Proterozoic Lode Gold Deposits in the Borborema Province, Northeast Brazil and their Exploration Significance*

MARIA GLÍCIA DA NÓBREGA COUTINHO[1] and DAVID H. M. ALDERTON[2]

[1]Companhia de Pesquisa de Recursos Minerais CPRM, Brazil Geological Survey
22292-170 Rio de Janeiro, RJ, Brazil
[2]Royal Holloway and Bedford New College, Geology Department,
University of London Egham Hill, Eham, Surrey, TW20 OEX, England, U.K.

Manuscript received on October 23, 1995; accepted for publication on April 3, 1998;
presented by DIÓGENES DE ALMEIDA CAMPOS

ABSTRACT

Many Precambrian shield areas and some younger metamorphic terranes contain gold-bearing quartz veins, the development of which seems to be closely related to that of shear zones. The Borborema Province in NE Brazil contains several examples of shear zone hosted gold deposits including two mines: Cachoeira de Minas and São Francisco mines. The two major tectonic features of relevance to the genesis of these deposits are: (i) the sinuous, anastomosing strike-slip shear zone system; and (ii) the extensive calc-alkaline magmatism, both of which are related to the Brasiliano-Pan African tectonic event (0.9-0.5 Ga). Gold-bearing quartz veins are widespread and occur in a variety of geological settings, however the fold belts are the preferred sites for ore deposits.

As shown later, the present study confirms that later granite-related hydrothermal activity plays an important role in the genesis of shear zone-related gold mineralization, e.g. as in the Canadian Shield (Colvine *et al.*, 1988). The mineralization model invokes a mixed source for the fluids and the ore components; the importance of granitic magmatism and convecting meteoric fluids is highlighted.

Although the genetic model developed here has been derived from studies in the Borborema Province, it is also relevant to other regions.

Key words: Proterozoic lode gold, gold mineralization, Borborema Province.

INTRODUCTION

Although gold was first discovered in the Borborema Province, Northeast Brazil, in the early 1940's and exploration has continued for the past 50 years, this research is the first attempt to study the genesis of these deposits.

Over the past 50 years small-scale exploitation has been carried out by 'garimpeiros' (local prospectors). These operations tend to use simple, rudimentary processes ('garimpo') and mainly work placer deposits and superficial lode gold veins. Nowadays mining companies are showing increasing interest in the region. Although gold-bearing quartz veins are common in the Precambrian terranes of the province, gold is very heterogeneously distributed: 2 mines, 8 deposits, 205 occurrences (CPRM, 1983) and several hundred 'garimpos'. Two gold mines have been developed: São Francisco mine, located near Currais Novos (Rio Grande do Norte State) and Cachoeira

---

Correspondence to: Maria Glícia da Nóbrega Coutinho

*Part of the requirements to fulfill a PhD thesis

Sponsored by the CNPq.

de Minas mine, situated near Princesa Isabel (Paraíba State). Both are small deposits (metal reserve ≤ 10 tonnes Au) with a grade ranging from 2.3 to 2.7 g/tonne of gold. The ore consists of gold-bearing quartz veins which are mined by open cast methods, the gold being recovered by cyanide heap-leaching.

The following gold deposits or occurrences were examined: São Francisco and Cachoeira de Minas mines, both related to fold belts; Itapetim District, where gold occurs either hosted by supracrustal fold belts (Sertãozinho-Pimenteiras areas) or granitoids (Santo Aleixo area, Cacimba Salgada, Canafístula and Garapá occurrences); and Boqueirão dos Cochos where gold-bearing quartz veins occur hosted by Archaean basement.

GEOLOGY

The Borborema Province is a mosaic of Archaean-Early Proterozoic massif terranes surrounded by Proterozoic fold belts (Santos & Brito Neves, 1984; Brito Neves & Cordani, 1991; see Fig. 1). The basement consists of gneiss-migmatite-granite terranes metamorposed from granulite to upper amphibolite facies (4.0 kb and 720°C). The fold belts are represented by supracrustal rocks consisting of metavolcanic-sedimentary sequences. The province is cut by two E-W crustal-scale lineament systems or first order shear zones, about 150 km apart (Ebert, 1970), between which is a complex anastomosing network of thrust faults and subsidiary strike-slip shear zones (Santos *et al.*, 1984; Caby, 1989; Caby *et al.*, 1990; Corsini *et al.*, 1991; Vauchez *et al.*, 1992). The province was reworked during the 0.9-0.5 Ga Brasiliano thermal-tectonic cycle, which was characterised by widespread emplacement of granitic rocks (Fig. 2; Almeida *et al.*, 1981; Sial, 1986; Sial & Ferreira, 1988; Hackspacher *et al.*, 1987; Jardim de Sá *et al.*, 1987).

Earliest tectonic evolution (the Trans-Amazonian thermal-tectonic cycle), starting at around 2.1-1.8 Ga (Macedo *et al.*, 1984), has been documented in some fold belts (Jardim de Sá, 1988), but in many areas evidence has been obliterated by the Late Proterozoic Brasiliano event which produced a complex structural pattern of polyphase folding, NE, E-W and WNW-ESE-trending ductile strike-slip faults, and horizontal stretching consistently parallel to the trend of the belts (Corsini *et al.*, 1991).

The Proterozoic supracrustal rocks consist of schists and gneisses and minor amphibolite and are predominantly mylonitic with a penetrative foliation. Schists contain a high component of felsic and minor mafic volcanics and greywackes and gneisses are predominantly granite-derived. There is a predominance of calc-alkaline and minor tholeiitic volcanism associated with metasediments. Maximum metamorphic conditions for metavolcanic-sedimentary rocks are estimated at 5.5 kb and 600°C suggesting a depth of ≈ 25 km, characteristic of amphibolite facies.

