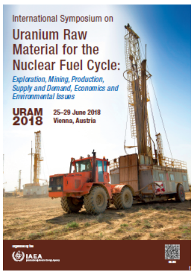


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# Conventional and unconventional uranium resources in the Carajás Mineral Province, Brazil: prospectivity criteria for IOCG and granite-related deposits

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INTRODUCTION

The Amazonian Craton (South America) hosts several favourable areas for uranium exploration that are still barely acknowledged. The most significant of the recognized resources are in the Carajás Province, the oldest known Archean crustal fragment in the craton. Identified uranium resources are unconventional, hosted by the world-class IOCG deposits from the Carajás Copper-Gold Belt [1, 2]. Nevertheless, the potential for granite-related resources is notable, as Paleoproterozoic A-type granitic plutons cover several thousands of square kilometres of the province's surface and present very high uranium background values [3-4].

This work aims to present an overview of the uranium potential in the Carajás Mineral Province and regional prospectivity criteria for uranium-rich IOCG and granite-related uranium deposits, based on Airborne geophysics and regional- to deposit-scale structural and geological data.

TECTONOSTRATIGRAPHIC FRAMEWORK

There are three main rock-generation ages in the Carajás Province tectonostratigraphic evolution, namely in the Mesoarchean (3.02 to 2.83 Ga), Neoarchean (2.76 to 2.55 Ga) and in the Paleoproterozoic (1.88 Ga). The oldest rocks are gneisses, greenstone belts and granitoids developed under an accretionary-collisional system, reported as the Itacaiunas Belt [5-6]. Collisional peak metamorphism was dated at 2.85 Ga, and metamorphic fabrics are of medium to high amphibolite facies [6-7]. This rock association represents the basement of the Carajás Basin (2.76 to 2.70 Ga), a Neoarchean rift-related metavolcanossedimentary sequence [8-9] that hosts supergiant BIF-related iron ore deposits and other exhalative resources, such as Cu-Zn volcanogenic massive sulphides [9]. Coeval bimodal magmatism is represented by several A-type granites and mafic-ultramafic intrusions. Late stage granitic dykes persist to emplace until 2.55 Ga and are spatially and chronologically related to several magnetite-rich IOCG deposits [2, 10]. At about 1.88 Ga, the region experienced an anorogenic magmatic event, which also affected all the central-eastern side of the Amazonian Craton, known as the Uatumã magmatism. This event produced a second generation of A-type granites in the province [3], emplaced at shallower depths and related to widespread hydrothermal activity in a brittle, fluid-dominated extensional environment

Neoarchean rocks were only deformed and metamorphosed in the Paleoproterozoic. There are two events of ductile to ductile-brittle deformation and metamorphism that can be recognized. The oldest one is the Transamazonian Orogenic Cycle (2.20 to 2.05 Ga), a collisional system that agglutinated several Archean nuclei and Rhyacian magmatic arcs and greenstone belts [6, 11], related in the province to low green schist (south) to high amphibolite (north) metamorphic fabrics and structures. To the north, the Archean units are limited by a collisional suture from Rhyacian plutonic assemblages that are imbricated over the province [6]. The youngest one is the Sereno Event, an intracontinental orogeny correlated to Orosirian accretionary-collisional belts that surrounded the Amazonian protocraton at 2.00 to 1.98 Ga [6]. Sereno fabrics are of very low grade, from sub-greenschist to greenschist facies.

The Mesoarchean main structural trend is ductile in character and of an E-W direction, while the Transamazonian trend varies between ENE-WSW and NE-SW. The Sereno structures are widespread, although less penetrative and of a ductile-brittle style, in an X-shaped pair of oblique structures in WNW-ESE and ENE-WSW directions [6].

## URANIUM RESOURCES IN CARAJÁS MINERAL PROVINCE

The Carajás Mineral Province hosts some of the largest and oldest IOCG deposits in the world, known for their relatively high uranium contents in comparison to the majority of other deposits from the same class. Main orebodies are Archean (2.70 to 2.55 Ga), but several of them present a Paleoproterozoic (1.88 Ga) granite-related hydrothermal overprint, responsible for local remobilization, endowment in copper sulphides and, as a result, the formation of high grade oreshoots and/or spatially-related secondary orebodies, considered by some authors as a second IOCG-like event [2, 10, 12].

