

A-type granites and related rocks through time

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A-type granites (including their volcanic equivalents) and related rocks form a conspicuous part of the granite spectrum. They have been recognized only relatively recently and they are characterized by several attributes that clearly set them apart from other granitic rocks. A-type granites were originally defined as relatively dry (anhydrous), and they have high contents of alkalis and most high field strength trace elements. They commonly have been emplaced in an extensional tectonic regime not directly related to lithospheric convergence (i.e., they have been considered 'anorogenic' or 'post-tectonic'). These granites also span almost three billion years of Earth's history and they are associated with a varying set of mineralization types (e.g., Sn, F, Nb, Ta, Au, Fe, U, and REE).

A new IGCP Project that will focus on the classification, petrology, geochemistry, tectonic significance, and metallogenic importance of the A-type granites is being proposed. The overall aim of the project will be to correlate the petrology, geochemistry, and metallogeny of A-type granites in various tectonic settings through the geologic time. It is clear that no single mechanism can account for the wide range of petrotectonic associations registered by the A-type granites, and one prime aim of the project will be to comprehensively scrutinize petrogenetic scenarios, and whether or not they show secular variation with geologic time.

A-type granites: definitions, facts and speculations

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The current alphabetical scheme of classification for granites includes the S-, I-, M-, A-, and C- types. Though A-type granites are known as a discrete group since a long time, the term was coined for the first time in 1979 in the famous Loiselle & Wones abstract, which was not followed by a paper clarifying the ideas of the authors about the nature and origin of this specific type. Various definitions based on petrological and/or chemical criteria were offered, with "A" standing for "anorogenic", "alkalic" (in Iddings and Shand senses), "anhydrous", and even "aluminous". These definitions will be evaluated and the large variety of associated rocks emphasized.

A-type granites occur in geodynamic contexts ranging from within-plate settings to plate boundaries, though their locations and times of emplacement are not random. Rare in the lower crust, in which they are replaced by some charnockitic suites, they are fairly common at shallower depths, especially at the subvolcanic level where they typically form ring complexes rooting caldera volcanoes. Characteristic features include hypersolvus to transsolvus to subsolvus alkali feldspar textures, iron-rich mafic mineralogy, bulk-rock compositions yielding alkali-calcic to alkalic (in Peacock sense) affinities, high LILE + HFSE abundances, and pronounced anomalies due to high degrees of mineral fractionation. Isotopic features evidence sources containing a significant mantle input.

Experimental data show that A-type magmas contain dissolved OH-F-bearing fluids, i.e. they are not anhydrous, form under reduced as well as oxidized conditions, and yield high-temperature liquidus, so that anhydrous iron minerals, such as fayalite, crystallize early. Though many published geochemical models imply solely crustal derivation, no convincingly A-type felsic liquids were experimentally produced from crustal materials, nor have any leucosomes of A-type composition been detected within migmatitic terranes. As they occur within continents as well as on the ocean floor and because of the nature of associated igneous suites, A-type granites are likely to come from mantle-derived transitional to alkalic (in Iddings sense) mafic to intermediate magmas.

Interestingly, the uncommon felsic materials found in the meteoritic and lunar record yield dominantly A-type features. Contrary to the more common S- and I- types of granite, A-type granites are, therefore, not typical of Earth and were produced in planetary environments that differed markedly from those prevailing currently on Earth.

Cenozoic and proterozoic A-type silicic magmas of the Western US

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The principal episodes of A-type magmatism in the western US were in the Mesoproterozoic and in the Neogene. The compositional characteristics of these disparately aged groups are remarkably similar so understanding the young rocks will help constrain the origin of the older suite. Both include rocks with all of the classical characteristics of A-type granites and range from peralkaline to peraluminous. However, both age groups include rocks with a wide range of Fe/Mg ratios. Moreover, not all of the silicic rocks of either age have A-type characteristics; volcanic arc granites are found in both suites.

Extension is a fundamental control on the generation of the Neogene A-type magmas and a link to contemporaneous mafic magmas produced during extension seems clear. Nd isotope ratios are higher in the A-type rocks than in slightly older volcanic arc rocks: their isotopic compositions overlap with contemporaneous mafic rocks. These data and trace element patterns indicate that A-type magmas probably form by melting of hybridized continental crust which contains a significant juvenile mantle component not derived from a subduction zone. Mafic magmas appear to have lodged in the crust and then re-melted by subsequent injections. Parental mafic magma formed as a result of lithospheric extension and decompression or as a result of decompression related to convective-flow driven by the foundering of a subducting lithospheric plate. The variable subduction signatures are probably the result of lithospheric contamination and not an indication of tectonic setting. The evidence from the young rhyolites shows that A-type granites are not simply melts of continental crust at low pressure or of crust that is dehydrated or melt depleted.

