Gold deposits (gold-bearing tourmalinites, gold-bearing conglomerates, and mesothermal lodes), markers of the geological evolution of French Guiana:
geology, metallogeny, and stable-isotope constraints

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Les minéralisations aurifères (tourmalinites, conglomérats et gîtes mésothermaux) marqueurs de l'évolution géologique de la Guyane

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Key words: Gold deposits, Conglomerates, Tourmalinites, Mesothermal lodes, French Guiana.

Abstract

In French Guiana, three types of Proterozoic gold deposits can be recognized (gold-bearing tourmalinites, gold-bearing conglomerates, and mesothermal ore deposits) and used as metallogenic markers in the two-stage geodynamic evolution proposed by Vanderhaeghe et al. *(1998) and updated at the Guiana Shield scale by Delor* et al. *(2000, 2001, 2003a, b this volume).*

During the first stage of crustal growth by calc-alkalic and TTG magmatic accretion, an early (pre-D1 deformation) stock of gold and disseminated sulphides associated with regional tourmalinization accumulated in the Paramaca volcaniclastic sequences in subaquatic conditions (example of the stratiform/stratabound Dorlin deposit). These gold-bearing tourmalinites were locally modified under upper–middle crust conditions during emplacement of discordant mesothermal quartz veins.

During the second stage of crustal recycling and tectonic accretion, a wide variety of syntectonic ore deposits including gold-bearing conglomerate and gold mesothermal types were emplaced during all increments of D2 transcurrent deformation, which was responsible for the progressive deformation of the North Guiana Trough, from its creation through to its burial and final exhumation:

- The gold-bearing conglomerate type of ore deposit, hosted by the Upper Detrital Unit in the North Guiana Trough, presents several facies markers of the progressive burial of the deposits, e.g. (i) gold-oxide "paleoplacer" of "Banket" type, (ii) debris-flow type with syndiagenetic and/or epigenetic deposits, (iii) epigenetic disseminated-sulphide facies, and (iv) epigenetic mesothermal quartz stockworks. Overall, it formed under low to medium-grade metamorphic conditions with, however, relicts of an earlier hydrothermal event as indicated by preserved hydrothermal pebbles in polygenic conglomerates.

- The gold mesothermal type of ore deposit (dominant Au-Fe-Cu type associated with brittle-ductile faults and rare Au-As mesothermal deposits), hosted by the metavolcanic and metasedimentary rocks of the Paramaca Series and also by late-D2 small granite stocks, is always associated with major fault zones. Overall, it formed under low-grade metamorphic conditions. It is characterized by hydrothermal chlorite+muscovite+albite+carbonates±biotite alteration. Muscovite+chlorite+carbonates predominate in hydrothermally

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altered metavolcanic and metasedimentary rocks, whereas albite+carbonates predominate in hydrothermally altered granites.

Hydrothermal fluids have a variety of origins. Stable-isotope (C, H, O) data indicate a dominant participation of external fluids, near seawater, in the Dorlin subaquatic stratiform/stratabound deposit, whereas metamorphic fluids become dominant in ore deposits formed at deeper levels, such as gold-bearing conglomerates and mesothermal deposits. Sulphur isotopes, trace elements, and sulphide mineralogy show a consistent magmatic component, represented by magmatic fluids or by leaching of magmatic rocks.

Résumé

En Guyane, trois types de minéralisations d'or d'âge protérozoïque ont été distingués (tourmalinites aurifères, conglomérats aurifères et or orogénique mésothermal) et utilisés comme marqueurs métallogéniques dans le scénario en deux stades d'évolution géodynamique proposée par Vanderhaeghe et al. (1998) et mis à jour, à l'échelle du bouclier guyanais, par Delor et al. (2000, 2001, 2003a, b ce volume).

Durant le premier stade de croissance crustale par accrétion magmatique calco-alcaline et TTG, un premier dépôt de sulfures disséminés et d'or (pré-déformation D1), associé à une tourmalinisation régionale se met en place dans les séquences volcanoclastiques du Paramaca en conditions subaquatiques (cas du gîte stratiforme/"stratabound" de Dorlin). Ces tourmalinites aurifères ont été ensuite portées dans les conditions de la croûte supérieure à moyenne et localement remaniées par des veines de quartz mésothermales.

Pendant le deuxième stade de recyclage crustal et d'accrétion tectonique, une grande variété de minéralisations syntectoniques comprenant des conglomérats aurifères et des minéralisations mésothermales aurifères se sont mises en place durant tous les incréments de la déformation D2 transcurrente, responsable d'une déformation progressive du Sillon Nord Guyanais, depuis son initiation jusqu'à son enfouissement et son exhumation finale :

- les conglomérats aurifères, portés par l'unité Détritique Supérieure du Sillon Nord Guyanais, comprennent plusieurs faciès, marquant l'enfouissement progressif des dépôts, i.e. (i) « paléoplacers » à or-oxydes de type « Banket », (ii) coulées de débris à minéralisations syn-diagénétiques et/ou épigénétiques, (iii) faciès de sulfures disséminés épigénétiques, jusqu'aux (iv) stockwerks de quartz épigénétiques mésothermaux. Ils se sont formés sous un métamorphisme de degré faible à moyen, préservant des reliques d'un événement hydrothermal précoce, comme l'indique la présence de galets hydrothermaux dans les conglomérats polygéniques ;

- les minéralisations aurifères orogéniques mésothermales (à Au-Fe-Cu dominant associé à des failles ductiles - fragiles et à Au - As plus rare), encaissées par les séries volcaniques et sédimentaires métamorphisées du Paramaca et par de petits stocks de granite tardi-D2, sont toujours associées à des zones de failles majeures. Elles se sont généralement formées dans des conditions métamorphiques de bas degré et sont caractérisées par une altération hydrothermale à chlorite + muscovite + albite + carbonates ± biotite. Muscovite + chlorite + carbonates sont dominants dans les encaissants volcaniques et sédimentaires, tandis que albite + carbonates sont dominants dans les encaissants granitiques.

Les fluides hydrothermaux ont plusieurs origines. Les isotopes du soufre, les éléments en trace et la minéralogie des sulfures provenant des différents types de gisements indiquent une composante magmatique constante, issue soit de l'extraction des fluides magmatiques au cours de la mise en place des magmas et de leur cristallisation, soit du lessivage de roches magmatiques riches en sulfures. Les isotopes stables (C, H, O) indiquent une participation dominante de fluides externes. Dans le cas du gisement aurifère de Dorlin de type stratiforme/"stratabound" et mis en place dans des conditions sub-aquatiques, les fluides externes ont une composition proche de l'eau de mer. Dans le cas des minéralisations formées à plus grande profondeur, comme les conglomérats (pro parte) et les gîtes mésothermaux aurifères, les fluides hydrothermaux ont une signature métamorphique. Ce sont des fluides d'origine indéterminée (magmatique, marine, météorique ?), équilibrés avec les roches encaissantes dans les conditions du métamorphisme régional.

Introduction

French Guiana represents less than 10% of a much larger geological entity, the Guiana Shield, which underlies the North Amazonian part of Brazil, the easternmost point of Colombia, eastern Venezuela, and the "three Guianas" (Guyana, Suriname, and French Guiana). The Guiana Shield (Fig. 1, after Delor *et al*., 2003a, b) is a major Precambrian shield (Choubert, 1974) consisting of Archean protoliths, known only in the northwesternmost Imataca Complex (Montgomery, 1979; Santos *et al*., 2000; Tassinari *et al*., 2001) and in the southeasternmost Amapa terranes (João and Marinho, 1982; Gama de Avelar *et al*., 2003), between which Paleoproterozoic formations (2.2 to 2.0 Ga) are widely developed, including mainly low-grade metamorphosed sedimentary and volcanic formations and granite, and medium-grade metamorphic terranes. Evidence of Proterozoic-younging crustal growth has been documented closer to the Amazon Basin (Tassinari *et al*., 2000), where the Uatumã plutonic and volcanic sequences are dated at 1.97 to 1.8 Ga, the Roraima sedimentary deposits at 1.88 to 1.7 Ga, and doleritic magmatism at 1.78 Ga (Santos *et al.*, 2002). Finally, alkalic magmatic rocks have been dated at 1.7 to 1.3 Ga.

The Guiana Shield and the West African Craton belonged to a single Proterozoic continental landmass until the opening of the Atlantic Ocean, which started with extensive Late Jurassic volcanic activity (Choubert, 1935; Rowley and Pindell, 1989).

Delor *et al*. (2003 b) describe the geology of French Guiana. French Guiana has gold deposits (Milesi *et al*., 1995; Fig. 2) that constitute its main economic interest, as well as many deposits of columbotantalite (pegmatites and secondary deposits), tin (pegmatites and secondary deposits), lithium (pegmatites), copper (disseminations in basic rocks), iron (stratiform deposits in schists and Fe-rich quartzites), manganese (rare gondites and schists), diamonds (alluvial deposits in which diamonds were discovered in 1930 by local miners, eluvial deposits (Solere (de) and Serre, 1976; BRGM, 1979) associated with meta-ultrabasite rocks or komatiites (Marot, 1988) and volcaniclastic komatiites (Capdevila *et al*., 1999), platinum, uranium, bauxite, and kaolin (primary and secondary).

The high gold potential of the circum-Atlantic Paleoproterozoic terranes, particularly well known in West Africa (6500 t in Birimian terranes, Milesi, 2001), but also in Venezuela, Guyana, and Brazil (Omai open-pit mine, Salamangone, La Camora underground mine, and Las Christinas deposit; Table 1) has attracted attention to potential gold mining in French Guiana. Compared to the world's "heavyweight" gold producers, French Guiana is a lightweight. Nevertheless, it should be borne in mind that between 1857 and 1994, this territory of less than 100 000 km^2 officially produced 195 t gold, *i.e*. slightly more than mainland France (approximately 160 t) during the same period. Ninety-five percent of this production came from alluvial and eluvial deposits. This augurs well for the potential of primary rock deposits in the district.

Over the past 20 years (1976–1995), the geological and mineral exploration work carried out by the Bureau Minier Guyanais (BMG) and by the BRGM as part of the "Inventaire Minier" in French Guiana has considerably improved our knowledge of the area's mining potential - 15 exploited mines and 8 potential deposits have been recorded - and metallogeny. This work has led to the discovery of the Changement, Loulouie, Espérance, Saint-Pierre, Montagne Tortue, Repentir, Dorlin, Yaou, Maraudeur, and Griegel deposits.

Data on some of these deposits have been updated through BRGM scientific and mapping projects (1987-2002), through our field visits, and through an examination of available borehole cores. These data relate mainly to deposits in northern French Guiana (Espérance, Saint-Pierre, Adieu-Vat, Loulouie, and Changement), and to two deposits in the south (Dorlin and Yaou). All are Au-S deposits; few data have been acquired on disseminated gold deposits in the Upper Detrital Formation.

This paper, companion to those of Delor *et al*. (2003 a, b), consists of two major parts. The first details the main geological, structural, and mineralogical information about the seven gold deposits mentioned above obtained in large part by the BRGM from 1987 to 2000, and suggests a simplified classification of primary gold deposits on the basis of their geological setting and chronology. The second part presents the sulphur, carbon, oxygen, and hydrogen isotope data from these gold deposits that have been gathered over the last seven years, and proposes a preliminary interpretation of ore deposition for the different types of deposits.

Geological setting and gold deposits of Guiana

Lithology

French Guiana is essentially composed of Paleoproterozoic rocks (2.2–2.0 Ga) that were affected at about 2.1 Ga by tectonic, metamorphic, and intrusive events of the Transamazonian Orogeny (Fig. 1):

- The oldest dated basement in French Guiana has been found in the north and south. Along the Atlantic Ocean coastline, the "Ile de Cayenne" trondjhemitic-gabbroic formations have provided the oldest zircon ages, *i.e.* 2.208 ± 0.012 Ga for the emplacement the Fe-rich gabbros of "Pointe des Amandiers" (Delor *et al*., 2001). Inherited ages of 2.216 Ga have also been obtained from the cores of three zircons from a low-Al trondhjemite associated with basic tholeiitic-type lavas (Milesi *et al*., 1995). Such inherited ages suggest that partial reworking of the oceanic bimodal magmatic suites could have occurred during production of the *ca*. 2.18 to 2.16 Ga TTG melts, in northern and southern French Guiana.

- A younger suite of granodiorite, tonalite, and TTG association dated at between *ca.* 2.15 Ga and 2.13 Ga forms a large batholith (Central Guiana Complex, CGC) in central French Guiana (Delor *et al.*, 2001; Fig. 2).

