrusions. It extends over ~10,000 km2 from northern Austria into the Czech Republic and Germany as one of the biggest middle to late Carboniferous plutonic complexes within the Variscan

Orogenic Belt. The evolution of the SBB begins with the partial melting of Cadomian basement series at 360 to 350 Ma (Lower Carboniferous) and the formation of large masses of geochemically diverse granitoids (Weinsberg granite, Rastenberg granodiorite) between 350 and 320 Ma. Incorporated into this complex are small gabbroic to dioritic intrusions with marked mantle components. The subsequent intrusion of small amounts of I-type granites and huge amounts of S-type granites follows (Mauthausen, Schrems, and Eisgarn type granites) between 330 and 300 Ma (Middle Carboniferous). The leucocratic muscovite granite of the Homolka type are included in the Eisgarn pluton and form a stump of several square kilometres situated west of Nová Bystřice. Smaller bodies then occur in Austria west of the village of Eisgarn. These bodies were formed by the intrusion of strongly differentiated peraluminous magmas, which are among the youngest within the Moldnubian pluton (327 ± 4 Ma: Rb-Sr WR, 317 ± 2 and 315 ± 3 Ma: muscovite Ar-Ar; Breiter and Scharbert 1995).

The Homolka massif body is dominated by medium-grained porphyritic muscovitic granites that grade into medium- to coarse-grained muscovitic leucogranites at the margins. Potassium feldspar, plagioclase and quartz dominate. About 5 to 15 mod. % of muscovite is found in the rock. Topaz, andalusite, apatite, phosphate, zircon, monazite, uraninite, columbite, cassiterite and secondary limonite occur in minor to accessory amounts. Locally, fine-grained subvolcanic granites with porphyritic texture occur. Typical for these rocks are up to 6 mm large outcrops of automorphic feldspar and up to 4 mm large rounded outcrops of quartz.

The mechanism of formation of these specific granites remains unclear. As we observed the variable abundance of phosphate, Li-mica and topaz in the studied granites was controlled by late magmatic to post magmatic processes. The alteration of primary magmatic minerals (greisenization) is the result of the interaction of late magmatic Sn- and Li-rich solutions. These solutions were enriched in phosphorus released by alteration of feldspars during alteration processes. The similar granite intrusion at Beavouir Massif in Massif Central are counted to be of entirely magmatic origin with only very late alteration stage.

Lithium mobility in felsic magmas: Insights from the Krafla Volcanic Zone, Iceland

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Understanding how lithium (Li) is distributed in the crust is critical to improve the genetic models of Li-bearing ores, whose identification and efficient exploitation are key for the current energy transition. Fractional crystallisation and degassing appear to be the main magmatic processes that shape Li inventories in magma reservoirs. Post-eruptive processes, such as hydration of glass and cooling of the volcanic deposits on the surface may, however, overprint the original magmatic Li contents of minerals and glasses hindering the evaluation of the behaviour of Li in magma reservoirs. The unforeseen intersection of felsic magma by the Iceland Deep Drilling Project (IDDP-1) at the Krafla Volcanic Zone (KVZ), located in the North Volcanic Zone (NVZ) of Iceland, offers an outstanding opportunity to disentangle the behaviour of Li in magmas. Here, we report new Li elemental and isotopic compositions of rhyolitic lavas at KVZ, covering different stages of groundmass crystallisation, and from felsic cuttings recovered by the IDDP-1 well, which comprises crystal-poor obsidian and crystal-bearing to crystal-rich particles, in order to evaluate the most effective way to enrich rhyolitic melts in lithium. Surface rhyolites and IDDP rhyolite cuts share a similar crystal cargo that consists of plagioclase, pyroxene, Fe–Ti oxides, zircon, and apatite. Quartz and alkali feldspar are only found in the groundmass of the pervasively crystallised portions of surface rhyolites and as phenocrysts in crystal-bearing to crystal-rich IDDP-1 rhyolite cuts. Lithium behaves incompatibly in all the studied mineral phases and Li content in glass increases with crystallinity. The absence of alkali feldspar in crystal-poor rhyolite cuts from the IDDP-1 and glassy portions of lavas appears to explain that spherulites in lavas are more enriched in Li (60–100 µg/g) than their surrounding glass (25–35 µg/g), and that crystal-poor IDDP-1 glasses are lower in Li content (28–30 µg/g) than glasses from crystal-bearing to crystal-rich IDDP-1 cuts (55–65 µg/g). Lithium concentrations in plagioclase and pyroxene from lavas vary as a function of cooling rate, having their maximum concentrations in slowly cooled portions of lavas. There is no significant Li isotope fractionation from basalt to rhyolite at KVZ. While bulk IDDP-1 obsidian shards and glassy lavas overlap in their Li isotope compositions (average δ^7Li = +4.38 ± 0.17 ‰), lavas with pervasive groundmass crystallisation and crystal-rich IDDP-1 particles are isotopically heavier (δ^7Li = +7.43 ± 0.16 ‰ and δ^7Li = +7.21± 0.86 ‰, respectively). While lavas with pervasive groundmass crystallisation show the lowest Li element contents (7.4 ± 0.7 µg/g), bulk lithium concentrations of crystal-rich IDDP-1 particles overlap those from bulk IDDP-1 obsidian shards and glassy lavas (22.3-24.5 µg/g). Deviation towards heavier isotopic compositions together with lower Li element concentrations might be related to degassing-controlled Li mobility during cooling of the deposit. Bulk crystal-rich IDDP-1 isotopic compositions seems to reflect the cumulative effect of the minerals present in such cuts rather than degassing. Overall, alkali feldspar crystallisation seems to be key to induce effective Li enrichment of shallow rhyolitic melts at KVZ. Rapid cooling of surface deposits is important to avoid open-system degassing, which reduces the Li concentrations of volcanic rocks. Lithium isotopic compositions of volcanic rocks seems to indicate whether open-system degassing has occurred in a volcanic deposit, but it could also reflect the cumulate nature of hypabyssal rocks that contain abundant quartz.

On spodumene-rich pegmatites: Eastern Brazilian Pegmatite Province

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Spodumene-rich pegmatites (SRP) are an important source of lithium, a prominent critical raw material and the main driver for the green energy transition. In Brazil, the main lithium deposits are the swarms of SRP of the Araçuaí Pegmatite District. These pegmatites are especially important due to their high modal contents (up to 30%) of coarse-grained spodumene crystals disseminated in a quartz-feldspar matrix of rather homogeneous ore bodies. In the Araçuaí Pegmatite District, the SRP pegmatites have been interpreted as residual magmas from post-collisional plutons mostly composed of Cambrian two-mica granites with pegmatoid cupolas formed under a low-P/high-T metamorphic regime in the late tectonic stage of the Araçuaí Orogen. Former isotopic studies yielded K-Ar ages of 470-490 Ma for SRP mica samples from the Araçuaí District. However, the timing and mechanism of formation of SRP in the area are open to debate based on more precise data. A key limitation for reconstructing their genesis and evolution is the difficulty of obtaining reliable geochronological information, due to: i) their complex and

exotic mineralogy, often lacking the most common phases used in geochronology; ii) a general higher uranium content in accessory minerals, especially zircon, causing diffuse metamictization and consequent re-opening of the U-Pb isotopic system; iii) the late H_2O-rich fluids activity promoting hydrothermal alteration and resetting of isotopic systems. Our study is focused on samples from drill cores and well-preserved outcrops of an SRP found 3 km from an intrusive pluton exposing two-mica and pegmatoid granites. The studied SRP (~ 800 m long and 40 m thick) shows a thin (<1m thick) marginal zone rich in albite and quartz, discontinuously enveloping a thick internal zone rich in coarse-grained spodumene crystals (20–30 vol%) associated with perthitic K-feldspar, quartz, white mica and albite. The common accessory minerals are Li-phosphates, Nb-Sn-Ta oxides, and zabuyelite. The two mineralogically different zones were sampled and cassiterite grains were separated and imaged in cathodoluminescence. Cassiterite U-Pb analyses were performed by LA-MC-ICP-MS. Data were corrected for the presence of Pb_c using a linear regression on a Tera-Wasserburg diagram calculating two lower intercept ages at 512.39 ± 6.38 Ma (n = 18, MSWD = 2.2) and 506.68 ± 7.30 Ma (n = 19, MSWD = 3.1) for the pegmatite core and border zones, respectively. These ages support formation of the pegmatites during the post-collisional stage of evolution of the Araçuaí magmatic belt.

Fluid flow in, out of, and around cooling intrusions

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Overview Keynote, Friday 15th September, 10:45 - 11:30

Cooling magmatic intrusion provide heat to drive hydrothermal systems and – if hydrous – can also experience internal fluid transport and provide fluid input to the surroundings. The details of these processes are a key element for magmatic-hydrothermal ore formation, geothermal power production, and may influence the subsolidus evolution of the intrusion itself. This contribution reviews how geologically constrained numerical simulation aids understanding and inspires advanced field-based studies.

In the case of hydrous magmas, progressive cooling from the outside leads to crystallization and may develop permeability for magmatic fluid transport where crystallinity is such that it provides a framework of locked crystals. Inbetween these, melt and magmatic fluid can compete for transport (Parmigiani et al., 2017). Large-scale simulation of this process (Lamy-Chappuis et al., 2020) reveals an inward progressing, ring-like domain inside the cooling intrusion in which magmatic fluids circulate towards its highest point where they can be released. Initial fluid content in the melt, intrusion depth, etc. determine whether focused vs. diffuse fluid release occurs. The continuous inward progression provides an efficient means for extracting fluid-partitioning chemical components from the whole intrusion.

As a major consequence, the processes may be essential for the formation of porphyry copper-type magmatic-hydrothermal ore deposits. While efficient tapping of the magmatic fluid is one important facet, a hydrology that leads to focused ore precipitation some km above the intrusion is another one. Advanced numerical simulation (Weis et al., 2012) showed that a classic, static permeability distribution in the surrounding rocks would suppress such focused precipitation. Rather, the rising and hot magmatic fluid heats the overlying rock to temperatures where it becomes nominally ductile, reducing permeability and counteracting fluid flow. In turn, this leads to overpressuring of the to-be-released magmatic fluid to supra-lithostatic pressures until it is able to hydro-fracture the ductile material, resulting in periodic fluid release, likely in the form of hydrofracture fronts that are reflected by the multi-generation stockwork veining in porphyry deposits. Finally, meteoric convection in the uppermost crust cools the upper part of the magmatic fluid plume, resulting in a significant cooling of the magmatic fluid and a lithostatic to hot hydrostatic transition in fluid pressure. In this uppermost part of the magmatic fluid plume, porphyry ore formation is predicted to occur and detailed ^{18}O SIMS analyses of petrographically well-constrained vein quartz growth zones seem to confirm this prediction from numerical simulation (Fekete et al., 2016).

Non-hydrous intrusion may act as drivers of geothermal systems and the system evolution has feedbacks on the sub-solidus evolution of the intrusion itself. Again, this is due to the fact that permeability is not a static property but reacts to parameters such as temperature: the initial hot intrusion is impermeable to fluid flow; however, as it cools and crystallizes the crystallized parts eventually become permeable and the circulating fluids may penetrate these parts. Depending on the temperature at which this happens (often assumed to be closely linked to the brittle to ductile transition of the resulting magmatic rock) fluids may reach temperatures in excess of the critical temperature of water (374 °C). These parts of the geothermal system may form attractive “superhot” geothermal resources and are considered to be an integral part of many, if not all, high enthalpy geothermal systems (Scott et al., 2015). An understudied aspect of this is that sub-solidus fluid-rock interaction may take place that could alter the isotopic and chemical characteristics of the intrusive rock.

The contribution concludes with an outlook on how open research questions on fluid flow in, out of and around cooling intrusions may be addressed and where I see the currently biggest needs for additional research, be it field-based, analytical, experimental or in advanced numerical simulation.

Fekete S., Weis P., Driesner T., Bouvier A., Baumgartner L., and Heinrich C.A. (2016): Contrasting hydrological processes of meteoric water incursion during magmatic-hydrothermal ore deposition: an oxygen isotope study by ion microprobe. Earth and Planetary Science Letters 451, 263-271

Lamy-Chappuis B., Heinrich C.A., Driesner T., and Weis, J.P. (2020) Mechanisms and patterns of magmatic fluid transport in cooling hydrous intrusions. Earth and Planetary Science Letters 535, 116111.

Parmigiani, A., Degruyter, W., Leclaire, S., Huber, C., Bachmann, O., 2017. The mechanics of shallow magma reservoir outgassing. Geochem. Geophys. Geosyst. 18, 2887–2905.

Scott S., Driesner T., and Weis P. (2015): Geologic controls on supercritical geothermal resources above magmatic intrusions. Nature Communications 6, 7837; DOI: 10.1038/ncomms8837

Weis J.P., Driesner T., and Heinrich C.A. (2012): Porphyry-Copper Ore Shells Form at Stable Pressure-Temperature Fronts Within Dynamic Fluid Plumes. Science 338, 1613-1616.

The Porosity of Hot, Shallow Granites

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The range of porosities and permeabilities of hot granitic rocks in the shallow crust has implications for interpreting geophysical signals of unrest beneath volcanoes, exploiting geothermal systems, and understanding magma outgassing and types of ore deposition. Geophysical and petrological studies indicate that fluids with high electrical conductivity can be stored in, and transmitted through granites. This study investigates the physical features on a microscopic scale that allow granites to be porous and permeable, using two sets of samples that were brought from depth to ambient conditions rapidly: cores drilled into hot granite of the Kakkonda geothermal field (Japan), and granite lithic clasts erupted by Laguna del Maule volcano (Chile). Depths (2-5km) and temperatures (650-800°C) of the samples are constrained from geothermobaromerty, and in the case of the Kakkonda granite, measurements during drilling and fluid inclusion homogenisation. A variety of techniques to quantify porosity were applied to cover a range of pore sizes and ensure a representative sample volume. Helium pycnometry of 2 inch core samples indicate a connected porosity range of ~5-8 vol.%. 2D Scanning Electron Microscopy (SEM) on polished samples and 3D X-ray tomography imaging

show a range of intragranular pores, cavities, fractures and miaroles connected by an intergranular pore network. The porosity is dominated by connected space along grain boundaries (i.e. intergranular), most of which has widths <5µm based on Euclidean distance maps.