1.4 and 1.2 Ga bimodal A-type magmatism in SW New Mexico and SE Arizona, USA

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The tectonic evolution of southern Laurentia in the mid-Proterozoic (1.6 to 1.0 Ga) is only vaguely understood, although growing evidence from the Grenville Province of eastern North America indicates that a long-lived, predominantly convergent margin may have governed the tectonic evolution of southeastern Laurentia during most of Proterozoic time. Our work in the northern Burro Mountains, southern New Mexico have demonstrated that at least three magmatic events are present, a 1633 Ma, ~1440-1460 Ma and a 1200-1000 Ma (cf. Rämö et al., 2003). Recent data (lithology, Nd isotopes) from other Proterozoic areas in southwestern New Mexico and southeastern Arizona have confirmed the presence of these magmatic events over a wider region, although more geochronology is still required for precise temporal characterization. Three areas are now known to have an A-type bimodal magmatic assemblage: Jack Creek granite and comingled minette (~1465 Ma) and the Redrock pluton with xenoliths of anorthosite and leucogabbro (~1220-1225 Ma) in the northern Burro Mountains, rapakivi granite and diabase in the Little Hatchet Mountains, and the Morenci area in southeastern Arizona with a rapakivi granite - leucogabbro association; the latter two are suspected to be consanguineous with the Redrock granite association based on field relationships, chemistry, and isotopic signature. The metamorphic (cratonic) rocks from the Burro Mountains and the Sierra Vista region have Nd model ages up to 1.9 Ga and thus register an unusually old source component in the Mazatzal crust. The 1.4 and 1.2 Ga associations presumably reflect recurrent extension or transtension-related magmatic events in southern Laurentia, but the overall tectonic context is yet to be determined.

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Contrasting rift-margin volcanism in the St. Francois Terrane of Missouri at 1.47 Ga

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Orthogonal tectonic fabric of Paleoproterozoic rocks in the mid-continent influenced development of the St. Francois Terrane (SFT) at all scales. At the largest scale, the Missouri Gravity Low (MGL) is a NW-trending rift defined by gravity and magnetic data. This 800 x 80 km structure is cut by the Reelfoot Rift (~ 0.6 Ga) and Mid-Centroid Rift (~1.1 Ga). Geophysical models suggest that the MGL is filled by 12-20 km of granite, rhyolite, and clastics covered by a Paleozoic veneer. SFT uplift exposed the SE end of the MGL where two rift-margin volcanic fields erupted during strike-slip faulting. The SW rift boundary coincides with releasing bends and the Eminence-Van Buren volcanic series (EVB); the NE boundary coincides with a restraining bend and the Mudlick volcanic series (MLV). The latter is in a contractional duplex. Both boundaries are regional faults with net sinistral slip formed with $\sigma_1 = E-W$ (horizontal).

The EVB are caldera-erupted ignimbrites with 65-90° dips, thickness > 7 km, and volume > 360 km³; these are covered by 300 m of post-collapse, sub-horizontal effusives dated at 1470 ± 2.7 Ma. Volcaniclastics and air fall tuff mark the synvolcanic unconformity. The ignimbrites are crystal-poor rhyolites exhibiting alkali exchange, secondary alkali feldspar, sericite, and silicification. The MLV series (1461 ± 4 Ma) comprises > 96 km³ of fissure-erupted effusive rocks produced by mingling of mafic and granitic magmas. The resulting hybrid approximates quartz latite composition and exhibits undercooling, flow structure, propylitic alteration, and intrusion by 1.35 Ga gabbro. Ages and eruptive volume > 456 km³ indicate that faulting across the MGL tapped syntectonic magma and produced major intra-rift volcanic events along both margins at about 1.47 Ga. Contrast in eruptive style resulted from magma emplacement in transtensional and transpressional sites.

Hf isotope compositions of Laurentian anorogenic granites

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Granitic rocks are commonly used as a means to study chemical evolution of continental crust. In particular, their isotopic compositions reflect the relative contributions of mantle and crustal sources in their genesis. In Laurentia, a distinctive belt of Mesoproterozoic anorogenic granites of ~1.4 Ga age was emplaced across a composite shield comprised by Archean and Proterozoic crust. Zircons are an ideal mineral to constrain the granite petrogenetic history because they are repositories of both age (U-Pb geochronology) and tracer (Lu-Hf isotopic) information.