- North and south of this Central Guiana Complex, volcano-sedimentary units occur in two "synclinoria", a southern greenstone belt and a northern greenstone belt (Gruau *et al.*, 1985; Marot, 1988; Ledru *et al*., 1991; Manier, 1992; Vernhet *et al*., 1992; Manier *et al*., 1993; Egal *et al*., 1994, 1995; Milesi *et al*., 1995; Vanderhaeghe *et al*., 1998; Delor *et al*., 2001; Voicu *et al*., 2001; Nomade *et al*., 2001a, b), which merge westward toward Suriname into a single greenstone belt, first defined by Bosma *et al*. (1983) and Gibbs and Barron (1983, 1993):

i) The lowest stratigraphic formations, common to both southern and northern greenstone belts, consist essentially of lava and pyroclastic rocks (Marot, 1988; Ledru *et al*., 1991; Tegyey, 1993; Manier *et al*., 1993; Egal *et al*., 1994, 1995; Milesi *et al*., 1995; Vanderhaeghe *et al*., 1998). Their compositions range from basalt to rhyolite as young as 2.156 ± 0.006 Ga, intercalated with scarce sericite-chlorite

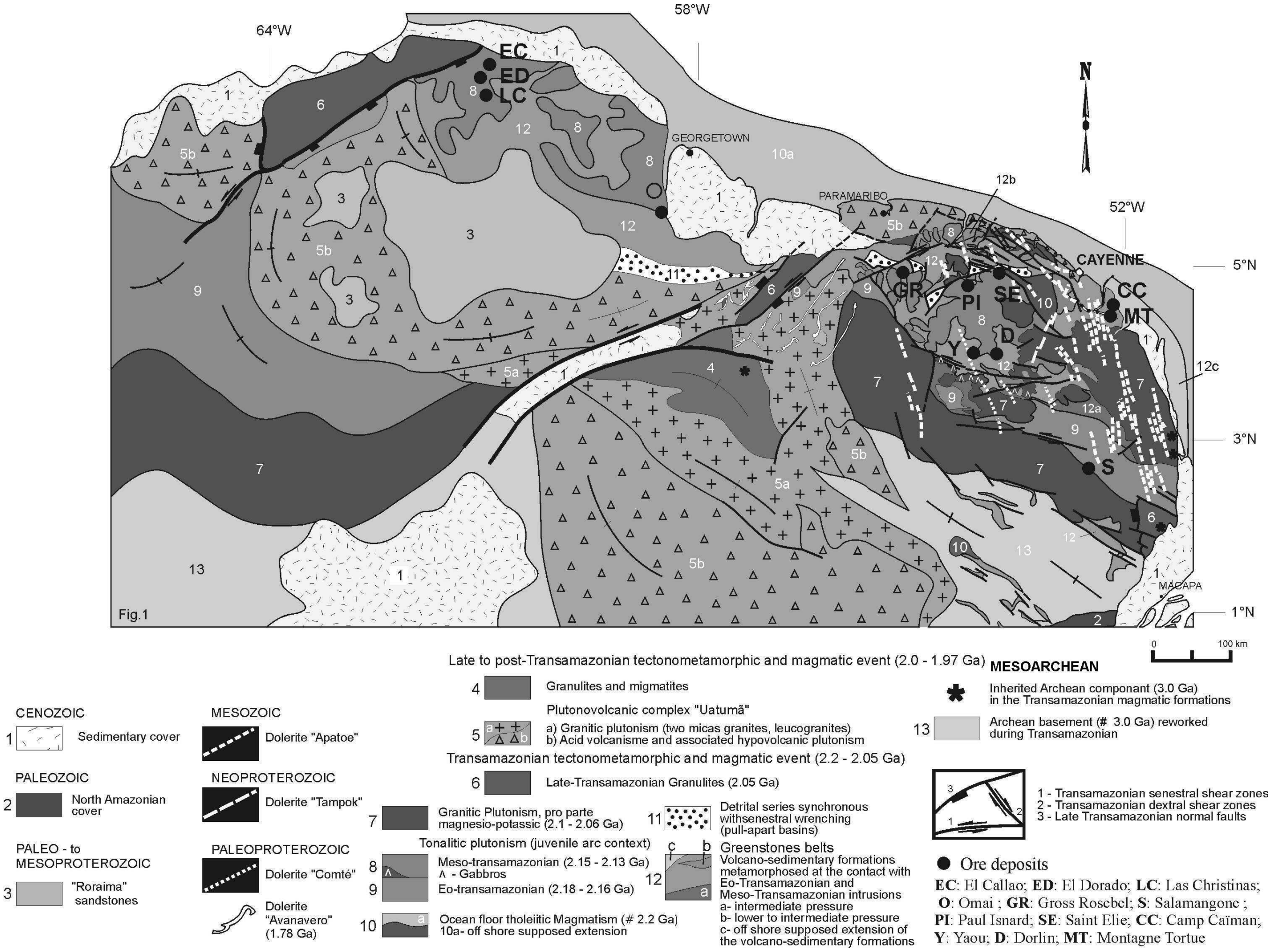


Fig. 1.- Geological sketch map of the Guianas showing the location of the main gold deposits (after Delor *et al.*, 2003a).

Fig. 1.- Schéma géologique des Guyanes (d'après Delor et al.*, 2003, ce volume), indiquant les principaux gisements aurifères.*

schist and the so-called Armina flysch-type formation. Both the northern and southern greenstone belts have a minimum age of 2.132 ± 0.003 Ga, constrained by the age of intrusive emplacement (Delor *et al.*, 2001), and contain inherited components indicating Archean crustal recycling, as evidenced by negative values of the Sm-Nd epsilon ratios (Delor *et al.*, 2001, 2003) and inherited zircons dated to ca. 3 Ga in the Camopi area.

ii) The overlying Upper Detrital Unit (UDU) crops out exclusively in northern French Guiana where it constitutes a geological entity, the "North Guiana Trough" (NGT), with an estimated thickness of 5000 m (Lasserre *et al.*, 1989; Ledru *et al.*, 1991). It is composed of sandstones and conglomerates, including monogenic gold-bearing conglomerates, with a minimum age of 2.115 ± 0.004 Ga (maximum age of detrital zircon, Milesi *et al.*, 1995).

- The youngest magmatic units are mainly granitic suites consisting of massive, granular intrusives, including an Mg-K type (amphibole±pyroxene-bearing granites) and anatexites. The dominant 2.105 to 2.09 Ga component is widely developed in southern and western French Guiana (Delor *et al.*, 2001), whereas late leucogranite (2.08 to 2.06 Ga) appears to be restricted to the north (Vanderhaeghe *et al.*, 1998; Delor *et al.*, 2001).

Dyke swarms cut all previously mentioned rock types. Most trend NNW-SSE (more rarely WNW-ESE) and are Early Jurassic (Deckart, 1996; Deckart *et al.*, 1997; Nomade, 2001a, b). The main dyke swarm is located in the northeast, close to the mouth of the Oyapok River, and marks the precursor stages of the opening of the Atlantic Ocean. However, in the west, a NW-SE-trending dyke a few tens of kilometres in length gave paleomagnetic signals that differed from those of the Early Jurassic dykes (Théveniaut and Delor, 2003); K-Ar dating gave a Neoproterozoic age of 0.810 ± 0.029 Ga.

Deformation events

Deformation events associated with the *ca*. 2.20 Ga oldest basic rocks and subsequent oldest tonalitic magmatism (northernmost and southernmost French Guiana) cannot be clearly defined structurally because of strong tectono-thermal overprinting by later events.

Indeed, over the past decades, structural constraints have been established mainly through the study of volcano-sedimentary greenstone belts and regionally associated plutonic rocks. A two-step tectonic evolution has been documented in northern French Guiana with the recognition of two major tectono-metamorphic events, D1 and D2 (Ledru *et al*., 1991; Milesi *et al*., 1995; Vanderhaeghe *et al*., 1998). These events affected the greenstone belts and the granite-gneiss complexes (Lasserre *et al*., 1989; Ledru *et al*., 1991; Egal *et al*., 1992, 1994), whereas only the major D2 deformation has been recognized in the Upper Detrital Unit (UDU) in northern French Guiana.

According to above-mentioned authors, the first tectonic event (D1) is marked in the south Maroni area by the northward-thrusting of Paleoproterozoic granite-gneiss complexes over the Paramaca Formation (Jegouzo *et al*., 1990) and/or is associated with deformation related to the emplacement of granitic batholiths. Absolute time correlations are difficult to make in the volcano-sedimentary sequences, and more accurate constraints have been established on the basis of plutonic rock relationships. Thus, the earliest datable deformation structures are round, imbricated magmatic fabrics associated with central French Guiana calc-alkalic and TTG batholiths (2.15 to 2.13 Ga), and down-dip mineral lineations indicative of normal movement in thermal aureoles around *ca*. 2.13 Ga tonalites in the northern basin (Delor *et al*., 2001, 2003 b).

These details point to the close relationship between all D1 events (thrusting and magmatism-related deformation) and calc-alkalic and TTG plutonism.

A second transcurrent tectonic event (D2) gave rise to large zones of E-W to NW-SE sinistral strike-slip faults mapped across French Guiana (Marot, 1988; Lasserre *et al*., 1989; Ledru *et al*., 1991; Egal *et al*., 1992; Milesi *et al*., 1995; Vanderhaeghe *et al*., 1998; Delor *et al*., 2001, 2003 b).

In southern French Guiana, this sinistral shearing gave rise to regional-scale sigmoidal foliation trajectories (Delor *et al*., 2001) between major crustal discontinuities such as the South Guiana Shear Zone (Lasserre *et al*., 1989; Jegouzo *et al*., 1990). In northern French Guiana, this sinistral shearing was coeval with the opening of the "North Guiana Trough", which consists of a series of "pull-apart"-type basins aligned approximately E-W (Ledru *et al*., 1991; Egal *et al*., 1992, 1994, 1995). The D2 event is the major event responsible for the genesis of gold (Milesi *et al*., 1995; Voicu *et al*., 2001).

The above-mentioned 2.1 to 2.0 Ga granitic suite is widely documented in southern and western French Guiana (Milesi *et al*., 1995; Delor *et al*., 2001) and was emplaced during D2. Its age is therefore estimated to be close to that of the D2 tectono-metamorphic event.

We should also mention a particular generation of granite that is commonly identified on detailed maps in several mining districts. It consists of small, undeformed or cataclastic, microgranular or granophyric, trondjhemitic intrusives that clearly crosscut all the deformed rocks. These late-D2 deformation intrusives were emplaced at a shallower level than the two earliest generations of massive granitoids.

Metamorphism

Metamorphism is irregularly developed in northern French Guiana. Greenschist (muscovite-chlorite associations) to middle amphibolite (biotite±garnet) facies regional metamorphism is associated with both deformations events, whereas thermal metamorphism occurred near the very abundant granitoids (Ledru *et al*., 1991; Egal *et al*., 1994, 1995; Milesi *et al*., 1995; Vanderhaeghe *et al*., 1998; Delor *et al*., 2003). Earlier pressure estimates of 7 kbar, based on aluminosilicate stability versus paragonite-muscovite solid solutions, have been re-evaluated to 3 to 4 kbar (Delor *et al*., 2003 b) with possible arguments in favour of an anticlockwise P-T path (andalusite-kyanite retrograde path). In central French Guiana, metamorphism is essentially of greenschist facies (Milesi *et al*., 1995). In the southern greenstone terranes, higher-temperature metamorphic conditions are recorded through a pervasive biotite-garnet isometamorphic zone.

Petrologically, and despite a clearer high-temperature imprint in the southern terranes, metamorphic gradients are indicative of medium to low pressures, with no evidence of notable tectonic thickening, as previously emphasized by Milesi *et al.* (1995) for the D1 deformation. A lower grade thermal gradient within certain goldfields is compatible with high thermal gradients related to plutonic bodies. Metamorphism was therefore due to both TTG and granitic-type plutonism, with evidence of thermal aureoles, within an overall context of low to moderate crustal thickening (Delor *et al*., 2003 b).

The new geological maps as well as recently obtained dates (Delor *et al.*, 2003 b) exclude the presence of high-grade metamorphic terranes in French Guiana, in contrast to what had been maintained by Voicu *et al.* (2001). Terranes in the Arawa-Degrad region, mentioned by Voicu *et al*. (2001), contain amphibolite-facies rocks in thermal aureoles of granitoids dated at *ca*. 2.1 Ga in a D2-related transcurrent context (Delor *et al*., 2003). Thus, we disagree with the conclusions of Voicu *et al*. (2001) regarding the presence of high-grade metamorphic terranes similar to

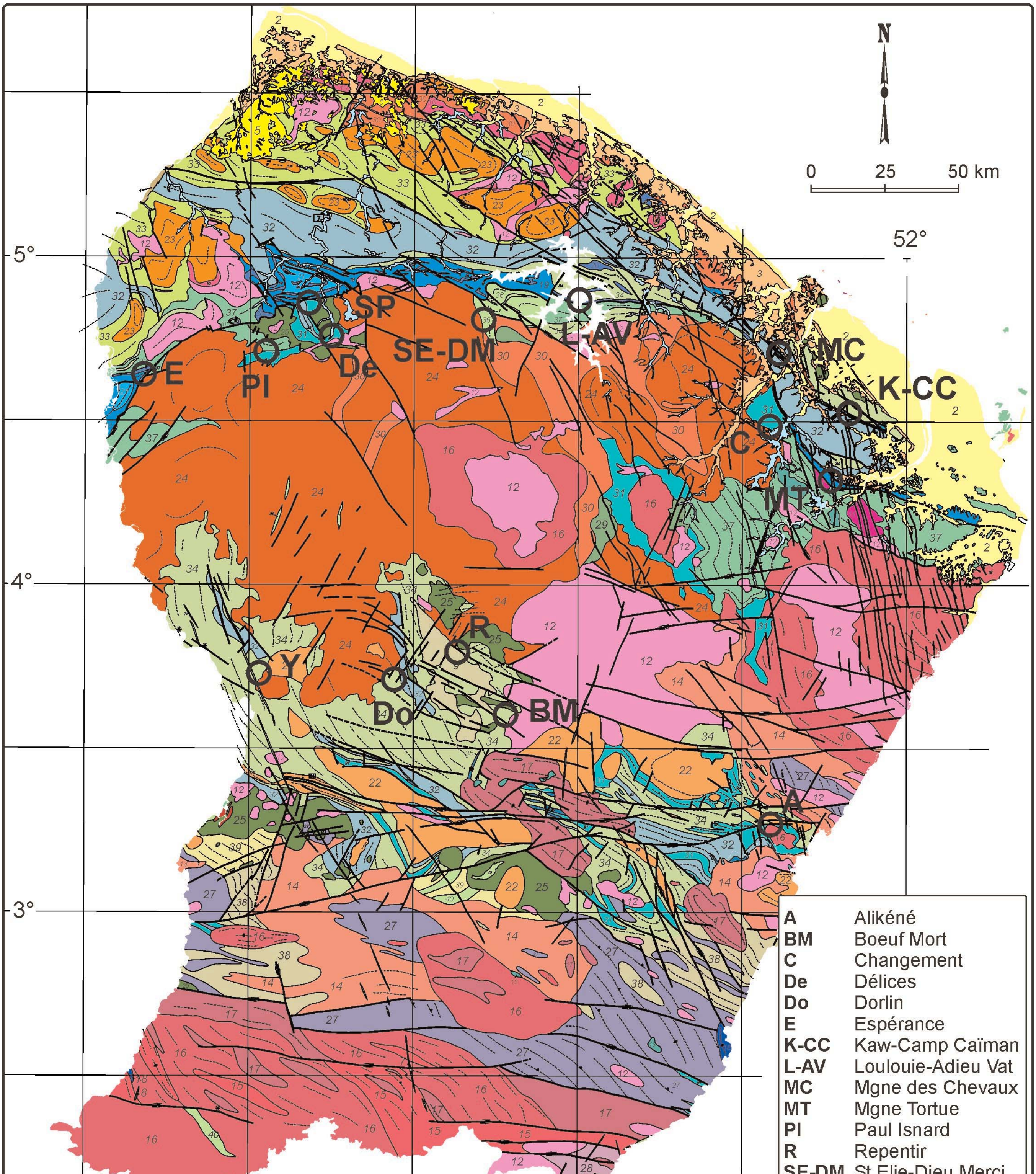
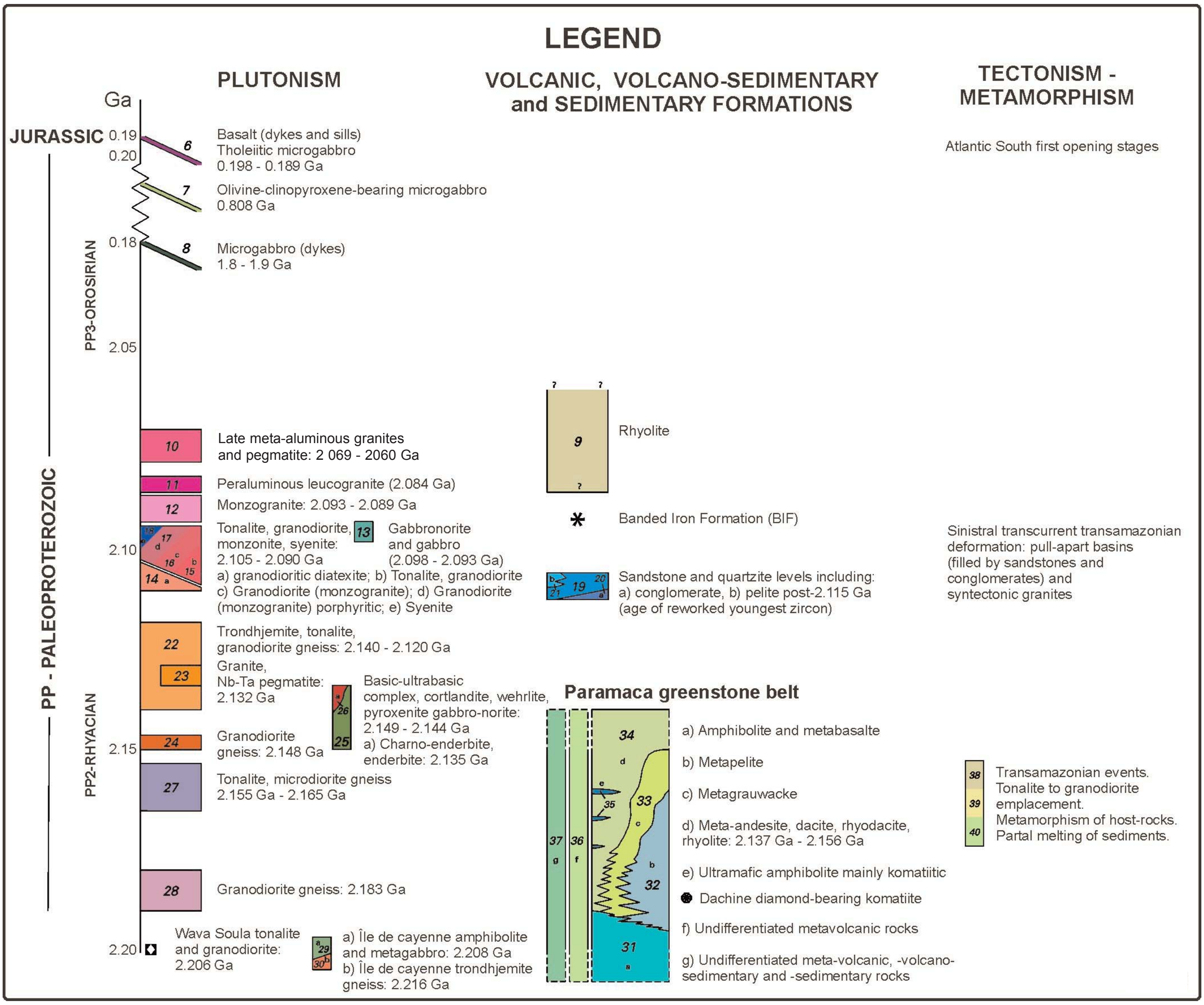


