

Granite: A Planetary Point of View

B. Bonin, J. Bébien and P. Masson

CNRS-UMR 8616 'Orsayterre', Département des Sciences de la Terre, Université de Paris-Sud, F-91405 Orsay Cedex, France

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Abstract

The telluric planets and the asteroid belt display the same internal structure with a metallic inner core and a silicate outer shell. Experimental data and petrological evidence in silicate systems show that granite can be produced through all types of magmatic processes.

On Moon, 4.4–3.9 Ga granite clasts displaying dry mineral assemblages correspond to discrete intrusive events. Large K/Ca enrichment and low REE abundances in granite relative to KREEP are consistent with silicate liquid immiscibility, a process observed in melt inclusions within olivine of Lunar basalts. On Mars, black-and-white rhythmic layers observed on the Tharsis rise along the flanks of Valles Marineris and the peripheral scarps of the Tharsis Montes giant volcanoes suggest the eruption of possibly felsic pyroclastites. Samples analysed in the Mars Pathfinder landing site yield basic to intermediate (45 to 62 wt.% SiO₂) compositions. Though no granites were found so far in the Martian SNC meteorites, a component close to terrestrial continental (granitic) crust is inferred from trace element and isotope systematics. Like the Martian northern hemisphere, Venus has suffered extensive volcanic resurfacing, whereas folded and faulted areas resemble terrestrial continents. The hypothesis of a granitic component is again 'tantalizing'. Finally, extra-terrestrial granite is also found as enclaves within iron meteorites and ordinary chondrites.

Granite, a major component of the Earth's crust, can be generated in all geodynamic settings. The low density of granite favours continental accretion. Thus, the occurrence or absence of granite and of associated silicic volcanism within the other telluric planets is not a trivial question. Granite is generally thought to be produced through 'wet' processes. Lunar evidence shows that dry conditions may apply as well. In Venus, a large planet with high rates of magma production, it is speculated that significant volumes of granite can develop.

Key words: Granites, geochemistry, extra-terrestrial, Lunar, Martian.

Origin and Intensive Parameters in the Crystallization of Ultrapotassic Syenites: The Serra Do Man Pluton, Northeastern Brazil

Marco A.F. Ferreira^{1*}, Valderez P. Ferreira¹, Alcides N. Sial¹ and Marcio M. Pimentel²

¹ NEG-LABISE, Department of Geology, C.P. 7852, Federal University of Pernambuco, Recife, PE, 50732-970, Brazil

² Institute of Geosciences, University of Brasilia, Brasilia, D.F., 70,000, Brazil

* Permanent address: Natural Science Center, Department of Biology, Federal University of Piaui, Teresina, PI, Brazil

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Abstract

The late Neoproterozoic ultrapotassic Serra do Man pluton intruded supracrustal schists and igneous rocks of the Alto Pajeu tectonostratigraphic terrane, in the Borborema province of northeastern Brazil. This quartz-alkali feldspar syenite is composed of microcline, albite, normally zoned aegirine-augite, winchite (formed after pyroxene), titanite and apatite, with the major-element geochemistry in consonance with early fractionation of pyroxene-titanite-apatite assemblage. Chondrite-normalized REE-patterns are LREE-enriched (La/Lu \sim 20) with discrete negative Eu anomaly, and primitive mantle-normalized elemental concentration diagrams display enhanced negative Nb, P and Ti anomalies that are also observed in patterns of similar rocks in NE Brazil. Whole-rock $\delta^{18}\text{O}$ values are rather high (avg. $+8.7\text{‰}_{\text{SMOW}}$) and in the $+7.8$ to $+8.6\text{‰}_{\text{SMOW}}$ range when clinopyroxene-corrected. A five-point whole-rock Rb-Sr isochron yields an age of 580 ± 28 Ma with high Sr_o (0.7108), which together with ϵNd (0.58 Ga) value of -17 and t_{chur} of 2.3 Ga allow hypothesizing a Paleoproterozoic enriched-mantle source for the syenites in the ultrapotassic province of the Alto Pajeu terrane. The aegirine-augite, titanite, and quartz assemblage attests to a high oxygen fugacity prevailing during magmatic crystallization. The almost complete absence of primary hydrated phases assures that the magma was rather anhydrous, and its viscosity, at the liquidus temperature, was relatively high. Density is slightly higher than expected for syenitic magmas (2.8 g/cm^3), being explained by a relatively high iron content of the magma. Geothermobarometry suggests shallow emplacement and temperatures of $700\text{--}750^\circ\text{C}$ and $850\text{--}900^\circ\text{C}$, respectively, for the solidus and liquidus of the magma.

Key words: Ultrapotassic, syenite, intensive parameters, petrogenesis.

Mantle and Crustal Sources in the Genesis of Late-Hercynian Granitoids (NW Portugal): Geochemical and Sr–Nd Isotopic Constraints

G. Dias^{1*}, P.P. Simões¹, N. Ferreira² and J. Leterrier³

¹ Departamento de Ciências da Terra, Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal,
E-mail: gracie@ct.uminho.pt

² Instituto Geológico e Mineiro, Rua da Amieira, 4466-956 S. Mamede de Infesta, Portugal

³ Centre de Recherches Pétrographiques et Géochimiques, CNRS, B.P. 20, 54501 Vandoeuvre-lès-Nancy, France

* Corresponding author

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Abstract

Large volumes of granitoids were emplaced in the Hercynian Central Iberian Zone during the last ductile deformation phase (D3, 300–320 Ma). The biotite-rich granitoids are the most abundant: (1) syn-D3 granodiorites-monzogranites (313–319 Ma) with calc-alkaline and aluminopotassic affinities; (2) late-D3 granodiorites-monzogranites (306–311 Ma), related to subalkaline and aluminopotassic series. These granitoids are associated with coeval gabbro-norite to granodiorite bodies and/or mafic microgranular enclaves. Both granitoids and basic-intermediate rocks show petrological, geochemical and isotopic evidence of interaction between felsic and mafic magmas.