Calc-alkaline magmatism associated with the Brasiliano Orogeny resulted in hybrid S-I type granites, the chemistry of which is consistent with derivation in either a continent-continent collision or continental magmatic arc tectonic setting. The E-W-trending shear zones were infilled preferentially by the syntectonic magmas.

Deformation is predominantly in the plastic regime, although plastic-brittle deformation also occurs. Many subsidiary N to NE second-order shear zones (Corsini *et al.*, 1991; Vauchez *et al.*, 1992) consist of mylonitic rocks: gneisses, schists and minor amphibolites and are the most important setting for gold mineralization.

Despite debate about the geology of the Borborema Province, most discussion centres on the crucial point, the definition of the precise tectonic setting. A lack of isotopic studies for unravelling the history of these polydeformed terranes, now obscured by metamorphism and tectonic activity, makes the reconstruction of their evolution extremely difficult.

Recent studies address the degree to which structural stacking of volcanic and sedimentary packages of the fold belts represent accretion terranes (Santos, 1996). However, it is critical to establish if the regional structures are solely crustal features, or if any could represent fossil subduction zones (Guimarães, 1989; Beurlen *et al.*, 1991).

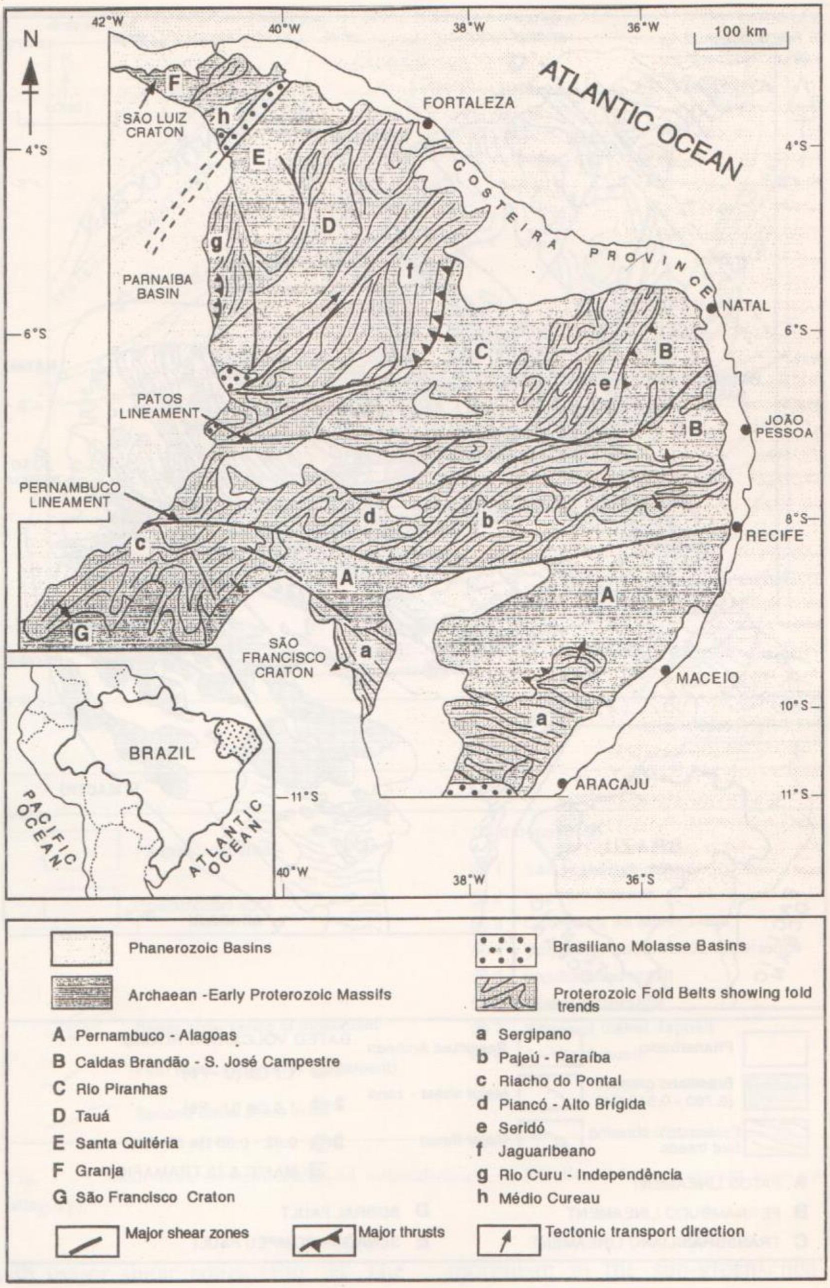

Fig. 1 — Simplified geological map of NE Brazil, including the Borborema Province and its limits (modified from Santos & Brito Neves, 1984).

The regional structures may also represent boundaries between subprovinces, across which significant changes in pressure and temperature conditions of adjacent rocks are recorded. Furthermore, if migration of the principal arc has occurred in response to repeated changes in both the position and angle of subduction, the whole tectonic assemblage will usually have been telescoped by accretion.