We measured the Hf-isotope composition of zircons from 31 dated anorogenic granites intruding basement provinces from the southwest U.S. to the upper mid-continent. Hf isotopic measurements were done by MC-ICPMS both on solutions prepared by separation chemistry and on individual zircon grains using laser ablation for comparison. Hf-isotopic values are as follows:

Province	Age (Ma)	¹⁷⁶ Hf/ ¹⁷⁷ Hf (initial)	εHf (present)	εHf (initial)
Penokean (2)	1474	0.281845	-33.9	-1.2
central Yavapai (6)	1429	0.282027	-27.6	+4.2
western Yavapai (5)	1414	0.281976	-29.0	+2.1
Mojave (12)	1411	0.281891	-32.3	-1.0
Granite-Rhyolite (4)	1393	0.281933	-30.4	+0.2
s. Granite-Rhyolite (2)	1372	0.282109	-23.9	+5.8

Isotopic compositions for all 1.4 Ga granites are broadly similar, yet within individual crustal provinces they have distinct, low-variance Hf-isotope values independent of intrusion age. Differences between groups most likely reflect different 1.6-2.0 Ga crustal sources. Granites in the southern Granite-Rhyolite and central Yavapai provinces have the highest εHf(i), reflecting their more juvenile sources, whereas Mojave and Penokean granites show contributions from more evolved crustal sources. The Hf-isotope compositions of the 1.4 Ga granites therefore appear controlled predominantly by melting or assimilation of heterogeneous lower crust, consistent with other geochemical indicators.

A-type granites and AMCG suites; An isotopic study from SE Finland

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Rapakivi granites, a genuine A-type, in the *locus classicus* region of SE Finland are, at the current erosion level, associated with minor volumes of more mafic rocks. These are best exposed in the 1.64-Ga, 350-km² Ahvenisto complex on the northern flank of the Wiborg batholith. About 70% of the complex comprises silicic rocks (reduced biotite ± hornblende granites), 25% is gabbro-anorthositic rocks (leucogabbro-norite, some olivine-bearing gabbroic rocks, rare anorthosite), and 5% intermediate monzodioritic rocks (ferrodiorite, jotunite). The silicic rocks usually cut the monzodioritic rocks and the silicic and monzodioritic rocks always cut the gabbroic rocks; anorthosite is found as rafts in the gabbroic rocks. No significant difference is, however, observed in U-Pb mineral ages (Alviola et al., 1999).

The radiogenic isotope composition (whole-rock Nd-Sr, feldspar Pb) of the rock types of the Ahvenisto complex is astonishingly uniform in view of the large lithologic variation observed and the varying sources (continental crust, mantle) implied. For example, initial ϵ_{Nd} values show ranges of +0.5 to -0.9 (gabbroic rocks), -0.9 to -1 (anorthosite), -0.3 to -1.1 (monzodiorite), and -0.1 to -2.2 (granite), whereas the S&K μ_2 values are ~9.65 for the gabbroic and monzodioritic rocks and more varying (9.65-9.79) for granite. Sr_i is 0.7036 ± 0.0002 (1 σ) for the gabbroic rocks, 0.7037-0.7041 for anorthosite, and 0.7037 ± 0.0003 for the monzodioritic rocks. Our new, preliminary oxygen (laser fluorination from zircon) isotope data differentiate the mafic and silicic rocks of the complex more efficiently. The $\delta^{18}O$ value for a biotite-hornblende granite (8.09) is clearly higher than that of a leucogabbro-norite (7.15) and a monzodiorite (7.04). This points to the presence of a marked sedimentary source component in the silicic rocks of the complex.

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Geochronology of a rare alkaline magmatism: The blue sodalite-syenite ore (NE Brazil)

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The South Bahia Alkaline Province (PASEBA) is composed by an association of four alkaline batholiths and several stocks, predominantly composed by nepheline-syenites and having sodalite-syenites as subordinate facies. These rocks intrude Archaean to Paleoproterozoic granulitic-migmatitic terrains.

In this work, are present the results of a systematic geochronological investigation at these sodalite-syenite occurrences by U-Pb (titanite) and Pb/Pb (zircon) techniques. The data were obtained at the Laboratory of Isotope Geology of the Federal University of Pará (Pará-Iso).

The sodalite-syenite ore occurs as facies of the batholiths and stocks. It has irregular shape and always cover area with less than 2 km². It has an extremely variation in the granulation (fine phaneritic to pegmatitic) and occurs associated with the magmatic zircon (light brown, up to 2 cm) and titanite (brown to light brown, transparent).

Single zircon Pb-Pb evaporation data give to sodalite-syenite ore ages of 696 ± 3 Ma (Floresta Azul Complex – northeast) and 720 ± 9 Ma (Itarantim Massif – south). The titanites from Itajú do Colônia Stock (central part of SBAP) define an upper concordia intercept at 732 ± 8 Ma.

These results show that the crystallization age of the sodalite-syenite ore (696 – 732 Ma) is situated in the range of other magmatic ages (739 – 676 Ma) obtained for alkaline batholiths from PASEBA. This data support the existence of a rift system in the south part of São Francisco Craton during the Rodinia break-down.