The mantle-derived melts, represented by shoshonitic gabbro-norites, were probably derived from an enriched and isotopically homogeneous source ($Sr_i = 0.7049$ to 0.7053 , $\epsilon_{Nd} = -2.1$ to -2.5). In some syn- and late-D3 plutons there are evidences of essentially crustal granites, represented by moderately peraluminous monzogranites of aluminopotassic affinity. They have similar Nd model ages (1.4 Ga) but different isotopic compositions ($Sr_i = 0.7089$ to 0.7106 , $\epsilon_{Nd} = -5.6$ to -6.8), revealing a heterogeneous crust. Potential protoliths are metasedimentary (immature sediments) and/or felsic meta-igneous lower crust materials. Large amounts of hybrid magmas were generated by the interaction of these coeval mantle- and crust-derived liquids, giving rise to slightly peraluminous monzogranites/granodiorites of calc-alkaline and subalkaline affinities, which display more depleted isotopic compositions than the crustal end-members ($Sr_i = 0.7064$ to 0.7085 , $\epsilon_{Nd} = -4.4$ to -6.2). Petrogenetic processes involving mingling and/or mixing and fractional crystallization (at variable degrees) in multiple reservoirs are suggested.

A major crustal growth event occurred in late-Hercynian times (~305–320 Ma) related to the input of juvenile mantle magmas and leading to the genesis of composite calc-alkaline and subalkaline plutons, largely represented in the Central Iberian Zone.

Key words: Iberian peninsula, Hercynian, hybrid granitoids, protoliths, geochemistry.

Magmatic Gradients in the Cretaceous Caleu Pluton (Central Chile): Injections of Pulses from a Stratified Magma Reservoir

Miguel A. Parada^{1*}, Paula Larrondo¹, Claudio Guiresse¹ and Pierrick Roperch²

¹ Department of Geology, University of Chile, Casilla 13518, Correo 21, Santiago, Chile, E-mail: maparada@cec.uchile.cl

² Institut de Recherche pour le Développement (IRD), Casilla 53390, Correo Central, Santiago, Chile

*Corresponding author

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Abstract

The Caleu pluton (Central Chile) extending over 338 km² and with more than 1,400 m of vertical relief intrudes the N-S trending Lower Cretaceous volcano-sedimentary and volcanic successions at a depth equivalent to a pressure of 2 kb. The host, stratified volcanic successions, are tilted about 30°–40° E, whereas the pluton shows paleomagnetic evidence of either tilting of <15° E or clockwise rotation by few degrees.

A gradient of westward increasing SiO₂ content is recognized across the pluton, giving rise to three N-S elongated zones: Gabbro/Diorite Zone (GDZ), Tonalite Zone (TZ) and Granodiorite Zone (GZ). Biotite and hornblende compositions also exhibit a westward decreasing gradient in Mg/(Mg+Fe), indicating that the more mafic the zone is, the more oxidizing is its crystallization condition. Horizontal inward gradients of progressively less evolved rocks are recognized across GDZ and TZ, whereas no horizontal gradients were found in the GZ. Vertical compositional gradients are recognized in the GDZ and TZ, which consist of an upward increase in SiO₂ and decrease in MgO, FeO, Fe₂O₃, and compatible trace elements. A vertical compositional boundary was recognized along a traverse across the TZ separating two magma pulses with similar trends of compositional variations.

The three zones of the Caleu pluton were derived from a common isotopically (Sr–Nd) depleted source. Each zone probably evolved independently, as their compositional characteristics would have not been acquired *in situ*. The resulting compositional characteristics of the zones would have been developed prior to the intrusion, in a subjacent stratified reservoir placed at about seven kilometers below the pluton.

Key words: Magmatic gradients, geochemistry, pluton zoning, petrogenesis, Central Chile.

Common Crustal Source for Contrasting Peraluminous Facies in the Early Paleozoic Capillitas Batholith, NW Argentina

J.N. Rossi¹, A.J. Toselli¹, J. Saavedra², A.N. Sial³, E. Pellitero² and V.P. Ferreira³

¹ INSUGEO, Universidad Nacional de Tucuman, Tucuman, 4000, Argentina

² Inst. de Recursos Naturales y Agrobiología, Universidad de Salamanca, Salamanca, Spain

³ NEG-LABISE, Department of Geology, UFPE, C.P. 7852, Recife, PE, 50732-970, Brazil

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Abstract

The Ordovician Capillitas batholith, part of the northern Pampean ranges, NW Argentina, exhibits two peraluminous granitic facies in its eastern portion: (a) coarse- to medium-grained, porphyritic mafic facies with biotite, cordierite and aluminosilicates, carrying sillimanite-, cordierite-, and andalusite-bearing migmatitic enclaves and schlieren and (b) enclave free, mica poor, coarse-grained, porphyritic felsic facies, with andalusite and sillimanite. Banded hornfels aureoles contain cordierite poikiloblasts, biotite, plagioclase and quartz. The low-P mineral assemblage in these granites, enclaves and restites, suggests partial fusion of a supracrustal protolith. The two facies plot as two separate groups in geochemical variation diagrams, suggesting that they evolved from different magma batches derived from the same source, rather than from in situ fractional crystallization. The composition of felsic facies granites corresponds to pelite and metagraywacke-derived melts, whereas cordierite-bearing mafic granites follow a trend indicating mixing of pelite-derived melts and corresponding restites. The mafic-facies granites approach more the continental crust composition than the felsic-facies ones, which display more pronounced Ba and Sr negative anomalies. The average $(La/Yb)_N \sim 11$ rules out a high pressure garnet-rich source and the low normalized Sr contents, in both granitic facies, suggest a recycled metasedimentary protolith. Absence of mafic intrusives that could have assimilated pelitic schists, allow us to infer that melting took place at rather low T and under high water activity. Heat to trigger partial fusion could have been radiogenically generated and stored in the upper crust during deformation and thickening of the continental crust, with further release during decompression. The Capillitas batholith, emplaced close to an I, S-type granite boundary line in this region appears to be an Argentinean analogue of the Cooma Series supersuite in the Lachlan Fold Belt, emplaced close to the eastern Australian I, S-type granite boundary line.