MINERALIZATION

Mesothermal gold-bearing quartz veins are widespread in the Borborema Province and occur in a variety of host rocks: Archaean basement,

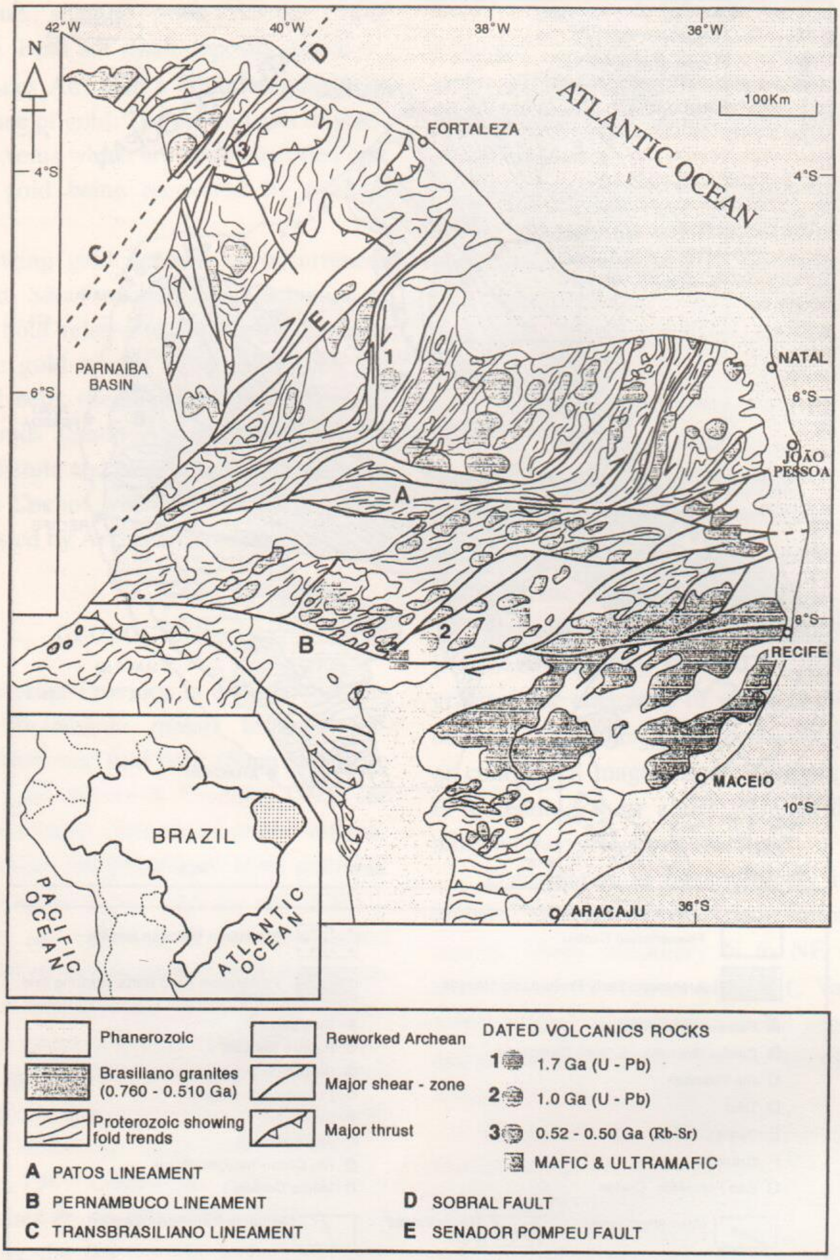

Fig. 2 — Geological map of NE Brazil showing the distribution of Archaean and Proterozoic units and highlighting the distribution of Braziliano age granites, volcanic rocks, and mafic/ultramafic rocks (modified, after Sial, 1987).

Early-Middle Proterozoic metavolcanic-sedimentary fold belts, and the Early to Late Proterozoic granitoids. The widespread gold-bearing quartz veins hosted by calc-alkaline granitoids reflect a genetic link between the magmatism and the gold mineralization.

Many subsidiary N to NE trending structures allowed the migration of metal-bearing hydrothermal fluids and provided sites for mineralization. Lode gold deposits occur either within the shear zones, on the limbs of folds commonly associated with thrust faults and strike-slip faults, or in close

