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EMERALD DEPOSITS OF BRAZIL AND ITS GENETIC LINK WITH INFILTRATIONAL METASOMATIC PROCESSES

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Introduction

The main metallogenic Brazilian provinces are related to Precambrian shields enclosing important deposits associated to various geological environments. Among all these mineralizations, geustone deposits are of great importance in Brazil and found in many Brazilian states: agate, amethyst, tourmaline and topaz assume the most important production in weight terms while emerald is characterized by its high commercial value and represents the main exportation of uncut and cut gems.

In 1961, the first economic occurrence of emerald was discovered at Salininha (Bahia State) and renewed interest for prospection of this gemstone in the State. After 1963, other important occurrences were encountered and Brazil soon, becomes the most representative world producer in volume and also in emerald quality. For instance, four economic emerald deposits are in production: the prospecting pits (called garimpos) of Carnaíba, Socotó (Bahia State), Santa Terezinha de Goiás (Goiás State) and the private mine of Itabira (Belmont Gemas Ltda Company, Minas Gerais State) (Fig. 1).

Socotó and Carnaíba emerald deposits (Bahia State)

These deposits are associated with two proterozoic leucogranitic massifs (Santana, 1981; Rudowski et al., 1987a, b; Sabaté et al., 1987), intruding the volcanosedimentary terranes of the Serra da Jacobina and the gneissic-migmatitic archean basement.

The Socotó prospecting pits are localized in the northern part of the Campo Formoso granite, in serpentinites occurring as imbricated structures on the Archean basement. The ultrabasic horizon, oriented N 150-180° and dipping 50 to 70°W, is intruded by coarse grained albitic and/or tourmalinic pegmatoids with minor quartz or quartz $\pm$ plagioclase tourmaline veins. The pegmatoids, which consist of a successive swarm of parallel veins, developed a metasomatic zoning at the contact within serpentinites. This zoning is characterized by a regular succession of zones with sharp replacement fronts and different mineralogy (Rudowski et al., 1987a, b). Emerald is intimately associated to a monomineralic F-rich phlogopitite formed symmetrically on each flank of the pegmatoid; it can also be linked to the veins. In addition, the pegmatoid shows the presence of scheelite, molybdenite, pyrite, phenakite and apatite.