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Mesozoic alkaline magmatism as a window to interpret geotectonic evolution of the Central Andes

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The alkaline petrographic province from Southern Peru to Northwestern Argentina is represented by small stocks intruding the basement of the Eastern Andes. Spatial distribution of those magmatic complexes seems to be related to thermal anomalies and deep crustal fractures produced during extensional tectonic processes. The petrology is characterized by felsic alkaline rocks SiO₂-saturated (nordmarkitic trend) and SiO₂-undersaturated (pulaskitic trend).

The magmatic association is characterized by high HFS/LIL element ratios, suggesting a source of asthenospheric basic rocks, enriched in incompatible elements comparable to those erupted in actual rift systems, showing no evidences on influence of subduction processes in the generation of these magmatic rocks. Oxygen and carbon isotopes in carbonate phases of different magmatic rocks show truly primary, magmatic values shifting isotopic composition as result of hydrothermal activity and temperature decrease.

For these petrogenetic process should have been interacted an oblique subduction of an asyismic oceanic ridge vs. hotspot migration beneath the continent. This situation generated pull apart basins and asthenospheric mantle upwelling with the subsequent alkaline magmatism. Cenozoic Andean tectonic inverted partially the Mesozoic extensional structures.

Cretaceous Gross Spitzkoppe stock in Namibia: genuine A-type granites related to continental rifting

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Anorogenic Damaraland igneous province in western Namibia comprises mafic, silicic and alkalic volcanic and plutonic rocks that were emplaced at 124-137 Ma into the Neoproterozoic Damara orogenic belt between the Congo and Kalahari cratons. The magmatism was related to the Tristan mantle plume and continental rifting that led to separation of South America from Africa. Silicic plutonic rocks include hornblende biotite granite and minor peralkalic granites (Brandberg), peraluminous granodiorite and tourmaline-bearing biotite granite (Erongo) and topaz granites (Gross Spitzkoppe, Kleine Spitzkoppe). The plutons are associated with mafic and silicic dikes, as well as some lamprophyre dikes.

The Gross Spitzkoppe stock consists of topaz-bearing biotite (siderophyllite-annite) granites (Frindt et al., 2004a and b; Frindt and Haapala, 2004). Bimodal association is indicated by synplutonic mafic dikes and magmatic mafic enclaves. The stock contact is marked by marginal pegmatite and layered aplite. Mirolitic cavities and pegmatite pockets contain gem-quality topaz and beryl, and hydrothermal alteration has locally produced wolframite-bearing greisen. Texturally different granite types show only little variation in chemical composition: SiO₂ 74.4-76.9, TiO₂ 0.03-0.15, Al₂O₃ 11.8-12.9, Fe₂O₃ 1.0-2.2, FeO 0.4-1.2, MgO 0.0-0.1, CaO 0.2-1.0, Na₂O 2.8-3.9, K₂O 4.6-5.6, P₂O₅ 0.00-0.16, and F 0.2-0.7 wt.%. High contents of incompatible elements (Rb 446-831, Nb 60-176, Ta 3-15, Ga 24-42 ppm) and low Sr (5-48 ppm), Ba (0-164 ppm), and Eu/Eu* (0.0-0.23) suggest high fractionation. The granites can be classified as ferroan alkali-calcic rocks, and they show the chemical and mineralogical characteristics of aluminous A-type and within-plate granites. Isotope studies (Nd, Sr) suggest dominant crustal source with significant mantle component (Frindt et al., 2004b). The preferred genetic model is magmatic underplating.

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^{207}Pb - ^{208}Pb decoupling of alkali feldspar from a late Mesozoic A-type granite in eastern China: Implications for magma dynamics

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During our ongoing isotopic study of late Mesozoic A-type granites in eastern China, an unexpected ^{207}Pb excess is found for alkali feldspar but not for zircon separated from Laoshan A-type granite. A concordant age of 120.2 ± 1.7 Ma is in situ dated by SHRIMP II technique, but TIMS analysis yields a decoupling between $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$ ratios for alkali feldspar. The distribution pattern of these two Pb isotopic ratios fails to be concurrently accounted for either with single-, two-stage Pb evolution or plumbotectonic model.

Given the petrogenetic connection with the lower crustal source for the generation of Laoshan A-type granite, an evident ^{207}Pb excess ($\Delta 207 = 18$ to 24%) was accordingly calculated if the lower crust of plumbotectonic model was taken as the reference. In order to reasonably account for the observed ^{207}Pb excess, an initial disequilibrium of excessive ^{231}Pa is envisaged as a favorite interpretation. Since A-type granitic magma is exclusively water undersaturated, the fossil ^{231}Pa excess is attributed to the low degree dynamic melting of old lower crust dehydrated under conditions of granulite facies.