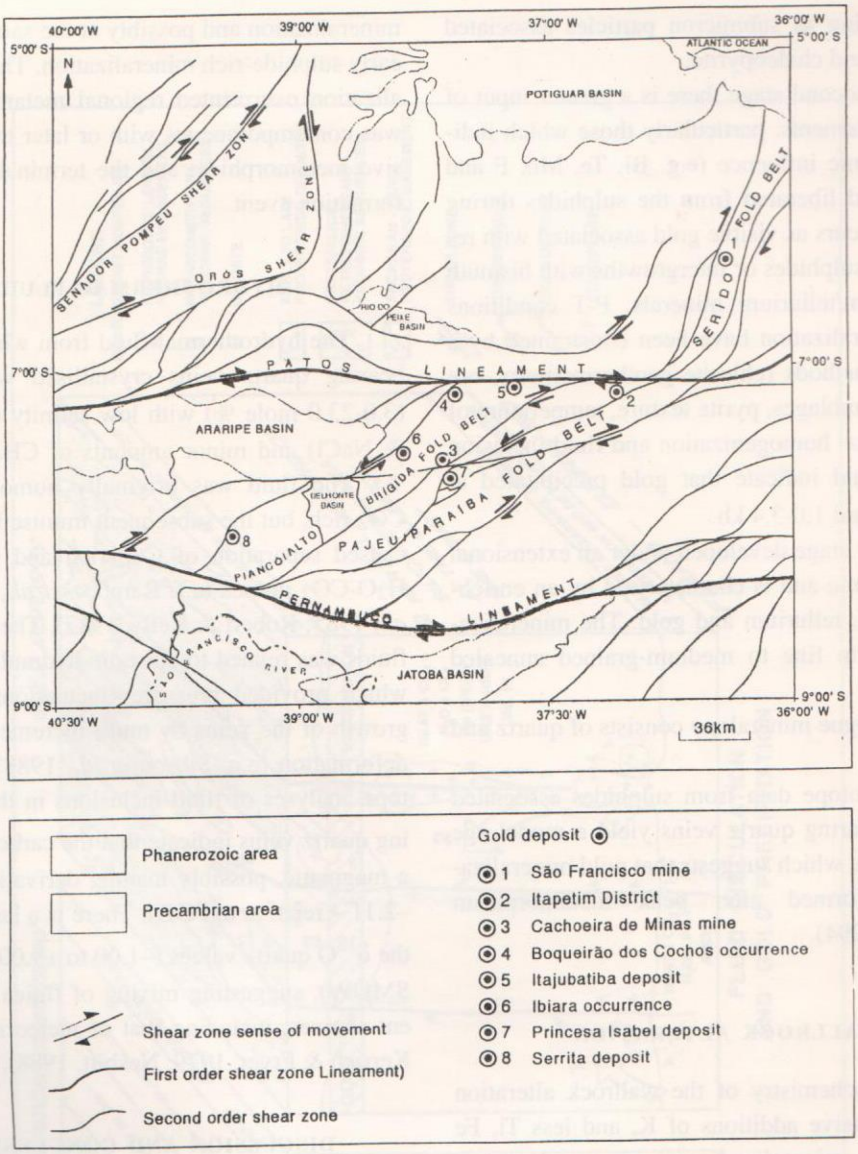

Fig. 3 — Shear zone system and gold mineralization in NE Brazil (interpretation from radar imagery).

association with major shear zones (Fig. 3). The relationship between the quartz veins and the deformation indicates that mineralization and shearing overlapped in time. A lead isotope study of the host rocks to the mineralization has yielded a Pb-Pb isochron age of ≈ 1.0 Ga, regarded as the time of regional high-grade metamorphism, and stabilisation of amphibolite facies crust. Mineral assemblages in all lithologies confirm that these rocks were subsequently subjected to retrogressive metamorphism in the sub-greenschist facies (350°C; Coutinho, 1994).

Ore-mineral studies combined with structural information suggest three stages of mineralization:

In the first stage, during plastic deformation, the mineral assemblage is characterised by titanium, iron oxides and the early sulphides (pyrrhotite and pyrite), which were formed by the destabilisation of mafic minerals in the host lithologies. Fluids enriched in CO_2 and S provided conditions for the precipitation of metals, with gold occurring as submicron particles associated with pyrite and chalcopyrite.

In the second stage there is a greater input of additional elements, particularly those which indicate a plutonic influence (e.g. Bi, Te, Mo, F and B). The gold liberated from the sulphides during this stage occurs as visible gold associated with recrystallised sulphides or intergrowths with bismuth and selenium/tellurium minerals. P-T conditions during mineralization have been constrained by a variety of methods (chlorite geothermometry, ore mineral assemblages, pyrite texture, temperature of fluid inclusion homogenization and fluid inclusion isochores) and indicate that gold precipitated at 270-350°C and 1.0-3.4 kb.

The last stage developed under an extensional tectonic regime and is characterised by an enrichment in lead, tellurium and gold. The mineralization occurs in fine to medium-grained annealed sulphides.

The gangue mineralogy consists of quartz and tourmaline.

Lead isotope data from sulphides associated with gold-bearing quartz veins yield a model age of 0.8-0.6 Ga, which suggests that gold mineralization was formed after peak metamorphism (Coutinho, 1994).

WALLROCK ALTERATION

The geochemistry of the wallrock alteration indicates massive additions of K, and less Ti, Fe and Mn. The mineralized areas are enriched in a distinctive suite of trace elements: Ba, Pb, Th, V, Zn, Sc, Ga, Y, Rb, Nb, and Nd. Depletions in Ca and Na are typical. The high values of K, Ba, Rb, and B in the potassic and tourmaline-rich alteration suggest a magmatic-hydrothermal paragenetic association. The same pattern of wallrock alteration occurs in different host lithologies, suggesting that the rocks were all subjected to the same metasomatic processes and also that the hydrothermal fluid composition was not controlled by the chemistry of the host rocks (c.f. Kerrich, 1989).

The relationships between deformation, gold mineralization, and wallrock alteration indicate that the wallrock alteration took place before gold mineralization and possibly at the same time as the early sulphide-rich mineralization. The gold mineralization overprinted regional metamorphism and was contemporaneous with or later than retrogressive metamorphism and the terminal plutonic-deformation event.

HYDROTHERMAL FLUIDS

The hydrothermal fluid from which the gold-bearing quartz veins crystallised was CO_2-rich (3.0-23.0 mole %) with low salinity ($\approx$ 6.0 eq. wt % NaCl) and minor amounts of CH_4 (3-10 mole %). The fluid was originally homogeneous and CO_2-rich, but the subsequent immiscibility process caused separation of CO_2-rich and CO_2-poor or H_2O-CO_2 phases (c.f. Ramboz *et al.*, 1982; Ho *et al.*, 1985; Robert & Kelly, 1987). The unmixing of fluids was related to episodic hydraulic fracturing, which provided pressure fluctuations during the growth of the veins by multi-increment crack-seal deformation (e.g. Sibson *et al.*, 1988). Stable isotope analyses of fluid inclusions in the gold-bearing quartz veins indicate that the carbon ($\delta^{13}C$) has a magmatic, possibly mantle, derivation (–7.60 to –2.11 – relative to PDB). There is a large scatter in the $\delta^{18}O$ quartz values (–1.00 to +9.00 – relative to SMOW), suggesting mixing of fluids from different sources, including that of meteoric water (see Kerrich & Fryer, 1979; Nesbitt, 1988).