Fig. 2.- Location of the main gold deposits on the geological map of French Guiana (after Delor *et al*., 2001, 2003 b).

Fig. 2.- Position des principaux gisements aurifères sur la carte géologique de la Guyane (d'après Delor et al.*, 2001 et 2003 b).*



those of Suriname, which have been dated at Bakhuis Mount (Suriname) at between 2.07 and 2.05 Ga (Roever *et al*., 2003), rather than 2.02 to 1.95 Ga (Voicu *et al*., 2001). These points are important, as we will see in the discussion about models for the emplacement of the different types of gold deposits.

Schematic two-stage tectono-metamorphic evolution of French Guiana

A two-stage model of geological evolution has been proposed by Vanderhaeghe *et al*. (1998) and refined by Delor *et al*. (2000, 2001, 2003 a, b); it involves (a) a first stage of "crustal growth by magmatic accretion", following the formation of an oceanic crust, and (b) a second stage of "tectonic accretion and crustal recycling".

The first stage is marked by (i) the formation of an oceanic crust, documented by the 2.208 ± 0.012 Ga age obtained on the Fe-rich gabbros of "Pointe des Amandiers" (Delor *et al*., 2001), and (ii) the emplacement of calc-alkalic volcano-plutonic complexes, including the Ile de Cayenne Complex (ICC) dated at 2.174 ± 0.007 Ga on a low-Al "plagiogranite"-type trondhjemite (Milesi *et al*., 1995) and the Central Guiana Complex.

The second stage of "tectonic accretion and crustal recycling" is marked by:

- Formation of the sedimentary basins separating the middle and northern volcano-plutonic complexes;

- Convergence, during the Transamazonian Orogeny, of the juvenile blocks intercalated between the Ile de Cayenne Complex and the Central Guiana Complex;

- Oblique convergence that led to the formation of foreland basins in a pull-apart system (Ledru *et al*., 1994; Milesi *et al*., 1995);

Deposit name	Gold Resources: t @ grade (g/t)	Type of deposit	Mining Companies
Yaou [1]	~ 24.64 t @ 2.2 g/t.	Yaou A: Au orogenic mesothermal associated with syn-D2 granitoids; Yaou B: pre-D2"stratabound" and syn-D2 epigenetic Au orogenic mesothermal («Turbidite-hosted»).	Guyanor, Goldenstar, Cambior
Dorlin[1]	~11.05 t @ 1.3 g/t	Gold stratabound type formed by: (i) stratiform tourmaline-gold ore and (ii) orogenic mesothermal ore («Turbidite-hosted»)	Guyanor, Goldenstar, Cambior.
Saint-Elie[2].	~ 5.9 t @ 4.2 g/t	Au orogenic mesothermal	Guyanor
Paul Isnard[4]	~ 46 t @ 2.5 g/t	Au orogenic mesothermal	Guyanor
Camp Caïman[2 5]	~ 65 t @ 1.8 - 3.2 g/t	Au orogenic mesothermal	ASARCO
Sophie-Repentir[4] (district)	~ 45 t @ ~1.5-2 g/t	Au orogenic mesothermal	
Omai[3 5] (Guyana)	~ 130 t @ 1.6 g/t	Au orogenic mesothermal	Cambior & Government of Guyana
Salamangone[3] (Brazil)	~ 50 t	Au-As orogenic mesothermal: epigenetic quartz vein in ductile shear-zone, hosted by tonalite-granodiorite	
Gross Rosebel[3 5 6] (Surinam)	~ 60 t @ 1.6 g/t	Au-Py orogenic mesothermal along geological contact, folds and sheared corridors; potassic alteration.	Cambior, Goldenstar
Las Cristinas[7] (Venezuela)	~ 320 t @ 1.13 g/t	Au-Cu orogenic mesothermal	MINCA

Table 1.- Selected Paleoproterozoic deposits of the Guianas ([1]Cambior, 1997; [2]Chambre Syndicale des Industries Minières, 1999; [3]Lafrance *et al.*, 1999; [4]Harris, 1998, 1999; [5]Voicu, 2001; [6]Wasel and Donald; [7]MINCA, 2003).

Tabl. 1.- Principaux gisements paléoprotérozoïques des Guyanes ([1]Cambrior, 1997; [2]Chambre Syndicale des Industries Minières, 1999; [3]Lafrance et al.*, 1999; [4]Harris, 1998, 1999; [5]Voicu, 2001; [6]Wasel et Donald, 2003; [7]MINCA, 2003).*

- Emplacement of high-K granite dated at 2.093 ± 0.08 Ga (Milesi *et al.*, 1995), indicative of thickening (Vanderhaeghe *et al.*, 1998);

- A final stage of oblique convergence with lateral extrusion of blocks, which led to the burial of foreland basins and the emplacement of leucogranites dated at 2.083 ± 0.08 Ga along major shear zones (Milesi *et al.*, 1995).

D1 versus TTG tectono-thermal continuum: From 2.20 to 2.13 Ga (Eo- to Meso-Transamazonian), dominant tonalitic magmatism and regionally associated greenstone belts are interpreted to have existed in a scenario of "island-arc plutono-volcanism" (Vanderhaeghe *et al.*, 1998) with southward-directed subduction.

D2 versus granitic-suite sinistral wrenching:

- At *ca.* 2.10 Ga, granitic magmatism occurred in response to the closure of island-arc basins and the change from southward-directed subduction to sinistral wrenching. Late UDU detrital-basin opening continued during this stage in areas of maximum crustal stretching (pull-apart basins).

- Final transcurrent movement coeval with 2.08 to 2.06 Ga leucogranites in French Guiana was amplified farther west in Suriname and culminated with the production of the Bakhuis Ultra-High-Temperature granulites dated at ca. 2.08 to 2.06 Ga and associated with emplacement of gabbro or ultramafic rocks (Delor *et al.*, 2001, 2003 this volume).

Gold deposits of Guiana: geological and metallogenic characteristics

Since gold was first discovered in French Guiana in 1857, total gold production has been close to 195 t, from dredging, artisanal, or small-scale industrial operations. The revival of exploration in the 1970's (particularly through the BRGM's "Inventaire Minier" between 1975 and 1995) led to the discovery of new primary and secondary deposits, thus encouraging industrial investors. The economic potential of the primary gold-bearing deposits shows a net increase. Table 1 summarizes economic data for the main deposits of Guiana and provides an order of magnitude of the gold potential (Milesi, 2001).

During the "Inventaire Minier" and a number of BRGM scientific research programs, regional, kilometre-scale hydrothermal alteration was observed along the greenstone belts and the major shear zones (*e.g.* northern greenstone belt, North Guiana Trough shear zone, southern greenstone belt, etc. (Milesi and Picot, 1995; Milesi *et al.*, 1995). Moreover, several districts were re-examined in order to update their mining potential and identify hydrothermal alteration haloes.

Three main types of primary ore deposits have been recognized in French Guiana, on the basis of textural features and geological setting (Fig. 2):

1. Stratiform/stratabound gold-bearing tourmalinites (essentially pre-D1), in which gold is associated with disseminated sulphides, hosted by the volcanic and sedimentary rocks of the Paramaca Formation.

2. Gold-bearing conglomerates (D2-related): disseminated gold hosted by the Upper Detrital Unit of the North Guiana Trough. Mineralization is found in polygenic conglomerates containing detrital oxides and hydrothermally altered and schistose metasedimentary pebbles, as well as in quartzites and more rarely in monogenic conglomerates (Vinchon *et al.*, 1988; Ledru *et al.*, 1991; Manier, 1992; Milesi *et al.*, 1995).

Deposit (at stage of emplacement)	*Type of primary deposit*	*Morphology*	*Ore*	*Gangue*
Dorlin. *stage 1 of magmatic accretion*	1. Stratiform tourmaline-gold deposit	Disseminated sulphides (pre-D1)	Py, Ccp, Apy, (Gn, Sp, Bi-tell.), gold.	Qtz, Drv, Chl, Carb, Ser.
Dorlin. *stage 2 of tectonic accretion*	2. Orogenic mesothermal Quartz veins («Turbidite-hosted» type)	Quartz stockwork (syn-D2)	Py, Ccp, Cug, Gn, Sp, Bi-Tell., (gold).	Qtz, Carb, Chl, Ser, Srl, Ep, Tlc

Legend: Apy: arsenopyrite, Bi-Tell.: tellurides of Bi, Ccp: chalcopyrite, Cug: grey copper gris, Gn: Galena, Py: pyrite, Sp: sphalerite, Carb: carbonates, Chl: chlorite, Ep: epidote, Srl: Fe-tourmaline, Drv: Mg-tourmaline (dravite), Qtz: quartz, Ser: sericite, Tlc: talc.

Table 2.- Main characteristics of the Dorlin Paleoproterozoic ore deposit (after Lerouge *et al.*, 1999).

Tabl. 2.- Principales caractéristiques du gisement aurifère paléoprotérozoïque de Dorlin (d'après Lerouge et al.*, 1999).*

3. *Mesothermal-orogenic ore deposits (D2-related)*: This type of discordant polymorph mineralization is represented by quartz-carbonate-sulphide veins and stockworks, essentially hosted by the Paramaca Formation and granitoids. The most numerous are vein-type occurrences with sulphide haloes related to different phases of the D2 tectonic event (Lasserre *et al.*, 1989; Manier, 1992; Manier *et al.*, 1993; Milesi *et al.*, 1995), although some are associated with late phases of D1 tectonics.

Type 1: Stratiform/stratabound gold-bearing tourmalinites (essentially pre-D1)

The best example of this type of ore deposit is the Dorlin tourmalinite-hosted gold deposit, which consists of an orebody produced by polydeformation of a large stratabound sulphide deposit hosted by volcanic and sedimentary rocks of the Paramaca Formation, metamorphosed to greenschist facies (Milesi *et al.*, 1988; Lerouge *et al.*, 1999).

Regional tourmalinization: In the southern greenstone belt, an earlier stratiform tourmalinization (pre-S1 schistosity) can be seen in an area of over several tens of square kilometres in the Dorlin district; it formed within a unit of volcaniclastic rocks and lavas of the Paramaca Formation. It has been metamorphosed to greenschist facies and cut by granites and pegmatites dated respectively at 2.127 ± 0.007 Ga and 2.123 ± 0.011 Ga (Milesi *et al.*, 1995). It contains low-grade gold mineralization and represents an earlier stock of disseminated gold.