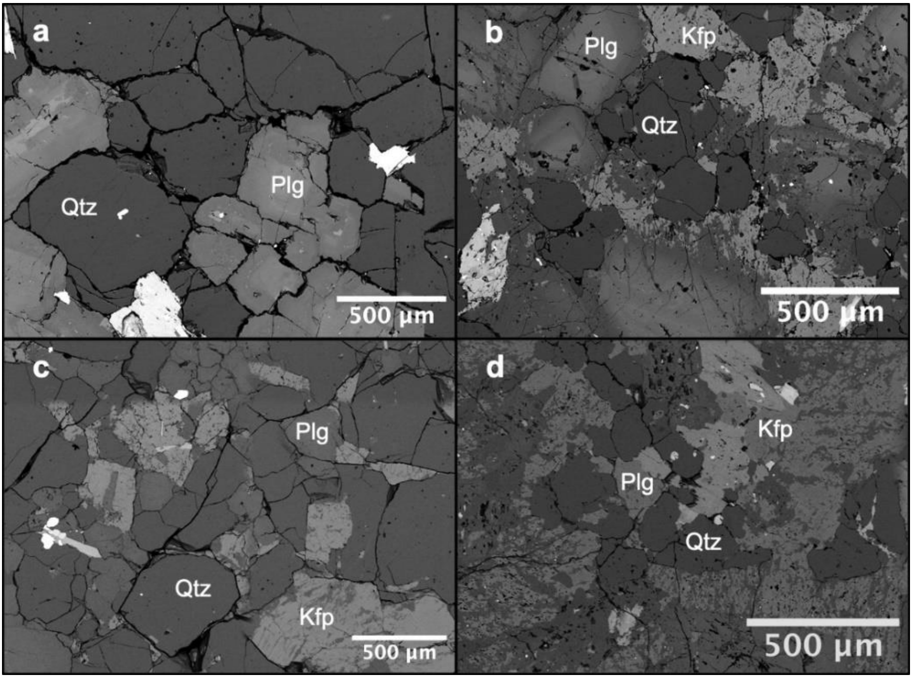
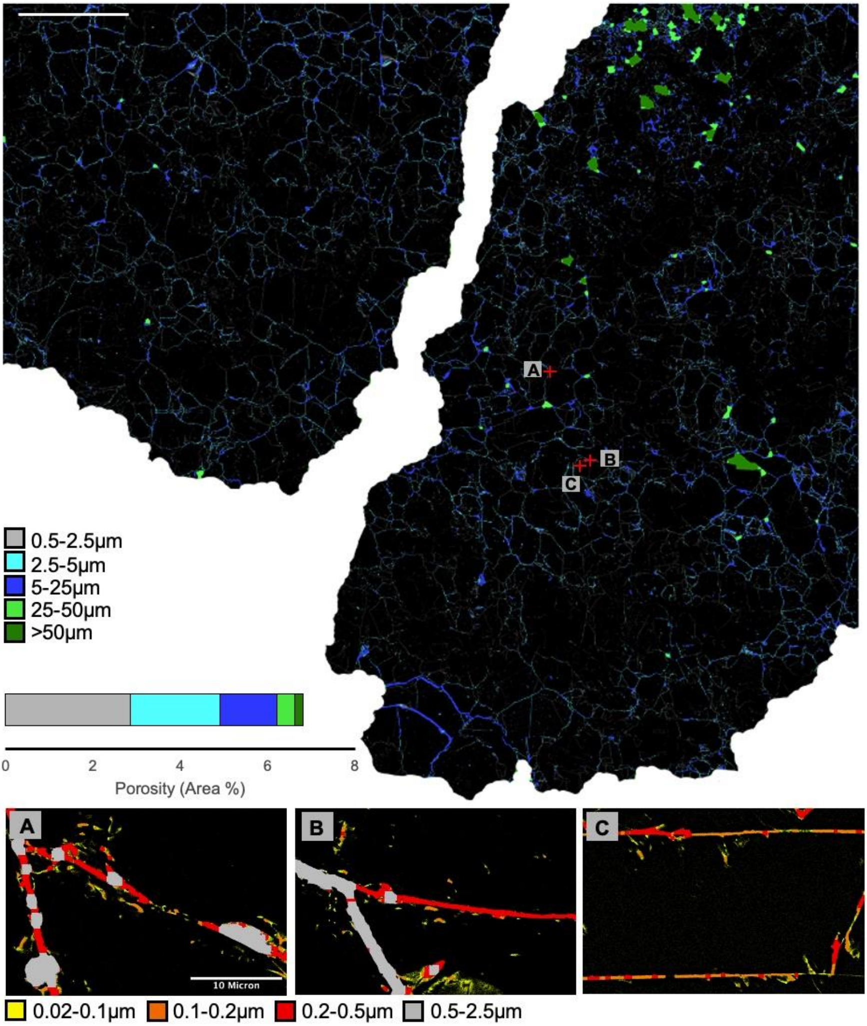


Image analysis also indicates a total porosity range of ~4-7 area%, similar to but slightly smaller than porosities determined by helium pycnometry, suggesting that the finest pores were not resolved. Additional imaging by FEG SEM resolves intergranular pore space with widths as fine as 0.007µm. We conclude that some granites can store ~4 vol.% magmatic fluids in 0.007-25µm intergranular pore space, which is consistent with electrical resistivity anomalies under volcanoes. Permeability simulations remain for future work, however, flow capabilities are inferred from the 5-8 vol.% connected porosity and the chemical footprint of fluids in the studied samples. The permeability at low porosities could facilitate the final stages of magma outgassing as granite solidifies and have implications for geothermal resources.



Contrasting Na-metasomatism related to granitic magmatism in Cretaceous active continental margin of East Asia: Evidence from ‘syenites’ in Hakata Island, Ehime Prefecture, southwest Japan

Toko Fukui*, Satoshi Saito, Toshiro Takahashi, Kazuya Shimooka

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Metasomatism is ascribed to pervasive fluids, leading to mass transfer and ultimately contributing to chemical evolution of continental crust. In southwest Japan, several meter- to tens of meter-scale bodies of metasomatic rocks previously reported as ‘metasomatic syenitic rocks’ are distributed in Cretaceous granitic batholiths (Murakami, 1976). In this study, we describe field occurrences, petrographic remarks and geochemical characteristics of adjacent two contrasting ‘syenites’ (type-1 and type-2) and host granitoids in Tobyo-bana, northernmost Hakata Island, Ehime Prefecture, southwest Japan.

Both of type-1 and type-2 ‘syenites’ expose as small discrete body (~30-40 meters length and ~5-10 meters width) in host granitoids and are rich in Na, probably formed through Na-metasomatism of Cretaceous granitoids. The type-1 shows massive and dense

lithology and preserves the original structure of the host rocks, while the type-2 has vugs and locally shows banding. The distance between two ‘syenite’ bodies is ~40 m. Both bodies display irregular and gradual contacts at cm scale against the host granitoids.

Both of ‘syenites’ are mainly composed of alkali feldspar (perthite and mesoperthite), clinopyroxene, garnet and titanite. Mafic mineral aggregates of granular grains of clinopyroxene and garnet occur in type-1, while garnet containing granular clinopyroxene and alkali feldspar is observed in type-2.

The whole-rock compositions of the ‘syenites’ are lower in SiO2, K2O and Rb, and higher in Na2O, Sr and Ba than the host granitoids. Among the two ‘syenites’, the type-1 has higher FeO(total), MgO, CaO, Sr, Y and Ba, and lower Al2O3 than the type-2. The total REEs in the type-1 are considerably higher than type-2, and those of host granitoids are between type-1 and type-2. Both of ‘syenites’ has negative Eu anomaly, showing more pronounced negative Eu anomalies of type-2 compared to type-1. The type-2 shows marked positive Ce anomaly. Identical Sr-Nd isotopic signatures between the ‘syenites’ and host granitoids imply that the magmatic fluids from host granitoid magma have induced metasomatism.

Chemical changes during metasomatism are estimated from the isocon diagram assuming Ce to be immobile element. Compared to the host granitoids, the type-1 is characterized by increases of siderophile element, and decreases of Si, B, W and Pb, whereas the type-2 is characterized by increases of alkali metal element and

HFS elements, and decreases of Ca, Cs, Pb and Eu. The contrasting chemical characteristics observed in the two adjacent 'syenites' bodies imply that two distinct hydrothermal fluids have induced metasomatism of Cretaceous granitoids in the studied area.

Age and origin of Sn mineralization in the Eastern Erzgebirge (Germany)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The prolific Erzgebirge metallogenic province in E Germany and NW Czech Republic is part of the Saxothuringian zone of the Paleozoic Variscan orogenic belt. Various types of polymetallic magmatic-hydrothermal deposits are of particular prominence, of which many are well endowed in Sn. Several ongoing exploration projects target the intrusion-related Sn systems located predominantly in the western and eastern portions of the Erzgebirge.

This study focuses on the Eastern Erzgebirge. Supracrustal successions of Neoproterozoic to Early Paleozoic age in this region experienced peak metamorphism at ca. 340 Ma –followed by rapid uplift and exhumation– accompanied by several distinct episodes of felsic magmatism. A first generation of granites dates at ~330-320 Ma, followed by massive rhyolitic flows, tuffs, and ring dykes at 315-310 Ma that are linked to the formation of the Altenberg-Teplice and Tharandt calderas. Tin (± Li, W, Cu and Mo) greisen bodies and quartz-cassiterite veins are prominent in the southern part of the study area, where they are spatially associated with the Altenberg-Teplice caldera. In contrast, no Sn mineralization is known in spatial association with the Tharandt caldera.

Here, we report new U-Pb LA-ICP-MS ages of cassiterite from occurrences from Sn-bearing mineralization at Zinnwald, Altenberg, Niederpöbel, Schmiedeberg, Bärenfels, Sadisdorf and Krupka –all within or adjacent to the Altenberg-Teplice caldera. Uranium-Pb ages of the different localities span between 314 and 307 Ma, with most overlapping within error (lower intercept ages, Tera-Wasserburg concordia). Greisen formation and associated cassiterite crystallisation thus occurred shortly after the formation of the 315-310 Ma microgranitic dykes linked to the Altenberg-Teplice caldera collapse. The new results show clearly that Sn mineralization in the Eastern Erzgebirge originated only during a relatively short-lived magmatic-hydrothermal event and occurred later than previously assumed ages (>318 Ma).

Flavors of liquids precipitating REE-bearing NYF pegmatites and comparison with their LCT counterparts

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Pegmatites are extremely coarse-grained rocks of granite-like composition, that exhibit both magmatic and hydrothermal characteristics. They are known to sometimes contain exceptional mineralization of gem-quality crystals, such as varieties of beryl and tourmaline. Critical elements such as Li, Be, Cs, Nb, and Ta can be concentrated near their cores. Rare-earth elements (REE), increasingly important in the transition toward green energy sources, also precipitate in these extreme environments, with the help of ligands such as CO32-, PO43-, and F-. The dichotomy of igneous and hydrothermal features has led to much debate on the formation mechanisms of pegmatites, specifically regarding the nature of the liquid from which pegmatites crystallize.

Here, we examine two contrasting pegmatite settings, NYF (niobium-yttrium-fluorine) pegmatites with extensive REE-mineralization from the Pikes Peak batholith (PPB) in Colorado, and LCT (lithium-cesium-tantalum) pegmatite data from the Karibib district in the Damara

Belt, Namibia, in order to characterize chemical evolution and determine the influence of the tectonic setting on composition and mineral assemblages in the pegmatites.

Granite in the PPB is the type-example of an A-type (anorogenic) granite emplaced in an extensional tectonic setting. Rare-earth element and Nb minerals in these pegmatites include a plethora of exotic phases of REE-Nb-oxides, REE-silicates, REE-fluorocarbonates, and rarely REE-phosphates. Quantitative maps of REE-phases from the PPB pegmatites, obtained by electron microprobe, give insights into the paragenesis and texture of light REE-rich relative to heavy REE-rich minerals and other late-crystallizing phases. The latter is essential to assess the crystallization history of the mineralization. Mineral trace element data via LA-ICP-MS obtained in different zones in the pegmatites and their host granite track the compositional evolution of the liquid during pegmatite crystallization. LCT pegmatites from the central Damara orogen in Namibia formed in a (post) collisional setting and crystallized from liquids with different compositions of flux elements and rare metals.

We suggest that at least parts of the pegmatites crystallize from a solute-rich aqueous liquid, enriched in incompatible flux elements which lower the solidus. The nature and composition of this liquid are central to determining which mineral phases precipitate in the pegmatite, and if the pegmatite is mineralized at all. The flux elements specifically are thought to play a role in fractionating heavy REE from light REE. Clearly, characterizing the crystallizing pegmatitic liquids is paramount to understanding the formation of economically valuable mineralization.

Mineralogical, mineral chemical and whole-rock geochemical variation in the upper 4.5 km of the Cornubian Batholith – initial 3D glimpses from the Eden Geothermal Project

Philip Henes*, Robin Shail, Christopher Dalby, Gavyn Rollinson, Sam Broom-Fendley, Jens Andersen

*Camborne School of Mines, University of Exeter, United Kingdom - philip.henes@gmail.com

Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Cornubian Batholith has been investigated extensively and, based on gravity and seismic refraction investigations, is estimated to have a minimum thickness of 7-8 km. However, direct knowledge of compositional variation at depths >1 km have only been obtained from geothermal wells at two locations in the Carnmenellis Granite. The Eden Geothermal Limited EG-1 well was completed in the St Austell Granite in November 2021 and reached depths of 4,871 m (TVD) and 5,277 m (MD). The well has provided the opportunity to examine the deepest parts of the batholith, as previous studies in the area have been constrained to surface clay quarries and mining activity, which did not exceed 1 km depth.

Geophysical logs were used for initial characterisation. Granite types were defined based on varying K, Th and

U characteristics in spectral gamma-ray logs. Sonic logs and image logs were used to identify zones of alteration and different structural domains. Collectively, these were used to pick 68 intervals for mineralogical and geochemical analysis. Qualitative and quantitative data from automated mineralogy (QEMSCAN) allowed for characterisation of modal mineralogy, mineral associations, and for mineral textural variations. Whole-rock geochemical and electron microprobe data were used to further constrain the variations of granite downhole, building upon the classification scheme of Simons et al. (2016, 2017).

The spectral gamma-ray data was used to calculate the heat production, building upon the work of Beamish and Busby (2016). An average of 7.5 µW m-1 was calculated for EG-1. This is higher than those from Beamish and Busby (2016) for the St Austell area but samples used for those calculations were from uranium-depleted shallow boreholes and airborne gamma-ray measurements.

Ultimately the heat production of granite is controlled by its mineralogy which is informed by the geological evolution of the granite during its emplacement, and by alteration events post granite emplacement. Characterising the granite intercepted in EG-1 will allow for a better understanding of the evolution of the Cornubian Batholith, which has potential for improving targeting for geothermal systems in the region.

Beamish D and Busby J (2016) Geothermal Energy, 4.1:4

Simons B et al. (2017) Lithos, 278–281, 491–512.