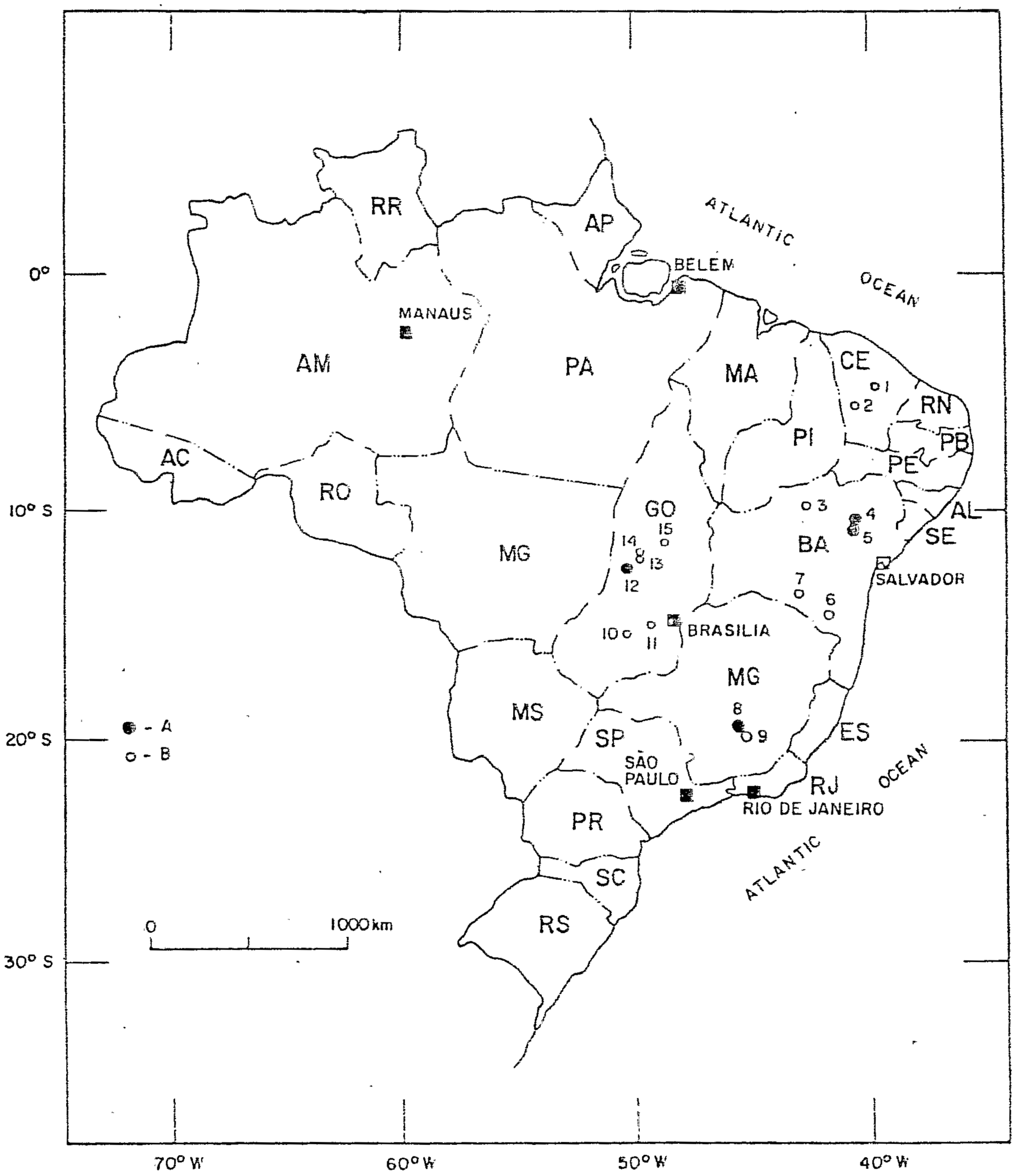

Figure 1 — Emerald and green beryl mineralizations of Brazil. A: economic deposits B: Ocurrences. Ceará State - 1: Coque; 2: Tauá. Bahia State - 3: Salininha; 4: Socotó; 5: Carnaíba; 6: Anagé with the prospecting pits of Sossego, Fazenda Açude, Pombos; 7: Brumado. Minas Gerais State - 8: Itabira; 9: Santana dos Ferros. Goiás State - 10: Itaberaí - Fazenda das Lages; 11: Pirenópolis; 12: Santa Terezinha; 13: Maria Rosa; 14: Porangatu; 15: Pela Ema-Minuaçu.

The Carnaíba prospecting pits are developed around the Carnaíba granite and are divided in two main districts (Couto & Almeida, 1982; Moreira & Santana, 1982): Carnaíba de Cima, with the pits of Trecho Velho, Novo, Bica, Cabra, situated at 1000 m above sea level, and Carnaíba de Baixo, with pits developed in roof pendants of serpentinites into the granite (Bode, Gavião, Lagarta and Formiga) or with pits mined in country rock terrane (Marota, Braúlia).

The emerald mineralization is related to intrusive albitic (albite-oligoclase), quartz-albitic pegmatoids, or quartz veins crosscutting the serpentinites. Two kinds of veins are distinguished: the fracture veins called "frinchas" and contact veins "esteira". These later are developed along the lithological contact quartzite-intercalated serpentinites (Fig. 2), case of Trecho Novo, Cabra and Bica, assuming the main emerald production of Carnaíba. The "frincha" vein is generally vertical with a medium width of 0.5 m, without lithological control and the emerald is of good quality. Molybdenite mineralization is intensive (Trecho Velho). The presence of molybdenite is an important feature of Carnaíba de Baixo district which at the moment is responsible for the total Brazilian molybdenite production. In Marota, the emerald production is insignificant. The pits are the deepest of the area (80 - 100 m) and show evidence for the presence of numerous coarse to fine grained albitic pegmatoid dykes with an important molybdenite dissemination. In Braúlia prospecting pits, a typical and complete metasomatic sequence is developed at the contact of a retrometamorphosed tourmaline-albitic pegmatoid sequence, 10 cm wide, within serpentinites, as previously described by Rudowski et al. (1987a, b). From internal to external zones, we have: a coarse grained phlogopitite zone (3 cm wide) with green beryl and apatite; a fine grained phlogopitite zone with chromite (35 cm); a composite phlogopitite zone with talc, chromite and magnetite (50 cm); a serpentinite, talc, chromite, magnetite zone with some disseminated phlogopite.