The deposits show a wide range of host rocks but share several characteristics, like an intense Fe metassomatism associated with the occurrence of low sulphidation sulphides, LREE enrichment, high yet variable amounts of Co, Ni, Pb, Zn, As, Bi, W and U, spatial and chronological correlation to A-type granitic plutons / dykes, and breccia-like textures [1-2, 10]. Archean and Paleoproterozoic orebodies differ from each other, however, in their hydrothermal assemblage and ore minerals, reflecting variations in the fluids oxidation stage, pH, fO2 and fS2 [10, 12]. Older deposits are magnetite-rich and thought to be formed in deeper crustal levels, while the secondary younger orebodies are hematite-rich, silica-saturated, and developed in shallower environments [2]. In addition, Archean deposits were deformed and metamorphosed by the Transamazonian and Sereno events, while Paleoproterozoic deposits are post-tectonic, preserving their original textures and mineralogy [13].

The most significant uranium-bearing minerals are uraninite, thorianite and thorite [10]. Allanite and monazite concentrations may also be relevant, although uranium grades are much smaller. All phases occur as inclusions or within massive sulphide and Fe-oxides masses in the ore mineral assemblage. Additionally, uraninite and allanite are common accessory minerals in the potassic alteration assemblage, usually occurring as inclusions in biotite and garnet.

Known uranium resources are of 150,000 tU [14], but that value is highly underestimated, as it considers only four out of a dozen known IOCG deposits (Salobo, Sossego-Sequeirinho, Cristalino and Igarapé Bahia-Alemão). Grades are low, ranging from 60 to 130 ppm U [14]

Paleoproterozoic granite-related (and metasomatic?) uranium deposits remain undiscovered in the province, but the exploration potential for that mineral system is remarkable, especially where plutons and dykes are affected by late to post-magmatic structures and alteration. Uranium background values are very high in comparison to other A-type granites, varying from 10 to 43 ppm U, while Th/U ratio is between 1.11 and 4.71. The A-type granites are subalkaline to alkaline, developed through fractional crystallization and presenting variable sources derived from Archean crust [3-4]. Hydrothermalism and brittle deformation also affect the granites, along NE-SW and NW-SE structures. Greisen zones are common within the granitic bodies, sometimes related to tin mineralizations [4].

## DISCUSSION: PROSPECTIVITY CRITERIA FOR URANIUM RESOURCES

Some authors suggest that high uranium grades in IOCG systems are dependent on higher background values of host rocks, as observed in Australian IOCG-U provinces [15-16]. In the Carajás Province, however, uranium (and gold) grades are usually higher at Paleoproterozoic oreshoots and orebodies, especially those that are close or crosscut by coeval granites. This indicate that uranium (and gold?) endowment is at least in part linked to granite-related hydrothermal input. The uranium source, in this case, would be mostly magmatic rather than leached from host rocks.

The energy drive for Paleoproterozoic fluid circulation is thought to be related to the granitic magmatism, but the critical control for both magmatic and hydrothermal activities seems to be structural. Granitic plutons and dykes were emplaced in sites where structures are denser and their geometry roughly follows previous structural patterns. Besides this, the structural framework of the host rocks, reactivated under brittle conditions during granitic intrusion, coincides with the main granite-related and IOCG-like alteration zones.

Structures that acted as primary fluid pathways usually present breccia textures and silicification, showing a singular prominent topography that is recognizable even in SRTM (Shuttle Radar Topography Mission) images. Regional alteration assemblage that indicates proximity to mineralized sites includes quartz, chlorite, epidote, albite, carbonate, actinolite, scapolite, greenish biotite, sericite, tourmaline and stilplomelane. The main oxide is hematite, but occasionally magnetite is also found, while sulphides include chalcopirite, bornite and chalcocite. This mineral assemblage can pervasively replace the host rocks or occur in zoned sintaxial veins, usually forming stockworks.

Airborne radiometric data are a powerful tool to regional targeting for IOCG and granite-related deposits. The uranium concentrations normalized using thorium (Ud) strongly correlate with the extensional structures.

Field relations also confirm that Ud anomalies are coincident with regional undeformed Paleoproterozoic alteration zones. Ud maps also highlight several potential sites for uranium research inside the granitic plutons, especially along crosscutting structures of NE-SW and NW-SE directions.

CONCLUSIONS

The development of prospectivity models for the Carajás Mineral Province is challenging, as three different mineralization ages are recognized. Isolating objective prospectivity criteria for each metallogenic epoch and mineral system is critical to the development of more precise exploration guidelines in the region.