Simons B et al. (2016) Lithos, 260: 76-94

Fluid percolation in crystallizing felsic magmas: Insights from tourmaline analysis, Stone Mountain Granite (Georgia, USA)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Fluid transfer processes play a major role in magma fractionation at shallow depths (<10 km) where magmas stall rheologically and solidify. In this scenario, the conditions of fluid expulsion during progressive cooling of granitic crystal mushes remain poorly understood. Here we propose to reconstruct the chemical and physical conditions of fluid percolation in solidifying granites using tourmaline, in part, as precious indicator of fluid composition at the time of magma crystallization. An ideal setting to study tourmaline in granites and to unravel how fluids migrate through a felsic crystal mush system is the Stone Mountain Granite (Georgia, USA). The Stone Mountain Granite (SMG) is located approximately 20 km northeast of the city of Atlanta. It was generated as part of the Alleghanian orogeny (~300 Ma), associated with the formation of the supercontinent Pangea. The SMG is a quartz monzonite containing tourmaline, that forms a dome monadnock, and is the largest exposed granitic body in the Southeast US. The SMG displays “cat paws” or clusters of tourmalines surrounded by a leucocratic

halo. These features are dispersed throughout the plutonic body. New results based on the combination of field observations, electron probe micro-analyzer (EPMA), and secondary ion mass spectrometry (SIMS) analyses of tourmalines in granite help to unravel the physical and chemical conditions of fluid transport in crystal mushes. Fieldwork includes the structural analysis of 80 representative locations using a 1.14 m² “window” (Fig. 1) across the surface of the dome monadnock.

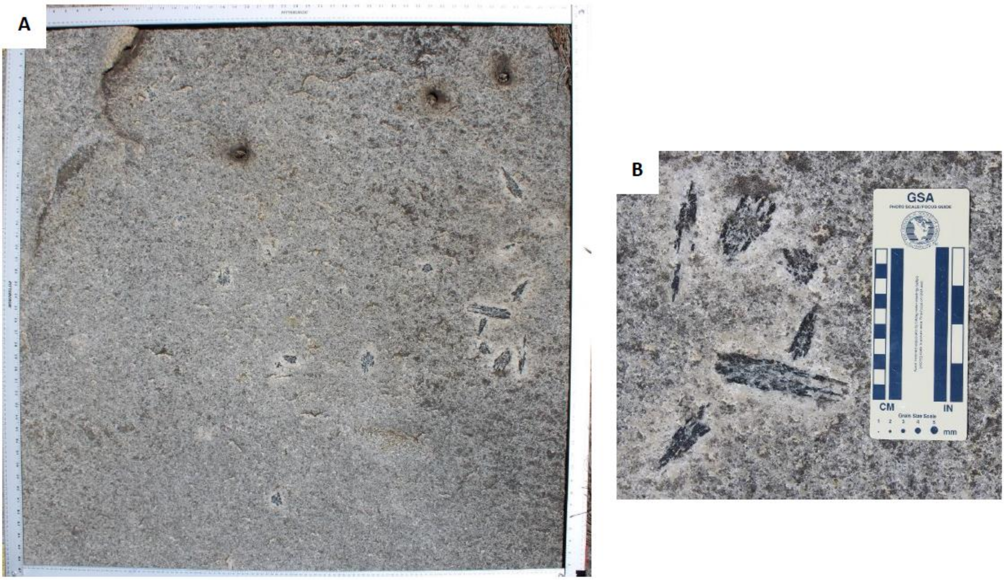

Figure 1: A. Example of “window” (1.14 m²) used for collecting measurements of tourmaline size, orientation, number, density, shape and area on the surface of the granite host. B. A closer look at “cat paws” that are present in panel A.

The collected snapshots provide the analysis of size distribution, shape, area (i.e., tourmaline and leucocratic halo vs. granite), number, density, and orientation of the tourmalines. EPMA data reveals the geochemical composition of tourmaline, as well as the felsic halos of pegmatoid quartz and feldspars, to facilitate reconstruction of the processes of crystallization of tourmaline within the granite and the granite host itself. Also, we will collect high-precision SIMS data of boron isotope composition (^{10}B and ^{11}B) of tourmalines, and determine the fluid source, geochemical interaction with the host granite, and the process of crystallization during felsic magma cooling and solidification. This study will shed light on the ultimate processes of crystallization of Stone Mountain Granite as a “fossil magma chamber” and mobilization of residual fluids in the Earth’s upper crust.

Genesis of magmatic ore deposits by exsolution, concentration, and emplacement of immiscible melts: a modelling perspective

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Junior Keynote, Friday 15th September, 12:00 - 12:30

The exsolution of immiscible melts and fluids within late-stage, shallow igneous systems represents a crucial process associated with the formation of plutonic rocks and volcanic activity of various compositions. Some immiscible melts exhibit a significant enrichment in economically valuable metals. Consequently, the separation of these melts from the parent magma, followed by their concentration and emplacement, has been proposed as a mechanism underlying the genesis of orthomagmatic ore deposits. However, this genetic hypothesis remains a subject of debate.The genesis of the magnetite-apatite deposit on the flanks of El Laco, a ca. 2-5 Myr andesitic stratovolcano located in the Atacama region of Northern Chile, has been the focal point of the ongoing debate. El Laco features a series of massive magnetite bodies on its flanks, displaying structures and textures that resemble volcanic formations. These features comprise vesiculated lava flows with meter-scale gas escape pipes, exposed feeder systems comprising dikes, volcanic breccias, and small diatremes, as well as tephra deposits with clast sizes from ash to bombs (see Fig. 1). Remarkably, these formations are predominantly composed of magnetite, with some alteration to hematite.

The distribution of the magnetite bodies around the perimeter of the central edifice is suggestive of association with an elliptical edifice collapse structure. Magnetite-apatite or Kiruna-type deposits are important sources of iron, predominantly in the form of magnetite, along with minor hematite. These deposits can also contain rare earth elements, cobalt, and uranium within apatite and other phosphates. They commonly manifest as either intrusive bodies with sharp contacts or as effusive and explosive volcanic products, and are generally associated with intermediate to felsic igneous systems. In addition to structural and textural similarities, this deposit class exhibits Fe-and O-stable isotopic signatures indicative of magmatic to high-temperature magmatic-hydrothermal conditions.

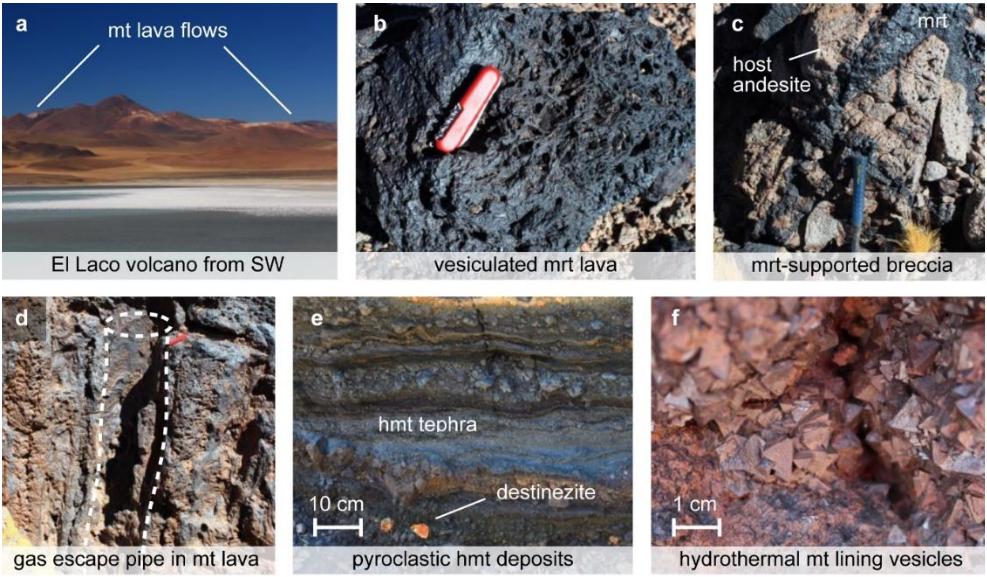

Figure 1: Photographs of El Laco seen from SW ***(a)****, vesiculated marmite (mrt) lava* ***(b)****, mot-supported breccia* ***(c)****, gas escape pipes in a magnetite (mt) lava flow* ***(d)****, hematite (hmt) tephra layers with embedded nodules of destinezite (hydrated Fe-phosphate-sulphate)* ***(e)****, and late-stage hydrothermal mt lining larger vesicles.*

Various processes have been proposed to account for their genesis, including precipitation from magmatic-hydrothermal fluids, as well as emplacement of magmatic magnetite-brine suspensions formed by flotation of magnetite crystals attached to hydrous fluid droplets within a shallow magma chamber. Here, I present a genetic hypothesis (see Fig. 2) involving the separation of an immiscible, iron-rich melt from an intermediate to felsic parent magma, followed by ascent along fractures related to edifice collapse. In a recent study, we conducted geochemical analyses and employed thermodynamic modelling to corroborate the presence of Fe-Si liquid immiscibility observed in melt inclusions at El Laco. We combined viscometry measurements of Fe- and Si-rich melts with scaling analysis of immiscible melt segregation to evaluate the time and length scales associated with the separation and concentration of the ore-forming melt. Using a numerical rock deformation model and scaling analysis of bubbly fracture-bound flow, we demonstrated that edifice collapse can generate fracture zones that extend towards the edifice flanks. Along these failure zones, the denser ore liquid ascends towards the surface driven by vapour exsolution. In ongoing research, we further elucidate the fluid mechanics of immiscible melt separation. We employ a numerical model of three-phase flow to investigate this process across a range of crystallinities. Our findings highlight the efficiency of ore melt concentration within mushy systems characterised by intermediate crystallinity. In such systems, the segregation of the ore melt transitions from droplet settling to the formation of a connected drainage network, which can extend over several meters to a kilometre within a mush of silica-rich melt and crystals. This aligns with petrological studies indicating that melt immiscibility occurs at crystallinities within the range of 30-50%. The geochemical and textural similarities mentioned before suggest that magnetite-apatite deposits in other locations may also form through similar processes.

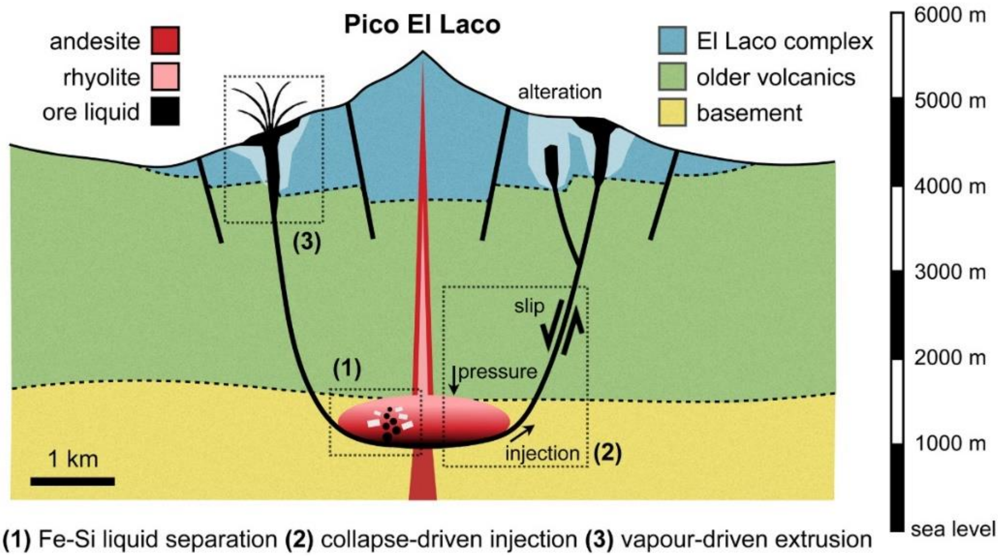

*Figure 2: Schematic of proposed genetic model for the El Laco ore deposit comprising **(1)** separation of an Fe-rich immiscible melt from a subvolcanic silicate magma bodies followed by **(2)** injection of the concentrated ore melt into edifice collapse structures, and **(3)** fracture-bound ascent driven by vapour exsolution upon decompression.*

Nevertheless, several questions remain regarding the conditions that promote the exsolution of metal-rich melts. One factor at El Laco appears to have been contamination of the parent magma with iron-, phosphate-, and/or sulphate-rich lithologies. Moreover, for future exploration it is crucial to understand the factors that govern the spatio-temporal distribution of these deposits. These factors may involve complex interactions between the physical properties of the parent magmas, immiscible melts, host rock characteristics, and tectonic context. Finally, similar processes involving the exsolution, segregation, concentration, and emplacement of exotic metal-rich melts could play a significant role in the formation of a broader range of magmatic to magmatic-hydrothermal ore deposits.

The role of crustal anatexis in porphyry copper ore formation during flat-slab subduction