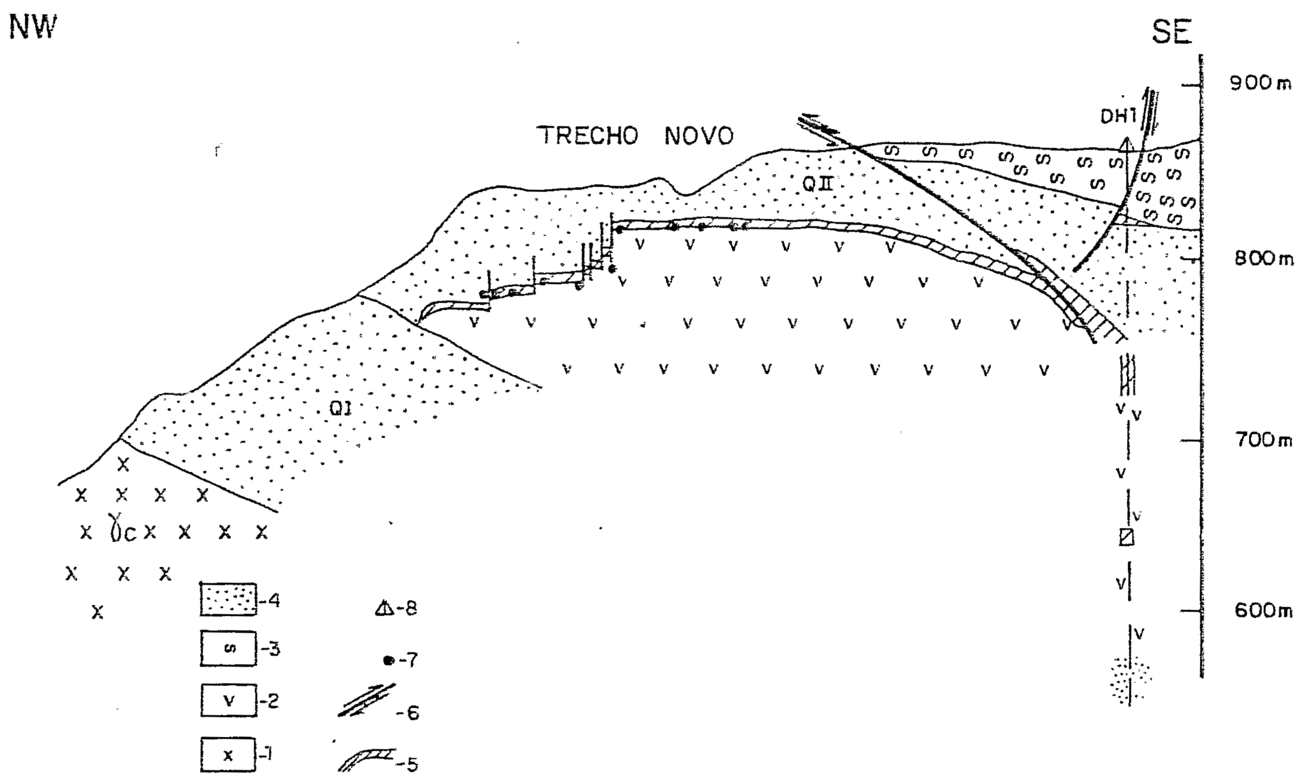

Figure 2 -- Geological section of Trecho Novo prospecting pits (Carnaíba, Bahia) showing the infiltrational metasomatic process developed along fractures and the lithological contact serpentinite-quartzite. 1: granite; 2: serpentinite; 3: basic rock; 4: quartzite; 5: metasomatic zones; 6: fault. 7: drifts; 8: drilling hole n. 1.