As D_{Pa} value of zircon/melt is at least three orders of magnitude greater than that of alkali feldspar/melt pair (empirical estimations are from 204 to 312 vs. 0.13, respectively), Pa should thermodynamically prefer zircon rather than alkali feldspar under the similar physicochemical conditions. A reversal sequence of magma crystallization is thus proposed to reconcile the apparent paradox of fossil ^{231}Pa excess. Taking into account the limited half-life of ^{231}Pa ($t_{1/2} = 32760$ yrs), only if zircon did not start to crystallize until 160 ka ($\approx 5 \times t_{1/2}$ of ^{231}Pa) later, then the signal of initial disequilibrium of fossil ^{231}Pa excess should be substantially diluted or totally decay away. Thus, the occurrence of fossil ^{231}Pa excess from alkali feldspar rather than zircon compellingly constrains that lifetime of Laoshan A-type granitic magmatism is at least not shorter than 160 ka.

A-type granites: >25 years later

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Since being defined in 1979 by Loiselle and Wones, A-type (alkaline, anhydrous, anorogenic ect.) granites have proven controversial. In this period, major progress has been made in their geochemical and isotopic characterization and, based on experimental studies, in constraining their magmatic P-T and $f\text{O}_2$ conditions. For example, commonly juvenile Nd-O isotopic signatures support a direct, or relatively rapid indirect link to mantle sources. However, in spite of this progress, it remains true that A- is also for 'ambiguous', likely because these magmas can be generated in various tectonic settings, from diverse protoliths through a number of processes, such that no universally applicable model is possible. Controversial aspects include: (1) use of elemental discrimination diagrams for their identification; (2) their tectonic significance (is 'A' for anorogenic?) and temporal relationship to 'post-collisional' magmatism; (3) petrogenetic models (protolith- versus process-based models and crustal- versus mantle-derivation); (4) importance of tectonic models involving delamination (e.g., slab breakoff) and (5) massive sulphide-related A-type rhyolitic volcanism. A particularly promising subject meriting further research is temporal differences between Archean, 1.8-1 Ga and <1 Ga A-type suites and implications for Earth evolution.

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QUILF equilibria for trachytes and pantellerites from the Kenya Rift

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Whole rock and mineral compositions have been determined for samples from the Eburru volcanic complex. Mineral assemblages contain alkali feldspar, fayalite, clinopyroxene, ilmenite, and magnetite, making the use of QUILF equilibria appropriate.

Mineral compositions are alkali feldspar $Ab_{62}Or_{38}$ in trachytes and $Ab_{58}Or_{42}$ in pantellerites. Cpx in the pantellerites have a step-wise shift towards higher Na_2O contents and are aegerine-augite. They, like the cpx in the trachytes, are essentially pure-end member Fe compositions. Olivines follow suite and are typically Fa_{99} . Amphibole in pantellerite is ferrosichterite.

Controversy exists over whether peralkaline rocks such as these are generated by fractional crystallization of mantle magmas or partial melting of crustal rocks. Mineral compositions, because they tend to be pure end member compositions, suggest extensive fractional crystallization. Magma temperatures also provide a means to evaluate the competing hypotheses. QUILF calculations for the trachytes range from 719-756 °C and pantellerites from 665-708 °C. These temperatures are probably above the solidus for crustal melting for the trachyte, while the lowest temperature pantellerites would represent approximately solidus temperatures. Finally, the QUILF thermobarometer demonstrates that Eburru magmas existed at very low (ΔFMQ is +0.5 to -1.6) oxidation states. Low oxygen fugacity plays a major role in the stability fields of mineral phases during crystallization.

Grenville U–Pb zircon ages of surface and subsurface samples from Texas and southern New Mexico

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Bimodal magmatism at 1340–1370 Ma and ~1250 Ma is well known from the basement of Texas and New Mexico. Younger, Grenville-age magmatism has been thought to be restricted to the Llano uplift of central Texas and the Franklin Mountains of west Texas. New U–Pb zircon ages on subsurface samples show that compositionally diverse Grenville-age (1070–1110 Ma) magmatism was widespread in the region. In addition to 1110 ± 19 Ma, bimodal, A-type magmatism in the El Paso area, an anorthosite xenolith from a shallow Eocene intrusion yielded 1068 ± 30 Ma. In the center of the Rio Grande rift, retrogressed monzonitic granulite xenoliths from Potrillo Maar have zircon ages of ~1072 Ma. The suite of exposed and subsurface samples is suggestive of AMCG magmatism.

The largest Grenville age intrusion in the region is the ~1160 Ma Pecos mafic intrusive complex (PMIC), with subcrop > 200 km long beneath the Central Basin Platform. This layered complex is distinct in the predominance of noritic cumulates.