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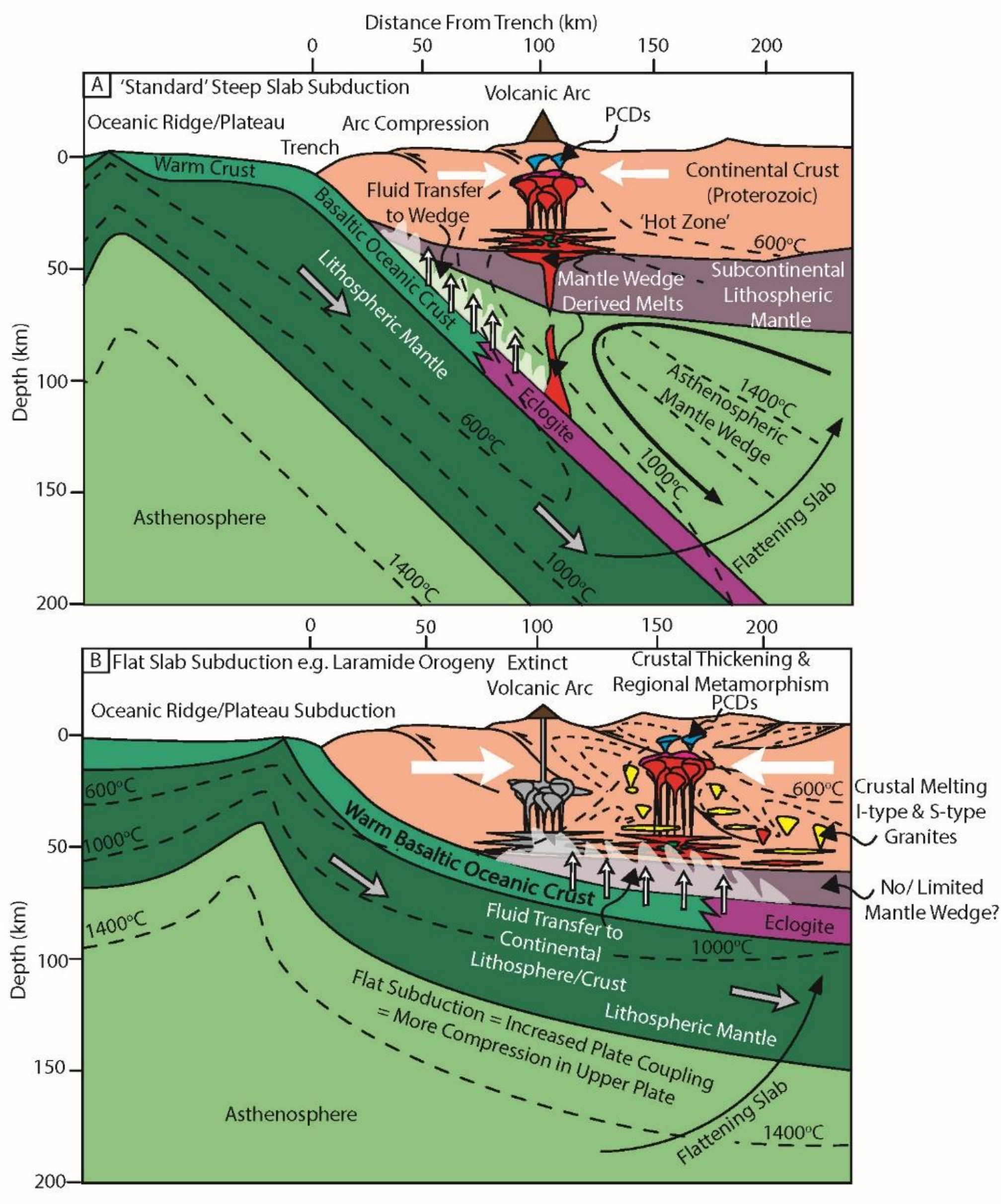
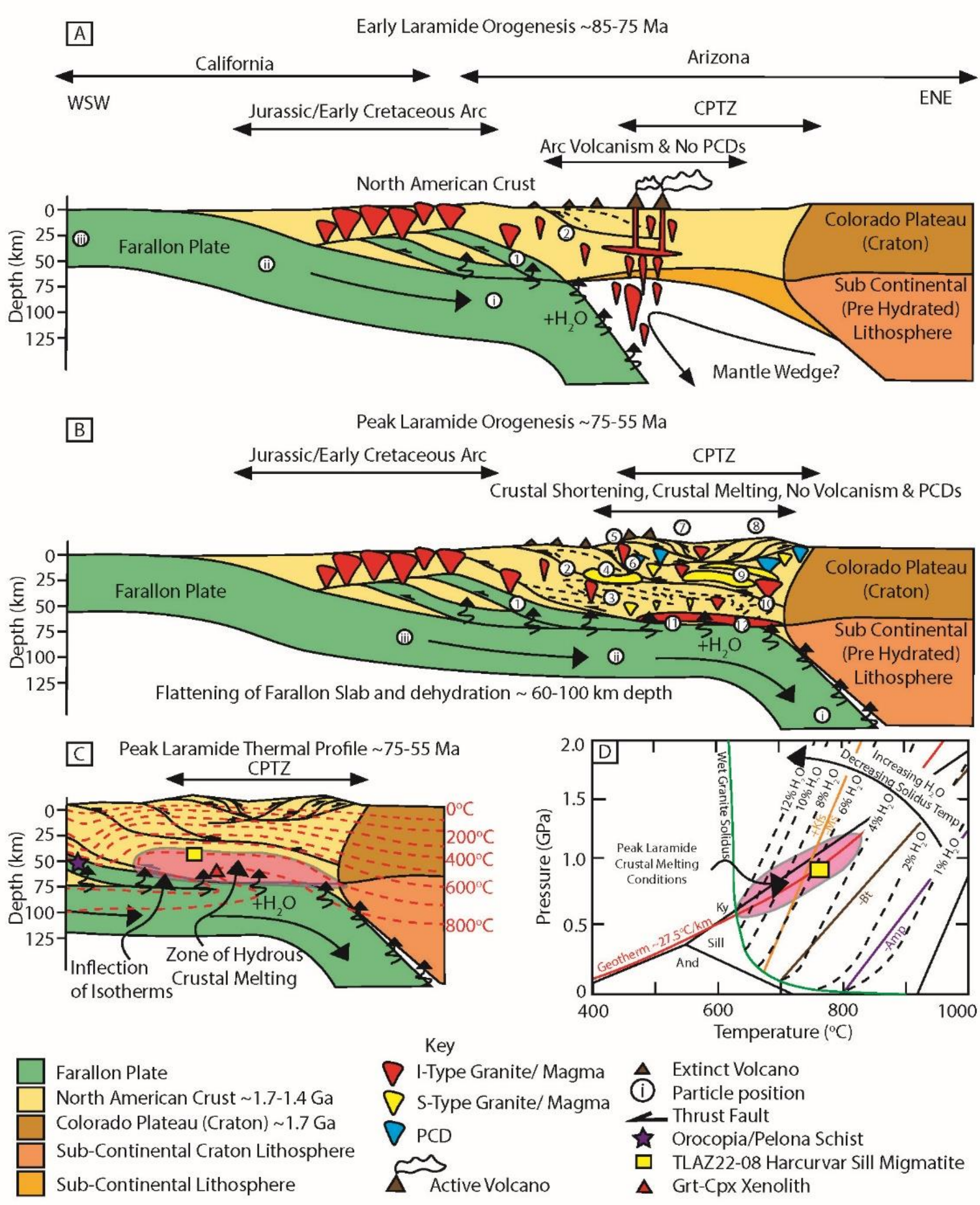
Oral, Friday 15th September, 09:00 - 09:15

The prevailing paradigm for the formation of porphyry copper deposits along convergent plate boundaries involves deep-crustal differentiation of metal-bearing juvenile magmas derived from the mantle-wedge above a subduction zone. However, many major porphyry districts formed during periods of flat-slab subduction when involvement of the mantle-wedge would have been significantly reduced, if not absent, leaving unclear the source region of ore-forming magmas. To resolve this

paradox, we investigate deep crustal processes during the formation of the Laramide Porphyry Province of Arizona, which formed between 80–50 Ma during flat-slab subduction of the Farallon Plate beneath North America.



We show that: (1) Laramide-age granitic rocks have unradiogenic isotopic signatures implying a crustal origin; and (2) Proterozoic basement rocks underwent water fluxed anatexis between 73–60 Ma at pressure–temperature conditions of 0.75 GPa and 750–780°C. This defines an elevated geothermal gradient of ~28°C/km coincident with the zenith of granitic magmatism and porphyry genesis (73–56 Ma) and dehydration of the shallowly-subducting Farallon slab (75–65 Ma). To explain the formation of the Laramide Porphyry Province, we propose that volatiles derived from the subducting Farallon slab passed straight into Proterozoic lower crust, promoting crustal anatexis without the requirement of any significant juvenile mantle-wedge derived magmatism.


A
Early Laramide Orogenesis ~85-75 Ma
California
Arizona
WSW
ENE
Jurassic/Early Cretaceous Arc
CPTZ
Arc Volcanism & No PCDs
North American Crust
Farallon Plate
Colorado Plateau (Craton)
Sub Continental (Pre Hydrated) Lithosphere
Mantle Wedge?
+H2O
Depth (km)
B
Peak Laramide Orogenesis ~75-55 Ma
Jurassic/Early Cretaceous Arc
CPTZ
Crustal Shortening, Crustal Melting, No Volcanism & PCDs
Farallon Plate
Colorado Plateau (Craton)
Sub Continental (Pre Hydrated) Lithosphere
Flattening of Farallon Slab and dehydration ~ 60-100 km depth
C
Peak Laramide Thermal Profile ~75-55 Ma
CPTZ
0°C
200°C
400°C
600°C
800°C
Inflection of Isotherms
Zone of Hydrous Crustal Melting
D
Pressure (GPa)
Temperature (°C)
Wet Granite Solidus
Peak Laramide Crustal Melting Conditions
Increasing H2O Decreasing Solidus Temp
Geotherm ~27.5°C/km
Ky
Sill
And
-Bt
-Amp
Key
Farallon Plate
North American Crust ~1.7-1.4 Ga
Colorado Plateau (Craton) ~1.7 Ga
Sub-Continental Craton Lithosphere
Sub-Continental Lithosphere
I-Type Granite/ Magma
S-Type Granite/ Magma
PCD
Active Volcano
Extinct Volcano
Particle position
Thrust Fault
Orocopia/Pelona Schist
TLAZ22-08 Harcurvar Sill Migmatite
Grt-Cpx Xenolith

Rare earth element partitioning and systematics of apatite in silicic magmas

Weiran Li*

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Junior Keynote, Friday 15th September, 08:30 - 09:00

Apatite ($Ca_{10}(PO_4)_6(F,Cl,OH)_2$) is a common accessory mineral in igneous rocks and well known as an important host of trace elements (especially rare earth elements - REEs) in magmatic systems that can be used to investigate the petrogenesis of igneous rocks, magma evolution, and generation of ore deposits. Estimating concentrations of REEs in silicate melts using apatite requires knowledge of REE partitioning between the two phases (usually expressed as D_{REE}). Although the values of D_{REE} have been reported by previous experimental studies and analyses of natural rocks, a generalized model for predicting D_{REE} was lacking. In our recent work[1] we determined D_{REE} for apatite in phonolite and compiled experimental data from the literature that cover a wide range of pressure (0.01-2 GPa), temperature (950-1250 °C), and composition (basalt-granite, basanite-phonolite) conditions, to establish a model based on lattice strain theory and thermodynamics expressions of the melt compositional effect on D_{REE}. Our results show that (*1*) the size of the 'ideal' trivalent cation (r_0) in fluorapatite (FAp) and hydroxyapatite (HAp) varies between those of Gd and Nd; (2) there is a large variation and uncertainty in the calculated Young's modulus (*E*;

mostly between 300-400 GPa); and (3) the dominant factor of D_{REE}, i.e. strain-free partition coefficient (D_0), increases with decreasing temperature and increasing silica content of the melt, and is pressure-independent. To parameterize the melt compositional effect, we adapted a regular solution model for silicate melts from the literature which accounts for three different types of components in melt structure. By fitting the thermodynamics expression to the D_0 derived from experimental data using a generalized-least-squares regression, we obtained the best fit when incorporating two major network-modifying components, i.e. Fe and Ca, in the equation for D_0. We applied the model to apatite in granites reported in the literature and acquired estimates of REE concentrations in melts that are sensible given the whole rock chemistry and REE fractionation.

Based on the current understanding of the partitioning of REEs and other trace elements, we performed a statistical analysis of the large compilation of apatite compositional data from the GEOROC database to investigate the trace element systematics of apatite in silicic magmas. We find that about 95% of the apatite reported for granite is fluorapatite containing low Cl contents (median $X_F \approx 0.75$, median $X_{Cl} \approx 0.007$, maximum $X_{Cl} \approx 0.22$). For the apatite whose REE compositions were reported (n=1255), light REEs (LREE: La to Nd) show a rather weak / no correlation with middle REEs (MREE: Sm to Dy, except Eu) or heavy REEs (HREE: Ho to Lu), whereas MREEs are strongly correlated with HREEs (*r*>0.9). Eu shows a moderate, positive correlation with Sr and Ba, and a less strong, negative correlation with MREEs and HREEs, indicating effects of plagioclase feldspar fractionation. Moreover, LREEs (especially Ce) show a strong, positive correlation with Th but a much weaker correlation with U, implying LREE+Th uptake by monazite that formed earlier in the systems. More detailed analysis of the dataset will be conducted to identify chemical characteristics of apatite in different types of granites and other rocks and to facilitate the use of apatite as a robust proxy for tracking the origin and evolution of magmas.

[1] Li, W., Costa, F., Oppenheimer, C., Nagashima, K. (2023) CMP.

Formation of lithium-rich pegmatites via rapid crystallization and shearing – case study from the South Tibetan Detachment, Himalaya

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Lithium is a rare element of increasing economic importance. Although Li is enriched in upper continental crust, average concentrations are only 24 ppm, so Li-concentrating processes are required for economic extraction. Pegmatites represent one of the main economic sources for lithium, with some deposits reaching weight percent levels and containing the rare minerals spodumeneand petalite. However, proposed processes by which Li concentrates in pegmatitic liquids to saturate Li minerals either have been qualitative, or have required as many as 7 cyclic refining processes. Although fractional crystallization must play a role in concentrating Li, a key problem in explaining high Li concentrations is that it is relatively compatible in many minerals. A typical bulk distribution coefficient (Kd) between minerals and melt of ~0.5 for common granites implies inefficient Li accumulation in fractionating melts. How, then, can Li concentrate so effectively? Here, we propose a mechanism for producing highly Li-enriched melts that appeals to a balance between the kinetics of crystal growth and diffusion of Li and water, coupled with deformation. Importantly, although Kd for mafic minerals and micas ranges from mildly incompatible to compatible (0.2 to 1.7), Kd for quartz and feldspar is ≤0.05, For a specific balance between the rates of crystallization and diffusion (which both depend on temperature), crystallization of quartz, feldspar, and other anhydrous minerals will form inviscid boundary layers that are enriched in both water and Li. In contrast, crystallization of micas produces viscous boundary layers that are depleted in water and Li. Deformation may preferentially liberate the water-rich boundary layers. This model expands a concept presented in Tiller et al. (1953) but accounts for local crystal effects and implicates deformation to extract melts effectively. Given the differences in Kd among minerals, the most effective melts for forming Li-rich pegmatites should be highly quartzo-feldspathic. Such parent liquids – leucogranites – are found worldwide, but are especially common in the Himalaya, in the uppermost Greater Himalayan Sequence, within and below the South Tibetan Detachment shear zone. Our model implies the c. 2200 km-long STDS along the Himalayan orogen has the potential to host large lithium deposits.

Internal texture and compositional characteristics of the zircons from the Luozha leucogranites, southern Tibet: Insights into the magmatic-hydrothermal evolution of the Himalayan leucogranites

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The prospect of rare metal prospecting in the Himalayan leucogranites has recently attracted much attention. Rare metal enrichment and mineralization are closely related to the magmatic evolution, especially the hydrothermal process of the highly differentiated granites. However, the knowledge of the magmatic-hydrothermal evolution of the Himalayan leucogranites is still limited.

To further understand the magmatic-hydrothermal evolution process of the Himalayan leucogranites, systematic textural observation and element compositional analysis were performed on the zircons from the early Miocene two-mica granites (ca. 20 Ma) in the Luozha area, southern Tibet. All the igneous zircons in the leucogranites are characterized by low CL (cathodoluminescence) intensity, which is consistent with their high contents of U (up to 45,000 ppm) and Th (up to 1,300 ppm). Based on the internal textures, the igneous origin zircons can be divided into two types. The Type I zircons, which occur as outer rims surrounding the inherited cores, exhibit clear oscillatory zoning, as is the case of magmatic zircons. Type II zircons also often occur as outer rims surrounding the inherited cores, sometimes constituting the entire grain. They are characterized by mottled or spongy internal textures with abundant mineral inclusions, such as uraninite, thorite, and xenotime. The distinctive porous and murky textures suggest that the Type II zircons were formed under the influence of hydrothermal activity. Significant lanthanide tetrad effect has been observed in the Type II zircons, further supporting that they crystallized from a residual aqueous-like fluid. The occurrence of a large number of hydrothermal zircons in the granites indicates that the magma system has undergone a high degree of differentiation with hydrothermal fluid exsolution. The Type II zircons show significantly higher HfO_2 (1.90–5.29 wt.%), LREE (72.4–1560 ppm) and Ta (5.45–265) contents and lower Zr/Hf (10.1–26.6), Nb/Ta (0.06–1.83) ratios than the Type-I zircons (1.37–1.79 wt.% for HfO_2, 42–463 ppm for LREE, 0.31–45.1 ppm for Ta, 30.5–41.0 for Zr/Hf, 0.31–4.18 for Nb/Ta), documenting the changes in melt structure and chemical composition during the magmatic-hydrothermal evolution. Using the zircon REE oxy-barometers, the calculated oxygen fugacities range from -6.8 to -1.0 for the Type I zircons and range from -6.1 to -0.2 for the Type II zircons. The results suggest a reduced fugacity for the leucogranite magmatic system.