DISCUSSION AND CONCLUSIONS

These studies show that the gold deposits in Borborema Province are a result of a complex interaction of tectonic evolution, structure, igneous activity, and fluid mobilization. A genetic model for the gold deposits is proposed to account for the sources of the metals and fluid, and the mechanisms for their mobilization, transport and deposition (Fig. 4). The model is similar to those proposed for Archaean or Phanerozoic gold deposits. As with previous models a complex evolution and mixture of sources and components are envisaged. The main point which emerges from the present study is the importance of granitic magmatism and convecting meteoric fluids, as is invoked for

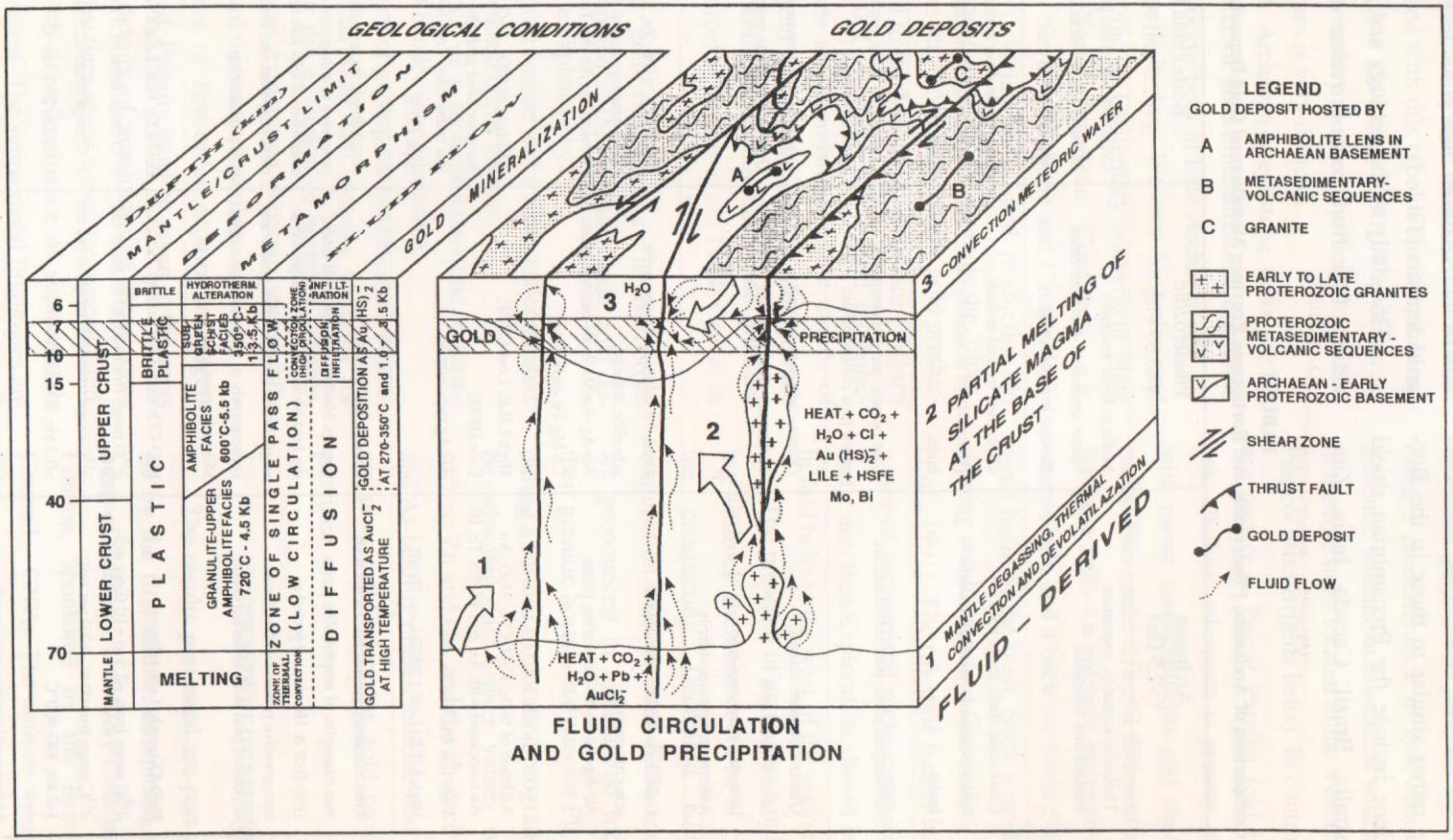

Fig. 4 — Schematic diagram showing a model for the gold mineralization in Borborema Province.

classical porphyry Cu or granite-hosted Sn-W mineralization.

Gold-bearing quartz veins with geological characteristics rather similar to those in the Borborema Province include the Precambrian shield areas of Australia, Brazil, Canada, India, Zimbabwe and South Africa. The Borborema Province gold deposits could represent a Proterozoic equivalent of the Archaean high-grade metamorphic lode gold deposits (Table I).