Dorlin, a subaquatic stratiform/stratabound hydrothermal system centred on its feeder zones: The Dorlin deposit, located in layers of dacitic to andesitic volcaniclastic rocks and lavas, has undergone D1 and D2 deformation (Table 2). The hydrothermal system is centred on feeder zones, represented by hydrothermal breccias and a network of veinlets, pipes, and alteration stringers (Milesi *et al.*, 1988; Lerouge *et al.*, 1999; Fig. 3). The alteration has been massively developed through small, interconnected fractures with the successive replacement of Fe-Mg minerals and feldspar (Tegyey, 1986, 1988; Milesi *et al.*, 1988; Lerouge *et al.*, 1999). The hydrothermal system is zoned, with an outer chlorite+sulphides zone (M1) and an inner Mg-tourmaline+sulphides zone (M2). A layer of fine-grained siliceous sedimentary facies (chert) at the top of the system indicates deposition within a subaqueous environment. The local presence of a polygenic breccia with volcanic and chert clasts in the cores of the hydrothermal system, as well as the absence of early mineralization within the volcaniclastic hanging wall, suggest that this system developed at the water–volcanic rock interface during a quiescent period of the volcanic activity.

Mineralization of the stratabound ores (Fig. 4): The Dorlin M1 and M2 main deposits are represented by disseminated sulphides with low gold grades ranging from 1 to 5 g/t (Milesi *et al.*, 1988). The ores consist essentially of pyrite with traces of chalcopyrite, arsenopyrite, and grey copper. Sphalerite, galena, pyrrhotite, digenite, tennantite, covellite, and tellurides are rare. Gold is native and occurs as three types: prevailing gold in primary inclusions in pyrite, gold with a low silver content (<15%) coeval with the tellurides, and native gold in veinlets crosscutting pyrite grains.

Hydrothermal alteration of the stratabound ores: The M1 alteration consists essentially of chlorite with disseminated pyrite and minor quartz and calcite. Chlorite is represented by ripidolite with an Fe/Fe + Mg ratio ranging from 0.45 to 0.6 and by pychnochlorite with an Fe/Fe + Mg ratio ranging from 0.4 to 0.45, after the classification of Hey (1954). The M2 alteration consists of abundant tourmaline (more than 15 to 20% of the rock), quartz, disseminated pyrite and carbonates.

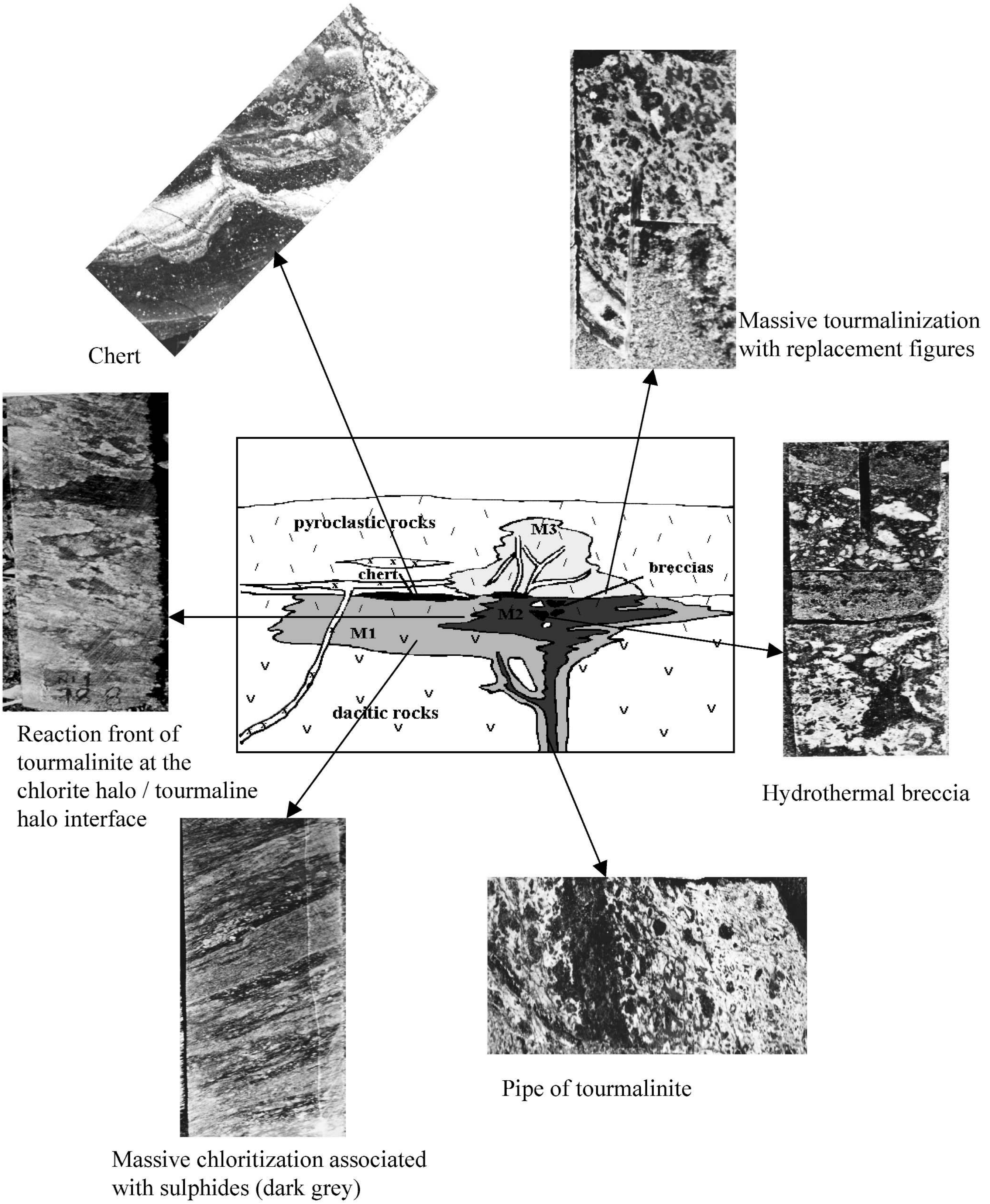
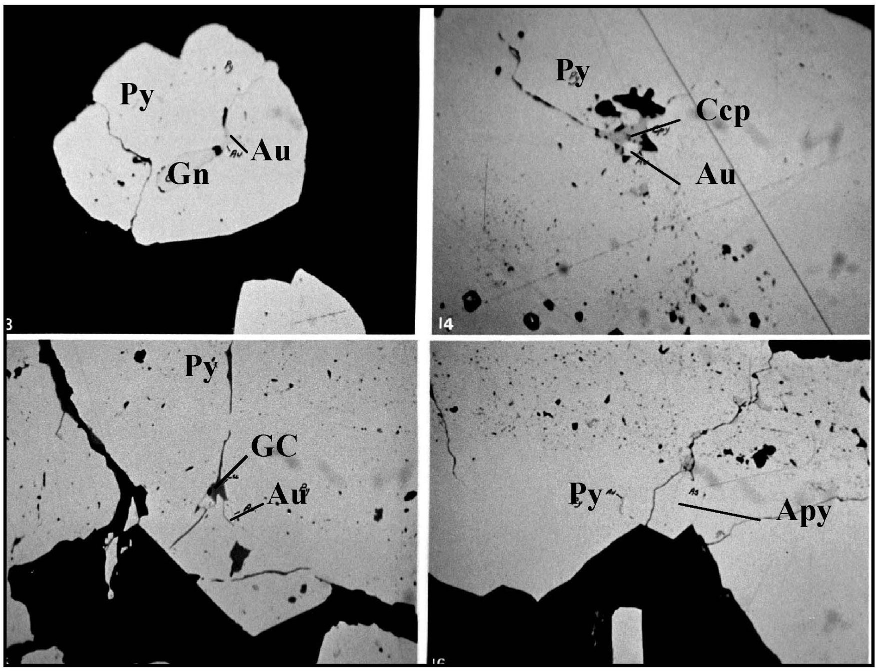


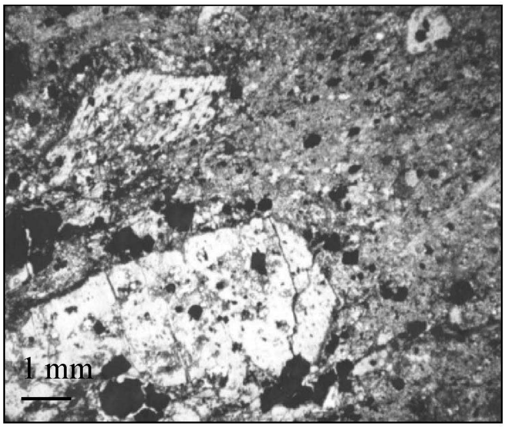
Fig. 3.- Section through the hydrothermal system: M1, chlorite outer halo; M2, tourmaline inner halo; M3, late stockwork (after Lerouge *et al*., 1999). Photographs of drill-hole samples characteristic of each zone.

Fig. 3.- Coupe schématique du système hydrothermal ; M1 : halo externe à chlorite, M2 : halo interne à tourmaline, M3 : stockwerk tardif (d'après Lerouge et al.*, 1999). Photographies d'échantillons de sondages caractéristiques de chaque zone.*

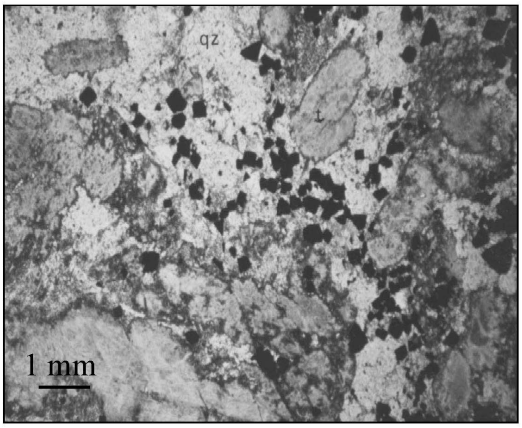


a. microphotographs of the main minerals of the ore assemblage.

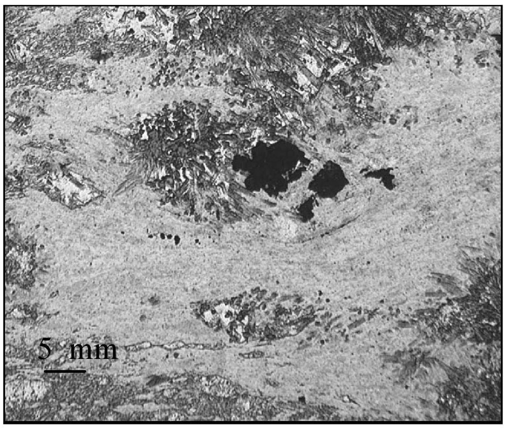
Apy: arsenopyrite
Au: native gold
Ccp: chalcopyrite
GC: grey copper
Gn: galena
Py: pyrite



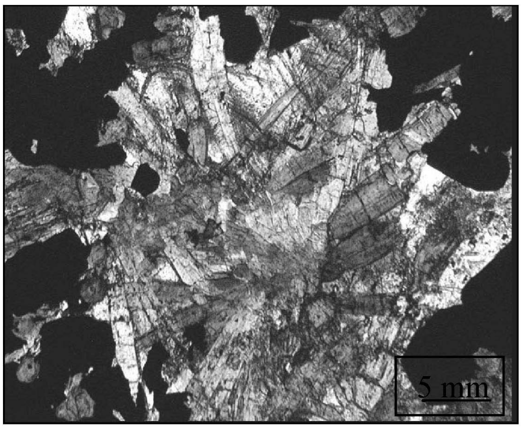
b. Chlorite alteration with relics of magmatic plagioclase



c. Tourmaline alteration. Rock preserves locally a magmatic texture



d. Massive chlorite alteration with frequent tourmaline



e. Massive tourmaline alteration with sulphides

Fig. 4.- Microphotographs of ore assemblage and associated hydrothermal minerals from the Dorlin stratabound-type gold deposit.

Fig. 4.- Microphotographies des minerais et des altérations hydrothermales associées du gisement aurifère de type « stratiforme/stratabound » de Dorlin.

Deposit name, *facies*	*Type of deposit*	*Morphology*	*Ore*	*Gangue*
Montagne Tortue (GU20P), *«Banket» type*	«Modified paleoplacer at gold-oxides»: quartz-pebbles-bearing monogenic conglomerates (shows analogy with "Banket-type" of Tarkwa, Ghana).	Disseminated gold and oxides	gold, oxides, Ti-Mag, Chr, Zrn	Ms
Montagne Tortue, *«Debris flow» type*	«Modified paleoplacer »: gold-oxides-bearing debris flow polygenic conglomerates (shows analogy with "Kawere-type", Tarkwa, Ghana).	Disseminated gold	gold, oxides	Ms
Montagne de Kaw, *«sulphides facies type»*	Syn-D2 epigenetic pyrite + gold disseminated mineralization developed along monogenic conglomerates (shows analogy with Jacobina, Brazil).	Pyrite, disseminated gold	Py, gold	Ms, Cld
Espérance *«sulphides facies type»*	Disseminated mineralization with Au-Fe-Cu signature, hosted in hornfels.	Disseminated sulphides and stockworks	Py, Po, Ccp, Mag, Cv, gold, silver	Qtz, Bt, Tur, Amph, Carb, Chl, Ms
Montagne Tortue, *«quartz vein type »*	Orogenic mesothermal gold mineralization along shear-zone cutting polygenic conglomerates.	Veins and stockworks of quartz	gold	Qtz, Ab, Tur, Ms
Montagne des Chevaux, *«quartz vein type »*	Orogenic mesothermal gold mineralization along shear-zone cutting monogenic conglomerates.	Stockworks of quartz	Py, gold	Qtz, Ms, Ky

Legend: Ab: albite, Amph: amphibole, Bt: biotite, Carb: carbonates, Chl: chlorite, Chr: chromite, Cv: covellite, Ccp: chalcopyrite, Cld: chloritoid, Ky: kyanite, Mag: magnetite, Ms: muscovite, Po: pyrrhotite, Py: pyrite, Qtz: quartz, Ti-Mag: Ti-magnetite, Tur: tourmaline, Zrn: zircon.

Table 3.- Main characteristics of gold-bearing Paleoproterozoic conglomerates of French Guiana.

Tabl. 3.- Principales caractéristiques des conglomérats aurifères paléoprotérozoïques de Guyane.

Tourmaline is represented by a schorl-dravite with an Fe/Fe + Mg ratio ranging from 0.3 to 0.6 dravite changing at contact with pyrite (Tegyey, 1986). Carbonates consist of ankerite and minor calcite.

Mesothermal ores: The early stratabound hydrothermal system is locally cut by a syn-D2 mesothermal stockwork (M3) composed of quartz, muscovite, carbonates, and sulphides. Galena in this M3 stockwork yields a model age of 2.067 ± 0.001 Ga (Pb-Pb method, Marcoux and Milesi, 1993). Thus, this age either has no significance since it represents a model age, or, if it is significant, it postdates emplacement of the epigenetic stratabound ores at Dorlin (upper age limit) and marks an earlier increment of D2 deformation.