Key words: Cordierite, mafic and felsic facies, Paleozoic, common source, peraluminous.

The Umarizal Igneous Association, Borborema Province, NE Brazil: Implications for the Genesis of A-Type Granites

I. McReath^{1*}, A.C. Galindo² and R. Dall'Agnol³

¹ Departamento de Mineralogia e Geotectônica, Instituto de Geociências, Universidade de São Paulo, 05508-900 São Paulo SP, Brazil, E-mail: ianmcr@usp.br

² Departamento de Geologia, Centro de Ciências Exatas, Universidade Federal do Rio Grande do Norte, Caixa Postal 1639, 59072-970 Natal RN, Brazil

³ Centro de Geociências, Universidade Federal do Pará, 66075-900 Belém PA, Brazil

* Corresponding author

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Abstract

The Umarizal igneous association (NE Brazil) consists of three A-type plutons, intruded over an interval of about 15 Ma, during the post-collisional phase of the Brasiliano orogeny. All the plutons have Sr isotopic compositions which indicate important or dominant crustal contributions. Crystallization of the Umarizal sill, formed of fayalite quartz syenite and syenogranite, and of the Lagoa stocks, formed by mangerite and granite, commenced under water-undersaturated conditions at pressures around 700–800 MPa and temperatures around 900°C, and continued during magma rise with the crystallization of hornblende at about 480–570 MPa. Crystallization of the Ação stock, which contains a rapakivi-like facies, commenced at similar temperatures, and hornblende appeared at slightly less than 800°C and around 500 MPa. Different f_{O_2} conditions controlled the compositions of the ferromagnesian phases and the nature of the oxide mineral assemblage. Simple fractional crystallization models from homogeneous parent magmas are insufficient to explain the chemical variation of the rocks suites.

Key words: Brasiliano/Pan-African, mangerite, geothermometry, geobarometry, crystallization history.

Geochemical Characteristics and Variations of the Ryoke Granitoids, Southwest Japan: Petrogenetic Implications for the Plutonic Rocks of a Magmatic Arc

T. Kutsukake

Laboratory of Geological Sciences, Department of General Education, Aichi University, Toyohashi, 441-8522, Japan,
E-mail: kutsukake@vega.aichi-u.ac.jp

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Abstract

Geochemical characteristics and variations of the Ryoke granitoids, southwest Japan, have been elucidated, based on more than 70 analyses from the Mikawa and Kinki districts for major and trace elements including REE. The Ryoke granitoids are the products of a continental-margin arc magmatism of Pacific Asia during late-Cretaceous period, and represent its magmatic front. They are classified into the Older and Younger groups, according to their intrusive ages and textural and petrographic characteristics. The Older Ryoke granitoids were emplaced at ca. 20 km depth during 100–85 Ma, and deformed and recrystallized together with the host Ryoke metamorphic rocks. The Younger Ryoke granitoids are post-tectonic plutons, emplaced at ca. 15 km depth (85–75 Ma), and accompanied by the formation of contact aureoles. The majority belongs to I-type and ilmenite-series granitoids. The granitoids of both groups are geochemically quite similar: calcic (alkali-lime index ~65), very low in Fe^{+3}/Fe^{+2} ratio and both metaluminous and peraluminous. They have low Rb (<100 ppm) and actinide contents, and moderate abundances of other LIL and HFS elements. They fall exclusively within the volcanic arc granite field in all the trace element discrimination schemes. Trace element geochemistry and chondrite-normalized REE patterns suggest that the I-type Ryoke granitoids were generated by the dehydration melting of amphibolite, of basaltic and basaltic-andesitic composition, or hydrous melting of tholeiitic basalt at 1 GPa and higher pressures. The heat-source for the melting of protoliths should be the underplating basalts, of which remnants are seen as the mafic rocks enclosed and/or intruded by the Ryoke granitoids.

Key words: Late Cretaceous, arc magmatism, geochemistry, Ryoke granitoids, southwest Japan.

Geology and Geochemistry of Granites Around Jaswantpura, Jalore District, Southwestern Rajasthan, India

A. Maheshwari¹, S.S. Garhia², A.N. Sial³, V.P. Ferreira³, V. Dwivedi¹ and V.K. Chittora⁴

¹ Department of Geology, University of Rajasthan, Jaipur, India

² B-21, Anand Vihar, Jagatpura, Jaipur, India

³ NEG-LABISE, Department of Geology, UFPE, C.P. 7852, Recife, PE, 50732-970, Brazil

⁴ 10/957, Malviya Nagar, Jaipur, India

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Abstract

The Neoproterozoic granite plutons around Jaswantpura, western India, form a large complex of granitic rocks and, at least, four distinct granite types, based on cross-cutting relationships, have been found: coarse- to medium-grained biotite granites; medium- to fine-grained two- mica granites; coarse- to medium-grained porphyritic hornblende granites and fine-grained biotite granites with accessory hornblende. Younger acidic and basic dykes cut these granites. The Jaswantpura granites show a narrow range of variation in terms of their chemistry. The hornblende granites are hypersolvus with mild peralkaline character as reflected by the enrichment in incompatible trace elements including Zr, Nb, La and REE but are characterized by relatively low Sr and Al_2O_3 . The biotite granites are subsolvus, mildly to moderately peraluminous and are characterized by relatively high SiO_2 , Al_2O_3 , Rb and low Zr, Nb and REE contents compared to the hornblende granites. The mineralogical and chemical characteristics of the different granite types exposed in the Jaswantpura area point to a continental crust source.

Key words: Granite, Neoproterozoic, geochemistry, petrogenesis, crust.