This study of the geology and gold mineralization of the Borborema Province will be of great

TABLE I

Comparison of Archaean, Phanerozoic and Borborema Province Mesothermal Gold Deposits.

Features	Archaean (>2.5 Ga)	Phanerozoic (<0.57 Ga)	Borborema Province (<2.5 and >0.57 Ga)
Host rocks	Tholeiitic-komatitic sequences Banded iron formation	Mafic to felsic volcanics Minor serpentine. Metasediments Banded iron formation	Granitoids and felsic porphyries Mafic to felsic volcanics Metasediments
Structure	Crust-scale shear zones with development of subsidiary reverse faults	Controlled by fold or fault Faults related to second-order faults	Crust-scale shear zones with development of subsidiary reverse faults
Tectonic setting	Convergent plate: post collisional arc	Late oceanic arc predominantly and minor post collisional arc	Convergent plate: continental arc or accretion terrane (?)
Wallrock alteration	Quartz-carbonate veining Mica V-or-Cr-rich Dolomite-magnesite-talc Ankerite-magnesite-siderite	Quartz-carbonate veining Carbonate, albite, sericite, chlorite	Intense K metasomatism Quartz-tourmaline veining
Ore Minerals	Gold, Fe sulphide, arsenopyrite, scheelite, stibnite Au-Ag-As-Sb-W-Bi-bearing phase	Gold, Fe sulphide, arsenopyrite, scheelite, stibnite, Au-Ag-As-Sb-W-Bi-bearing phase Ca-Mg-Fe carbonate	Gold; Fe, Cu, Pb, Zn, Mo sulphides; Se/Te bearing mineral phase; Bi minerals; Au-Ag-Te-bearing phase;
Geochemistry	Addition of SiO_2, K_2O, CO_2, H_2O, Au Au associated with As, Ag, W, Sb, Te, Bi Very low Cu, Pb, Zn, Mo High LILE; Low LREE; Low HFSE	High LILE; Low LREE; Low HFSE Au-Ag typically >1	Addition of SiO_2, K_2O, CO_2H_2O, Au; Au associated with Pb, Ag, Te, Bi, Se and minor Mo. Very low Zn, Cu High LILE
Metamorphism and timing of mineralization	Predominantly greenschist facies with rare examples of amphibolite facies (Bib Bell & Hemlo) subjected to retrogressive processes. Gold was deposited post peak metamorphism	Greenschist facies (except Mother Lode deposit where the host rocks were first subjected to amphibolite metamorphic grades and subsequently to retrograde processes) Mineralization later	Amphibolite facies subjected to retrograde processes at sub-greenschist facies conditions. Gold was deposited post peak metamorphism and wallrock alteration was pre-shearing
Fluid inclusions Stable isotopes in fluids and range of P-T conditions	H_2O-CO_2 rich; Low salinity $\partial^{18}O$ range from +2.5 to +10.0 per mil $\partial^{13}C$ range from 0 to –10.0 per mil 1-2 kb; 300-400°C	H_2O-CO_2 rich; Low salinity $\partial^{18}O$ range from +2.0 to +4.0 per mil $\partial^{13}C$ range from –8.0 to –17.0 per mil >0.2 kb; 200-350°C	H_2O-CO_2 rich; Low salinity $\partial^{18}O$ range from –1.0 to +9.0 per mil $\partial^{13}C$ range from –2.1 to –7.6 per mil 1-3.4 kb; 270-350°C
Source of fluid	Metamorphic, magmatic, mantle	Metamorphic, meteoric	Magmatic, mantle, meteoric

Observation: Table prepared from the following sources: Barley *et al.*, 1989; Mueller & Groves, 1993; Phillips & DeNooy, 1988; Nesbitt, 1991; Coutinho, 1994.

assistance to exploration programmes in the region. However, because of the complex geology of accreted magmatic-volcanic terranes, mineral deposits associated with this type of environment are not easy to locate (Sawkins, 1990). The demarcation of the boundary between principal arc and back arc regimes is very difficult.

Although Archaean greenstone belts are an important source of gold mineralization, economic gold deposits occur both in Late Archaean (ca. 2.7 Ga) greenstone belts (e.g. Western Australia) and in Late Paleozoic to Quaternary convergent plate boundaries (North American Cordillera, e.g. Mother Lode, Nevada; Bralorne and Cassiar, British Columbia). Variations in gold production do occur in Archaean terranes, for example the 'older' Pilbara terrane (ca. 3.5 Ga) has lower gold production compared to the Murchison Province (Yilgarn Block; 2.8-3.0 Ga) where BIF – and tholeiitic-hosted deposits are abundant. Possible causes of much lower gold production from the older terrane include the likelihood of sulphide – and gold-depleted source-rocks (Groves *et al.*, 1984; Groves & Foster, 1991).

Different gold productivities in Borborena Province compared to the Archaean lode gold deposits could be explained by:

(i) The gold source was a more differentiated, more gold-depleted upper mantle;

(ii) A lack of a tholeiite-komatiitic volcanic sequence and banded-iron formation;

(iii) A lack of geological studies, such as geochemical, geophysical and isotopic analyses for understanding the evolution of accreted terranes, followed by an exploration program specifically targeted toward this tectonic setting.

A number of first-order exploration targets can be selected. Priority must be given to the areas with a high density of anastomosing shear zones where the subsidiary shear zones are concentrated. Fold belts with a predominance of supracrustals are the best targets. The supracrustal lithologies are favourable to the development of S-C fabric and have thus ensured the most efficient circulation of the mineralised fluids. Although granites appear to be both the source of the gold and the hydrothermal fluids, proximity to granites is not important.