Between the PMIC and the Llano uplift, core from an alkali-feldspar granite yielded a 1078 ± 23 Ma age. This age is similar to undeformed granites in Llano uplift. In the Texas Panhandle, core from a thick tholeiitic sill yielded a zircon age of 1081 ± 8.3 Ma. These ages, A-type characteristics of granitic rocks, and Fe-enrichment in mafic suites indicate that Grenville-age magmatism in the TX–NM subsurface was widespread, this magmatism was coeval with granites in the Llano Uplift of central Texas, and compositions of dated samples suggest “A-type” magmatic affinities rather than a subduction-related tectonic setting.

K-Ar age and stable isotope geochemistry of A-type granitoids in the Divrigi-Sivas region, Turkey

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The bimodal, A-type Dumluca and Murmana granitoids, consisting of felsic monzonitic/syenitic and mafic monzogabbroic/monzodioritic rocks, intrude the Cretaceous ophiolitic suture zone. These intrusions, resulted from the slab break-off stage of the Neo-tethyan convergence system, are also associated with giant contact metasomatic skarn and hydrothermal iron oxide deposits that occur where three rock types are in close proximity: ultramafics, limestones, and granitoids. New hornblende and biotite K-Ar dates yield cooling ages ranging from 71.5 ± 0.1 to 77.4 ± 1.5 Ma, and from 62.1 ± 0.3 to 76.6 ± 1.6 Ma for the felsic and mafic rocks, respectively. $\delta^{18}\text{O}$ values of the felsic rocks of the Dumluca and Murmana plutons average 10.5‰ and 11.7‰, respectively. Mafic rocks from these plutons have average values of 8.2‰ and 9.6‰, respectively. The felsic rocks from the Dumluca and Murmana plutons are clearly distinct in terms of their $\delta^{34}\text{S}$ values, averaging 4.7‰ and 15.7‰, respectively. The mafic rocks of the two intrusions also are very different in terms of $\delta^{34}\text{S}$ values, averaging 2.4‰ and 7.4‰, respectively for the Dumluca and Murmana plutons. The felsic parts of these A-type plutonic suites exhibit the high ^{18}O -granitic characteristics with the $\delta^{18}\text{O}$ values greater than 10‰ that can be derived mainly from a significant crustal contribution during magma genesis and ascent. The mafic parts show an apparent “mantle-derived” ^{18}O -granitic pattern with lower $\delta^{18}\text{O}$ values, between 6‰ and 10‰. However, most of the values fall at the higher end of this range and may have resulted from a minor crustal contribution into a mantle-derived mafic magma source. $\delta^{34}\text{S}$ values from the mafic rocks are low relative to $\delta^{34}\text{S}$ values of cogenetic felsic rocks. However, there is a significant difference between the two suites, with Dumluca having $\delta^{34}\text{S}$ values nearer to mantle values than those of Murmana. In addition, Dumluca $\delta^{18}\text{O}$ values are generally lower than those from Murmana. From these data it is clear that the Murmana suite incorporated significantly more crustal material during ascent than the Dumluca suite. In addition, we suggest that a significant source of sulfur for almost all of these magmas is the crustal rocks, probably those containing evaporitic components (i.e., sulfates).

Petrogenesis of the peralkaline, cryolite-tin-mineralized albite granite from Pitinga, Brazil

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The magmatic, subsolvus Madeira albite granite crystallized from a F-rich, H₂O-bearing melt enriched in Sn and HFSE. It is composed of a peralkaline, cryolite-bearing core facies and a peraluminous to metaluminous, oxidized, fluorite-bearing border facies, the latter generated by autometasomatic processes. A hypersolvus granite is comagmatic with the albite granite. In the albite granite, crystallization of quartz started at $\sim 700^\circ\text{C}$, the quartz-K-feldspar cotectic line was attained at $\sim 650^\circ\text{C}$; at a lower temperature, the ternary feldspar solvus was reached and crystallization of albite started. The solidus was strongly depressed, allowing reequilibration of feldspar compositions along the solvus. At the solidus, around 500°C , feldspars approached end-member compositions. Massive cryolite and pegmatitic rocks in the centre of the stock were derived from residual melts. An albite-rich rock associated with the core facies is representative of this residual melt. The early facies of the Madeira pluton are comagmatic and show the characteristics of typical rapakivi granites. Nd isotopes imply that these granites and the hypersolvus and albite granite facies were derived from a Paleoproterozoic crustal source. The early facies and the albite granite are not comagmatic.

Oxygen isotopes in zircon from A-type granites in southern Finland: An indicator of separate terrains?