Architecture of Late Orogenic Plutons in the Araçuaí-Ribeira Fold Belt, Southeast Brazil

C.M. Wiedemann^{1,2*}, S.R. de Medeiros³, I.P. Ludka², J.C. Mendes² and J. Costa-de-Moura²

¹ IMPG – Institut für Mineralogie, Petrologie und Geochemie der LMU, Theresienstr. 41/111, M-80 333, University of Munich, Germany, E-mail: wiedeman@petro1.min.uni-muenchen.de

² Department of Geology, IGEO – Federal University of Rio de Janeiro – UFRJ, Brazil, E-mail: proj-es@igeo.ufrj.br, silviar@unb.br

³ Institute of Geosciences, University of Brasilia (UnB), Brasilia, D.F., 70, 910-970, Brazil

*CAPES and National Research Council (CNPq)

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Abstract

Post-collisional to late orogenic magmatism (580 to 480 Ma) in the Araçuaí-Ribeira Fold Belt, SE Brazil, is characterized by the predominance of high-K metaluminous, allanite-titanite-bearing granitoids. Small lenses of coronitic gabbro, anorthosite, pyroxenite and phlogopite-peridotite are also common in deeper exposed areas of this fold belt. In the region of southern Espírito Santo State, the deep erosional level associated with a steep topography reveals the internal architecture of the intrusions: a tendency to funnel-shaped bodies, with sub-vertical hemi-ellipsoidal/conical roots changing upwards to shallow-dipping tops. Associated stocks, sills and dykes of basic and acid rocks generally intrude the enclosing gneisses along the foliation planes, local ductile shear zones and parallel to fold hinges. The contact between intrusions and the enclosing rocks is sharp in deeply eroded plutons e.g., Santa Angélica, Venda Nova, Mimoso do Sul and Várzea Alegre, but at shallow levels e.g., Castelo, Pedra Azul and Conceição de Muqui agmatic stoping zones occur along the borders. A magmatic foliation within the granitoids is usually well marked, but the schistosity in the surrounding gneisses wraps around the plutons. The intrusions have a bimodal chemical distribution and generally are reversely zoned with mafic cores (gabbro, diorite to tonalite) surrounded by a mingled (marble cake) zone where basic and acid rocks are interfingering, and an external zone of syenomonzonite and granite. Widespread evidence of mingling and mixing between contrasting magmas of gabbroic and granitic and/or syenomonzonitic compositions is characteristic for all intrusive complexes.

We suggest that replacement of lithospheric mantle by hot asthenospheric mantle induced partial melting of the crust. The mantle exchange was due to lithospheric mantle delamination and slab breakoff following collisional orogenesis. The bimodal plutons result from interaction among the contrasting magmas. Ascent and emplacement followed older regional structures, such as regional fold hinges and ductile shear zones.

Key words: Pluton architecture, magma mingling, late-orogenic magmatism, calc-alkaline plutons, SE Brazil.

Evidence of Polyphase Deformation in Gneissic Rocks Around Devgadhi Bariya: Implications for Evolution of Godhra Granite in the Southern Aravalli Region (India)

Manish A. Mamtani ¹, B. Karmakar ¹ and S.S. Merh ²

¹ Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur - 721 302, West Bengal, India,
E-mail: mamtani@gg.iitkgp.ernet.in

² Department of Geology, M.S. University of Baroda, Vadodara - 390 002, Gujarat, India

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Abstract

In this paper, field evidence documenting the polydeformed nature of banded gneiss that comprises a part of the Godhra Granite and Gneiss in the southern portion of Aravalli Mountain Belt (AMB), India, is presented. The structural geometry involving an episode of recumbent-reclined folding in the gneiss lying in the vicinity of Devgadhi Bariya town is worked out. The banded gneiss occurs as enclaves in the granite. Therefore, it is suggested that the banded gneiss of the region is older than Godhra Granite. Microstructures preserved in the granitic rocks are documented and it is suggested that the granitic rocks underwent deformation and strain during their evolutionary history. Variation in the mesoscopic scale fabric of the gneiss and granite along a south-to-north traverse within the study area is documented, and different possibilities for evolution of Godhra Granite are discussed.

Key words: Deformation, gneiss, granite, Aravalli Mountain Belt, India.

Crustal Evolution of the Pernambuco-Alagoas Complex, Borborema Province, NE Brazil: Nd Isotopic Data from Neoproterozoic Granitoids

A.F. da Silva Filho¹, I.P. Guimarães¹ and W.R. Van Schmus²

¹ Departamento de Geologia, Univ. Fed. de Pernambuco, 50739, Recife, PE, Brazil

² Department of Geology, Univ. of Kansas, Lawrence, KS, 66045, USA

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Abstract

The Borborema Province in northeast Brazil forms the western part of a major 600 Ma Brasiliano-Pan-African mobile belt that extends from Brazil through Central Africa in a pre-drift reconstruction of Gondwanaland. The Pernambuco-Alagoas (PEAL) complex is a large area within the Borborema Province, and consists of high-grade migmatitic gneisses and granitic batholiths. Although the PEAL complex has previously been called a “massif” or “terrane”, in reality it comprises many different types of protoliths or plutons. The protoliths for many of the migmatitic gneisses are difficult to decipher due to the varied deformation and metamorphism during the Cariris Velhos and Brasiliano orogenies. Nd isotopic data discriminate two major crustal domains in the PEAL complex: the Garanhuns and the Água Branca domains. Rocks of the Garanhuns domain have Nd T_{DM} in the range of 1.8 to 2.4 Ga, indicating that most of it is underlain by Paleoproterozoic crust, and does not include significant Mesoproterozoic or Neoproterozoic crustal additions. The Marimondo-Correntes batholith is inside the Garanhuns domain, but includes younger T_{DM} ages similar to those found in the Água Branca domain. This batholith includes contributions from younger sources and may intrude a block of younger allochthonous crust thrust over the older crust of the Garanhuns domain. Rocks of the Água Branca domain show T_{DM} within the range of 0.90 to 2.10 Ga, with most Nd model ages between 1.5 and 1.0 Ga. The pre-Brasiliano crust in this domain thus includes substantial amounts of Mesoproterozoic to Neoproterozoic additions. The presence of some older model ages suggests that the Águas Belas domain may have some vertical crustal zonation, with Paleoproterozoic and Neoproterozoic crustal segments tectonically interleaved during successive accretional or collisional episodes, including the ultimate Brasiliano collision at 600 Ma. The Mesoproterozoic Nd model ages, therefore represent mixing of different crustal and mantle sources, rather than a discrete episode of Mesoproterozoic crustal formation. Various metaluminous or peraluminous granitoids of Brasiliano age from the Buíque-Paulo Afonso, Águas Belas-Canindé, and Marimondo-Correntes batholiths show T_{DM} ranging from 0.90 Ga to 1.10 Ga, suggesting that they either were wholly derived from juvenile material of the 1.0 Ga Cariris Velhos orogeny or contain substantial contributions of juvenile material from the 0.6 Ga Brasiliano cycle. Some high-K to shoshonitic granitoids from the Águas Belas domain show Mesoproterozoic (~1.4 Ga) T_{DM} model ages. The model ages recorded in these plutons could suggest either that the magma was derived from enriched lithospheric mantle associated with the Cariris Velhos orogeny or that it was a mixture between enriched lower crust of Transamazonian age and juvenile material from the Cariris Velhos or Brasiliano orogenies.