At the scale of the district, a vertical zoning of the mineralization relative to the granite is observed over a height of 400 m; it is characterized by a notable enrichment of molybdenite and quartz in Carnaíba de Baixo and a diminution of the quantity and quality of emerald. Drill holes undertaken at Carnaíba de Cima show, between depths of 800 and 600 m, the presence of fracture-type stockworks sometimes constituting zones 10 m wide, enriched quartz, tourmaline, green beryl and molybdenite (Fig. 2).

Santa Terezinha de Goiás emerald deposit (Goiás State)

The Santa Terezinha de Goiás mining area (Fig. 1), is located on the northern part of the Crixás greenstone belt. The associated sequence belongs to the Araxá Group (1600-1100 Ma) and is composed of mica schists and quartzites with intercalations of basic-ultrabasic intrusions and acidic sills. During the Uruçuano orogenesis (Espinhaço 1200-1100 Ma), regional metamorphism and deformation result in: North-South trending folds; formation of talc-chlorite carbonated schists, tremolite chlorite schists, metacherts (ferrous or magnesiferous), ferrugineous quartzites and matamarl intercalations; the intrusion of the São José do Alegre granitoid (Costa, 1986). The prospecting pits occur in a synformal structure affected by three phases of deformation (Lima et al., 1984); the structural control of the mineralization appears important: the mineralized zones present a stratiform aspect, 60 m wide and 400-500 m long, and developed in fractures parallel to the axial plane of the second regional folding oriented N 165-175° and dipping 20-30°W. The main mineralization is located in the hinge fold called "canões" by the prospectors, generally verticalized. This tectonic style is accompanied by important fracturing in the fold flanks, called "esteiras", which sometimes are linked with the presence of best quality emerald nests: the "frisos".

In addition, the mafic schists are intruded by pegmatoid veins whose expression is of minor importance at the scale of the district (Cassedanne & Sauër, 1984). Generally, emerald is confined to the talc schists and the biotitic rich rocks (F-rich phloglopitite). Finally, emerald can also be encountered in ferrous or manganesiferous metacherts intercalated within the talc schists.

Itabira emerald mining field (Minas Gerais State)

The Belmont mine is located at the contact between Archean paragneiss and a highly deformed granitoid called "leucogneiss". The paragenesis sequence is composed of metarenites and metagraywackes with intercalated metamorphic mafic formations. The "leucogneiss" correspond to a suite of granitic intrusions called Borrachudos granite type (Schorscher et al., 1982).

The mafic Belmont mine formations are transformed into biotite, talc-chlorite schists, and present a north-easterly direction and a width of 750 to

1000 m. They are intruded by a number of pegmatite bodies which are concentratet between the "leucogneiss" and the schists; these pegmatites are strongly weathered and they consist mainly of kaolin masses and quartz.

Emerald is linked either to the veins, or to the associated metasomatic zones (green chlorite schist, phlogopite schist) with chrysoberyl or alexandrite. The pegmatite veins crosscutting the "leucogneiss" are emerald-free but they contain beryl and/or aquamarine (Hänii et al., 1987).

Conclusions

Emerald deposits of Brazil form an original Precambrian mineralization type. They are always located in a characteristic geological environment composed of: - an Archean basement with tonalitic gneisses, migmatites, diatexites or granito-gneisses associations; volcanosedimentary series with intercalated iron formations, basic to ultrabasic horizons, cherts, quartzites belonging sometimes to a greenstone belt (case of Santa Terezinha de Goiás), and occurring as imbricated structures (Socotó) or affected by complex folding (Carnaíba) and deformation with an uncertain position relative to the basement (Santa Terezinha de Goiás, Itabira); granitoids and their magmatic to tardi-magmatic equivalents.