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The anorogenic intrusions of southeast Finland, extending into Russia, are the oldest representation of anorogenic rapakivi-related magmatism across southeastern Fennoscandia and are dated at 1.65–1.62 Ga. Zircon from the diabase dikes give very near mantle values for $\delta^{18}\text{O}$. Zircons from the A-type granites are higher with $\delta^{18}\text{O}$ values between 7.20–8.15‰. The Bodom and Obbnäs plutons, both placed within the “older rapakivi” age group having U-Pb ages of 1.645 ± 5 Ma, have significantly lower $\delta^{18}\text{O}$ values (~6.20‰) than the other anorogenic granites of southeast Finland. The Bodom and Obbnäs granite plutons are very close to one another, geographically, and despite geochemical differences show similar $\delta^{18}\text{O}$ values that are almost identical. The anorogenic rocks of southwest Finland represent a younger episode of rapakivi-related magmatism relative to the anorogenic rocks in southeast Finland, and were emplaced at 1.59–1.54 Ga. The granites from Eurajoki and Laitala show similar $\delta^{18}\text{O}$ values in zircon to those in southeastern Finland, ~8.50‰. Zircon from Åland has $\delta^{18}\text{O}$ of ~6.10‰, similar to those of the Bodom and Obbnäs intrusions in the east. The oxygen isotope ratio of 1.65–1.54 Ga A-type granites in southern Finland show a decreasing trend from north to south, and this variation is observed independent of their age of emplacement. It appears that the oxygen isotope compositions are able to see through the petrographic and geochemical similarities (and differences) of the rapakivi granite suite and provide petrogenetic characteristics related to their source and implications for the tectonic evolution of the Svecofennian orogen.

Kalar complex (Siberian craton) – The oldest example of the anorthosite-mangerite-charnockite- granite (AMCG) association

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Two large massifs of Kalar complex are located at the suture between the Aldan and Stanovik Provinces of the Siberian craton. They cut the host high-P mafic granulite, gneiss, and enderbite. The massifs are composed mostly of coarse-grained anorthosite with small amounts of mafic rocks, they are bordered to the north by charnockitic rocks. The rocks are different deformed and high-grade metamorphosed.

The intrusive age of Kalar complex was determined by U-Pb method for the single grains of zircon from anorthosite, gabbro and charnockite at 2623 ± 23 Ma. The age of metamorphism of anorthosite was obtained as 1849 ± 15 Ma. Zircons from the host synmetamorphic enderbite yield a single U-Pb isochron with an upper intercept of 2627 ± 16 Ma.

Orthopyroxen- and fayalite-bearing charnockite are all of high K, Fe-enriched, and alkali-calcic affinity. It show A-type and within-plate geochemical characteristics, with high HFSE, REE, and Ba. The typical feature of anorthosite is strong depletion on the most of incompatible elements, excluding Ba and Sr. The initial ϵ_{Nd} of charnockite (-1.0 to -2.4) are very close to the host enderbite (-1.0 to -2.8), whereas $\epsilon_{\text{Nd}}(\text{T})$ of anorthosite are characterized by large variations (+0.5 to -5.4).

The new geochronological, geochemical, and isotope data show:

- (1) Kalar complex is the oldest member of AMCG association;
- (2) the massifs were emplaced in extension regime shortly after collision of the Olekma-Aldan and Stanovoy microplates and have postcollision setting similar as the most part of AMCG massifs of the Grenvill fold belt;
- (3) the parental magma of charnockite was derived mainly from the late Archean lower crust;
- (4) the initial magma of anorthosite may represent melt derived from the mantle source that have assimilated different older crustal material in the different deep levels.

Helium and sulfur isotopic geochemistry of Furong tin deposit in Hunan Province

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The Furong tin deposit is a newly discovered super-large tin deposit. It is located at the south of the Qitianling granite in South Hunan. It is closely connected with the Qitianling A-type granite complex both in time and in space. This deposit differs from other tin deposits associated with S-type granite.

The helium and sulfur isotopes of sulfide samples from Furong tin deposit are measured. The ³He/⁴He ratios in fluid inclusions from 14 sulfides range from 0.13 R_a to 2.95R_a. In general, the ³He/⁴He ratio of the mantle is 6~7R_a, that of the crust is 0.01~0.05R_a. Compared to the ³He/⁴He ratios of Furong tin deposit, the ore forming fluid in this deposit can be considered as a mixture of two end-member components, the mantle fluid and the crustal fluid. The δ³⁴S ratios of 31 sulfides vary in the range of -22.8‰~+0.1‰. Except a few samples, most samples show relatively homogenization signatures in sulfur isotope composition, with δ³⁴S ranging from +0.1‰ to +9.1‰. This suggests that the sulfur might be derived from a magmatic fluid. This conclusion is in accordance with the helium isotope result.

The Qitianling granite belongs to A-type granite which formed in a post-orogenic extensional settings. Furong tin deposit is located at the contact zone (outer or inner) or granite of Qitianling granite, and its main tin-mineralization time is consistent with the intrusion time of Qitianling granite. The relationship reflects that their forming settings of geodynamics might relate with the Mesozoic lithospheric extension in South China.