Key words: Brasiliano, Neoproterozoic, granitoids, Sm-Nd model ages, Gondwana.

Hercynian Acid Magmatism and Related Mineralizations in Northern Portugal

A. Almeida^{1*}, H.C. Martins^{1,2} and F. Noronha¹

¹ Centro de Geologia da Universidade do Porto, Faculdade de Ciências, Pr. Gomes Teixeira, 4099-002 Porto, Portugal,
E-mail: aalmeida@fc.up.pt

² Departamento de Geologia, Universidade de Trás-os-Montes e Alto Douro, Apartado 202, 5000-911 Vila Real, Codex,
Portugal

* Corresponding author

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Abstract

Cabeceiras de Basto (CB), Vieira do Minho (VM) and Vila Pouca de Aguiar (VPA) granite plutons are located in the so-called Central Iberian Zone, northern Portugal. U–Pb zircon and monazite geochronology yielded the minimum emplacement age of 311 Ma for CB and the crystallization ages of 311 Ma for VM and 299 Ma for VPA, constraining the time interval of the third Hercynian deformation phase, relative to which these massifs can be grouped as follows: syn- to late-tectonic (CB and VM) and post-tectonic (VPA) granites.

CB is a composite peraluminous two-mica granite pluton, occupying the core of a N 130° E antiform. Geochemical and isotopic data suggest a heterogeneous crustal source of mid-Proterozoic age (1.2 Ga). The granites are specialized in Sn, Li and, to a lesser extent, W mineralizations. Fractional crystallization is the main concentrator mechanism for these elements. Late-magmatic hydrothermal alteration processes (feldspar albitization and plagioclase and biotite muscovitization) enhanced the concentration promoted by the magmatic differentiation.

Both the VM and VPA plutons are controlled by deep regional fault zones and consist of composite biotite granites, generated in the lower crust and installed in higher structural crustal levels, resulting in thermal metamorphism (P: 2 kb; T: 500–600°C) capable of generating crustal convecting fluids. They are spatially related to important Sn, W and Au mineralizations. Although they are not highly specialized, they have contributed significantly as heat sources for the ore concentrations.

Key words: Hercynian granites, Li, Sn, W metallogenic specialization, Portugal, Iberian Peninsula.

Tin-Bearing Sodic Episyenites Associated with the Proterozoic, A-Type Água Boa Granite, Pitinga Mine, Amazonian Craton, Brazil

H.T. Costi^{1,2*}, R. Dall'Agnol¹, R.M.K. Borges¹, O.R.R. Minuzzi³ and J.T. Teixeira⁴

¹ Grupo de Pesquisa Petrologia de Rochas Granitóides, Centro de Geociências, Universidade Federal do Pará - C.P. 1611 - 66075-900 - Belém - PA - Brazil

² Laboratório de Microscopia Eletrônica de Varredura/Museu Paraense Emílio Goeldi, Av. Perimetral, 1901, 66077-530 - Belém - PA, Brazil, E-mail: tulio@museu-goeldi.br

³ Mineração Taboca S.A. - Vila Pitinga, 69737-000, Presidente Figueiredo - AM - Brazil

⁴ Grupo Paranapanema S.A. - Praia do Botafogo, 228, 15º andar, Bloco A - Rio de Janeiro, RJ - Brazil

* Corresponding author

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Abstract

This paper reports the first occurrence of tin-mineralized episyenites in the Amazonian craton. The Água Boa and Madeira plutons in the Pitinga region are stanniferous Proterozoic A-type granites of the rapakivi series featuring metasomatic episyenitization. The biotite granite facies of the Água Boa pluton is metasomatically altered to sodic episyenite and minor potassic episyenite and micaceous episyenite. The sodic episyenites formed by: (a) albitization of K-feldspar, (b) vug formation by dissolution of magmatic quartz, (c) vug filling by albite, chlorite, lithian muscovite, cassiterite \pm fluorite \pm K-feldspar and (d) deposition of late quartz \pm cassiterite in remaining cavities. In the potassic episyenites, vugs produced by quartz dissolution are filled by secondary K-feldspar, which also replaces magmatic phases. Micaceous episyenites formed by zinnwaldite replacement of secondary albite in the sodic episyenites. In contrast to the sodic episyenites, the potassic and micaceous episyenites contain only traces of cassiterite.

Relative to unaltered biotite granite, the sodic episyenites are strongly depleted in SiO_2 , K_2O , LREE and Sr, moderately depleted in HREE, and enriched in Na_2O , Al_2O_3 , Rb and Sn. The potassic episyenites resemble the sodic episyenite in SiO_2 and Al_2O_3 but exhibit higher values of K_2O , Ba, Y and Rb; their Na_2O , REE, and Sn concentrations match those of the biotite granite host.