Role of crust-mantle derived aqueous fluid in Magmatic-Hydrothermal crystallization of the ~2.5 Ga hydrous Bundelkhand Granitoid (India)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Magmatic and hydrothermal realms (magmatic fluids) are increasingly recognized as a large integrated system and key to deciphering the crystallization history of transcrustal granitoid. Pulsed mantle-derived magma (mafic recharges) emplacement below or within the continental crust is considered important to the origin and evolution of large granitoid by providing heat and mass [1]. However, the role of exsolve aqueous fluid from mantle-derived hydrous basalts in the evolution of transcrustal granitoid is less studied. Such exsolve aqueous fluid of deeper origin intruding into granitoid mush likely influences the crystallization history and causes microstructural adjustments. Here we highlight solute-rich aqueous fluid (mantle-derived) exsolved from the mantle-derived mafic magma of basaltic compositions, the latter occurs as mafic dyke swarms intrusive into the ~2.5 Ga Bundelkhand granitoid in the Bundelkhand Craton (India), to have caused 'recrystallization' forming extensive subgrains along boundaries of the early crystallized quartz and feldspars, through dissolution-reprecipitation in the latter stage of crystallization of granitoid. We utilize the TitaniQ, K-feldspar- and two-feldspar thermometers and zircon dissolution features. Our results show that quartz and feldspar started to crystallize at typical agmatic temperatures at ~900°C (hypersolidus), and progressed with more than one thermal fluctuation (mafic recharges) to very low-temperature conditions (<600°C for subgrains), a significantly lower temperature than the generally inferred granitoid solidus (680°-700°C). Subgrains developed around the early formed quartz are characterized by lower Ti/Al (0.02-0.53) compared to the early developed central part Ti/Al (1.9-12). Hydrous zircon also have higher concentrations of Al (53-2207 ppm). Further, Rhyolite-MELTS results suggest that quartz and feldspar may have precipitated from the high temperature (950°C) Fe-Mg-Na-K-rich aqueous fluid of crust-mantle origin at <650°C around >5kb (>15 km). We suggest that precipitation from a solute-rich mafic aqueous fluid of crust-mantle derivation is a late, but significant process for low-temperature crystallization of Bundelkhand granitoid leading to the transition from magmatic to hydrothermal conditions. This work has implications for understanding the role of deep fluid in mediating the lower temperature crystallization of granitoid, thus influencing models of crustal growth and geochemical differentiation.

[1] Sensarma et al. (2021). Precambrian Research, 352. doi.org/10.1016/j.precamres.2020.105951

Geochemical approach for investigating the composition and origin of lithium-bearing pegmatite melts using fluid and mineral inclusions in pegmatites from the Namaqua Belt, south Africa

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Understanding the composition and origin of the melt responsible for lithium-bearing pegmatites is crucial for developing accurate geological models and assessing their economic potential (Benson et al., 2017; Černý et al., 2012; Linnen et al., 2012). This study proposes an integrated geochemical approach that combines fluid, mineral inclusions, trace elements, and isotopic analyses within the garnet, tourmaline, and quartz host to gain insights into the genesis of these pegmatite melts. Even though data collection and analysis are still ongoing, this

abstract outline the research methodology and anticipated outcomes.

This study focuses on the detailed investigation of fluid and mineral inclusions within garnet, tourmaline, and quartz using state-of-the-art analytical techniques. These inclusions provide critical information about the composition, temperature, pressure, and evolution of the pegmatite-forming fluids. Additionally, this study aims to analyse trace elements and isotopes in the host minerals to track the source of the melt and understand the processes involved in its formation. The study involves the collection of representative samples from lithium-bearing pegmatite from Namaqua Belt in south Africa, and Uis mine in Namibia. These samples will undergo detailed petrographic analysis, followed by the detailed examination of fluid inclusions and mineral inclusions. Trace element concentrations of fluid and mineral inclusions, and garnet, tourmaline, and quartz host as well as isotopic compositions of the host mineral will be analysed using advanced laboratory techniques.

Although no data are available at present, I anticipate that the results will shed light on the composition and origin of the melt responsible for the formation of lithium-bearing pegmatites. This study will contribute to the existing body of knowledge on the genesis of pegmatite melts, potentially enabling more accurate exploration and exploitation of lithium resources. Furthermore, the integrated approach presented here can serve as a model for future investigations into other types of pegmatites or similar geological systems.

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Černý, P., London, D., Novák, M., 2012. Granitic pegmatites as reflections of their sources. Elements, 8 (4), 289−294.

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Origin of Li-enriched pegmatites from fluid-present crustal anatexis

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Oral, Friday 15th September, 11:30 - 11:45

The formation of anatectic pegmatites, particularly those enriched in lithium, is a greatly debated topic that saw an explosion of interest in the last five years, warranting renewed attention on the subject. While there is consensus that simple (i.e. non mineralized) pegmatites may be directly connected to migmatites, the origin of their Li-bearing counterparts is viewed by most literature as being connected to their rarely outcropping parent granites. Felsic anatectic pegmatites range from granitic to trondhjemitic in composition and derive (either directly or indirectly) from the partial melting of pelitic metasediments through processes that are still largely unconstrained. In order to define the origin of anatectic pegmatites we studied a pegmatitic field confined to the thermal aureole of the Adamello pluton (Italy) composed of simple and Li-bearing pegmatites. We constrained the potential P-T conditions for migmatites partial melting in the area and then modelled the system's chemical evolution using open system phase equilibria modelling techniques coupled with trace elements partitioning. Our results suggest that fluid presence during partial melting of the area metapelites is fundamental in creating pegmatitic magmas that compositionally match the observed pegmatites. During fluid-present melting the increased stability of biotite increases the consumption of K-feldspar, mainly formed from white mica subsolidus dehydration, and quartz. This ensures the predominant role of muscovite as the aluminium-bearing mineral phase in all the pegmatites and the extremely low rate of biotite fractionation during crystallization. Since biotite is the main lithium carrier in these systems, biotite-poor assemblages allow lithium to be concentrated in the terminal stages of fractionation. K-feldspar is the main fractionating mineral in the initial crystallization stages, causing the melt to rapidly evolve towards Na2O-rich trondhjemitic compositions, ultimately forming albite-bearing evolved pegmatites and leaving behind Kfs-rich pegmatites, which can be observed in many migmatitic terranes. Trace element modelling shows that the P-T-H2O conditions responsible for magma generation determine lithium liberation from the metapelitic source even though biotite does not dominate the melting reactions. Rather, the extractable granitic magmas modelled show a clear peak in Li concentration at 680-700°C (ca. 20 vol.% melt fraction), up to ca. 180-230 ppm Li, in those cases in which peritectic cordierite, featuring high DLi/melt, is not produced. Thus, lithium liberation at low pressure has a maximum in correspondence to the P-T range responsible for the maximum extraction of fluid present granitic magmas, suggesting that Li-bearing anatectic pegmatites most likely originate from migmatites undergoing fluid-present melting.

Widening of Ductile Shear Zones in Isotropic Mediums: A Study on fluid-rock Interaction in the ~2.6 Ga Bundelkhand Granitoids of North-Central Peninsular India

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Ductile Shear zones (DSZs) are sheet-like planar to curviplanar zones where the localization of strain is notably higher relative to the surrounding region. A plethora of existing studies have discussed the mechanism of nucleation of DSZs in isotropic medium along pre-existing heterogeneities and the significant role of fluids has been argued. However, the exact role of fluids in widening of DSZs in isotropic mediums like

granitoids is not well established and thus, the mechanism of evolution of DSZs from a single plane to a broad zone remains elusive. The Archean granitoids of Bundelkhand Craton preserve excellent outcrops exhibiting DSZs with varied thicknesses (and lengths). In field as well as under microscope, the transition from apparently undeformed host granites to intensely deformed ultramylonites with/without the development of proto- and meso-mylonites is recorded. The change in mineralogy, texture, and petrofabric from the high-strain core to low-strain/ undeformed hosts were studied to understand the exact role of fluid in prompting and driving the progressive change across the DSZs as well as the spatial variation of fluid content and the amount of mass transfer in either way. A gradual increase in grain size reduction, material flow, and ductile behavior of minerals showing preferred orientation along the trend of the DSZ is observed towards the core. It is also observed that the dynamic recrystallization often leads to a fully recrystallized ultramylonitic core where the DSZs are broad and surrounded by partially recrystallized material with a gradual lower grade of deformation towards the host. Also, the presence of secondary phyllosilicate (epidote- and chlorite-rich) materials increases with an increase in strain localization and shows a concomitant deformation pattern. However, in the fully recrystallized cores of DSZs, quartz is the dominant mineral and the phyllosilicate minerals are virtually absent. So, from the field and microstructural investigations, we suggest that the widening after the nucleation of DSZs along pre-existing fractures progresses by gradually dissipating fluid-induced strain softening away from the core of DSZs. Also, it can be envisaged that the broader DSZs with strain-hardened ultramylonitic core and well-developed strain-softened transition zones thus, have a more protracted history of deformation as well as a greater supply of fluid throughout and vice-versa. Finally, we construe that the alternating strain softening and strain hardening zones formed under the influence of a fluid play a key role in the widening of DSZs in the Bundelkhand granitoids, Bundelkhand Craton, North-Central India.

U-Pb Zircon Study of the San Rafael Sn(-Cu) Deposit (Peru): Chronology of Magmatic-Hydrothermal Events and Sources of Magmas

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The expected soaring demand for tin imposes a need to better understand the factors controlling the distribution and size of its host granite-related magmatic-hydrothermal deposits. The Oligocene Sn(-Cu) San Rafael deposit of southern Peru (Eastern Cordillera) represents one of world’s largest crustal Sn anomalies (>1.5 Mt of contained Sn metal at an average grade of

3.7 %), where Sn occurs as cassiterite (SnO_2) in vein- and breccia-type ore bodies crosscutting the granitoid complex. The precursor magmatism to Sn mineralization comprises a suite of texturally distinct, feldspar-biotite-cordierite-bearing, reduced, peraluminous (S-type) granitoid intrusions, and subordinate lamprophyres. The magmatic events include: 1) a megacrystic granite, 2) a fine-grained granite, 3) a medium-grained granite, 4) a tourmaline-bearing leucogranite, 5) a porphyritic granite, and 6) two lamprophyre dyke generations. Conspicuous mingling/mixing textures between the granitic and mafic magmas (co-magmatic enclaves and dismembered dykes) imply a roughly coeval crystallization and emplacement of these intrusions.

In this contribution, we present results of a pioneering zircon petrochronological study of a benchmark Sn deposit related to S-type granites, with the aim of resolving a detailed chronology of magmatic-hydrothermal events and ultimately tracing the source(s) of the mineralizing magmas. Our high-precision U-Pb zircon ages track a protracted crystallization over ~800 kyr of granitic magmas at San Rafael, and support a synchronous emplacement of individual intrusions. The age-spectra and Hf isotope composition of xenocrystic cores overgrown by juvenile Oligocene zircon point to a source within the oxidized volcanics and/or redbeds of the Middle Triassic Mitu Group. This finding is challenged by the very contrasting oxidation states of the two rock units. In situ U-Pb geochronology of three textural varieties of the main-stage cassiterite (infill, bladed, and euhedral) described within a quartz-chlorite vein resolves three distinct generations on the scale of a single sample.

Investigating the distribution of mercury in the transcrustal Sesia Magmatic System (Western Alps, Italy)

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The mercury (Hg) budget outgassed in the atmosphere from active volcanoes is genetically related to the underlying magmatic plumbing system. However, the source, distribution, and transport of Hg in magmas remain uncertain. Differentiation and/or crustal assimilation would increase Hg in igneous and volcanic rocks, while low concentrations (< 10 ng/g) would reflect degassing. Nonetheless, these hypotheses remain ambiguous because i) they have been proposed using rocks that are not from the same magmatic system and ii) the results could be biased by unintentional under- or overestimation of Hg caused by analytical challenges related to its high volatility, extremely low concentration (< 10 ng/g) in crystalline rocks, sample heterogeneity at the microscale, and laboratory contamination.

To investigate the source, distribution, and transport of Hg in continental magmatic systems, we designed the STECALMY project to present novel data showcasing Hg distribution in crustal lithologies using the Sesia Magmatic System (SMS) (Western Alps, Italy) as a case study. The SMS is an archetype of a quasi-continuous transcrustal igneous section exposing the deep-level of mantle-derived lithologies and gabbros in the lower crust to granites and the remnants of a volcanic caldera in the upper crust. Rocks representing these different lithologies are firstly powdered through different approaches and then analyzed through a Direct Mercury Analyzer and a Cold-Vapour-Atomic-Fluorescence spectrometer. These are used to set up a novel approach for sample preparation and analytical procedure to optimize Hg analyses in crystalline rocks. The first outcomes show that Hg is highly variable within any rock (peridotite, gabbro, paragneiss, granite, rhyolite), varying from ~ 2 to ~ 300 ng/g. Since Hg might be preferentially partitioned into sulfides, these results could reflect the heterogeneous distribution of sulfides within each lithology and possibly among different aliquots of the same sample. We also show new data on total Hg concentration in the upper crustal Valle Mosso pluton (VMP) of the SMS representing the uppermost part of the plumbing system feeding the large (≥15-km-diameter) caldera-forming system of Sesia volcano erupting in the Lower Permian (ca. 289 to 280 Ma). Hg analyses on the lower, central, and upper VMP granites exhibiting cumulitic, storage, and degassing textures (i.e., miarolitic cavities), respectively, will provide more robust constraints on the source and mobility of Hg before and during magma degassing.

Zircon evidence for super-wet arc magmas

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Oral, Friday 15th September, 09:30 - 09:45

Magmas emplaced in subduction zones have elevated contents of dissolved water relative to those emplaced in other tectonic settings. Measurements of water in glassy melt inclusions suggest that most mafic arc magmas which feed arc volcanoes contain 2-6 wt.% H_2O. However, the melt inclusion record is thought to be biased towards low H_2O concentrations because they are trapped after significant degassing, and additionally those with melt H_2O >6 wt.% are nearly impossible to quench. A growing body of evidence points towards higher concentrations of water dissolved in intermediate to felsic arc magmas at mid- to deep-crustal levels (>8 wt.%). Whether such super-wet magmas are commonplace or eventually reach the upper crust remains unknown. One contradictory line of evidence for abundant super-wet arc magmas comes from zircon petrochronology. Many models indicate that the bulk of zircon in the arc rock record crystallizes at shallow crustal depths (~200 MPa). Because these zircons record 100 kyr-1 Myr timescales

this would indicate that arc magmas undergo protracted storage at depths where super-wet magmas cannot exist due to low water solubility (4-6 wt.%).