Formation conditions: As regards formation pressure, the geological context suggests that the deposit was emplaced under surface conditions, at the seawater-volcanic rock interface. The chlorite thermometer of Xie *et al.* (1997) gives a formation temperature of about 364 ± 40°C, whereas the chlorite-quartz oxygen isotopic thermometer indicates lower temperatures of about 270°C. This difference in temperature is likely due to a partial chemical re-equilibration of chlorite with late fluid, with the oxygen isotope equilibrium being attained. The tourmaline-quartz oxygen isotopic thermometer indicates temperature of about 160 to 200°C, preferentially interpreted as a re-equilibration temperature.

Conclusions regarding type 1: The stratiform/stratabound gold-bearing tourmalinites are a marker of a hydrothermal system responsible for the first introduction of Au and B in the Paleoproterozoic terranes during magmatic accretion. This ore deposit was locally "modified" in the upper–middle crust by mesothermal fluids, which produced the D2-related M3 quartz stockwork. Thus, these structural, mineralogical, and isotopic data do not allow for the generalization of the "post-metamorphic" gold deposit model proposed by Voicu *et al.* (2001), following the model of Stüwe (1998).

Type 2: Gold-bearing conglomerates: disseminated gold hosted by the Upper Detrital Unit of the North Guiana Trough (D2-related)

Detrital sedimentary formations of the Upper Detrital Unit contain several gold-bearing occurrences hosted by polygenic conglomerates (below) and monogenic conglomerates (above) (Table 3). A variety of facies are observed in the Paleoproterozoic conglomerates:

(a) "Heavy-mineral beds" facies ("Banket-type"), characteristic of the Tarkwaian Ghanaian modified paleoplacer;

(b) Gold-bearing "debris-flow type" (Manier, 1992) ("Kawere-type facies"), in which reworked hydrothermal pebbles were recognized;

(c) D2-related "sulphide-bearing facies" type;

(d) D2-related "mesothermal quartz veins" ("orogenic type") developed along the beds of monogenic or polygenic conglomerates.

"Heavy-mineral beds" facies ("Banket-type")

Some monogenic conglomerates containing more than 90% quartz and minor quartzite pebbles and hosting gold and disseminated oxides have been identified in Guiana. They are represented by small, isolated channels and do not contain economic gold concentrations. The gold mineralization is associated with beds of heavy minerals (titanomagnetite, chromite, and zircon). Several examples have been found at Montagne Tortue (anomaly GU20P with a maximum of 18 g/t Au, occurrence no. 44 in Milesi *et al*., 1995). These gold-oxide-bearing conglomerates can be compared to the "Banket conglomerates" of Tarkwa (Milesi *et al*., 1992, 1995) and interpreted as "modified paleoplacers".

Finally, this "heavy-mineral beds" facies represents the less modified "paleoplacer-type" ores hosted by the conglomerates.

Gold-bearing "debris-flow type" ("Kawere-type facies")

Some polygenic conglomerates with sedimentological characteristics of "debris flows" (Manier, 1992; Manier *et al.*, 1993) contain a gold-oxide-bearing mineralization disseminated in a sandy, phyllosilicate-rich matrix (e.g. Montagne Tortue; Fig. 5). A good correlation exists between these debris flows and the main geochemical gold anomalies (>200 ppb) (Manier, 1992; Manier *et al*., 1993).

These conglomerates are rich in schistose pebbles of sedimentary origin and in reworked, hydrothermally altered pebbles, markers of earlier hydrothermal activity. The pebbles comprise essentially tourmalinites, fuchsite- and/or carbonate-rich sedimentary rocks, and metasiltites with anomalous Li, Nb, and K_2O, as well as abundant pebbles of quartz-vein origin with mylonitic or cataclastic textures and oxidized sulphides (Milesi *et al.*, 1995). This leads us to consider a possible reworking of an earlier hydrothermal event, which could have been associated with the last episodes of the D1 tectonic event or the first stages of the D2 tectonic event. It suggests that emplacement of the mesothermal deposit was diachronous.

Finally, these "debris-flow type" facies could be interpreted as "modified paleoplacers", as an earlier hydrothermal event was affected by epigenesis during diagenesis and/or the earlier stage of deformation.

D2-related "sulphide-bearing facies"

Rare "sulphide-bearing facies" with epigenetic gold-pyrite mineralization have been described at Espérance and Montagne de Kaw, both located at a major UDU-Paramaca Formation contact (Fig. 6). Mineralization consists of sulphide-bearing stockworks, veins, and impregnations, essentially hosted by polygenic conglomerates of the UDU. These stockworks were emplaced during several stages of D2 transcurrent deformation, as indicated by the presence of pre- to syn-D2 epigenetic sulphides.

Espérance

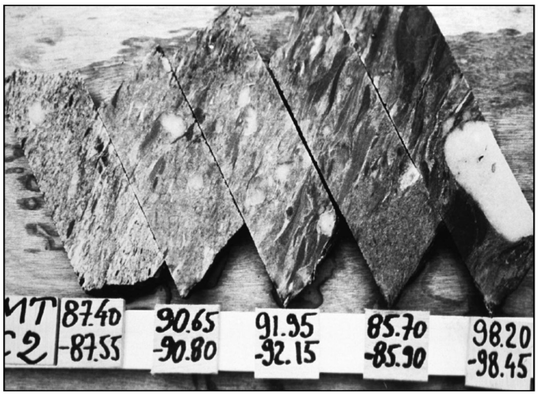
The Espérance district is bounded by a granite intrusion in the west and by gabbros in the south (Plat and Lamouille, 1982). No granite outcrops have been identified at the scale of the deposit, although the presence of garnet and biotite metamorphic clouds attests to the proximity of a shallow intrusive. The host rocks are conglomerates rich in schist, magmatic blue quartz, and quartzite pebbles, as well as detrital sandstones rich in magnetite (Milesi *et al*., 1995).

The hydrothermal system at Espérance consists of metre-thick, D2-related, multistage quartz stockworks (pre- to syn- and more rarely late-D2), preferentially found in irregular, metre-thick, garnet+biotite±amphibole±magnetite metamorphic clouds. Stockworks are composed of quartz+ sulphides+tourmaline+white mica±biotite±amphibole or quartz+sulphides+chlorite veinlets with minor amphibole, tourmaline, chlorite, carbonates, and adularia. These D2-related stockworks were emplaced (and partly deformed) during peak D2 transcurrent deformation.

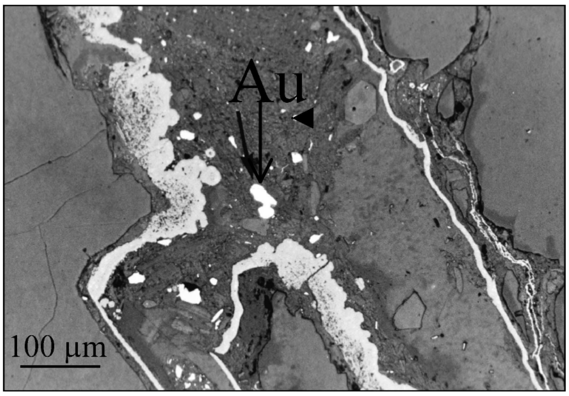
Brown biotite has a high Fe/Fe + Mg ratio of about 0.80 and TiO_2 contents ranging from 1.62 to 2.02 wt. %. It has been partially altered to chlorite, which shows the same high Fe/Fe + Mg ratio. Carbonates consist of both ankerite and calcite.

The formation temperature of some tourmaline+ biotite+amphibole veinlets has been estimated at about 550°C, using the biotite-tourmaline thermometer of Blamart *et al*. (1989). The temperature range of late chlorite+sulphide veinlets has been estimated at about 330°C, using the chlorite thermometer of Xie *et al*. (1997). The presence of adularia, typical of low-sulphidation epithermal ore, is very unusual.

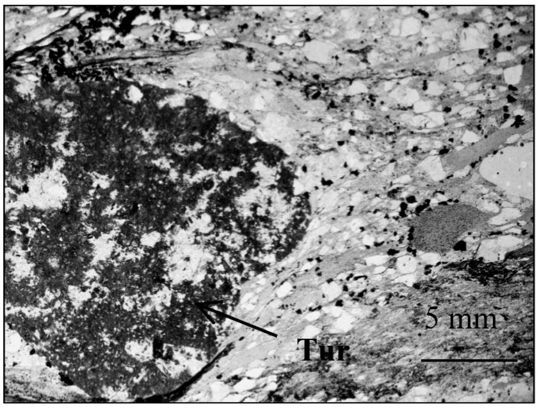
Pre- to syn-D2 ore consists of pyrrhotite prevailing over pyrite, pyrite, galena, and gold disseminated in polyphased stockworks.



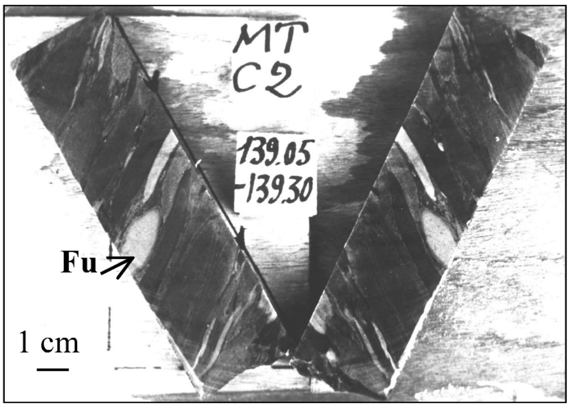
a. drillhole samples of debris-flows



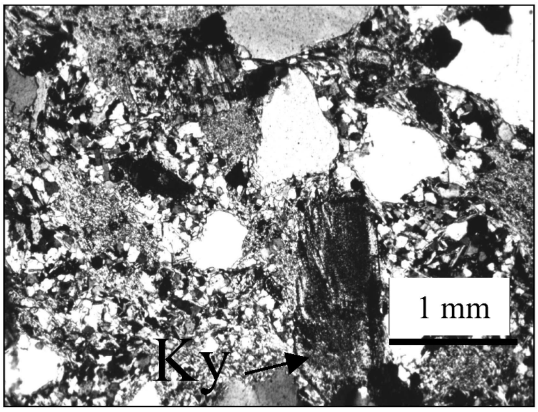
b. free gold (Au) - reflected light



c. Tourmalinite (Tur) pebbles in debris flows



d. Fuchsite (Fu) pebbles in debris flows

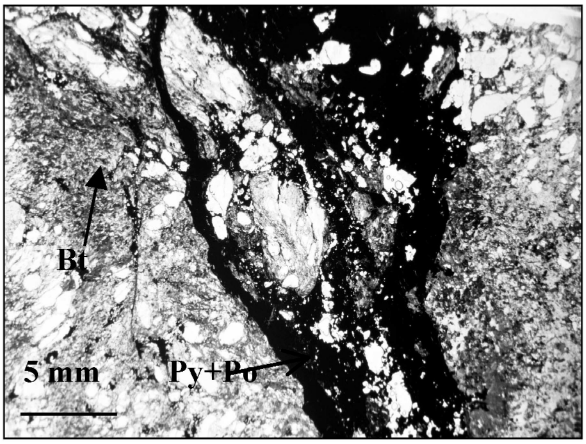


e. Kyanite (Ky) in matrix of conglomerate - Polarized transmitted light

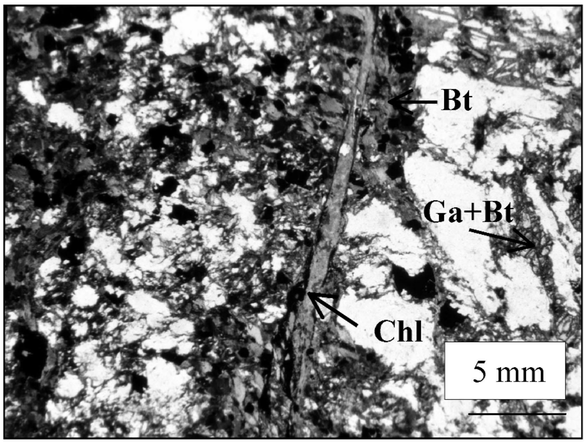
f. Andalusite (And) in matrix of conglomerate - Natural transmitted light

Fig. 5.- Gold-bearing conglomerates of Montagne Tortue: “debris-flow” type facies.

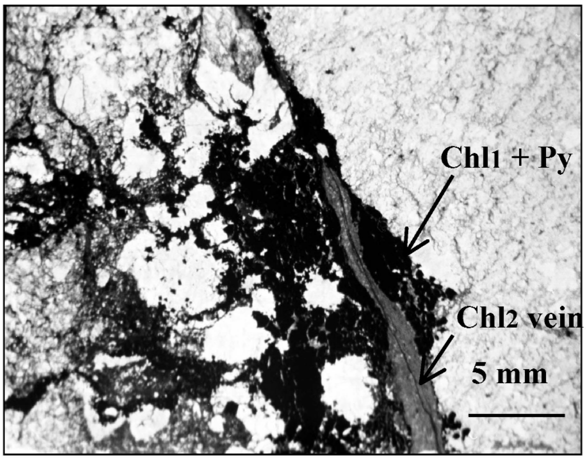
Fig. 5.- Conglomérats aurifères de Montagne Tortue : faciès de type coulée de débris.



