EPOCAS METALOGENETICAS DE YACIMIENTOS AURIFEROS DE BRASIL Y SUS RELACIONES CON LA TECTONICA

THE TIME-BOUND CHARACTERISTICS OF GOLD DEPOSITS IN BRAZIL AND THEIR TECTONIC IMPLICATIONS

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INTRODUCTION

Many authors have reviewed the distribution of ore deposits through geological time, and shown that certain types of mineralizations are confined to well defined geochronological intervals in the earth's history. In addition it has been considered that the tectonic environment provides a basis for understanding the distribution and origin of mineralization, in space and time.

This study deals with the recognition of the time-bound characteristics of the major Brazilian gold deposits and their correlation with tectonic environments.

For the development of this study a number of Au ore deposits have been selected, whose the main geological characteristic are presented in Table 1. The selection of the deposits was not only representative, but has a reasonable geographic distribution within the Brazilian territory as well (Figure 1). A search was done through the scientific literature for geological information, about the selected deposits, such as type of mineralization, mineralogical association, tectonic setting, host-rocks, and ages.

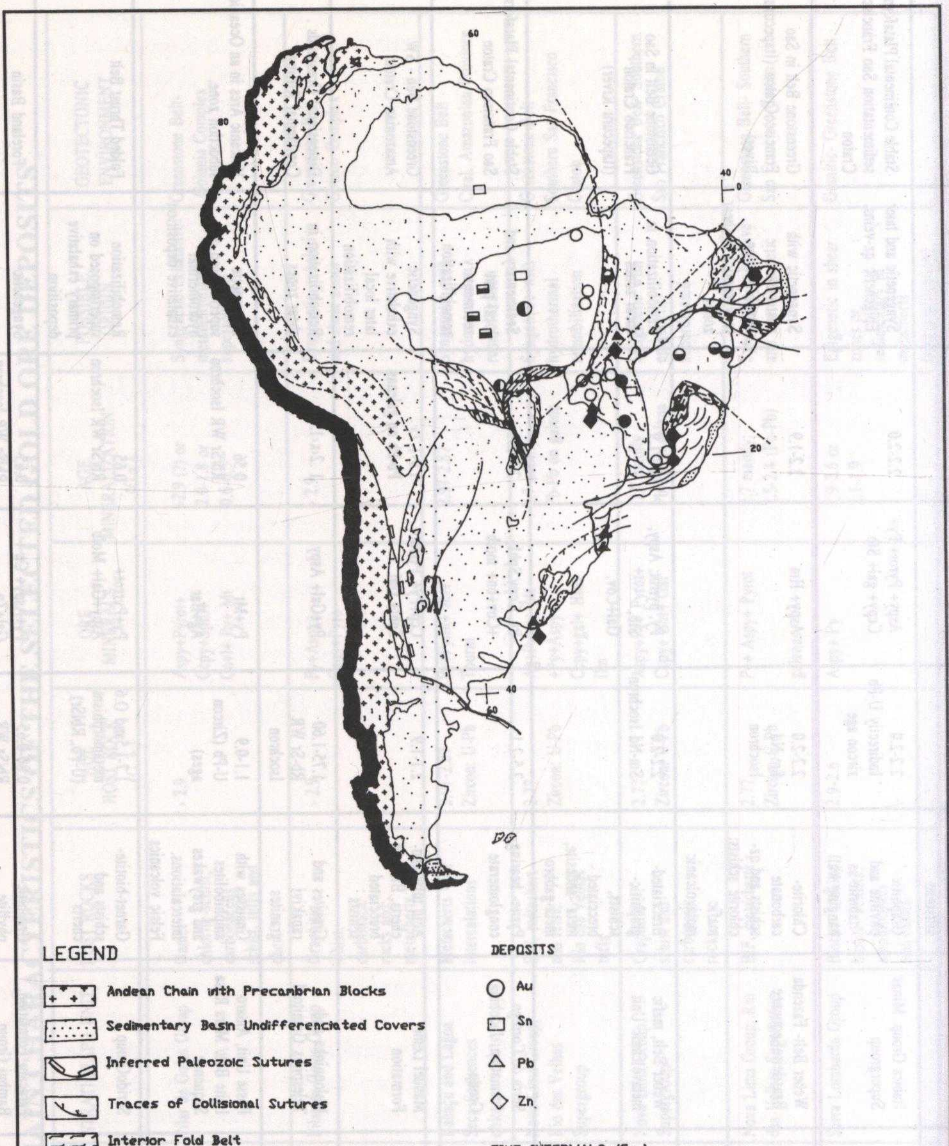
The determination of age of mineralization is one of the main problems of metallogenetic models, especially of those in Pre-Cambrian rocks.

