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Graphite-manganese coupling and cobalt enrichment in a Paleoproterozoic redox basin

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Graphite-manganese-bearing rocks in redox-sensitive environments can concentrate critical metals such as cobalt; however, the genetic links between organic carbon burial, manganese redox cycling, and Co enrichment in high-grade metamorphosed terranes remain poorly constrained. This study investigates the relationship between graphite-manganese mineralization and cobalt enrichment in the Paleoproterozoic (~2.1 Ga) Lagoa do Riacho manganese deposit, northern Borborema Province, NE Brazil, integrating X-ray diffraction (XRD), reflected-light petrography, scanning electron microscopy (SEM), and quantitative electron microprobe analyses (EPMA). The deposit forms a ~70 km-long N–NE-trending belt within the high-grade Canindé do Ceará Complex, where Mn-rich stratiform layers occur parallel to regional foliation and are structurally concentrated in synclinal fold cores. The protore is dominated by Mn-silicates and spessartine-rich assemblages intimately associated with disseminated graphite. Petrographic and SEM observations reveal systematic intergrowths between graphite and Co-bearing sulfides and sulfoarsenides, particularly cobaltite and siegenite, occurring as disseminated grains and preserving textures consistent with early syn-diagenetic nucleation. Co and Ni are strongly concentrated in sulfide-bearing garnetites and Mn-silicate rocks, whereas quartz-rich units display significantly lower abundances; copper shows a systematic association with sulfide assemblages, including chalcopyrite and covellite, particularly within garnet quartzite domains. Textural relationships indicate that sulfide and sulfoarsenide precipitation were spatially coupled with graphite before peak metamorphism. We propose a redox-controlled enrichment model in which Co and Ni were initially scavenged by Mn oxyhydroxides under oxic conditions, followed by burial-driven reduction, Mn carbonate formation, and precipitation of Co–Ni sulfides within organic-rich layers. Subsequent amphibolite- to granulite-facies metamorphism promoted recrystallization and limited remobilization while preserving primary stratiform metal distribution. The Lagoa do Riacho deposit thus represents a Paleoproterozoic Mn-Co-Ni system genetically linked to organic matter burial and redox cycling, highlighting the exploration potential of graphite-manganese-bearing rocks as critical-metal reservoirs.