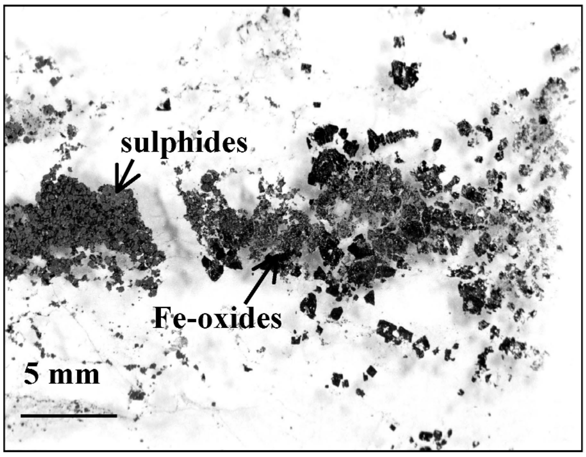
a. Biotite (Bt) alteration associated with pyrrhotite (Po) + pyrite (Py) mineralization at Esperance



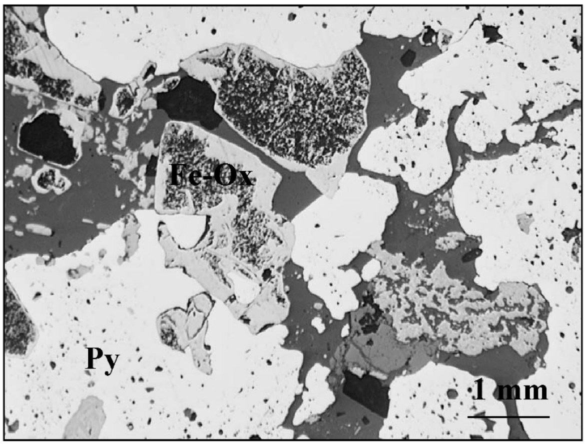
b. Biotite (Bt) alteration at equilibrium with garnet (Ga) and crosscut by chlorite (Chl) at Espérance



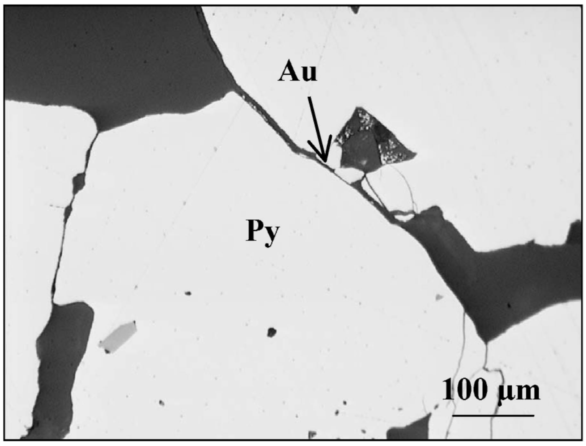
c. Chlorite (Chl) alteration with pyrite (Py) mineralization at Espérance



d. Sulfuration process in conglomerate from Permis Ricard



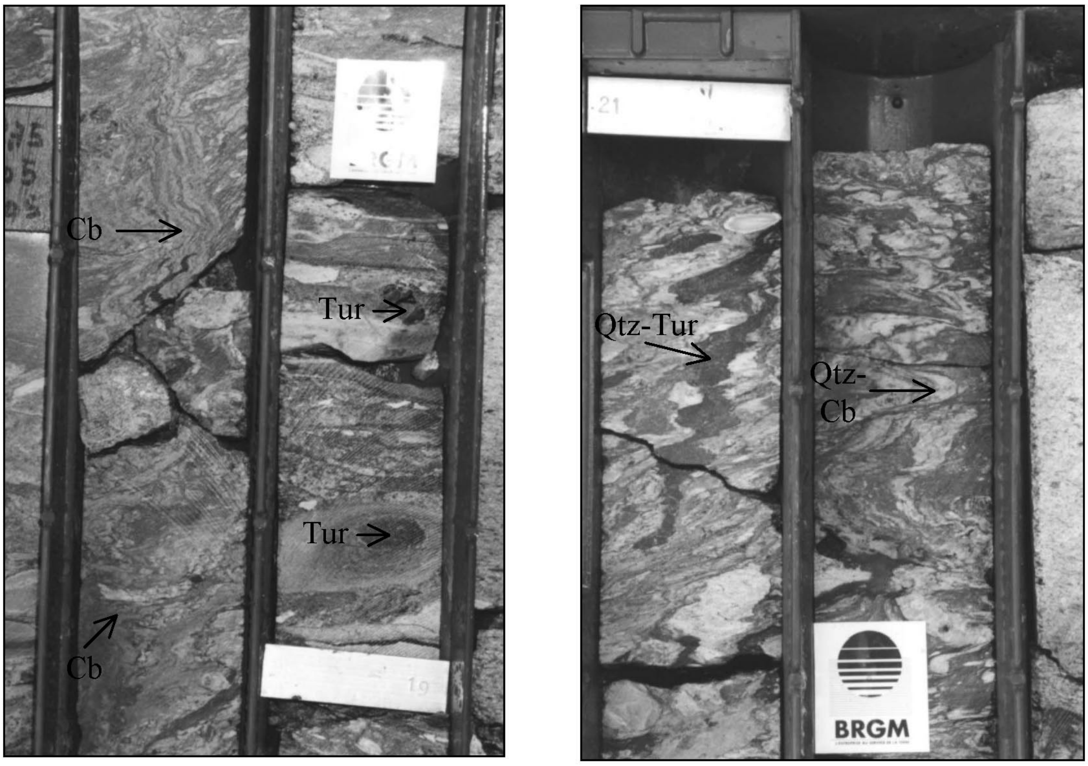
e. Permis Ricard - pyrite (Py) growing on Fe-oxides (Fe-Ox)



f. Gold (Au) in pyrite (Py) at Permis Ricard

Fig. 6.- Sulphide-facies type of gold-bearing conglomerates.

Fig. 6.- Conglomérats aurifères à sulfures.



a. D2-folded gold-rich carbonate stockwork (Cb) and tourmalinite pebble (Tur) reworked in the debris-flow.

b. D2-folded gold-rich quartz + carbonates (Qtz-Cb) and quartz + tourmaline (Qtz-Tur) stockworks.

Fig. 7.- Drill-hole samples from Tortue, illustrating the D2-related mesothermal quartz veins developed along the beds of monogenic and polygenic conglomerates.

Fig. 7.- Echantillons de sondages de Tortue, illustrant les veines de quartz mésothermales liées à la déformation D2, développées le long des niveaux conglomérats mono- et polygéniques.

Montagne de Kaw

No granite intrusives have been identified in the Montagne de Kaw district, although hectometre-scale B, W, Nb, Ce, Pb, and Zn geochemical anomalies attest to a granitic influence (Milesi *et al.*, 1995). Host rocks are arkosic sandstones and conglomerates with nearly 20% of pebbles from Paramaca volcanic rocks (Coste and Toux, 1992).

The mineralization consists of syn-D2 impregnated sulphides, oxides, and gold in conglomerates, the whole cut by rare, millimetre- to several centimetres-thick quartz±tourmaline veins. Sulphides and oxides are predominantly pyrite with minor chalcopyrite, pyrrhotite, and titanomagnetite.

Finally, this "sulphide-bearing facies" type is a marker of the changes that affected conglomerates in the upper–middle crust during D2 tectonic accretion. The presence of epigenetic pyrite allows a comparison between these "sulphide-bearing facies" and the mineralization hosted in a conglomeratic reservoir at Jacobina, Brazil (Milesi *et al.*, 2002).

D2-related "mesothermal quartz veins" ("orogenic type")

At various localities (*e.g.* Montagne des Chevaux, Montagne Tortue, Montagne de Kaw), a mesothermal quartz-vein ("orogenic-type") facies is developed along the beds of monogenic or polygenic conglomerates. It is represented by D2-deformed quartz+tourmaline+free gold±albite±white mica veins and stockworks crosscutting polygenic conglomerates (Fig. 7). In drill holes at Montagne Tortue, the gold content reaches 6 g/t (Martel-Jantin, pers. comm.). At Montagne des Chevaux, anomalous gold contents reached 4 g/t (Lasserre *et al.*, 1989; Milesi *et al.*, 1995). At Montagne de Kaw, late quartz±tourmaline veins could also be attributed to this ore type.

Along the Montagne des Chevaux-Montagne de Kaw UDU trend, the modified matrix of detrital rocks comprises chlorite, muscovite-paragonite (pair association), garnet, amphibole, chloritoid, and kyanite (fan-shaped assemblage preferentially associated with quartz veins and isolated crystals growing on andalusite). This mineral association of the matrix reflects the metamorphic "changes" undergone by the conglomerates during their burial and subsequent exhumation.

Finally, these mesothermal quartz-vein stockworks are also excellent markers of the changes undergone by the conglomerates in the upper–middle crust during D2 tectonic accretion.

Conclusions regarding type 2: The wide variety of gold-bearing facies hosted by Paleoproterozoic monogenic or polygenic conglomerates reflects the progressive "changes" that occurred in the conglomerates during burial, with (a) a "Banket-type" facies, characteristic of a less "Au-oxide-bearing modified paleoplacer" of Tarkwaian type; (b) a gold-bearing debris-flow type (Manier, 1992), characteristic of a "modified paleoplacer" that shares some similarities with the Ghanaian Kawere conglomerates; (c) a D2-related "sulphide-bearing facies" type comparable to the conglomerate-hosted "hydrothermal shear-reservoir type" of mineralization at Jacobina, Brazil (Ledru *et al*., 1997; Milesi *et al.*, 2002); and (d) a D2-related "mesothermal quartz-vein type" ("orogenic type"), developed along conglomerate beds during burial and subsequently modified during exhumation. These conclusions, based on mineralogical and structural data, are significantly different from those of Voicu *et al*. (2001), who consider the gold of the Upper Detrital Formation to be detrital, as in the Armina and Rosebel formations.

Type 3: Mesothermal-"orogenic" ore deposits (D2-related)

In Guiana, "orogenic-type" ore deposits, as defined by Goldfarb *et al*. (2001), occur along shear zones and are related locally to their associated magmatism. They were emplaced during stage 2 of crustal recycling and tectonic accretion. These shear-zone-related ore deposits have been defined in the two greenstone belts of French Guiana (Table 4). The hydrothermal paleofields are preferentially controlled by major tectonic and magmatic structures - the North Guiana Trough in the northern greenstone belt and the South Guiana Shear Zone in the southern greenstone belt (Milesi *et al.*, 1995). This type of ore deposit has been subdivided into several facies, depending on the host terrane and structures (modified from Milesi *et al*., 1995):

(1) Rare Au±As deposits, found only in the northern greenstone belt and hosted by slices of Armina sedimentary rocks intercalated at the major Paramaca Formation–UDU contact;

(2) Au-Fe-Cu deposits, found in the vicinity of large granitoids and related to brittle-fault zones;

(3) Ore deposits hosted by small granite stocks injected along brittle-ductile shear zones or the tectonic Paramaca Formation–UDU contact.

Au-As mesothermal deposits

In the 1990's, the structural and sedimentological relationships between shear zones and gold-bearing conglomerates were studied, particularly in the Kaw region because of its potential Au-As mesothermal Ghanaian-type mineralization (Milesi *et al*., 1990; Ledru *et al*., 1991), as indicated by marked structural and geological similarities and the presence of rare arsenopyrite and millimetre-scale rutile discovered during diamond exploration in the 1950's (Milesi *et al*., 1990). This work was followed by grassroots exploration for the "Inventaire Minier". Toux (1993) described black metasiltites intercalated along the Paramaca Formation–UDU contact and showing Au and As anomalies. Under the "Inventaire Minier" procedure, this prospect was transferred to the mining sector that discovered the Camp Caïman gold deposit, estimated by ASARCO (Chambre Syndicale des Industries Minières, 1999, 2000) to contain approximately 65 t gold (grading on average 3.2 g/t Au; Table 1). The Camp Caïman deposit is developed in saprolites along a fault cutting medium- to fine-grained, detrital sedimentary rocks containing veins of blue quartz (Adam *et al*., 1998).

Detailed descriptions of this ore deposit are not yet available; however, on the basis of the above-mentioned work, we suggest that it may be comparable to the Ashanti-type Au-As deposits in Ghana (Milesi *et al*., 1992; Oberthür *et al.*, 1994, 1998) and that it may be related to shear zones developed along a contact between Birimian flysch-type and Tarkwaian clastic sedimentary rocks and a greenstone belt.

Au-Fe-Cu mesothermal deposits related to brittle-fault zones

This type of ore deposit is related to brittle faults affecting Paramaca volcanic and sedimentary sequences, *e.g*. Changement, Délices, Citron, and part of Adieu Vat in the northern greenstone belt and Yaou B in the southern greenstone belt (Fig. 8).

Hydrothermal system: The mineralization occurs in a variety of morphologies, which are commonly found in the same deposit: veins, stockworks, breccias, and disseminated sulphides and gold. The most complex example is at Yaou B, where the ore deposit comprises two generations of well-developed vein networks that are distinguished macroscopically on the basis of the D2 deformation. The first

Name of deposit	*Type of primary deposit*	*Morphology-type*	*Ore mineralogy*	*Gangue mineralogy*
Camp Caïman	Au-As orogenic mesothermal veins and disseminated sulphides, related to shear-zones	Dissemination of sulphides and quartz vein (D2- related)	Py, Apy, Gold	Qtz, Chl, Ms
Adieu-Vat	Au-Fe-Cu-Pb orogenic mesothermal veins, hosted by brittle-ductile faults and granitoids	Stockwork (post-D1/pre-D2 to late-D2)	Py, Ccp, Mag, Gn, Gold	Qtz, Carb, Chl, Tur, Ep, Rt.
Bœuf Mort de Saül	Au-Fe-Cu-Zn-Pb orogenic mesothermal veins, hosted by brittle-ductile faults	Vein (postD1/pre-D2 to syn-D2)	Py, Po, Ccp, Sph, Gold	Qtz, Tur, Ms
Changement	Au-Fe-Cu-tellurides-Zn-Mo orogenic mesothermal veins and disseminated sulphides, hosted by brittle faults	Vein, stockwork and disseminated sulphides (post D1/pre D2 to late-D2)	Py, Po, Ccp, Mag, Apy, Marc, Cv, Sph, Gn, Mo, Pn, Gers, Mill, Bi-Tell., Fe-Ag-Au-Tell., Krennerite, Tetradymite, native gold (<60μm) free in Qtz, in Py	Qtz, Carb, Ms, Chl, Tur
Loulouie	Au-Fe-Cu-tellurides-Zn-Mo orogenic mesothermal veins and disseminated sulphides, hosted by brittle-ductile faults and granitoids	Stockwork and sulphides dissemination (in granitoids and host-rocks) (syn- to late-D2)	Py, Po, Ccp, Sph, Gn, Mo, Lin, Bis, Bi-Tell., Fe-Ag-Au-Tell., Tetradymite, Aikinite, Altaite, Hessite, native gold (< 40 μm) free or in pyrite or in fissures.	Qtz, Carb, Chl, Tur, Ms
Repentir	Au-Fe-Cu-Zn-Pb orogenic mesothermal veins, hosted by brittle-ductile faults	Vein and stockwork (D2-related)	Py, Po, Ccp, Gn, Sph, Au-Tell., Gold	Qtz, Carb, Ms, Chl
Sophie	Au-Fe-Cu-Zn-Pb orogenic mesothermal veins, hosted by brittle-ductile faults	Vein and stockwork (D2-related)	Py, Ccp, Sph, Gn, Gold	Qtz, Chl, Ms
Saint-Elie	Au-Fe-Cu-tellurides orogenic mesothermal veins, hosted by brittle-ductile faults and granitoids	Vein (sub-vertical & sub-horizontal, syn-to late-D2).	Py, Po, Ccp, Bi-Tell., Fe-Ag-Au-Tell., Gold.	Qtz, Carb, Bt, Chl, Ms, Tur, Scheel
Saint-Pierre	Au-Fe-Cu-tellurides-Pb orogenic mesothermal veins and disseminated sulphides, hosted by brittle-ductile faults and granitoids	D2-related Qtz vein / stockwork, and post D1/pre-D2 disseminated sulphides in host-rock and breccia	Py, Ccp, Gn, Fe-Ag-Au-Ni-Pb-Tell., Mag, Petzite, free native gold, Brt	Qtz, Carb, Ab, Chl, Rt, Mag, Ep, Tur, Ms
Yaou A	Au-Fe-Cu orogenic mesothermal veins, hosted by granitoids and brittle-ductile faults	Quartz-Albite vein / stockwork (syn-to late-D2)	Py, Po, Ccp, Mo, Cub, Mag, Pn, Tetradymite, native gold in Py	Qtz, Ab, Chl, Carb, Ms
Yaou B (See Figure 8a)	Au-Fe-Cu "stratabound" (pre-D1-D2) epigenetic disseminated sulphides, hosted by Paramaca volcaniclastic rocks	Disseminated sulphides along strata (pre-D1-D2).	Py, Po, Ccp, Cub, native gold in Py	Chl, Ab, Carb, Ms
Yaou B (See Figure 8b, c, d)	Au-Fe-Cu D2-related "stratabound" epigenetic mesothermal veins, hosted by Paramaca volcaniclastic rocks	Folded (pre-to syn-D2, Figure 8b) and "unfolded" (late D2, Figure 8d) veins with disseminated sulphides along strata.	Py, Po, Ccp, Gn, Brt, native gold in Py, free gold in Qtz or associated with Ccp	Qtz, Chl, Ab, Carb, Ms