The age of many deposits cannot be attributed to only one cycle of formation, because the measured ages may reflect

TABLE 1- THE MAIN CHARACTERISTICS OF THE SELECTED GOLD ORE DEPOSITS

NAME	LOCATION	TYPE	STRATIGRAPH UNIT	HOST ROCKS	AGE HOST ROCK (G. a.)	ORE MINERALS	AGE MINERALiZATION (G.a.)	POSSIBLE ORIGIN	GEOTECTONIC ENVIRONMENT
Mina III	Crixas (Goias)	Stratabound Stratiform	Pilar de Goias Group	Gamet chlorite-schist, carbonaceus schist, tuffs and chert	› 2.9	Aspy+Pyrot+ Ccpy+Sphl+ Covl+ Py+ Mt	›2.9 (?) or 2.0-1.8 or 0.6-0.5	Syngenetic exhalative metamórphism superimposed	Greenstone Belt- Goiania Complex
Meia Pataca	Crixas (Goias)	Stratiform	Pilar de Goias Group	Graphitic whist, carbonatic rocks and metacherts	› 2.9	Py+Aspy+ Ccpy+Pyro	› 2.9	Syngenetic exhalative and shear zones	Greenstone Belt Goiano Complex
Babaçu, Lagoa Seca	Carajas (Pára)	Stratiform Stratabound	Babaçu and Lagoa Seca Sequences chlorite- schists	Metacherts with intercalations	2.97-2.87 Zircon: U-Pb	Py+Pyrot+ Mt+ Tourm	2.97-2.87	Syngenetic with hydrotermal remobilization	Greenstone Belt - Ctral. Amazonian Province
Nova Lima District	QuadrilateroFe rrifero- NW Minas Gerais	Stratabound	Nova Lima Group, Rio das Velhas Supergroup	BIF, metachert and felsic Rio das Velhas tuffs	2.77 Zircon: U-Pb	Ag+Pyrot+ Mt +Py+Aspy+ Ccpy+gal+ Hm+ Ilm	2.7 mainly Pb-Pb on galena	Syngenetic with hydrothermal remobilization	Greenstone Belt - Southern Sao Francisco Craton
Sao Bento	Quadrilatero Ferrifero- NW Minas Gerais	Stratiform Stratabound	Nova Lima Group, Supergroup	Graphitic schist and carbonatic rocks	2.77 Zircon: U-Pb	Aspy+Py+ Pyrot+ Ccpy+ Bnt+ Gal	2.7 mainly Pb-Pb on galena	Syngenetic with epigenetic subordinated	Greenstone Belt- Southern Sao Francisco Craton
Cuiaba	Quadrilatero Ferrifero- NE Minas Gerais	Stratiform with qz-veins subordinated	Nova Lima Group, Rio das Velhas Supergroup	BIF, metacherts	2.77 Zircon: U-Pb	Py+ Aspy+ Pyrot galenas	2.7 mainly; 2.5-2.4 (Pb-Pb)	Syngenetic exhalative and later epigenetic	Greenstone Belt- Southern Sao Francisco Craton
Salamangone	Calçoene (Amapa)	Tabular qz- veins	Serra Lombarda Group	Biotite- tonalite, biotite- schists, amphibolites and cherts.	2.9-2.6	Aspy+ Py	2.9-2.6 or 2.1-1.9	Epigenetic in shear zones or sedimentary in metacherts (recrystallization)	Granitic- Greenstone Belt