Indeed, all the deposits are located near granitoids with straightly links as Carnaíba and Socotó, or indirect and uncertain relations as for Santa Terezinha or Itabira. In all the cases, we can notice the evident association of emerald with "pegmatites" intruding the basic and ultrabasic rocks. In Santa Terezinha, the rarity of "pegmatites" at the level of observation allow one opens a debate on the genetic model: is this deposit stratiform and syngenetic? Furthermore, in Itabira, the origin of the dyke swarms of "pegmatites" is open to debate: are they magmatic or metamorphic?

The emerald mineralization is contained in phlogopitites resulting from the metasomatic transformation developed in serpentinites, talc schists or tremolitic schists, of a volcanosedimentary sequence (generally greenschist metamorphic facies). This typical metassomatism is related to an infiltrational process (Rudowski et al., 1987a, b) and is characterized by geological, geochemical, textural and mineralogical evidences.

The metasomatic rocks show a regular zoning, each zone being of different mineral composition and separated by sharp and clear limits. The example of Braúlia prospecting pit is particularly illustrative. These metasomatic zonings were already described and theoritically well detailed by Korzhinskii (1965, 1970): they are the result from the flowing of a solution into rocks and the percolation by a system of fine pores; these last owing reactions into the rocks and changing in the composition of the solution, and so producing the described metasomatic column. Sometimes, they appear more complicated in the case of tremolitic intercalations within the talc schists or the serpentinites (Rudowski, in preparation). In all the deposits, these metasomatic columns exhibit a monomineralic central zone developed symmetrically on the sides of an infiltrating vein, or closed fissure, described as the typical F-rich phlogopitite. This infiltrational metasomatism is evidently controlled by tectonic and lithologic factors. In Carnaíba, the subvertical fracture veins are well developed near the granite and form the channel of the ascending fluids while the contact veins are developed along the lithological contact quartzite-ultrabasic formations. In this case, considering a moderate level of erosion, different from the actual and without granite outcropping, the famous debate of stratiform deposits, will be opened as discussed for stratiform tungsten deposits. Drill holes, underground mining and field observations demostrate clearly that the stratiform aspect is so to be related to a lithological control of the percolating fluids, data reinforcing the importance of the infiltrational process in Carnaíba minig district.

A tectonic control can be advanced also in Santa Terezinha de Goiás were the mineralization is well developed in the axial plane or in the hinge of the folds and associated contemporaneous fractures; also in Itabira were the deposits is located along the Borrachudos granitoidic type and along an important regional overthrust. The lithological control is assumed by the geological formations having different competence, or in the case of the Santa Terezinha by the impermeable talc schists and their facility to be deformed, leading the presence of "soap layers" in the volcanosedimentary serie.

The different features encountered in Carnaíba i.e. infiltrational K-metasomatism, Na-rich pegmatoid, concentration of Mo, W, silica near the granite and a vertical zoning of the mineralization, result from the infiltration and interaction of acidic magmatic fluids within basic formations. They are phenomena involving acid-base interactions described by Korzhinskii (1970) as "an acidic wave directly connected with the crystallization of a magma" intruding basic environments (carbonate or basic rocks), or as to the hydrothermal acidic-alkaline differentiation (Korzhinskii, 1958). So, as the magmatic solutions penetrate the serpentinites, the basicity of the solution increases related to the dissolution of bases, especially Mg, from the wall rocks. Thus, the concentration of all the other bases in the solution increases, specially the activity of the alkali oxides as potassium and sodium, and also the alkalinity of the solution. In this chemical system, a zone of alkalinity is formed around the basic rocks owing to a high diffusion of potassium inducing the K-metasomatism (potassium being more electropositive than sodium i.e. more basic) and proving definitively the predominant role of infiltration in this process.

The "acidic wave" produces a great base lixiviation in the lower part of the flux with the concentration and precipitation of the less mobile components as W and Mo (case of Marota and Braúlia prospecting pits) expliciting the molybdenum-silica rich cap developed around the granite. In the upper part of the hydrothermal fluid circulation system, the precipitation of the bases will predominate and so, producing the resulting vertical zoning observed in Carnaíba (with the major emerald concentration).