Petrographic and geochemical data have indicated a predominance of calc-alkaline and minor tholeiitic volcanism associated with metasediments in the fold belts located in the west (e.g. Seridó and Piancó/ Alto Brígida belts). In contrast, in the eastern part (e.g. Pajeú/ Paraíba fold belt), although calc-alkaline volcanism is present, it is associated with minor metasediments and abundant plutonic rocks. This could reflect a different tectonic setting for these belts – a volcanic arc environment for the eastern belt, and a back arc basin evolved to a marginal basin in the west. Such a model infers west-dipping subduction (see Guimarães, 1989; Beurlen *et al.*, 1991). The rift-style basins have a predominance of supracrustal rocks compared to the magmatic arc, thus exploration should be concentrated in fold belts to the west of the region.

The presence of an increase in K, Ba, Rb during wallrock alteration could be of great value during prospecting. Decreased K/Rb ratios, in conjunction with elevated K/Ba and Rb/Sr ratios, are pronounced in mineralized rocks relative to their granitic hosts. Analyses for Pb, Bi, Te, and Se during a surface exploration programme might also be advantageous. Lower values of base metals such as Zn and Cu, and the absence of any Sb-Hg- and As-bearing phases indicate that these elements are poor pathfinders for gold prospecting in the province.

ACKNOWLEDGEMENTS

The results presented are part of a Ph.D. thesis by the first author, completed, at the Department of Geology, Holloway College, University of London, sponsored by the Brazilian Research Council – CNPq. The authors would like to thank CNPq for providing financial support. Special thanks to Dr. T. Liverton, University of Brasília for reviewing the manuscript.

REFERENCES

Almeida, F. F. M. de; Hasui, Y.; Brito Neves, B. B. de & Fuck, R., (1981), Brazilian structural provinces. *Earth Sci. Rev.,* **17:** 1-29.

Barley, M. E.; Eisenlohr, B. N.; Groves, D. I.; Perring, C. S. & Vearncombe, J. R., (1989), Late Archaean convergent margin tectonics and gold mineralization: a new look at the Norseman-Wiluna Belt, Western Australia. *Geol.*, **17: **826-829.

Brito Neves, B. B. de & Cordani, U. G., (1991), Tectonic evolution of South America during the Late Proterozoic. *Precamb. Res.,* **53:** 23-40.

Beurlen, H.; da Silva Filho, A. F. & Guimarães, I. do P., (1991), Evolução metamórfica dos eclogitos da ocorrência de Fe-Ti da Fazenda Esperança, Bodocó, Brasil. *37th Congress Bras. Geol.*, São Paulo, SP, **4,** *Soc. Bras. Geol.,* 2025-2039.

Caby, R., (1989), Precambrian terranes of Benin-Nigeria and northeast Brazil and the Late Proterozoic south Atlantic fit. *Geol. Soc. Amer., Spec. Paper,* **230:** 145-153.

Caby, R.; Sial, A. N.; Arthaud, M. & Vouchez, A., (1990), Crustal evolution and the Brasiliano Orogeny in Northeast Brazil. In *The West African Orogenes and Circum-Atlantic Correlatives*, eds. Dallmeyer, R. D. & Lecorché, J. P., Springer-Verlag, (in press).

Cprm, (1983), Avaliação dos recursos auríferos do Brasil, Comitê do Ouro (Internal report; unpub.).

Colvine, A. C.; Fyon, J. A.; Heather, K. B.; Marmont, S.; Smith, P. M. & Troop, D. G., (1988), Archaean lode gold deposits in Ontario. Part I. A depositional model. Part II. A genetic model. *Ontario Geol. Sur., Miscellaneous Paper,* **139:** 136 pp.

Corsini, M.; Vauchez, A.; Jardim de Sá, E. F. & Archanjo, C., (1991), Strain transfer at continental scale from a transcurrent shear zone to a transpressional fold belt: The Patos-Seridó system, northeastern Brazil. *Geol.,* **19:** 586-589.

Coutinho, M. G. N., (1994), The geology of shear zone-hosted gold deposits in Northeast Brazil. PhD Thesis, Royal Holloway and Belford New College, Geology Department, University of London, England, 359 pp. (unpub.).

Ebert, H., (1970), The Precambrian Geology of the Borborema Belt; State of Paraíba and Rio Grande do Norte, Northeastern Brazil. *Geol. Rundsch.,* **59** (3): 1299-1326.

Groves, D. I.; Phillips, G. N.; Ho, S. E.; Henderson, C. A.; Clark, M. E. & Wood, G. M., (1984), Controls on distribution of Archaean hydrothermal gold deposits in Western Australia. In *Gold'82,* ed. Foster, R. P., Balkema, Rotterdam, 689-712.

Groves, D. I. & Foster, R. P., (1991), Archaean lode gold deposits. In *Gold Metallogeny and Exploration*, ed. Foster, R. P., Blackie, London, 63-103.

Guimarães, I. P., (1989), The petrological evolution and tectonic association of the Bom Jardim Complex, Pernambuco State, NE Brazil. Ph.D. Thesis, Imperial College, Univer. of London, (unpub.), 324pp.

Hackspacher, P. C.; Schums, W. R. V. & Dantas, E. L., (1987), Um embasamento Transamazônico na Província Borborema. *36th Congress Bras. Geol.*, Natal, RN, vol. **6,** *Soc. Bras. Geol.,* 2683-2696.