Garimpo Serra Pelada	Carajas (Para)	Stratiform	Rio Fresco Fomnation	Gray metasiltstone and cataclastic siltstone	2.5-2.2	Molb+ Cu+ Co+ Pd+Ag	2.5-2.2	Au-remobilized by metamorphism	Stable Continental Plataform
Passagem	Quadrilatero Ferrifero SE Minas Gerais	Qz -veins+ stratabound, stratiform ore bodies	Itabira Group, Minas Supergroup	Graphitic phyilite and Itabirite as hanging wall	2.2-2.0 Indirectiy U-Pb zircon age	Aspy+ Pyrot+ Py+ Ccpy+ gal+ Stb	2.2-2.0	Syngenetic and later Epigenetic qz-veins.	Stable Continental Plataform; sedimentation Sao Francisco Craton
Fazenda Brasileiro	Serrinha (Bahia)	Qz-veins and Stratiform	Weber Belt- Fazenda BrasileiroSequence	Chlorite-carbonate schists and qz-chlorite schists; mafic metavolcanic	2.2-2.0 Sm-Nd Isochron	Aspy+ Hm	2.2-1.9	Syngenetic with posterior remobilization (epygenetic) in shear zones	Greenstone Belt in Sao FranciscoCraton (Itapecuru River)
Fazenda Maríaa Preta	Serrinha/ Santa Luz (Bahia)	Qz-veins	Weber Belt, mafic metavolcanic Unit	Brecciated-graphitic-schists, brecciated - meta -andesite, meta-gabbro	2.2-2.0 Sm-Nd Isochron	Py, pyrrot; Aspy, Stb, Gal+Cov.	2.2-1.9	Remobilization in shear zones	Geenstone Belt in Sao Francisco Craton (Itapecuru River)
Jacobina	Jacobina (Bahia)	Stratiform Stratabound	Serra do Corrego Formation, Jacobina Group	Pyrite- bearing conglomerate	2.5-2.1	Py, Ccpy,Sphl +Cov+bn+ molb	2.5-2.1	Sedimentary and local post sedimentary remobilization	Stable Continental Plataform Sao Francisco Craton
Cabaçal	Araputanga (Mato Grosso)	Stratiform Stratabound	Manuel Leme Formation	Acid tuffs and cherts, BIF and brecciated schists	2.1-1.9	Ccp+Py+ Pyrrot+ Sphl+ Gal	1.9-1.75 Pb-Pb on galenas	Syngenetic exhalative with later local remobilization	Greenstone Ben - SW Amazonian Craton
Tapajos/Ana Floresta Regions	SW Para State and NE Mato Grosso State	Qz-veins	Maloquinha and Telespires Granitoid	Granites and rapakivi granites	1.75-1.60 Rb-Sr WR Isochron	Py+Gal+ Aspy	1 .2‹x‹1.6	Remobilization in shear zones	Distensional Granitoids . Continental Rifting
Mara Rosa	Mara Rosa (Goias)	Stratabound, Stratiform and qz-veins	Posse Unit, Amaro Leite Belt/ Mara Rosa Sequence	Gnaisses with amphibolites and greywakes intercalations. Felsic volcanics	1.1-0.9 U-Pb (Zircon ages)	Py+Mt Ag+Bar	0.56 Rb/Sr WR Isochron	Epygenetic superimposed on hydrothermal exhalative deposition	Volcanic Arcs in an Oceanic subdction zone.
Sao Francisco	Cunais Novos (Rio Grande do Norte)	Stratabound	SeridoGroup	Garnet-biotite-schists and cherts	1.7-1.5and 0.6 metamorphism (U-Pb,. RblSr)	Py+Pyrrot+ Aspy+Gal+ Molb	0.65 Rb/Sr WR Isochron	Remobilization superimposed on primary exhalative deposition	Folded Thrust Belt
Morro do Ouro	Paracatu (Minas Gerais)	Stratabound Stratiform	Paracatu Formation, Bambui Group member of sandstone	Graphitic-phyllite	0.80-0.65 Rb/Sr WR	Py+Aspy+ Cu + Gal+Zn	0.65 RblSr WR Isochron	Syngenetic	Foreland Basin



Modified by Tectonic Evolution of South America during the Late Proterozoic (1991, Brito Neves e Cordani).

Figure 1- Distribution of major gold, tin, lead and zinc deposits in Brazil.

not only the primary syngenetic genesis, but also the last epigenetic hydrothermal genesis, and the time-interval between the episodes can be very long.

However, for this synthesis, the ages of ore deposits were constrained in two differents ways:

a) First by direct radiometric dating of mineral deposits.

b) By considering the host-rock's ages and ore deposit type, whether syngenetic or epigenetic, and stratigraphic correlation criteria, for example.