Here, we investigate the controls of initial magma water contents on zircon saturation in arc magmas using thermodynamic modelling and experimental constraints on zircon saturation. We show that increasingly wet magmas have markedly lower liquidus temperatures and thus different crystallization trends. As a result, super-wet magmas (8 wt.% H_2O, 400 MPa) saturate zircon early in the crystallisation sequence (30% crystallinity) and at low temperatures (780°C). Therefore, zircons crystallized from super-wet magmas will result in homogeneous and low Ti concentrations.

We test the idea of early, low temperature zircon saturation in super-wet arc magmas by presenting new zircon data from porphyry Cu districts. In all cases, porphyry Cu deposits show homogeneous and low zircon Ti. Host precursor batholiths show higher and diverse Ti concentrations which transition to lower concentrations over time. This suggests a transition from damp to super-wet arc magmatism coincident with porphyry Cu deposit emplacement. We expand our hypothesis to other study sites where super-wet magmas are speculated to exist – such as the Adamello Batholith and the Altiplano Puna Volcanic Centre. These zircons show similar temporal trends of decreasing zircon Ti with the youngest rocks having low and homogeneous zircon Ti. Our findings hint that super-wet magmas are common products of mature arc magmatism and have paramount importance in ore deposit formation and shaping modern continental crust.

Titanite-hornblende alteration recording volatile exsolution: an example from the Famatinian Arc, Argentina

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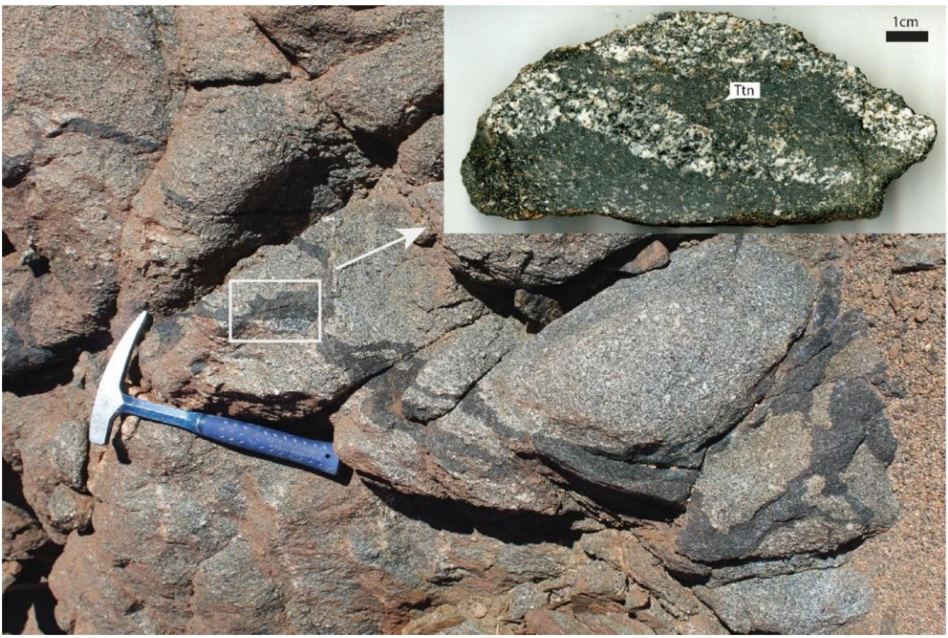
Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The concentration of magmatic volatile phases such as H2O in subduction zone magmas has been estimated in 5 wt. % or more. Despite being a minor component in magma, water especially when carrying F, Cl, S, etc., may play an important role in magmatic processes. For example, it is responsible for increasing magma buoyancy and decreasing its viscosity, it influences phase equilibria and even promotes magma hybridization and mush rejuvenation. Although the final fate of most of the volatile content is exsolution, it is possible to track the evidence of degassing of a pluton through the crystallization of new phases or modification of pre-existing phases, as has been demonstrated by the presence of “aqueducts” of hydrated mineral phases in granitic plutons. Here we present a summary of recent findings in the Archibarca hybrid intrusion of the

Ordovician Famatinian Arc in North-western Argentina, where there is an intense alteration of mafic and felsic magmas recorded by the presence of Hbl- and Ttn-rich alteration zones (±Bt ±Ep). The distribution and the structures formed by this assemblage indicate that the alteration is a product of degassing and transfer of volatiles between mafic and felsic members.

The Archibarca batholith is a mingled intrusion whose felsic member displays typical calc-alkaline features, but its mafic endmember has an alkaline affinity (4.4-5.4 wt. % K2O at 51-54 wt. % SiO2), and anomalous content of Ba (800-1100 ppm), P2O5 (0.6-0.7 wt. %) and TiO2 (1.8-1.9 wt. %). The contacts between felsic and mafic members are usually irregular and have flame-shaped dark rims (1-10 cm thickness) composed of Hbl+Ttn+Bt+Ep (Graphic 1). This assemblage is also found as patches in hybrid diorites in contact with granitic pegmatites, as mafic rims surrounding Qz-ocelli in hybrid diorites, and even in irregular dikes of metric scale that cut the hybrid rocks (Graphic 2). The observed titanite crystals record in their texture and trace element composition the breakdown of Bt and growth of Hbl, in turn, Hbl phenocrysts are replaced by an assemblage Act+Ep+Ttn.

The nature of these alteration zones rich in Hbl (±Act)+Ttn+Bt+Ep suggests H2O-rich and high oxidation conditions related to the exsolution of water-rich fluids in shallow magmatic environments, as supported by thermodynamic calculations done in GeoPS. These findings are part of several structures recording how fluids can modify the textural, mineralogical, and chemical nature of shallow-level plutons.



Understanding the controls on critical metal enrichment in granitic systems as part of the transition to renewable energy

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Critical metals such as Li, Nb, Ta, and Sn are needed for the renewable energy transition to net-zero. As a result, these metals are predicted to rise in demand, and it has become a top priority to identify future resources. In order to do this, it is important to understand processes driving their enrichment. It is well established that trace metals (e.g., Li, Nb, Ta, Be, Sn, and W) can be significantly enriched in peraluminous granites and that high concentrations of some metals exist in the circulating low enthalpy geothermal fluids associated with granitic batholiths, making them an important exploration target. However, the process controlling this geothermal enrichment remains poorly constrained. It is not well understood whether the trace metals are leached from the granites themselves, and if so, which minerals in the granites host such trace metals, or indeed whether the enrichment may also be derived from other sources (e.g., brines from a nearby sedimentary basin e.g., Sanjuan et al.2016). In this study, we focus on both the primary controls on enrichment during granite crystallisation, and

the mobilisation of critical metals into surrounding geothermal fluids. We present in situ trace element data to enable quantification of the primary enrichment of trace metals, as porosity is occluded during crystallisation in granites from Cornwall and Weardale, and aim to define the spatial distribution of trace metals within and between mineral phases. These data are relevant to understanding the extraction of highly evolved granitic melts from crustal mushes and will help inform planned leaching experiments to quantify how metals are extracted into circulating fluids. We discuss our results in the context of complementary published bulk geochemical datasets and outline our experimental plans to address the processes of enrichment of Li in low enthalpy geothermal waters. This kind of analysis is needed to help inform estimates of resource sustainability and may eventually be used, alongside other published datasets, to make models for the enrichment and mobilisation of critical metals in granites.

Sanjuan, B., Millot, R., Innocent, Ch., Dezayes, Ch., Scheiber, J., & Brach, M. (2016). Major geochemical characteristics of geothermal brines from the Upper Rhine Graben granitic basement with constraints on temperature and circulation. Chemical Geology, 428, 27–47.

Crustal path control during magmatic differentiation and ore mineralization in the Great Basin

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Oral, Friday 15th September, 09:15 - 09:30

Eocene magmatic intrusions in the Great Basin are associated with some of the largest precious and base metal mineral deposits globally. These intrusions were emplaced during the onset of slab rollback and the re-establishment of arc magmatism after flat-slab subduction. They show a characteristic East-West signature, where contemporaneous intrusion-related deposits in the East (Utah) and West (Nevada) are dominated by small and large Au/Cu ratios, respectively. Magma emplacement occurred in thick continental crust that was regionally zoned by the prior passive margin setting. Upper to middle crustal rocks in the west are primarily anoxic deep-sea and continental slope sediments compared to rocks that formed on the continental shelf and coast in the east.

Experimental studies have shown that in the presence of a fluid phase gold fractionates from copper under reducing magmatic conditions. Thus, substantial interaction with the different crustal sections may cause the diverging paths of intrusions across the Great Basin with reducing of magmas in Nevada driving relative gold enrichment.

Here we present results from a regional traverse of intrusions in Nevada and Utah stretching across over 400 km as well as findings from a detailed study of the Swales Mountain magmatic system, which lies about 25 km east of the Carlin gold-trend. In the regional study we trace magmatic redox conditions using three independent redox sensitive tracers: 1) an empirical model using zircon trace element compositions, 2) Ce-XANES in zircon to determine Ce speciation, and 3) S contents in apatite with low S content being interpreted as a signature for sulfide which partitions into apatite less than sulfate. All three datasets from our study are consistent with magmas becoming increasingly reduced with differentiation in Nevada, while Utah intrusions start out and stay oxidized. We complement this regional study with a detailed study of a composite intrusion at Swales Mountain where we measure S-speciation in apatite directly using S-XANES and in their textural context. S-speciation in Swales Mountain apatite varies from dominantly sulfate to significant sulfide contributions to the apatite S-budget. These signatures are correlated with specific mineral phases that host apatite, where augite hosts sulfate-dominated apatite, while oxides and feldspars have more sulfide-dominated apatite. We interpret these results as late-stage reduction of the magmas. Therefore, the regional and the detailed study support a model where the large-scale differences between Nevada and Utah in mineralization associated with Eocene intrusions are controlled by the crustal path that magmas take.

Unveiling the evolution of the Giant Quartz Reefs in the Bundelkhand Craton of North-Central India: A tectonic conundrum

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

The Bundelkhand Craton of North-Central India exhibits prominent ridge-like features in the form of Giant Quartz Reefs, indicating widespread silica-rich fluid activity within the craton, following ~NE-SW and ~NW-SE directions. However, the evolution of these reefs is still riddled with controversy related to its occurrence and age constraints, and unveiling it is crucial in understanding the tectonic evolution of the Bundelkhand Craton. Based on extensive field, detailed microscopic and mineralogical analysis, along with Anisotropy of Magnetic Susceptibility (AMS) investigation, we gained insights into the microscopic and magnetic fabric within the rocks. Additionally, satellite imagery aided our understanding of the reefs' large-scale brittle to ductile deformation signatures.

In the outcrops, these reefs exhibit color variations, ranging from milky white to grey, and shades of brown, green, and pink. Fractures parallel to the trend of the reef are often filled with secondary milky quartz veins, ranging from a few millimetres to several centimetres in thickness. Mesoscopic features like cataclastic texture, shear fabrics, to large-scale sigmoidal offset of reefs across its trend indicate the presence of brittle to ductile deformation regime in the region. Microscopic study shows the occurrence of various static and dynamic recrystallization features along with cataclastic texture and micro-fractures. Mineralogical study reveals that the main constituent of the reefs is quartz (~90%) along with a significant amount of feldspar and sericite, and thereby quartzolite nomenclature can be used following IUGS classification of plutonic igneous rocks.

AMS investigation shows that the bulk magnetic susceptibility (Km) of the reefs is very low ranging from -8 to 6 µSI units indicating their diamagnetic nature. However, a few samples showed higher Km values ranging from 8 to 15 µSI units owing to the intermixing of granites and reefs. The value of shape parameter (T) ranges from -0.307 to 0.469. This indicates the influence of both constrictional and flattening deformation regimes. The Km vs. Pj plot shows a scattered relationship indicating the deformational control in the formation of magnetic fabric.

Our studies reveal that these reefs may have exploited the most ubiquitously occurring fractures in the craton trending ~NE-SW and ~NW-SE and the angle between the mean trend of the reefs is ~60° signifying a conjugate relationship. It is also envisaged that a riedel shear kinematics was involved; governing the evolution of shear zones of the craton vis-à-vis influenced the emplacement and displacement of the giant quartz reefs.

Coupled OH-defects and trace element variations in quartz from an upper crustal, silicic magma reservoir

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Quartz is a major constituent of felsic igneous rock (e.g., granites, rhyolites) and can incorporate significant amounts of trace elements in its crystal lattice (Li^+, Al^{3+}, B^{3+}, Ti^{4+}, Ge^{4+}, etc.) through a variety of isovalent to Si^{4+} and coupled substitutions (i.e., $Si^{4+} \leftrightarrow Al^{3+} + H^+$). In this latter case, participation of hydrogen in the substitution mechanism can lead to the formation of hydroxyl dipoles (OH) with the oxygen anions from the quartz lattice. In magmatic quartz, incorporation of trace elements and OH-defects formation is controlled by melt physicochemical parameters (temperature, pressure, composition, and water fugacity). Their relative abundance has been proposed as a sediment provenance tool in detrital studies, however literature still lacks detailed studies on OH-defects distribution at the scale of a magmatic reservoir.

Here we present the results of a systematic study on OH-defects and trace elements abundance in quartz from the silicic intrusive and eruptive products of a well-studied Permian, transcrustal magmatic system exposed in the SW Alps (Sesia Magmatic System). Quartz grains were sampled across a floor-to-roof section of a granitoid intrusion (Valle Mosso pluton) and within two rhyolitic ignimbrite units produced during distinct, caldera-forming eruptions. A total of 120 quartz grains have been analysed using Fourier Transform InfraRed (FTIR) spectroscopy to investigate hydrous defects both qualitatively (defect species) and quantitatively (defect water content). LA-ICP-MS was then applied to the same crystals in order to determine trace element content.

Previously collected textural and bulk geochemical data indicate that the Valle Mosso pluton is the crystallized remnant of a single, zoned magma body, with a crystal-rich base and a thick (~3 km), high-silica cap (~77 wt% SiO_2). In this context, we observe coupled, systematic variations in defect water content and trace elements distribution: (1) intrusive quartz shows gradual increase of total defect water content (1 to 25 µg/g H_2O) with “stratigraphic” height across the intrusion, in parallel with increasing degree of differentiation; (2) volcanic quartz displays water contents (2 to 14 µg/g H_2O) comparable to that of the Valle Mosso pluton; (3) in both intrusive and eruptive units, Al-specific defects dominate over Li-specific defects and the total defect water content is anti-correlated with the amount of Li incorporated in the quartz lattice. A notable exception is provided by quartz grains from the cumulate, basal unit of the intrusion, which show a stark decoupling of Li and OH defects (i.e., low Li and OH defects content).