The main regional prospectivity criteria to target uraniferous IOCG deposits in the Carajás Province are:

• Coincidence between high Ud values and fault zones;
• Proximity to deep structures;
• Proximity to 1.88 Ga granitic plutons and dykes;
• Occurrence of silicified fault zones;
• Occurrence of crosscutting structures and higher structural density;
• Occurrence of undeformed, post-tectonic, hematite-bearing hydrothermal assemblages.

Prospectivity criteria for granite-related deposits are still being investigated, but the most favourable sites seem to be those pointed out by Ud anomalies and that are coincident with post-magmatic alteration sites.

REFERENCES

[1] TALLARICO, F.H.B., "O Cinturão Cupro-Aurífero de Carajás, Brasil". Unpublished PhD thesis, Universidade Estadual de Campinas, São Paulo, Brazil (2003), 12 pp.
[2] XAVIER, R.P. et al. "The iron oxide copper–gold deposits of the Carajás Mineral Province, Brazil: an updated and critical review". In: Porter TM (ed) Hydrothermal Iron Oxide Copper-Gold & Related Deposits: A Global Perspective. Australian Miner. Fund, Adelaide (2010), Vol 3, pp. 285-306.
[3] DALL'AGNOL, R. et al. "Petrogenesis of the Paleoproterozoic, rapakivi, A-type granites of the Archean Carajás Metallogenic Province, Brazil". Lithos 80 (2005) 101-129
[4] TEIXEIRA, N.P. et al. "Geoquímica dos granitos paleoproterozóicos da Suíte Granítica Velho Guilherme, província estanífera do sul do Pará". Rev Bras Geoc 35 (2005) 217-226.
[5] ARAUJO, O.J.B. et al. "A megaestruturação da folha Serra dos Carajás". Anais do 7º Congresso Latino Americano de Geologia (1988) 324-333.
[6] TAVARES, F.M. "EVOLUÇÃO GEOTECTÔNICA DO NORDESTE DA PROVÍNCIA CARAJÁS". Unpublished PhD thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro (2015) 115p.
[7] MACHADO, N. et al. "U–Pb geochronology of Archean magmatism and basement reactivation in the Carajás Area, Amazon Shield, Brazil". Precambrian Research 49 (2991) 1-26.
[8] GIBBS, A.K. et al. "Age and composition of the Grão Pará Group volcanics, Serra dos Carajás". Rev Bras Geoc 16 (1986) 201-211.
[9] DOCEGEO. "Revisão litoestratigráfica da Província Mineral de Carajás - Litoestratigrafia e principais depósitos minerais". Anais do 34º Congresso Brasileiro de Geologia, Belém (1988) 11-54.
[10] GRAINGER, C.J. et al. "Metallogenesis of the Carajás Mineral Province, Southern Amazon Craton, Brazil: Varying styles of Archean through Paleoproterozoic to Neoproterozoic base- and precious-metal mineralisation"Ore Geology Reviews 33 (2007) 451-489.
[11] CORDANI, U.G. et al. "A Serra dos Carajás como região limítrofe entre províncias tectônicas". Ciências da Terra 9 (1984) 6-11.
[12] MORETO, C.P.N. "Neoarchean and Paleoproterozoic iron oxide-copper-gold events at the Sossego deposit, Carajás Province, Brazil, Re-Os and U-Pb geochronological evidence". Economic Geology 110 (2015) 809-835.
[13] TAVARES, F.M. et al. "O Cinturão Norte do Cobre da Província Mineral de Carajás: épocas metalogenéticas e controles críticos das mineralizações". Anais do 15º Simpósio de Geologia da Amazônia, Belém (2017), CD-ROM.
[14] HEIDER, M. "Urânio". In. Anuário Mineral Brasileiro: principais substâncias metálicas. Departamento Nacional de Produção Mineral, Brasília (2016) 70-92.
[15] HITZMAN, M.W., VALENTA, R.K. "Uranium in iron oxide-coppergold (IOCG) systems". Economic Geology 100 (2005) 1657-1661.
[16] SKIRROW, R.G. "Controls on uranium in iron oxide copper-gold systems: insights from Proterozoic and Paleozoic deposits in southern Australia"11th SGA Biennial Meeting abstracts, Antofagasta, Chile (2011) 482-484.

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