Ho, S. E.; Groves, D. I. & Phillips, G. N., (1985), Fluid inclusions as indicators of the nature and source of fluids and ore depositional conditions for Archaean gold deposits of the Yilgarn Block, Western Australia. *Geol. Soc. S. Africa Trans.,* **88:** 149-158.

Jardim de Sá, E. F., (1988), An update of the Precambrian geology of northeast Brazil. In *International Meeting on Proterozoic Geology and Tectonics of High-Grade Terranins: Ile-Ife, Nigeria*, Programme and Lecture Series.

Jardim de Sá, E. F.; Macedo, M. H. F.; Legrand, J. M.; McReath, I.; Galindo, A. C. & Sá, J. M., (1987), Proterozoic granitoids in polycyclic setting. The Seridó region, NE Brazil. In *International Symposium Granites and Association Mineralization, (I.S.G.A.M.)* Salvador, BA, Brazil.

Kerrich, R., (1989), Geochemical evidence on the sources of fluids and solutes for shear zone hosted mesothermal Au deposits. In *Mineralization and Shear Zones*, ed. Bursnall, J. T., *Geol. Assoc. Can., Short Course Notes,* **6:** 129-198.

Kerrich, R. & Fryer, B. J., (1979), Archaean precious-metal hydrothermal systems, Dome Mine, Abitibi greenstone belt: Part II. REE and oxygen isotope relations. *Can. J. Earth Sci.,* **16:** 440-458.

Macedo, M. H. de F.; Jardim de Sá, E. F. & Sá, J. M., (1984), Datações Rb-Sr em ortogneisses e a idade do Grupo Seridó. *21th Symposium of NE Geology*, João Pessoa, PB, *Soc. Bras. Geol.*, **9:** 253-262.

MUELLER, D. & GROVES, D. I., (1993), Direct and indirect association between potassic igneous rocks, shoshonites and gold-copper deposits. *Ore Geol. Rev.*, **8:** 383-406.

NESBITT, B. E., (1988), Gold deposit continum: A genetic model for lode Au mineralization in the continental crust. *Geol.,* **16:** 1044-1048.

NESBITT, B. E., (1991), Phancrozoic gold deposits in tectonically active continental margins. In: *Gold Mettallogeny and Exploration*, ed. Foster, R. P., Blackier and Son Ltd., London, 432 pp.

PHILLIPS, G. N. & DE NOOY, D., (1988), High-grade metamorphic processes which influence Archean gold deposits, with particular reference to Big Bell, Australia. *J. Metamorph. Geol.*, **6:** 95-114.

RAMBOZ, C.; PICHAVANT, M. & WEISBROD, A., (1982), Fluid immiscibility in natural processes: use and miuse of fluid inclusion data. *Chem. Geol.,* **37:** 29-48.

ROBERT, F. & KELLY, W., (1987), Ore forming fluids in Archaean gold-bearing quartz veins at the Sigma mine, Abitibi greenstone belt, Quebec, Canada. *Econ. Geol.,* **82:** 1464-1482.

SANTOS, E. J. DOS, (1996), An outline of the Lagoa das Pedras Granitic Complex and its implication on accretionary tectonic of the Borborema Province, Northeast Brazil. *30th Internat. Geol. Cong.*, Beijing, China, Abstract Vol. **2.**

SANTOS, E. J. DOS & BRITO NEVES, B. B. DE, (1984), Província Borborema. In *O Pre Cambriano do Brasil*, eds. ALMEIDA, F. F. M. & HASUI, Y., Blucher, São Paulo, 123-186.

SANTOS, E. J. DOS; COUTINHO, M. G. N.; COSTA, M. P. A. & RAMALHO, R., (1984), A região de dobramento do nordeste e a bacia do Parnaíba, incluindo o craton de São Luís a as bacias marginais. In *Geologia do Brasil*, eds., SCHOBBENHAUS, C., ALMEIDA CAMPOS, D., DERZE, G. R. & ASMUS, H. E., DNPM, Brasília, 131-189.

SAWKINS, F. J., (1990), Metal Deposits in Relation to Plate Tectonics. Serie: Mineral and rocks, Spring Verlag, USA, *2nd edition*, 461p.

SIAL, A. N., (1986), Granite-types in Northeast Brazil: Current Knowledge. *Rev. Bras. Geoc.,* **16** (1): 54-72.

SIAL, A. N., (1987), Granitic rocks of Northeast Brazil. In: *First International Symposium on Granites and Associated Mineralizations*, I-ISGAM, Salvador, Brazil, 61-69.

SIAL, A. N. & FERREIRA, V. P., (1988), Brasiliano-age peralkaline plutonic rocks of the central structural domain, Northeast Brazil. *R. C. Soc. Ital. Mineral Petrol.,* **43** (2): 307-342.

SIBSON, R. H.; ROBERT, F. & POULSEN, K. H., (1988), High-angle reverse faults, fluid-pressure cycling, and mesothermal gold-quartz deposits. *Geol.,* **16:** 551-555.

VAUCHEZ, A.; AMARO, V.; ARCANJO, C.; ARTHAUD, M.; BOUCHEZ, J. L.; CABY, R.; CORSINI, M.; EGYDIO SILVA, M.; JARDIM DE SÁ, E. F.; NEVES, S. P.; SÁ, J. M. & SIAL, A. N., (1992), The Borborema shear zone system: a tectonic model. *37th Cong. Bras. Geol.*, São Paulo, SP, **1,** *Soc. Bras. Geol.*, 371-373.