The Gold deposits were selected for this first synthesis, because this kind of mineralization occurs in several geological settings in the South American Platform, and present a wide range of ore deposit types and ages.

The South American Platform can be divided into five cratons, the largest units being the Amazonian and São Francisco, and the smallest fragments Luiz Alves, Rio de La Plata and São Luiz. These cratonic areas are separated by late-Proterozoic Mobile Belts, which exhibit linear structures, and are composed of gneisses and migmatites as infrastructure and metavolcano-sedimentary rocks as supracrustal sequences (Fig. 1).

Four main orogenic periods can be established for the continental crust evolution during the Pre-Cambrian in South America, which may include one or more metamorphic events. The first between 2,9-2,6 Ga named Guriense or Jequié Cycle, the second, between 2,2 and 1,95 Ga characterizes the Transamazonian Cycle, the third about 1,4 to 1,2 Ga. approximately, named Uruaçu or Rondonian Cycle, and the last one between 750-600 Ma, which constitutes the Brasiliano orogenic cycle. The time-period between 1,9 to 1,45 Ga. was characterized as the main epoch of continental rifting in South America, which the best known example is the Espinhaço rift system. There are also indications of an extensional continental tectonic regime between 1200 and 900 Ma.

GOLD DEPOSITS

Figure 2 shows the gold distribution through geological time. The peak sizes are proportional to the measured reserves of the reported deposits, indicated in percentage.

In general, it can be observed that the ages of gold mineralization broadly coincide with the major Pre-Cambrian orogenic events, which took place in the South American Platform, during the 2,9-2,7 Ga; 2,2-2,0 Ga; and 0,75-0,55 Ga time intervals. However, there are indications of gold mineralization related to distensional continental tectonic regimes during 1,8-1,55 Ga and 1,25-0,9 Ga time periods.

The association of Archean gold deposits and greenstone belt sequences is very well known. Inside Brazilian territory, the major primary gold deposits are, related to greenstone belts as well, but two time-periods for these kind of mineralizations are observed, the oldest between 3,0 to 2,6 Ga and the youngest between 2,2-2,0 Ga. The first time interval is in close agreement with the peak mineralization ages for gold deposits in the world, reported by Groves and Foster (1991) at Late-Archean, between 2,7-2,6 Ga.

The period from 3,000 to 2,700 Ma mainly includes the gold deposits of the "Quadrilatero Ferrifero" (Nova Lima District, São Bento and Cuiabá Mines) and Carajás region (Lagoa Seca and