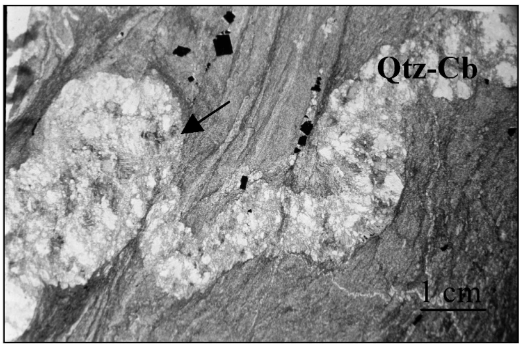
Legend: Apy: arsenopyrite, Brt: barite, Bis: Bismuthinite, Bi-Tell.: Bi-tellurides, Cv: covellite, Ccp: chalcopyrite, Chr: chromite, Cub: cubanite, Fe-Ag-Au-Ni-Pb-Tell.: Fe-Ag-Au-Ni-Pb-tellurides, Gers: gersdorffite, Gn: galena, Lin: linnaeite, Mag: magnetite, Marc: marcasite, Mill: millerite, Mo: molybdenite, Pn: pentlandite, Po: pyrrhotite, Py: pyrite, Sph: sphalerite, Ab: Albite, Amph: amphibole, Bt: Biotite, Carb: Carbonates, Chl: Chlorite, Cld: Chloritoid, Ky: kyanite, Ep: epidote, Ilm: ilmenite, Mag: Magnetite, Ms: Muscovite, Qtz: quartz, Rt: rutile, Scheel: scheelite, Tur: Tourmaline.

Table 4.- Characteristics of some Paleoproterozoic mesothermal gold-bearing deposits of French Guiana (after Milesi *et al.*, 1995; Lerouge *et al.*, 1999), emplaced during the second stage of tectonic accretion (D2).

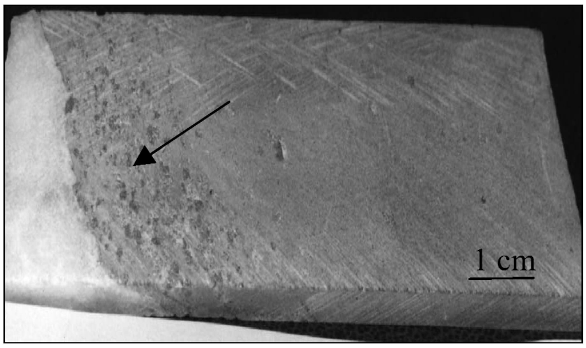
Tabl. 4.- Caractéristiques de quelques gisements aurifères mésothermaux paléoprotérozoïques de Guyane (d'après Milesi et al.*, 1995; Lerouge* et al.*, 1999), mis en place durant le deuxième stade d'accrétion tectonique.*

generation predominates and is represented by a fine, millimetre- to centimetre-spaced network of post-D1 and D2-deformed (folded and sheared) centimetre-thick quartz veins (Fig. 8b, c). The second generation is characterized by a decimetre- to metre-spaced network of late-D2, unfolded quartz+carbonate veins several centimetres thick (Fig. 8d). Sulphides in both generations occur mainly as an outer rim of disseminated, millimetre-sized grains in the hydrothermally altered host rock, and more rarely as free grains in quartz veins. Pressure shadows can occur around the first-generation sulphides (named post-D1/pre-D2 in Table 4). Sulphide granulometry and abundance increase in the late veins. Locally, pre-D2 (and/or possibly pre-D1) disseminated sulphides occur in the host rocks (Fig. 8a).

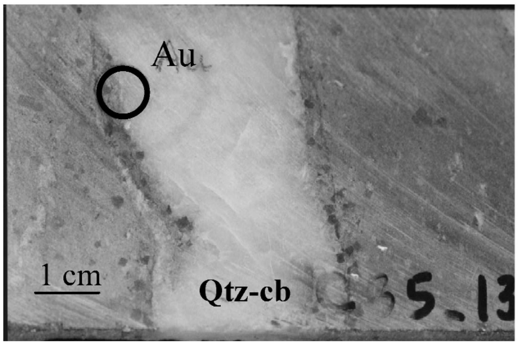
a. Early Au-Fe-Cu "stratabound" (pre-D1?-D2) epigenetic disseminated sulphides, at Yaou B



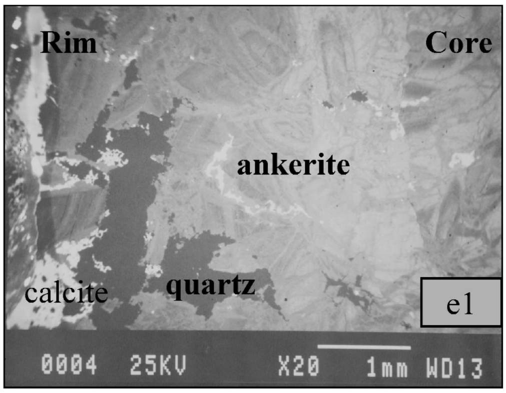
b. Earlier "folded" (pre-to syn-D2 quartz-carbonates (Qtz-Cb) vein at Yaou B

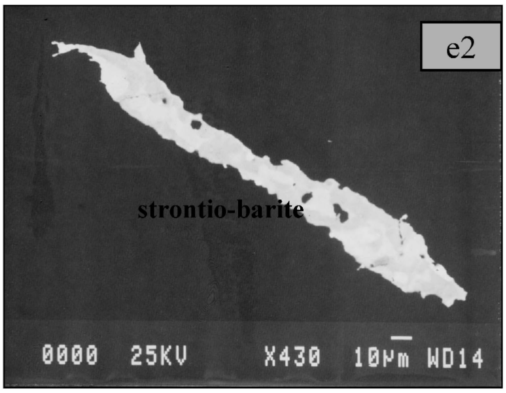


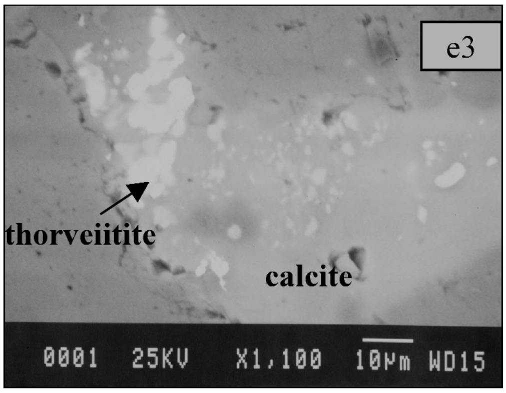
c. Sulphide dissemination at the rim of an "folded" quartz-carbonates vein, Yaou B



d. Late-D2 unfolded quartz-carbonates (Qtz-Cb) vein at Yaou B - free gold in quartz







e1 e2
e3

e. Mineralogical details of a quartz + carbonates vein (backscattered electron images)

1. zonality of a vein with calcite + quartz rim and massive ankerite core
2. Strontio-barite in calcite
3. Thorveiitite inclusions in calcite

Fig. 8.- Mesothermal gold deposits related to brittle-ductile faults and hosted by the Paramaca formations.

Fig. 8.- Gisements mésothermaux aurifères liés à des failles ductile-fragiles et encaissés dans les formations Paramaca.

Ore mineralogy: The mineralogical association of the gold-bearing ore is characterized by predominant Fe and/or Cu minerals (pyrite, pyrrhotite, marcasite, magnetite, chalcopyrite [$CuFeS_2$], and covellite [CuS]) and minor Ni and/or Co minerals (pentlandite [$(Ni,Fe)_9S_8$], gersdorffite [(Ni,Co)AsS], millerite [beta-NiS], and melonite [$NiTe_2$]), tellurides (krennerite [$(Au,Ag)Te_2$], melonite [$NiTe_2$], tetradymite [$Bi^{14}Te1_3S_8$], and hessite [Ag_2Te]), molybdenite, and sphalerite. This type of mineralogical association reflects a double hydrothermal signature, both a "basic type" (Ni-Co) and a "granitic type" (Mo-Bi), suggesting fluid interactions between the ultrabasic-basic pile (possible leaching) and granitoids.

Hydrothermal alteration: Most observed veins exhibit a complex organization due to polyphased infilling. Simple veins consist of calcite rims and a quartz core, whereas the more complex veins have been reworked by multistage ankerite and dolomite veinlets (Fig. 8e1). Macroscopic structural criteria help to distinguish between earlier (pre- to syn-D2) ("folded", Fig. 8b, c) and late-D2 ("unfolded", Fig. 8d) veins, whereas microscopic observations of the same veins provide evidence of local thermal recrystallization or strong shearing of deformed veins, and reveal the cataclastic texture of quartz in late "unfolded" veins. At Yaou B, different mineral species such as thorveiitite (Fig. 8e3), apatite, allanite, xenotime, and strontiobarite (Fig. 8e2) occur rarely in vein walls in association with calcite.

The diffuse alteration halo associated with quartz veins is composed of chlorite+muscovite+carbonates+albite ±quartz±biotite±tourmaline (Milesi *et al*., 1995). Chlorite is abundant and common. Rare chlorite from veins showed the same features as the abundant chlorite from the wall rock; thus no further distinction was made between the two types. Chlorite occurs mainly as ripidolite in all ore deposits of this type; minor pychnochlorite is present at Yaou B, according to the classification of Hey (1954). Although its Al content is relatively homogeneous, its Fe/Fe + Mg ratio varies between 0.34 and 0.56, regardless of the host rock. The highest ratio occurs in the rare cinerite layers. The lowest ratio occurs the highly hydrothermally altered samples. Fine white mica is represented by a phengitic muscovite. Carbonates are dominantly ankerite with minor calcite. Biotite occurs mainly at Yaou B; it is greenish and characterized by a large Fe/Fe + Mg ratio ranging from 0.31 to 0.56, very close to that of chlorite from the same samples. The TiO_2 content varies from 1.27 to 2.08 wt. %. Tourmaline is scarce at Adieu-Vat and Yaou B and abundant at Changement. Tourmaline occurs mainly as a schorl-dravite solid solution with high XFe (Fe/Fe + Mg) variations. Albite is always present, but in small amounts.

Formation conditions: Formation temperatures of the hydrothermal alteration associated with mineralization have been estimated using the chlorite thermometry of Xie *et al.* (1997) at Adieu-Vat, Changement, and Yaou B, along with the muscovite-biotite thermometry of at Yaou B. Chlorite thermometry provides temperatures of about 420 ± 50°C. Muscovite-biotite thermometry provides temperatures of about 350 to 380°C at pressures of 2 to 4 kbar. This temperature range is consistent with stability of the white mica+chlorite±biotite±epidote assemblage and the greenschist-facies conditions described by Egal *et al.* (1995) and Milesi *et al*. (1995).

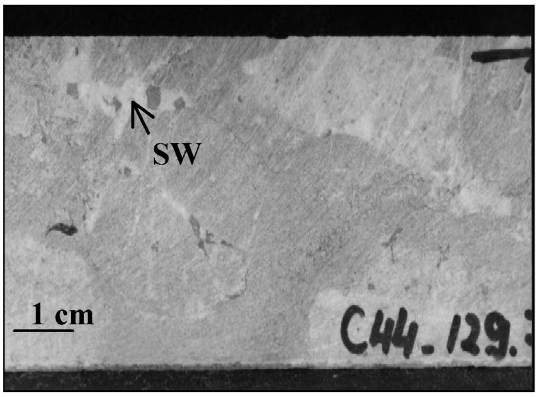
Finally, these "orogenic" mesothermal ore deposits were emplaced at temperatures of 350 to 380°C and pressures of 2 to 4 kbar. As we have observed from macroscopic and microscopic textural and structural studies, the ores were emplaced during different episodes of D2 tectonic accretion; we therefore disagree with Voicu *et al*. (2001) who concluded that "all deposits post-date peak metamorphism".

Gold-bearing ore deposits related to small D2 shear-zone granitoids

This type of ore deposit is spatially related to small granite stocks emplaced along D2 shear zones at Loulouie, Adieu-Vat, Saint-Pierre, and Saint-Elie (Lafrance *et al.*, 1999) in the northern greenstone belt, and Yaou A in the southern greenstone belt (Fig. 9). The mineralization cuts anastomosing, hydrothermally altered granitoids sills, as well as their host rocks (Paramaca Formation and UDU). Granitoids have a variety of compositions and textures. They consist of hypovolcanic microgranular albite granite at Loulouie and Saint-Pierre, a trondjhemite stock at Yaou A, granodiorite to tonalite at Adieu-Vat, and calc-alkalic granite and rhyolite at Saint-Elie (Milesi *et al*., 1995; Lafrance *et al*., 1999).