Pegmatites as recorders of the magmatic-hydrothermal transition in silicic magma reservoirs

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Junior Keynote, Friday 15th September, 09:45 - 10:15

Chemical differentiation through magmatic processes plays a key role for the highly evolved, broadly granitic composition of the upper continental crust. As an extreme endmember of differentiation, pegmatites represent an extremely coarse-grained textural variety of granitic rocks, and are characterized by abrupt variations in grain size and an abundance of crystals with skeletal and graphic growth habits. Despite their significance as mineral resources and decades of research, various open questions and controversies surround the genesis of pegmatites, including:

1. The nature of the pegmatitic liquid: The exact nature of the medium that forms pegmatites remains a subject of debate, with propositions ranging from relatively normal rhyolite melt, to flux-enriched hydrous silicate melt and miscible hydrosilicate liquids. Understanding the origin, composition, and formation conditions of these exotic fluids and melts is essential for comprehending the extreme grain size variation and mineral variety observed in pegmatites.

2. Timing and mechanism of pegmatite extraction: While pegmatites are generally considered as the products of late-stage crystallization of volatile-rich liquids extracted from granitic source bodies, the process of extraction and emplacement within or around granite bodies is not fully understood. In particular, open questions remain regarding the specific extraction triggers and transport mechanisms.
3. Rare element enrichment: Many pegmatites are enriched in fluid-mobile, rare and/or critical elements, such as REE, Li, Be, Cs, Nb, and Ta, resulting in exotic mineral assemblages including topaz, fluorite, beryl, tourmaline, and Li- and REE-phases. These enrichments make pegmatites interesting targets for economic ore extraction. However, the processes that lead to the unusual accumulation of these elements are not fully understood, and have been linked to either enrichment during high-degree fractional crystallization of associated granitic source bodies or low-degree partial melting of crustal sources.
4. Relationship between pegmatites and granites: While many pegmatites have a close spatial and temporal relationship with their host granites, the links between them are not always apparent, and pegmatites can be located kilometers away from the closest pluton. Pegmatites often exhibit similar trace element and isotopic compositions to pelites and other peraluminous crustal lithologies, suggesting that some pegmatites could form directly from low-degree

partial melting of crustal metamorphic rocks without granitic precursors.

This presentation aims to provide an overview of these open questions and highlight the challenges that remain in understanding these fascinating systems. By linking these questions to our ongoing research on silicic magmatic systems, we will approach them from multiple angles, including detailed field observations, geochemical analyses, experimental studies, and thermomechanical modeling approaches from three case studies:

1. Linking pegmatites and granites in the central Damara orogen, Namibia: This area hosting several extensive pegmatite belts is an example for a headless pegmatite locality, lacking immediate association between pegmatites and host granites in the field. Instead, pelite-hosted pegmatites mined for Li and Sn have been linked to low-degree partial melting of crustal rocks, suggesting an unrelated origin to widespread granitic activity in the area. We present whole-rock and mineral data from several pegmatites and surrounding granites in the Karibib pegmatite belt and couple them to U/Pb ages of multiple accessory minerals (apatite, monazite, columbite-tantalite, zircon and cassiterite), to investigate possible links between them.
2. Thermal evolution in pegmatite-granite systems: Coupled pegmatite-granite systems provide a unique opportunity to study the magmatic-hydrothermal transition within silicic magmatic systems. The A-type

Pikes Peak granite-pegmatite system in Colorado (USA) serves as an example for investigating compositional changes during the system's transition across the theoretical water-saturated solidus. The thermal evolution of the system is documented using several geothermometers such as Ti-in-quartz, 2-feldspars, and fluid inclusions, recording temperatures from >850 °C for high-temperature magmatic minerals in the granite to <400 °C for the pegmatite core.

3. Combining element diffusion to thermomechanical fluid transport models: Advancements in three-phase numerical models highlight the importance of crystal volume fractions in controlling the mode and rate of fluid transport in silicic systems. Integrating thermomechanical models with observations from pegmatites reveals that highly-enriched pegmatite-like compositions require high crystallinities (>70–75 vol% crystals) in the magma reservoir, at which fluid is effectively trapped in the crystal network. Fluid-mobile trace elements can become enriched beyond contents expected from closed-system equilibrium crystallization by fluid transport from more-evolved mush domains, as documented through a combination of fluid-transport models and experimentally-derived diffusivities. These observations indicate that pegmatites are likely generated from pressurized fluids with high concentrations of dissolved silicate melt and fluid-mobile elements.

Together, these case studies highlight the coexistence of igneous and hydrothermal environments in silicic magmatic reservoirs and contribute to the understanding of pegmatite genesis. Exploring the factors that control the spatial, temporal, and compositional associations between pegmatites and their source granites, including the role of “flux elements” and water in the parental liquid, contribute to a more comprehensive understanding of the multifaceted nature of silicic magmatic systems within the Earth’s crust.

Degassing structures and mush hybridization in shallow plutons

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Degassing of granitic magmas in the shallow crust is a significant process controlling the nature of volcanism and mineralization. Quoting Barnes et al. (2020, Geosciences) “Effects of the prodigious amount of water carried by arc magmas on the plutonic rocks themselves have generally been underappreciated”. This is possibly because the evidence may be subtle. Here, we use magmatic structures found in rocks of the Early Paleozoic Famatinian Arc, Puna Plateau, Argentina, to speculate on what these structures might be. These magmatic rocks were emplaced in the upper crust (~2 kb) and collectively, their magmatic structures suggest that the volatile-rich liquids enhanced hybridization by increasing the reach of evolved, granite-derived liquids into crystallizing mafic mushes by combining increased element diffusion and mass advection.

In levels of increasing subtlety, the magmatic structures related to degassing in heterogeneous diorite bodies emplaced within granitic magma include: a) ovoidal centimetric micropegmatite swarms (Graphic 1), b) decametric pegmatite blobs with hornblende-epidote-titanite, c) a rock dominated by quartz ocelli, d) complex network of narrow seams of evolved granitic/pegmatitic material with titanite invading enclaves (Graphic 2), e) felsic clouds in diorite matrix, f) biotite breakdown to hornblende or titanite, and hornblende and titanite alteration around granite intrusions, and g) "dyke-like" elongated patches of granite xenocrysts isolated inside diorite.

We envisage a process whereby local decompression of a H_2O-saturated granitic magma triggers the boiling off of volatile-rich liquids, creating a pressure gradient directing these liquids towards low pressure sites, such as mafic mushes. The low density and low viscosity of the pressurized volatile-rich liquid create ideal conditions for magma hybridization. The liquids can either be trapped underneath an impermeable mafic mush or invade the mushes, sometimes energetically, carrying a solid cargo. The hybrids generated are a complex result of the transfer of early-formed granite xenocrysts, and of evolved liquids pervading and reacting with the matrix. The process is powered by diffusion and advection, evidenced by hornblende alteration and hornblende-epidote-titanite pegmatites.

Trends in halogen content with other geochemical indicators from a global survey of granitoids

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

This study presents a global survey of the whole-rock fluorine content ([F]) of high-silica (>65%) granitoids from around the world. Due to complications in measuring fluorine, few publications about the geochemistry of granitoids report bulk concentrations of fluorine and other halogens. After surveying the literature, we compiled ~120 sources across 52 countries and territories that report whole-rock [F] of granitoids, which results in data for more than 1400 localities and 300 unique plutons. This data is currently being analysed for trends in whole-rock major and trace element, as well as mineralogy and inferred tectonic setting, with [F]. As expected, [F] content in granitoids behaves most similarly to other fluid-mobile, incompatible elements like Rb, and generally has a slightly positive correlation with the content of some high field-strength elements, including Y, and a slight negative one with others, like La. [F] also appears to follow a curve with [Ca] that may be explained by the saturation of fluorite, but does not follow a similar trend with [P] as would be expected for apatite. Preliminary analysis has also involved the terminology defined by Frost et al.

(2011), in which the plutons are grouped by Fe-number, MALI, and ASI, and grouping by granitic type, as first introduced by Chappel and White (1974). Additional observations include the highest [F] in A-type granites, as well as in peraluminous granites of all types. Of the authors that include mineralogical observations, most report fluorinated accessory phases like Ap, Flr, Trm, and Tpz, as well as potential hosts like zinnwaldite, a F-bearing solid solution mica, and amphiboles. Future work with this data set will continue to search for, examine, and describe trends in whole-rock composition and [F], as well as further attempts to locate works about granitoids in geologically diverse regions currently missing from the compilation.

Progression of viscous to brittle degassing pathways in the Sandfell laccolith, Eastern Iceland

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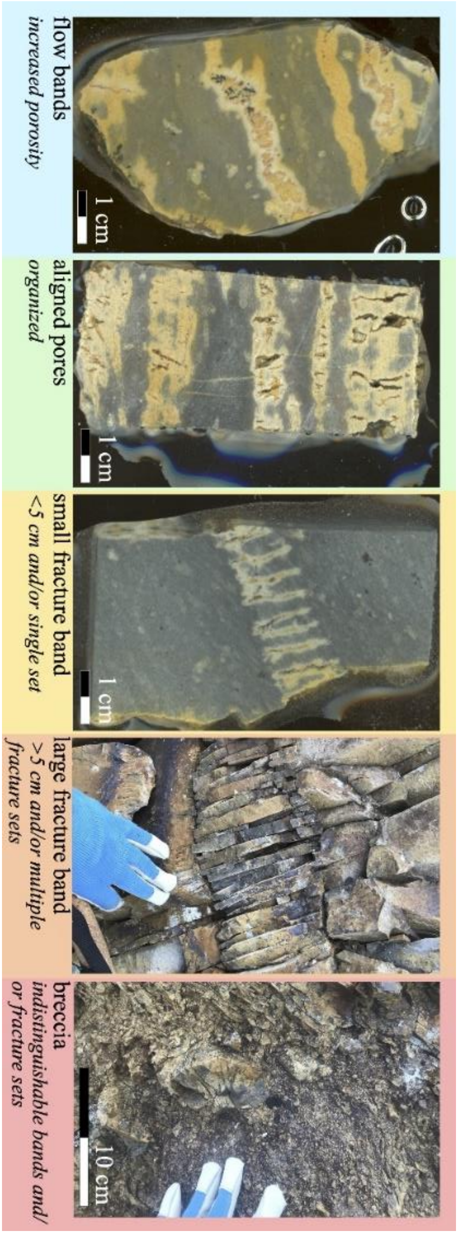
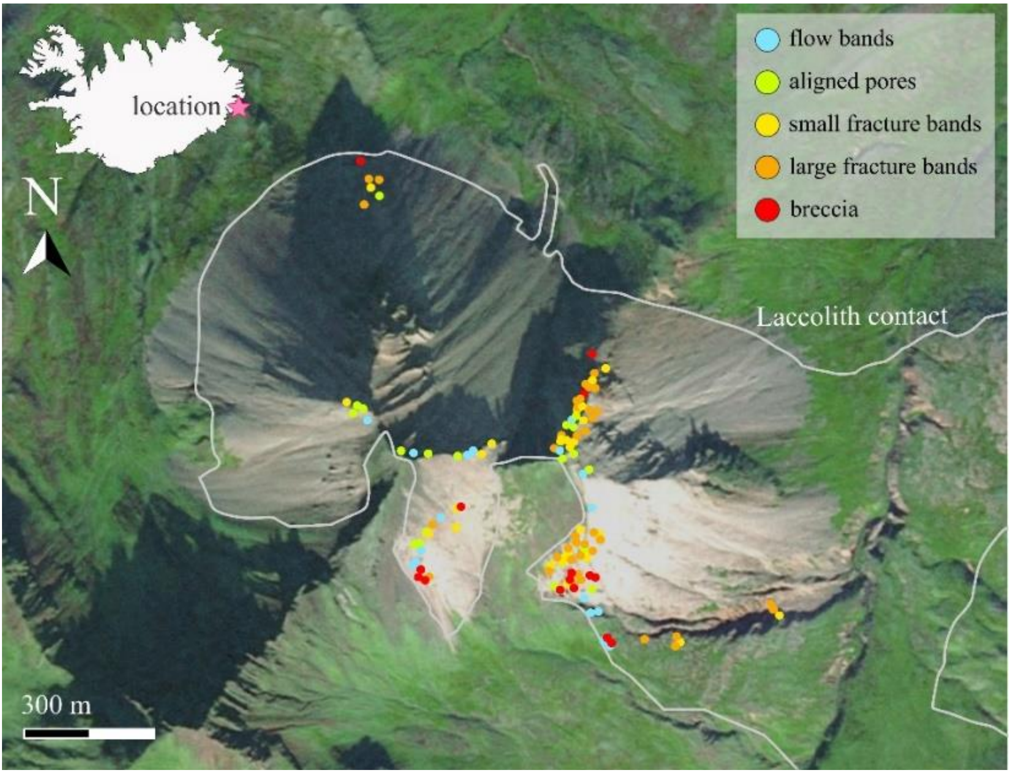
Oral, Friday 15th September, 11:45 - 12:00

Degassing mechanisms of silicic magma affect whether eruptions are explosive or effusive. For silicic intrusions, magma degassing is usually assumed to occur through bubble formation. However, we report on geological evidence of silicic magma degassing in the viscous and brittle regime under the influence of emplacement-related strain. Our case study is the Neogene Sandfell laccolith in Eastern Iceland. Because of its microcrystalline groundmass and <5 vol% phenocrysts, flow indicators, degassing pathways and subsequent deformation features are strongly pronounced. We systematically mapped these features throughout the laccolith and observed a spectrum of deformation, starting with (1) porous flow bands and (2) joined pores aligned in linear channels, (3) parallel tensile fractures confined to the flow bands (termed ‘fracture bands’), (4) wider fracture bands and the braiding of fracture bands until finally, (5) total brecciation. Each stage is preserved to some degree throughout the laccolith, and we have taken measurements and mapped the deformation regimes and plotted them in a 3D model. Textural analyses of stages (1) – (4) show that they are taking place in viscous magma with an already substantially microcrystalline groundmass. Stage (5) likely occurred in the brittle regime when crystallization was near completion. Our conceptual timeline is as follows: degassing initiated in the flow bands (1), and the growing pores eventually coalesced and organized into parallel planes within the flow band (2). As pore-fluid pressure increased and emplacement-related stresses were continuously applied, the tensile strength of the magma was exceeded, resulting in mode 1 fractures propagating into the otherwise viscous magma away from the flow band (3). As the cooling front moved inward, emplacement stresses would have reactivated the weaker flow/fracture bands when viscous deformation was unfavorable. Multiple fracture sets overprint each other in the same band when stress conditions had changed direction, and fracture bands joined together through propagation of individual fractures across layers of coherent magma (4). Sustained deformation in localized areas resulted in indistinguishable breccia (5).