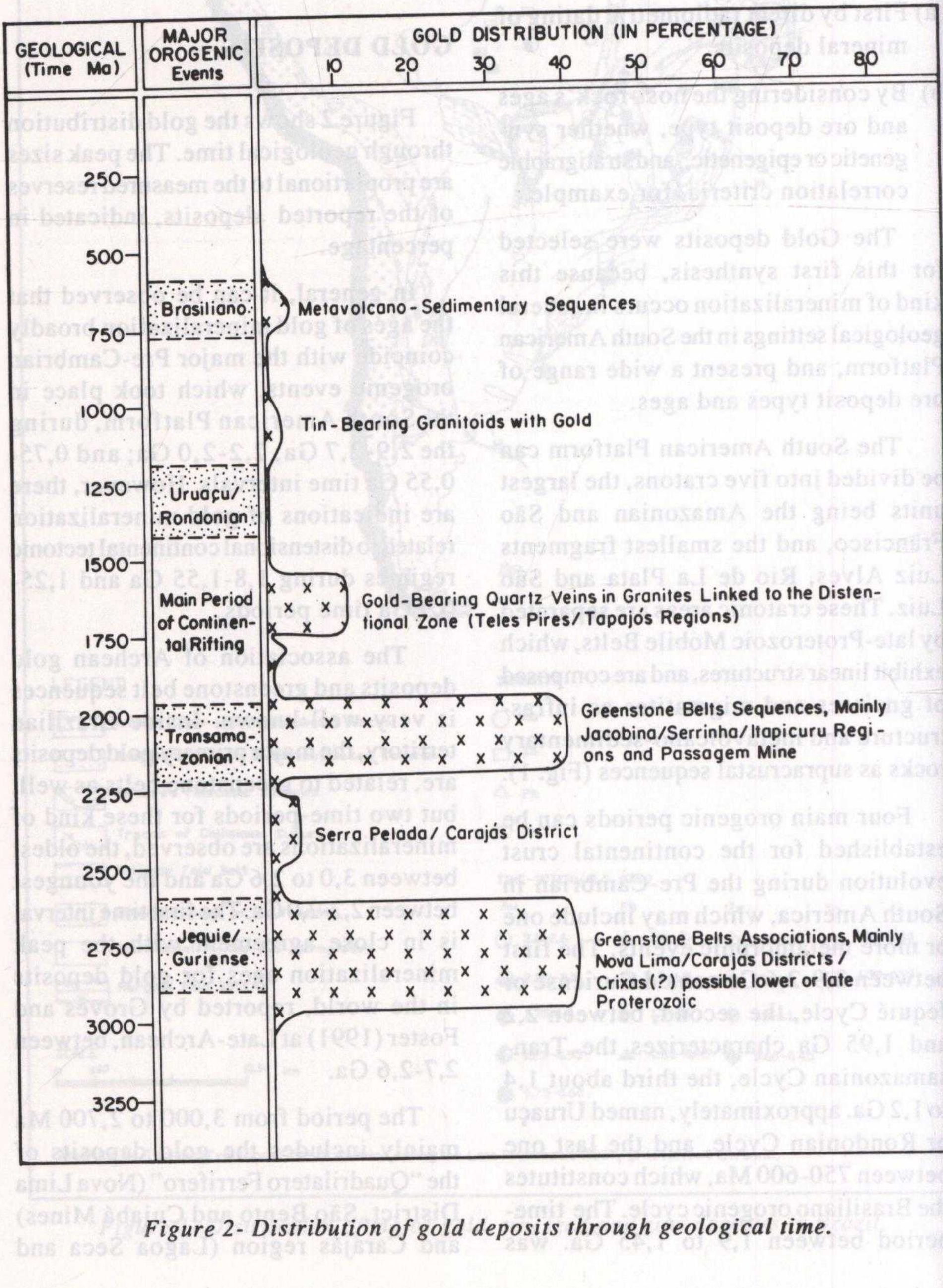


Figure 2- Distribution of gold deposits through geological time.

Babaçu), these ore deposits are related to greenstone belts in which the host rocks are: BIF, metacherts, chlorite-schists, carbonaceous- schists, graphitic schists and felsic tuffs. All of them are stratiform and stratabound, with some later remobilizations, which produced auriferous quartz-veins.

Although it is not very easy to make generalizations about tectonic environments for Archean gold deposits, it is possible to consider that the Brazilian Archean gold mineralization in greenstone belts are, in a broad sense, related to active marginal basins, with volcanism during the opening process , sub-aerial, shallow marine chemical and clastic sediments and subsequent compressional tectonism with assymetric folding, thrusts and upwelling of tonalitic-granodioritic batholiths.

Pb-Pb isotopic data on galenas from the "Quadrilátero Ferrífero" gold deposits yielded model age of 2,710 to 2,410 Ma. According to Thorpe et. al. (1984), the youngest ages were interpreted as reflecting late deformation and recrystalization of the orebodies and host rocks.

The Lagoa Seca and Babaçu deposits, in Serra dos Carajás District, have been considered as stratiform and stratabound. Their host rocks are siltstones, graywackes and mafic/ultramafic lavas and felsic volcanics. Sedimentation and volcanism took place between 2,97 and 2,87 Ga (Macambira and Lancelot, 1991). Thus, we can consider this time interval as a mineralization epoch. The relative short time span, about 100 Ma, for the sedimentation, volcanism and metamorphism, is typical for opening and closure of marginal basins.

Within the Archean greenstone belt of Crixás, in Goiás, the gold mineralization is associated to the ductile-brittle low angle shear zones and ore hosted in quartz-brecciated and veined graphitic schist units (Bittencourt et. al., 1991). Radiometric Rb-Sr ages on carbonaceous-chlorite-schists, amphibolites and marbles, obtained mainly in minerals concentrated from hydrothermal alteration zones, yield results between 730 and 500 Ma, which were interpreted by Fortes et al. (1993) as the age of mineralization. However, one can also consider that mineralization may be older (Archean or Lower Proterozoic, for example) and the late Proterozoic ages are related to an isotopic re-homogenization event in mineral scale, linked to the thermal activities which affected the region.