Metasomatic episyenitization is attributed to: (1) a high temperature gradient and fluid-rock ratio during subsolidus cooling of the Água Boa pluton, (2) quartz dissolution in the biotite granite facies by reaction with an high-temperature, silica-undersaturated fluid of probable magmatic origin, (3) hydrothermal cavity filling by a low-temperature, silica-saturated fluid of meteoric, or mixed magmatic/meteoric character.

Significant tin values in metasomatic sodic episyenites near the Pitinga mine suggest that exploration of similar rocks in other A-type granites may be worthwhile.

Key words: Amazonian craton, Pitinga, tin granites, episyenite, alkali metasomatism.

Geochemistry and Petrogenesis of Kunduru Betta Calc-Alkaline Ring Complex in the Dharwar Craton, Southern India

M.V. Subba Rao and B.L. Narayana

National Geophysical Research Institute, Hyderabad - 500 007, India, E-mail: postmast@csngri.ren.nic.in

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Abstract

The Kunduru Betta Ring Complex (KRC), at the southern margin of Dharwar craton, South India, comprises metaluminous sub-solvus syenites and quartz monzonite with a concentric disposition younging towards the center. An outer mafic syenite (of lamprophyric affinity) is followed by porphyritic monzonite, quartz monzodiorite and finally a quartz monzonitic stock at the centre.

SiO_2 , Al_2O_3 and Na_2O increase from the primitive lamprophyric mafic syenite to the quartz monzonite through the intermediate members, while CaO , MgO , $\text{Fe}_2\text{O}_3^{\text{T}}$, TiO_2 , P_2O_5 and MnO show an opposite trend suggesting fractionation of hornblende, clinopyroxene, biotite, apatite, sphene, and iron oxide minerals. Rb, Th and U increase with a complementary decrease in Sc, V, Cr, Co, Cu, Sr and Ba from the outer mafic syenite to the inner quartz monzonite. Y, Zr and Hf decrease from lamprophyric mafic syenite to quartz monzodiorite and the trend is reversed in the final quartz monzonite phase. However, the suite is characterised by a compositional gap between quartz monzodiorite and quartz monzonite. Total REE gradually decrease from the mafic syenite to quartz monzonite and the REE distribution patterns show LREE-enriched and HREE-depleted parallel distributions with negligible Eu anomalies.

The geochemical data suggest that the rock types were formed as products of progressive differentiation by crystal fractionation of calc-alkaline lamprophyric parent magma which was derived by partial melting of metasomatically enriched mantle in the Kabini lineament. Although the quartz monzonites conform to the trend of differentiated Kunduru Betta suite, the compositional gap between them and the quartz monzodiorite precludes their origin by simple differentiation. It is suggested that convective liquid fractionation might have resulted in the discrete body of quartz monzonite.

Key words: Calc-alkaline ring complex, Dharwar craton, enriched mantle, Kunduru Betta, geochemistry.

The Late Carboniferous Glacial to Postglacial Transition: Facies and Sequence Stratigraphy, Western Paganzo Basin, Argentina

Pablo José Pazos

Dpto. Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Pabellón II Ciudad Universitaria, Ciudad de Buenos Aires 1428, Argentina, E-mail: pazos@gl.fcen.uba.ar

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Abstract

Namurian-early Westphalian glacial-postglacial deposits have been documented in the Paganzo Basin, Argentina, but integrated sequence stratigraphic and sedimentological analyses of the glacial-postglacial transition are rare. In the Cuesta de Huaco section the glacial-postglacial transition encompasses the lower sequence of the existing schemes. Glacioeustatic changes in sea-level controlled the architecture and vertical arrangement of facies. The basal sequence boundary is coeval with the onset of glaciation when sea level fell, contemporaneous with glacial erosion and bypass of sediment. The upper sequence boundary is a high-frequency sequence boundary. The basal deposits are interpreted as an early transgressive systems tract (ETST) initiated during glacial retreat. The interval fines upward, contains current reworked diamictites, conglomerates and sandstones deposited in a subglacial to proglacial environment (Facies I-II) and ice-rafted glaciomarine rhythmites (Facies III). Postglacial brackish-marine black shales (Facies IV) represent the late transgressive systems tract (LTST). Micritic-limestone beds were deposited during a period of sediment starvation coeval with the maximum marine inundation in the basin (MFZ). It marks a turnaround in the stacking pattern that became coarsening and thickening upward during the overlying highstand systems tract (HST). It consists of fine-grained turbidites (Facies V) and classical turbidites with wave reworked beds at the top (Facies VI) deposited in a shallow deltaic systems. Intervening postglacial brackish deposits contain an ichnofauna dominated by trackways of arthropods and minor grazing traces, preserved in bedding planes, that resemble nonmarine ichnocoenoses and differ from the archetypal brackish ichnofaunas, even when palynological data support the saline-depleted environment.

Key words: Gondwana, Carboniferous, glaciation, sequence stratigraphy, ichnology.

Low Pressure Metamorphism, Deformation and Syntectonic Granite Emplacement in the Palaeoproterozoic Mahakoshal Supracrustal Belt, Central India

Abhinaba Roy, M. Hanuma Prasad and M.K. Devarajan

Geological Survey of India, Central Region, P.O. Seminary Hills, Nagpur - 440 006, India, E-mail: gsigdi@nagpur.dot.net.in, gsipgrs@nagpur.dot.net.in

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Abstract

Porphyroblast assemblage of andalusite, garnet, staurolite and cordierite in the metasedimentary rocks of the Palaeoproterozoic Mahakoshal supracrustal belt suggests low pressure/medium temperature metamorphism. These porphyroblasts exhibit both dynamic (syn-kinematic) and static (post-kinematic) growth. Field and petrographic studies indicate that the growth of andalusite and garnet porphyroblasts initiated during the early stages of D_2 (S_2 cleavage) deformation and outlasted it. The staurolite porphyroblasts appeared during the late stages of D_2 deformation and continued after it. Restricted occurrence of these syn-kinematic porphyroblasts to the vicinity of the shear zone suggest that intense deformation and repetitive cleavage development, apart from the elevated temperature conditions, enhanced the growth of the porphyroblasts. The cordierite porphyroblasts, whose growth is controlled essentially by the lithological composition, exhibit static growth, post-dating D_1 (S_1 cleavage) deformation. The mineralogical assemblages in the metasedimentary rocks suggest a peak P and T around 3.5 kb and 550–600°C respectively, which was attained during the D_2 deformation. The D_2 deformation was coeval with the development of reverse-oblique slip ductile shear zone and emplacement of linear, syn-kinematic granites along the southern margin of the belt. This indicates a contractional tectonic regime, wherein rising granitic plutons caused advective heat transfer to the middle and upper crust and created relatively higher temperature conditions at lower pressure.