Magmatic zoning in amazonian paleoproterozoic A-type granites

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The 1.88 Ga, oxidized A-type granitic plutons of the Jamon Suite, eastern Amazonian craton, Brazil, are intrusive in Archean granite-greenstone units. The less evolved rocks are biotite-hornblende monzogranites, locally enriched in cumulate amphibole ± clinopyroxene, that are concentrated in the border of the plutons. They are followed successively to the center of the plutons for biotite monzogranites and leucogranites, the latter defining generally small circular structures. Aeroradiometric surveys put in evidence the magmatic zoning of the plutons with increasing radiometric values being found in the more evolved leucogranites in the center of the bodies. All facies of the Jamon Suite are magnetite-bearing granites. Magnetic susceptibility decreases from the facies with higher modal mafic contents to the leucogranites, that is from the border to the center of the plutons. The magmatic zoning is marked by the decrease of modal mafic mineral content, plagioclase/potassium feldspar, amphibole/biotite and anorthite content of plagioclase. TiO₂, MgO, FeO, CaO, P₂O₅, Ba, Sr, and Zr decrease, and SiO₂, K₂O, and Rb increase in the same way. Magmatic differentiation was controlled by fractionation of early crystallized phases, including amphibole±clinopyroxene, andesine to calcic oligoclase, ilmenite, magnetite, apatite, and zircon. Negative Eu anomalies increased with differentiation. Fractional crystallization was the dominant process of magmatic evolution but magma mingling processes involving coarse biotite granites and leucogranites were also observed.

Mylonitic granites in NW of Iran: characteristic, genesis and tectonomagmatic implications

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Precambrian gneissic units have been seen in the geological maps of northwest Iran that have been cut with leucogranite rocks. According to field relationships and evidences, mineralogical studies and geochemical data, found that the acidic lithofacies are co-magmatic and which used to be thought of as gneiss, but these are actually mylonitic granites which have found gneissic feature through plastic and brittle deformation. Gradual changing of unmylonitic rocks into mylonitic ones, synchronous and adjacent observation of petrological phenomena and the similarities of mylonitic and unmylonitic rocks, show existence of porphyroclasts and megaclasts of primary rocks with trace elements distribution pattern such as Rb, Ba, Sr and Zr are indicate that mylonitization phase's effect on the region's rocks. From the tectonomagmatic point of view, presence of bimodal magmatism and anorogenic origin of granites, suggest that the presence of extensional geodynamic setting in the area. The granites are studied to be aluminous A-type granites. During transferring magma to upper levels and contaminated with wall rocks, these granites have found similarities with upper mantle.

Neoproterozoic collisional and anorogenic A-type granites of the Yenisey Ridge Orogen (southwestern framing of the Siberian craton)

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Three groups of Neoproterozoic A-type granites were recognized in the Yenisey Ridge: syncollisional Chirimba granites and quartz syenites (760 Ma), postcollisional Glushikha rare metal leucogranites (750-720 Ma) and anorogenic Tatarka leucogranites, granites and syenites (630 Ma) (Fig. 1).

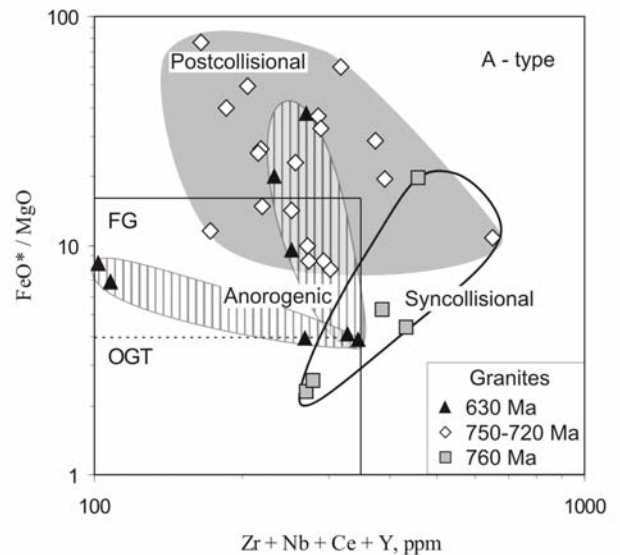


Figure 1: FeO*/MgO-Zr+Nb+Ce+Y diagram (Whalen et al., 1987) for three groups of A-type granites.

The Chirimba granites and associated with them S- and I-types granites were derived mostly from crustal source. The Tatarka granites associate with carbonatites, ultramafic and alkaline rocks that are differentiates of mantle and mantle - crust sources. Both the Chirimba and Tatarka rocks are high-temperature granites. The Glushikha rare metal (high-K) leucogranites relate to medium-low-temperature granites. They are probably late differentiates of subalkaline melts that were responsible for Chirimba granite formation.