The described deformation features document the development of a dynamic degassing mechanism of silicic magma, beyond vesicle formation and including emplacement-related strain. As a result of the interpreted procedure, fluid flow is efficiently channelized within and through the magma body, increasing permeability and acting as an open valve through which the magma can depressurize and avoid an explosive eruption.



The efficiency of copper extraction from magma bodies: Implications for mineralization potential and fluid-silicate melt partitioning of copper

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Poster, Thursday 14th September, 17:00 - 19:00 and Friday 15th September, 14:00 - 15:15

Multiple factors may downgrade the mineralization potential of an intermediate-felsic intrusion, such as the commonly invoked inefficient fluid exsolution and lack of ore-forming species (metals and their ligands) in magmas. However, other factors may affect mineralization potential of a magma body but have poorly understood roles in the formation of magmatic-hydrothermal ore deposits. Here, we present a comparison between two Cu mineralizing plutons and a Cu-poor, Fe mineralizing pluton in the Edong district. Efficient fluid exsolution and extraction occurred during the solidification of all three plutons, as evidenced by extensive skarn alteration around them. The results show that the oxidation state of the three plutons is similar (within a range of ~ΔNNO +0.9 to ΔNNO +2.5). A systematic comparison of the Cu contents of a certain suite of minerals of the three plutons show that the Cu concentrations of all minerals in the Cu mineralizing plutons are lower than those of the Cu-poor Fe mineralizing pluton. This indicates that the Cu

mineralizing plutons underwent more efficient copper extraction. Thus, igneous crystals with anomalously low Cu contents may potentially be used as a tool to identify Cu mineralizing magmatic units in a deposit with multiphase intrusions. We suggest that the inefficient copper extraction from plutons may be ascribed to the lack of reduced S species during fluid exsolution or different evolution paths of Cu and Cl during magma crystallization.

Special session “Past and future”

100 years of granite petrology

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Oral, Friday 15th September, 15:45 - 16:15

It is just over 100 years since Norman Bowen first published on the origin of granite (Bowen, 1922), considering granite as the end-product of Bowen Reaction Series; petrology’s residua system, with fractional crystallisation (FC) as the principal differentiation mechanism. Bowen staunchly advocated his FC position throughout his career, particularly at the famous GSA “Granite Controversy” meeting in 1947, where many, including H.H. Read, thought granite were the products of crustal fusion, wither by partial melting (PM) or granitization. A decade later, Bowen (with Tuttle) established the quantitative foundation for the origin of granite from experimental petrology. These benchmark experiments showed that granite could be produced by PM of crust, but Bowen’s enduring legacy for the granite community seems to be his assertion that most granites were produced by FC from the mantle. However, the Tuttle and Bowen (1958) experiments never established this connection, and Bowens earlier experiments on “petrology’s residua system” applied to alkaline rocks, not calc-alkaline (arc) rocks.

Granite petrology faded into the background during the 1960s as the new global plate tectonic theory exploded through the geosciences. Rejuvenation of the discipline came with the simple classification of granites into S- and I-types, derived from meta-sedimentary and meta-igneous sources, respectively (Chappell & White (1974). The concept was presented in September 1973, 50 years ago this month.

White & Chappell (1977) used the common linear variation observed in granite suites to develop the restite model, suggesting that chemical variation in granite suites was caused by progressive segregation of residual material from a relatively cool felsic melt. However, subsequent development of wholerock (WR) Sm-Nd, when combined with WR Rb-Sr isotopes, showed covariation consistent with mixing, suggesting that arc-related (Cordilleran) granites were crust-mantle hybrids (eg., De Paolo, 1981), leading to the concept of assimilation-fractionation crystallization (AFC). Subsequent isotopic studies consistently demonstrate such mixing arrays, but arguments still rage today whether the juvenile component is crust or mantle, hence how much A versus FC. However, a combination of FC, PM and hybridisation is necessary to obtain the full spectrum of arc-related rocks (eg., Annen et al., 2006).

A third, relatively anhydrous, and somewhat alkaline group, the A-type granites, have been recognised, which Collins et al. (1982) ascribed to a high-*T*, residual source, from which granitic melt had previously been extracted. A-type petrogenesis has involved considerable controversy ever since, again focussed on the relative roles of mantle and crustal source components, hence PM versus FC, but a fundamental difference with other granitoids is high magmatic temperatures, hence high Zr in the melt, and high zircon saturation temperatures compared to any other granitoid type. We are now full circle with the latest MI studies indicating a residual origin for A-types, formed under UHT metamorphic conditions (Carvalho et al., 2022).

During the 1980s granite petrologists began to incorporate the global tectonic paradigm via tectonic discrimination diagrams, utilising the ever-expanding WR datasets (eg., Pearce et al., 1984; Maniar & Piccoli, 1987; Barbarin 1999). More recent studies of Cordilleran systems have focused on the long-term geodynamic interplay between magmatic fluxes, crustal thickening events, arc-root foundering and isotopic evolution (eg., Schwartz et al. 2016; Chapman & Ducea, 2019). Others have emphasised “whole-of-crust” petrological processes, including the stochastic instability of magma chambers and their relation to volcanic eruptions (eg., Glazner et al., 2015; Cashman et al., 2017).

Twenty-first century petrology also has focussed on mineralogical information derived from microanalytical techniques. Such studies underscore the complex thermal and chemical evolution of magmatic systems. It has become clear that plutonic systems can exist at million-year scale, whereas many volcanic systems appear to flux at millennial scale or shorter, based on U-series isotope disequilibria (eg., Turner et al., 2003). Most recently, geospeedometry studies suggest that hybridisation can occur at annual-scale or less, implying that compositional diversity in granitic magmas may be rapid (Conroy et al 2020; Zhang et al., 2023). Such contrasting timescales invite a new paradigm for granite petrogenesis, where measuring and evaluating rates of magmatic process will help distinguish between the relative roles of FC vs PM and hybridisation as granite batholiths form.

More recently, phase equilibria modelling using Thermocalc or Perplex have provided considerable insights into petrological processes, particularly crustal melting. Notably, they demonstrate the potential of water to generate voluminous silicic melts at low-*T* (<800^{o}C) (e.g., Collins et al., 2020). Combined with the growing realisation that mafic arc magmas can be superhydrous, carrying 8-20 wt% H_2O (Urann et al., 2022), fluxed melting models involving aqueous fluid exsolution during step-wise magma ascent potentially provide an explanation for why granites are so abundant in the crust, particularly where mafic rocks are absent or rare (eg., Variscan orogen; Couzinié et al., 2021).

Nonetheless, there is still much to study and understand, after more than 100 years of granite petrology. These are some of the conundrums of arc petrology that I think still need addressing:

1. Why are the peak compositions of arc volcanic and plutonic rocks so different?

2. Why are the thermal and seismic profiles of plutonic and volcanic arcs so different?
3. Why are magmatic enclaves in granites/volcanics generally so different?
4. Why is the mineralogy of intermediate volcanic and plutonic rocks so different, especially the K-feldspar megacrystic granites?
5. Why don't petrological crystallisation experiments readily reproduce the calc-alkaline trend of magmatic arcs (eg., Marxer et al., 2022)?
6. Why do so many granite-related geothermometers yield low T (<800C), including zircon and plagioclase-hornblende, even though zircons and plagioclase show complex, protracted crystallisation histories?
7. If the magmatic flux is hottest and highest in Cordilleran arc systems, why is there a perception of less crustal melting?
8. What are the implications of rapid hybridisation for understanding compositional diversity in granitoids?

Granites & rhyolites, and volcanic-plutonic connections (vs. disconnection?)

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Oral, Friday 15th September, 16:15 - 17:45

Granite[1] and rhyolite[1] have been known to have similar mineralogy and geochemistry since the 19th century, but their relationship(s) have remained contentious to the present day. Early on, convincing examples were described that appeared to demonstrate connection between shallow granitic intrusions and erupted rhyolitic equivalents (e.g., Judd, 1874). Relationships between granite and rhyolite were obscured through the mid 20th century while the Granite Controversy raged (e.g., Gilluly, 1948, Read, 1957): were many or most granites not magmatic? – if they weren’t, questions of rhyolite connection were largely moot. The debate was for practical purposes settled: granites are magmatic! – when Tuttle and Bowen’s (1958) experimental work revealed that the compositions of quartz- + feldspar-saturated melts were essentially identical to those of highly felsic granites. Furthermore, the rhyolite compositional maximum also matched the granite maximum, indicating that intrusive and extrusive felsic magmas both responded to quartz + feldspar + melt equilibria. But this did not settle issues of how closely

[1] The terms “granite” and “rhyolite” are here *sensu lato*: felsic, or silicic, rocks (~65-80 wt% SiO_2) dominated by feldspars and quartz, distinguished by phaneritic vs. aphanitic texture.

granitic and rhyolitic magmas were related and how they were generated (anatexis vs. fractional crystallization).

As the 20th century progressed, broad field-based perspectives were interpreted to suggest that shallower granites had direct connections to erupted rhyolites (e.g., Buddington, 1959 [plausible]; Hamilton & Myers, 1967 [emphatic!]), but that deep crustal granites might have only tenuous connections to shallower granites and perhaps none to erupted rhyolites (Buddington, 1959). Emboldened by Chappell's and White's pioneering work (e.g., 1974), granitologists began to emphasize diversity beyond the obvious concentration of the more felsic examples as "petrogeny's residua" and tease out distinctions in sources. Similar source fingerprints emerged in case studies of rhyolites (e.g., Clemens and Wall, 1984), but hints of volcanic vs. plutonic petrogenetic distinctions emerged (less sedimentary component in rhyolites?).

Toward the end of the 20th and into the 21st century, studies attempting to relate upper crustal granites, "magma chamber"[2] processes, eruptions, and rhyolites have become common. Direct links between exposed plutons and volcanics remain challenging to verify for a host of reasons (e.g., Bachmann et al., 2007; Wallrich et al., 2023), but plausible proposed examples are now numerous (e.g., Seaman et al., 1995; Honn & Smith, 2008; Rioux et al., 2016; Tang et al., 2017; Tavazzani et al., 2020; Hartung et al., 2021; Chen et al.,

[2] "Magma chamber" (a subsurface, relatively large body of melt-rich material) and "mush" (crystal-rich, sluggishly mobile or immobile magma) are fraught terms used loosely here.

2021). Process-oriented studies aim, for example, at “mush”[2] behavior (melt segregation, reactivation and remobilization, potentially leading to eruption: e.g., Hildreth, 2004; Bachmann & Bergantz, 2004; Sparks et al., 2019; Weinberg et al., 2021; Schaen et al., 2021), and identifying fingerprints of eruption processes (e.g., Hawkins & Wiebe, 2004; Wiebe et al., 2021). There is considerable continuing interest in, and debate about, the impact of upper crustal mush-related fractionation to form cumulates and highly evolved extracted melts on compositional diversity of granites and rhyolites, and on the proportions of retained (plutonic) and expelled (erupted) magma, especially in giant eruptions.

Reticence regarding relationships between deeper crustal granites and erupted products (rhyolites) persisted until very recently. Glazner et al. have suggested (e.g., 2018) that erupted felsic magmas can be extracted as partial melts from deep crust and erupted with minimal upper crustal storage and modification. More broadly, a general view that massive, long-lived, integrated columns of magma storage, modification, transport, and eruption transect the entire crust has gained widespread support (e.g., Annen et al., 2006; Bachmann & Huber, 2016; Cashman et al., 2017). Such “transcrustal magmatic systems” are thought to be instigated in the mantle, but to be responsible for abundant granite and rhyolite through fractional crystallization, incorporation of crustal material, or both.

Multiple questions clearly remain as we progress onward from the 10th Hutton (Baveno, Italy, 2023) through the 21st century, some of them new and others that remain from the past in more focused form. My personal favorites are:

1. Are granites and rhyolites products of the same or distinct processes?
2. Do granitic plutons lose magma at some point by eruption? (essentially all plutons?; most plutons?; very few plutons?). If some but not all: Is eruption inevitable given certain initial conditions and precluded by other initial conditions, or is it stochastic – random and unpredictable?
3. Are erupted products the same as or distinguishable from those that are retained as plutonic rocks? (leading to the question: are very few, or some, or most plutonic rocks cumulates?)
4. Do large batholiths contain the residue of super-scale eruptions? Or are batholith construction and supereruptions mutually exclusive?
5. How do rhyolite-granite relationships and volcanic-plutonic connections fit into the “transcrustal magmatic systems” paradigm?

The formation of continental crust by crustal distillation: The critical role of phase equilibria

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Oral, Friday 15th September, 15:45 - 16:15

The occurrence of felsic continental crust makes Earth unique among the terrestrial planets. One way to produce such crust is crystallization-differentiation in transcrustal magmatic systems at convergent plate margins. The inferred average composition of continental crust is evolved (SiO_2-rich, lower Mg#) compared to primary arc magmas, requesting significant removal of (ultra-)mafic cumulates. Primary magmas are modified through a variety of processes including crystallization-differentiation, magma mixing, phenocryst retention, and assimilation. Geophysical constraints and natural occurrences reveal that the arc-crust is stratified with a lower mafic/ultramafic crust and an intermediate to granitic upper crust. The paucity of ultramafic to gabbroic cumulates in the upper crust infers that mantle-derived primitive melts acquire their evolved compositions predominantly in the deeper part of the magmatic system.

To quantify the relative contributions of the various processes experimentally constrained phase equilibria simulating the liquid lines of descent (LLD) of arc magmas from upper mantle to shallow level conditions are employed. This strictly simulates one endmember process, namely (fractional) crystallization. The role of pressure, temperature, oxygen fugacity (fO2), mantle extraction depths, and volatile content on the compositional evolution of derivative liquids were investigated and indicate that (1) fractional crystallization under crustal conditions produces andesitic-dacitic-rhyolitic liquids that closely resemble the compositions of upper crustal igneous rocks, but deviate at higher pressure; (2) the proportion of ultramafic cumulates required to obtain andesites to dacites is 45-70 wt.%; (3) shallow level differentiation provides a better fit in terms of aluminum content, but the required amount of cumulates is lacking; and (4) elevated fO_2 (NNO+2.5) result a closer agreement with natural compositions. It is evident that additional processes operate in these magmatic systems including mixing of variably evolved magmas along the LLD and incomplete separation of liquids and solids forming crystal-bearing to crystal-rich ascending magmas.

Alternative processes proposed to generate the felsic magmas dominating the upper crust such as (re)melting of pre-existing igneous crust and/or assimilation of mafic to pelitic lower/middle crust can be identified by evaluation of the cumulate / restite rock record that significantly differs from crystallization dominated cumulates. While deep arc cumulates crystallized from hydrous melts are plagioclase-poor and amphibole-rich, partial melting residues and cumulates originating from interaction with pelitic lithologies are plagioclase-rich two-pyroxene granulites and norites respectively.

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Oral, Monday 11th September, 16:45 - 17:00

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