Key words: Low pressure metamorphism, compressive regime, Palaeoproterozoic, Mahakoshal belt, Central India.

Arsenic Pollution in Groundwater of West Bengal, India – An Insight into the Problem by Subsurface Sediment Analysis

Tarakanath Pal, P.K. Mukherjee, S. Sengupta, A.K. Bhattacharyya and S. Shome

Central Petrological Laboratories, Geological Survey of India, 15 A and B, Kyd Street, Kolkata - 700 016, India,
E-mail: tnpal@hotmail.com

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Abstract

Arsenic values in groundwater above the maximum permissible limit of 0.05 mg/l have been reported from several areas of the lower delta region of the Ganga-Padma river system. It is confined to areas east of Hooghly River and to the shallow aquifer (<150 m below ground level). The aquifer sediments are channel fill sand and over-bank levee mud, deposited during late Holocene and Recent period. The present study at Chakdah in Nadia district and at Baruipur in 24-Parganas (S) district, West Bengal, demonstrates that tube wells yielding arsenious water occupy small, isolated clusters surrounded by safe water yielding tube wells. This is inferred to be the general pattern for the entire delta.

Arsenic values in sub-surface sediments from arsenious water zones are significantly higher than values from safe water zones. The major part of the sediments, consisting of non-magnetic and some feebly magnetic minerals, is arsenic free. Some iron-rich clastic minerals, like illite, biotite, chlorite, Fe-coated grains, and also the authigenic siderite concretions, which together constitute only a small part of the sediments, are carriers of arsenic and contribute the element to contaminate groundwater. Illite, biotite and chlorite degenerate to produce iron oxide/hydroxide coating on their surface and also on the surface of some other sand particles. Arsenic is adsorbed on the iron hydroxide coating creating one kind of sink for the element. Bacteria induced growth of siderite concretions grow initially on these clastic minerals and after attaining bigger size fall off as individual globules. Arsenic gets adsorbed on these concretions forming a second kind of sink for the element. Arsenic carrying river water inundates the lower delta at the time of seasonal flood. Arsenic percolates with the water downwards to the shallow aquifer. It gets fixed in the aquifer sediments in the two ways described and is retained in the traps thus formed.

Locally developed reducing condition causes dissolution of iron hydroxide coating on the surface of clastic arsenic traps and also of the siderite concretions. This leads to increase in arsenic level in groundwater at these sites. A currently active process of creation and periodic enrichment of the arsenic traps followed by their subsequent depletion through desorption and dissolution is suggested to be the reason for arsenic contamination of groundwater in this part of the delta.

Key words: Arsenic pollution, groundwater, subsurface sediment analysis, arsenic rich phases, West Bengal.

Basement Structure Below the Coastal Belt of Krishna-Godavari Basin: Correlation Between Seismic Structure and Well Information

P.R. Reddy, N. Venkateswarlu, A.S.S.R.S. Prasad and P. Koteswara Rao

National Geophysical Research Institute, Uppal Road, Hyderabad - 500 007, India

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Abstract

Seismic refraction modeling integrating the litholog data now available from the deep wells recently drilled by the Oil and Natural Gas Corporation (ONGC) indicates large subcrop extensions of the Rajahmundry Traps correlated with the Deccan volcanism along the coastal belt of Krishna-Godavari basin, India. It is suggested that the Rajahmundry Traps were erupted through a volcanic vent or a zone of basement faults along the present East Coast, possibly in and around Razole. The extensive development of the Rajahmundry Traps also implies that the mantle plume responsible for the Deccan volcanism had such large dimensions that matched or transcended the dimensions of the Indian Peninsular Shield.

Key words: DSS profile, deep crustal structure, Rajahmundry traps, Deccan volcanism, Krishna-Godavari basin.

Cumulatic Diorites Related to Post-Collisional, Brasiliano/ Pan-African Mafic Magmatism in the Vila Nova Belt, Southern Brazil

Luciane Garavaglia¹, Maria de Fátima Bitencourt² and Lauro Valentim Stoll Nardi³

¹ *Curso de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, Porto Alegre, Rio Grande do Sul, 91500-000, Brazil*

² *Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, Porto Alegre, Rio Grande do Sul, 91500-000, Brazil, E-mail: fatimab@if.ufrgs.br*

³ *Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500, Porto Alegre, Rio Grande do Sul, 91500-000, Brazil, E-mail: lnardi@if.ufrgs.br*