During the early-Proterozoic the second important pulse of gold mineralization in the South American Platform occur it occupies a time span between 2,250-1,900 Ma, which is characterized by greenstone belts sequences and some sedimentary deposits, related to stable continental platform environment, such as in the Jacobina deposit.

In the Fazenda Brasileiro and Fazenda Maria Preta ore deposits, gold is associated with quartz-veins injected by quartz-veinlets, hosted in metavolcano-sedimentary rocks of Rio Itapecuru greenstone belt, in São Francisco Craton, wich have an age about 2,2-1,9 Ga (Silva, 1992). The primary syngenetic deposition was affected by later remobilization in shear zones which produced hydrothermal mineralization. ^{39}Ar- ^{40}Ar ages on hydrothermal micas, yielded an age between 2,1-2,0 Ga (Vasconcelos, pers. comun.).

In the southwestern portion of the Amazonian Craton is located the Cabaçal mine, related to the Jauru greenstone belt. This deposit presents stratabound and stratiform characteristics and the ore bodies are hosted in acid tuffs, cherts and BIF. Pb-Pb analysis on galenas from the mineralization yielded an ages between 2,0-1,8 Ga (Pinho and Tassinari, unpublished data).

The Salamangone gold deposit, Amapá, northern Brazil, is composed of free gold and has arsenophyrite in tabular quartz veins hosted in biotite-tonalite. There are no ages avaliable for this mineralization, but it is possible to consider the late-tonalization process as responsible for the mineralization. Because the tonalites have a whole-rock isochron Rb-Sr age around 2,0 Ga (J. M. Lafon, pers. comun.), we estimated the Lower-Proterozoic time to have been a period of this gold mineralization.

In the South American Platform a profound change took place in geotectonic regimes during 1,9 to 1,5 Ga. In several regions, the platform was subjected to large scale continental rifting. The gold mineralization, at this time, occurs in shear zones, associated with anorogenic, within-plate A-type granitoids, typical of distensional zones, many of them exhibiting Rapakivi textures. These kind of mineralization appears mainly within the Amazonian Craton, in the Tapajós and Teles Pires regions. From 1250 to 900 Ma similar mineralization also occur in Rondonia area, northwestern Brazil.

The youngest time-interval for gold mineralization is between 0,75-0,55 Ga, which coincides with the Brasiliano Orogenic cycle. This period was charaterized by the development of mobile belts with simatic or ensialic features, strong granitization and migmatization episodes and crustal shortening with closure of marginal and intra-cratonic basins.

The Late-Proterozoic gold mineralization, like the São Francisco and Mara Rosa deposits, appears associated with metavolcano-sedimentary sequences, within folded thrust belt, which include felsic and mafic volcani-clastics rocks, schists, metacherts and carbonaceous phyllites. Both deposits are epigenetic, with the remobilization process overprinted on primary hydrothermal exhalative deposition, possibly in volcanic arcs in oceanic subduction zones betwen 900 and 550 Ma.(Kuyumin, 1991 and Schobbenhaus and Coelho Eds., 1988).

The Morro Agudo deposit presents stratabound and stratiform characteristics. The ore bodies are hosted in graphitic phyllites, at Bambuí Group, and slightly metamorphosed within a foreland basin about 650 Ma ago.

CONCLUSION

As the radiometric ages of gold deposits can be influenced by later hydrothermal activities and post-mineralization metamorphic episodes, the geologic age of ore deposits in Pre-Cambrian terrains, can not be determined only by geochronological methods. It would be very useful, also consider the geologic position of layers in wich the ores are hosted and geologic and metamorphic characteristics of mineralization in relation to the geotectonic evolution of region.

Although, in many Brazilian gold deposits, the mineralization ages are not very well constrained, the gold deposits show well defined time-bound characteristics, strongly related to the tectonic environments.

The gold deposits related to the greenstone belts and other kinds of supracrustal sequences have been associated to the major Pre-Cambrian orogenic periods in South America, while linked to the granitoids, are associated to the distensional tectonic epochs. There is no important gold mineralization related to collisional granitoids.

The tectonic regimes, metamorphism and climatic conditions, which are dependent on geologic time, have played important roles as controlling factors for mineralization.

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