In Carnaíba prospecting pits, green beryl and molybdenite are linked to an albitic pegmatoid and not to the more typical granitic pegmatite (sensu stricto). Beus (1966) referred to this albitic type as "granitic pegmatites of the crossing line" while Korzhinskii (1970) refers to them as to "desilicated pegmatites". Such desilicated pegmatites appear extremely linked to complex mineral-fluid equilibrium due to the reative nature of the basic rocks. In all the studied deposits, the passage between a pegmatite to a desilicated pegmatite, at the contact zone granitic-basic rocks was not clearly observed. Such an illustrative and convincing phenomena was seem in Anagé emerald mining district (Bahia State): the Pombos and Fazenda Acude occurrences (n. 6, Fig. 1) are developed in intercalated biotite-tremolitic talc schists within augen biotitic gneisses, crosscuted by a dyke swarm of pegmatites. In the granite-gneisses, no desilication is observed but in the talc schist, the pegmatite is transformed in white fine grained pegmatoid; this phenomenum can also be seem at the centimetric scale where the pegmatoid lenses are enveloped by a phlogopitic metasomatic zone.

Nowadays, it is admited, as shown by the illustrative example of some stratiform tungsten skarn deposits as Sangdong in Korea or King Island in Tasmania, that infiltrational metasomatic processes can pervade rocks over a thickness of many kilometers. The stratiform aspect of the Be mineralization of Santa Terezinha de Goiás and the lack of direct granite connexion have lead to a conclusion in favor of a syngenetic source of beryllium. This tendency, also expressed in models of scheelite calc-silicate bands or scheelite skarn, involves the stratabound concept. Schwarz (1986) advance such an hypothesis referring its formation to a "pneumatolitic metasomatic phase" considering the stratabound bodies as the Be source. At the moment, no arguments are valid since the lack of detailed geologic and geochemical studies. However, as already discussed, geological, geochemical and mineralogical evidences favoured the infiltrational metasomatic process; the formation of the talc schist and the phlogopitite is not a single metamorphic phenomenon but it can be included in an important geothermal anomaly implying emplacement of granitoidic plutons not present neccessarily at the same levels of the mineralized formations.

The questions relative to the origin of the pegmatites associated to these emerald deposits, was fully discussed in the case of Socotó, Carnaíba and Santa Terezinha de Goiás: an igneous origin seems evident. Relatively to Itabira, its more ambiguous and the pegmatites can be linked to the pegmatites described by Schorscher et al. (1982), related to the Brazilian tectono-thermal event (500 Ma).

In conclusion, two kinds of pegmatites are linked to emerald deposits of Brazil: - pegmatites having characteristics with and igneous origin, directly related to a granitoidic intrusive as for Carnaíba and Socotó, or indirectly as for Santa Terezinha de Goiás, - pegmatites of uncertain origin but probably related to the huge emission of pegmatites during the Brazilian orogenic event corresponding to the famous aquamarine-beryl-tourmaline-Nb, Ta pegmatite provinces of Minas Gerais, Pernambuco, Rio Grande do Norte and Ceará.

In all the cases, the formation of emerald necessitates the circulation of acidic Be-bearing pegmatitic fluids enriched also in F, B, Cl, CO_2 into channels developed in ultrabasic rocks rich in Fe, V and Cr. Besides, the importance of the emerald mineralization will depend of several factors: fluid-rock interaction, width of the ultrabasic formations, time of circulation of the hydrothermal system and the thermodynamic evolution of the associated fluid phase (boiling, dilution processes, drop in pressure which can alter the stability of the Be-metal complexes and provoking the ore precipitation).

The main process involved in the formation of the observed metasomatic columns is the infiltration of a fluid along opened fractures. The resulting rock assemblage could be referred to as an "infiltrational metasomatic process" or considering that the ultrabasic rocks play the same "basic role" as carbonate formations to as an "infiltrational metasomatic basic skarn".

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