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Abstract

The Capivaras Diorite, in the Vila Nova region, NW of the Sul-rio-grandense Shield, is composed of six NE- to NNE-oriented rock bodies of late-tectonic emplacement relative to the D3 deformation phase which forms subvertical high-strain zones in basement gneiss sequences. Within these intrusive bodies, a shape foliation is present, generally parallel to contacts and displaying a local solid-state deformational component. The internal structure of the Capivaras Diorite main intrusion is marked by a zone of intense flow and mingling, characterized by strong shape foliation and layers of variable texture and composition, which result from cumulative processes, heterogeneous flow and interaction of coeval, compositionally contrasting magmas. The central part of this intrusion is texturally homogeneous and slightly foliated, even though cumulative processes have remained important during its formation. Along the contact with basement gneisses, fine-grained diorites are found, which are considered to be compositionally close to the parental magma of the Capivaras Diorite. This magma has a mildly alkaline affinity and shows moderate to high contents of Zr, Ti and P. Highly-fractionated REE patterns, low Nb contents, as well as high contents of K, Sr, Ba, and Rb, are suggestive of its provenance from mantle sources which have been previously affected by subduction processes, such as those of mature magmatic arcs or post-collisional settings. Magmatic evolution was controlled by cumulative processes and gave origin to pyroxene orthocumulates, plagioclase-pyroxene orthocumulates, pyroxene adcumulates, and more rarely plagioclase adcumulates. The cumulative origin of these rocks is indicated by field, textural and geochemical features, which are distinct from those of crystallized liquids. The compositional diversity of cumulates has led to the generation of compositionally different melts. The early-formed pyroxene cumulates have caused Ca, Al, Na, Ba, and Sr enrichment in the magmatic liquid, leading to plagioclase crystallization and accumulation. Coarse-grained mafelsic cumulates were formed during the late stages of magmatic crystallization, due to volatile enrichment of the intercumulus liquid. Considering geological relations, as well as tectonic and compositional features of the Capivaras Diorite, it is interpreted as part of Neoproterozoic magmatism related to the post-collisional stage of Brasiliano/Pan-African Orogenic Cycle in southern Brazil.

Key words: Diorite, post-collisional magmatism, cumulates, differentiation processes, flow-segregation.

SPECIAL CORRESPONDENCE

Gondwana Lithostratigraphy of Peninsular India

Prodip Dutta

Department of Earth Sciences, Indiana State University, Terre Haute, IN 47809 USA, E-mail: gedutta@scifac.indstate.edu

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Abstract

The controversy regarding the stratigraphic interpretation of the Indian Gondwana succession in the Peninsular Basins has continued for more than a century, with the exception of the Damodar and Satpura Basins. While the stratigraphic reconstruction in Damodar and Satpur was based on the order of superposition of strata, elsewhere the relative ages were based on paleontological evidence that disregarded various physical criteria including the order of superposition.

Overlying the Precambrian crystalline basement, the Gondwana succession of late Permian to early Jurassic age can be classified into four sedimentary facies; a glaciogenic facies (Facies A), a coal-bearing facies (Facies B), a red shale-sandstone facies (Facies C) and a hill-forming coarse sandstone-conglomeratic facies (Facies D). The stratigraphic order of these four facies in ascending order from Facies A at the bottom to Facies D at the top is well established in the Damodar and Satpura regions. In both areas, Facies D overlies the underlying older sediments as well as the crystalline basement with a pronounced unconformity. However, in the Pranhita-Godavari and Son Basins (and elsewhere) the stratigraphic relations between Facies B, Facies C and Facies D are controversial. One such enigma is where the sequence of Facies C and Facies D are repeated several times in the geological column. This interpretation contrasts with the supposed genesis of climatically controlled lithic fill in Gondwana Basins.

Overturning the standard stratigraphic relation between Facies C and Facies D was based on fragmentary fossil evidence where the Lower Gondwana flora seems to be present in Upper Gondwana rocks. Turning the stratigraphy upside down was done without establishing the order of superposition between strata. Throughout the 20th century, most stratigraphers working in the Pranhita-Godavari and Son Basins worked within a fossil-based stratigraphic paradigm. This resulted in still more confusion, the magnitude of which can be appreciated as one browses through various interpretations presented in innumerable publications.

In this paper, we attempt to offer a lithostratigraphic interpretation of the Peninsular Gondwana Basins based only on physical criteria such as lithological association, their petrographical characteristics and the most fundamental tool of stratigraphy, 'the order of superposition'.

Key words: Gondwana, lithostratigraphy, Pranhita-Godavari, stratigraphy, Peninsular India.

CORRESPONDENCE

Evaluation of Natural Defects in Commercial Decorative Rock Deposits in Karnataka, India

D. Venkat Reddy

Geology Section, Department of Civil Engineering, Karnataka Regional Engineering College, Surathkal, Srinivasnagar - 574 157, Mangalore, India, E-mail: dvr@krec.ernet.in

Abstract

Karnataka state is a pioneer in the exploitation of commercial decorative rock resources and in establishing a firm base for the stone industry. The commercial stone industry in the state has grown in status contributing about 40% of the decorative/dimensional stones of both polished and rough blocks exported from the country. Karnataka state forms a part of the Indian Peninsular Shield and extends over an area of 1,91,792 km². Peninsular gneisses, Closepet granite and Younger dykes such as dolerite, felsite and pyroxenite of different ages are the main sources of commercial rock deposits. The state also produces premium varieties like ruby red and black (dolerite) granite and other popular varieties. The demand for the premium varieties is generally steady in international market. World famous commercial ornamental stone varieties are being exploited from Kanakapura, Bangalore, Malaikaval, Hassan, Sira, Tumkur and Illkal in Bijapur districts of Karnataka. Important commercial stones in the Karnataka stone industry are marketed with commercial names such as Imperial red, Himalayan blue, Ocean white, Sabal black, Ruby red, Hassan green, Sawan rose, Sira grey, English teak, Tiger's skin, Pink panther, Salt and pepper, Cat's eye, and Chilly red.

The success of the commercial stone industry solely depends upon the availability of large reserves of defect free rock deposits. Detection of defects in commercial rock deposits plays an important role in quality assessment. Macro defects can be detected by visual examination of commercial rock deposits. Micro discontinuities such as altered or twisted minerals can be detected by systematic micropetrographic analysis of the rock specimens. In Karnataka, too many organizations, entrepreneurs and individuals are investing huge amounts without evaluating the quality of the deposit. This results in poor quality stone and subsequent quarry abandonment. Quarry owners and stone exporters should be quality conscious about export-oriented natural stones in order to remain in the business and maintain the reputation of the Karnataka stone industry.

Key words: Karnataka, commercial stone industry, premium varieties, natural defects, trade name.