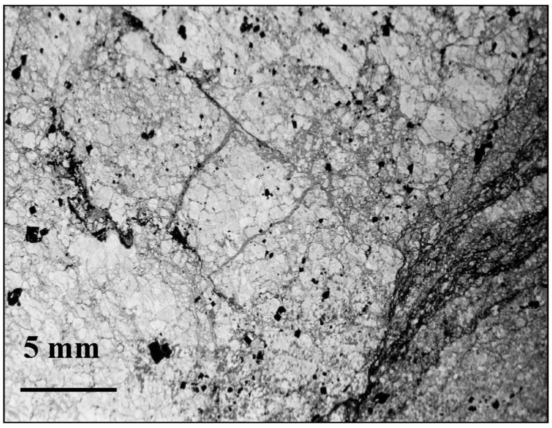
Hydrothermal system: The deposits have a varied ore morphology: (i) "vein type", represented by subvertical and subhorizontal quartz veins and/or cataclastic stockworks or tension gashes, and (ii) "sulphide-bearing ore", comprising sulphides disseminated in rocks and/or veins (Milesi *et al*., 1995; Lafrance *et al*., 1999). Their polyphased emplacement occurred during the different increments of D2 transcurrent deformation (pre-, syn- to late-D2). They line shear zones that are locally marked by corridors of "biotitic schists" (Lafrance *et al*., 1999). The dominant mineralization is associated with a large, diffuse hydrothermal halo affecting granitoids. However, the size of the alteration halo, the network structures, and the styles of deformation vary depending on the ore deposit.

Ore mineralogy: Overall, the gold composition of the various ore deposits is poor in silver. Gold occurs essentially as inclusions in pyrite in "sulphide-bearing ore" and in the walls of quartz veins and/or stockworks. It occurs more rarely

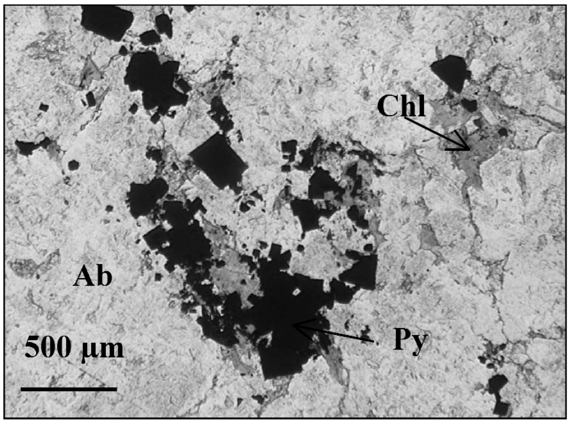


a. Late-D2 cataclastic carbonates + sulphides + quartz stockwork (SW) at Yaou A

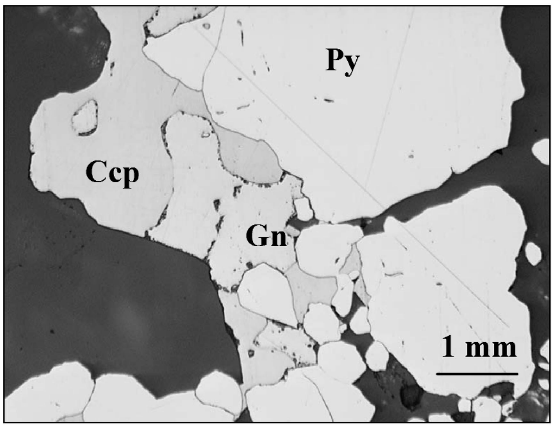
b. Drillhole samples from Saint-Pierre showing the contact between the gold-bearing quartz vein and the albitized granite sill



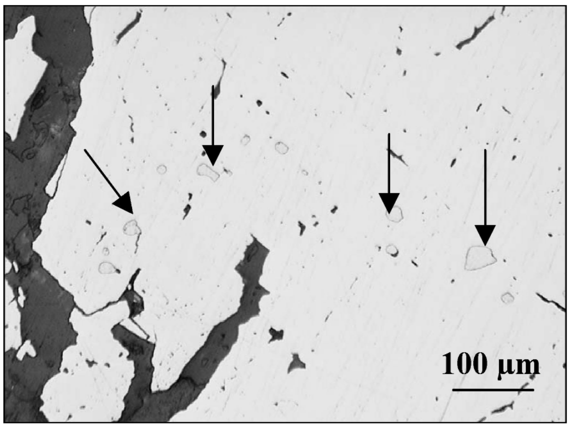
c. Late-D2 fracturation and massive albitisation at Yaou A



d. Massive albite (Ab) +chlorite (Chl) + pyrite (Py) alteration at Yaou A



e. Pyrite (Py) + chalcopyrite (Ccp) + galena (Gn) assemblage at Saint-Pierre



f. Inclusions of free gold (arrows) in pyrite at Yaou A

Fig. 9.- Mesothermal gold deposits hosted by small granitoids in D2 shear zones.

Fig. 9.- Gisements mésothermaux aurifères encaissés dans les petits stocks de granitoïdes des zones de cisaillement D2.

as free gold in quartz. Gold (<30 µm) is correlated with pyrite. Sulphides are mostly millimetre-sized euhedral pyrite with chalcopyrite and pyrrhotite inclusions. The mineralogical association consists predominantly of Fe-Cu minerals (pyrrhotite, chalcopyrite, and pyrite) with numerous accessory minerals (aikinite, altaite, arsenopyrite, barite, bismuthine, galena, greenockite, hessite, linnaeite, melonite, molybdenite, petzite, sphalerite, scheelite, and tetradymite).

Hydrothermal alteration: Cataclastic breccias predominate over veins in granitoids (Fig. 9a). Fractures and veins are filled essentially with calcite and quartz. The diffuse hydrothermal alteration is marked by massive albitization with minor muscovite, biotite, and carbonates. Potassic alteration has been mentioned at Saint-Elie (Voicu *et al*., 2001). Chlorite occurs mainly as ripidolite, according to the classification of Hey (1954). It is quite homogeneous in hydrothermally altered granitic sills, with values of about 0.36 to 0.44 at Saint Pierre, Loulouie, and Yaou A. Fine white mica is represented by a phengitic muscovite. High barium contents of about 1 to 2 wt. % BaO have been found only in the hydrothermal muscovite hosted by trondhjemites at Yaou A. Calcite is the dominant carbonate in granitoids.

Formation temperatures: They have been estimated using the chlorite thermometry of Xie *et al*. (1997) applied to volcanic rocks in contact with granite at Loulouie, Saint-Pierre, and Yaou A. An average temperature of 380°C was obtained, with a large uncertainty of 65°C.

Finally, the presence of granitoids indicates that the paleohydrothermal fluid field was emplaced along a fault previously filled as a result of shallow magmatism. Yao and Robb (2000) have studied similar small granitoids in Ghana, and they suggested a rheological control for the low-salinity H_2O-CO_2-N_2±CH_4 metamorphic fluids that controlled the ore deposits hosted by these granitoids.

Conclusions regarding type 3:

Mesothermal ore deposits emplaced in Guiana during stage 2 crustal recycling and tectonic accretion share many characteristics with the "orogenic" deposits hosted along shear zones that were locally infilled as a result of shallow magmatism. In Guiana, these "orogenic" ore deposits were emplaced during several episodes or increments of D2 tectonic accretion (post-D1/pre-D2 to late-D2), at temperatures of approximately 350 to 380°C and at pressures of 2 to 4 kbar, which correspond to the metamorphic conditions and regional pressures re-evaluated to 3 to 4 kbar by Delor e*t al.* (2003): (i) greenschist facies in central French Guiana (Milesi *et al*., 1995) and (ii) higher-temperature metamorphic conditions, recorded through a pervasive biotite-garnet isometamorphic zone in the southern greenstone terranes. We therefore disagree with Voicu *et al*. (2001) who stated that "all deposits post-date peak metamorphism". However, we cannot exclude a possible long thermal evolution of mineralized systems associated, for example, with re-opening, late overprinting, or remobilization, as the terranes remained at between 450 and 500°C during the late- to post-orogenic episodes (2 to 1.95 Ga), as indicated by Ar-Ar studies (Lafrance *et al*., 1999; Nomade, 2001, Nomade *et al*., 2001). Such late events may be consistent with the Pb-Pb model age of 2.0 ± 0.016 Ga obtained on mesothermal deposits in Guiana (Marcoux and Milesi, 1993).

The characteristics of the Guiana "orogenic" ore deposits allow a comparison with West African ore deposits that are hosted along shear zones and fold belts in Birimian flysch and greenstone belts (Milesi *et al.*, 1989, 1992; Oberthür *et al*., 1998). However, these ore deposits of French Guiana appear to be richer in tellurides than those of West Africa. Nevertheless, they can be compared to some veins described in Burkina Faso, Mali, and in the latest stages of the Ashanti Mine (Bowell *et al*., 1990; Klemd *et al*., 1996). In West Africa, Klemd *et al.* (1996) estimated that fluids were trapped at temperatures between 450°C and 500°C at 5 kbar, which corresponds approximately to regional metamorphic conditions. Following the models of Groves *et al.* (1992) and Cameron (1994), Klemd *et al*. (1996) considered the fluids to have been derived from a deep crustal or mantle source.

Gold deposits: stable-isotope constraints

Stable-isotope studies were performed in order to elucidate the origin and evolution of hydrothermal fluids in ore deposits. Isotopic work was performed on 69 samples from the three types of deposits containing sulphides:

Type 1: Stratiform/stratabound gold-bearing tourmalinites of Dorlin;

Type 2: Sulphide-facies type of gold-bearing conglomerates of Espérance, Permis Ricard, and Montagne de Kaw;

Type 3: Mesothermal deposits of Adieu-Vat, Changement, Loulouie, Saint Pierre, Yaou A, and Yaou B.

About 100 sulphur analyses of pyrite were performed on the three types of deposits. Forty carbon and oxygen analyses of carbonates, fifteen oxygen analyses of silicates, and eight hydrogen analyses of hydrated silicates were performed essentially on the Dorlin stratabound ore deposit (type 1) and on the mesothermal deposits (type 3). Results are given in Table 5.

Sulphur isotopes of sulphides

The common dominant pyrite+chalcopyrite+pyrrhotite assemblage, the scarcity of barite, and the systematic presence of carbonates in all the ore deposits studied suggest reducing conditions and H_2S as the prevailing sulphur species in the mineralizing fluids. At temperatures above 250°C, the sulphur

Sample Number	Facies	δ^{34}S Py (‰)	δ^{13}C Cal (‰)	δ^{13}C Dol-Ank (‰)	δ^{18}O Cal (‰)	δ^{18}O Dol-Ank (‰)	δ^{18}O Silicates (‰)	δD Silicates (‰)
DORLIN Montagne Nivré								
Ni1-59.3m	Pre -D1 Chl+ Qtz + Py dissemination (M1 outer alteration zone)	+0.7						
Ni1-118.9m	Pre -D1 Chl+ Qtz + Py dissemination (M1 outer alteration zone)	+1.4						
Ni1-119.0m	Pre -D1 Chl+ Qtz + Py dissemination (M1 outer alteration zone)	+2.1					Chl + 5.4	Chl -47
Ni2-115.6m	Pre -D1 Chl+ Qtz + Py dissemination (M1 outer alteration zone)		-5		+11.1		Qtz +12.2 Chl +5.6	Chl -40
Ni2-119.2m	Pre-D1 Chl+ Qtz + Py dissemination (M1 alteration zone)	+0.6	-4.8	-5.2	+11.3	+11.4		
Ni3-110.0m	Post-D1 and pre-D2 Ms-Qtz-Py stockwork and dissemination (Late M1-M2 alterations zones)	+2.0					Qtz + 12.4 Ms +6.9	Ms -38
Ni4-149.0m	Pre-D1 Tur+ Qtz + Py dissemination (M2 inner alteration zone)	+1.8					Qtz + 14.1 Tur +8.4	Tur -30
Ni5-108.0m	Pre-D1 Tur+ Qtz + Py dissemination (M2 inner alteration zone)	+1.0	-1.6	-1.2	+15.2	+14.6		
Ni5-135.4m	Pre -D1 Tur+ Qtz + Py dissemination (M2 inner alteration zone)	+0.3						
Ni5-185.4m	Pre -D1 Tur+ Qtz + Py dissemination (M2 inner alteration zone)	+2.0		-3.7		+13.1	Qtz +13.9 Tur +8.9	Tur -28
DORLIN THR prospect								
THR3-148.0m	Post-D1 to syn-D2 Ms-Qtz-Py stockwork	+1.6	-1.5	-1.6	+15.5	+14.5		
THR3-154.0m	Post-D1 to syn-D2 Ms-Qtz-Py stockwork	-2.9						
THR3-174.0m	Post-D1 to syn-D2 Ms-Qtz-Py stockwork	-2.8	-0.8	-0.8	+15.7	+14.8		
THR3-192.0m	Post-D1 to syn-D2 Ms-Qtz-Py stockwork	+2.2		-2.3		+15.3		
THR3-309.6m	Post-D1 to syn-D2 Ms-Qtz-Py stockwork	+0.5		-3.2		+14.4		
ESPERANCE								
ESP1-92.0m	Pre-D2 Py-Po-rich metamorphosed sandstone	+0.3						
ESP1-111.4m	Pre-D2 disseminated Py in tuff facies	+0.4						
ESP1-121.6m	Pre- to syn-D2 Qtz-Py vein in metamorphosed sandstone	+1.0						
ESP1-142.0m	Pre-D2 Bi-Ms metamorphosed sandstone	-1.3						
ESP1-149.0m	Tur-Ms metamorphosed sandstone	+0.1						
ESP2-100.3m	Pre-D2 metamorphosed sandstone	-0.2						
ESP2-115.0m	Pre-D2 metamorphosed sandstone	-0.7						
ESP3-66.3m	Pre- to syn-D2 Py-Chl vein in metamorphosed sandstone	+0.0						
ESP3-67.4m	Pre- to syn-D2 Py-Qtz-Py-Chl vein	+0.0						
ESP3-127.0m	Pre-D2 Py-Po-bearing metamorphosed sandstone	-0.8						
ESP3-127.3m	Pre- to syn-D2 Py vein	-0.1						
MONTAGNE DE KAW								
L9C1	Late-D2 sulphides-rich conglomerate	-3.4						
K23	Late-D2 sulphides-rich conglomerate	-3.3						
PERMIS RICARD								
PR1	Late-D2 pyritization of magnetite-hematite layers in conglomerate	+1.1						
SAINT PIERRE								
SPR3-100.1m	Pre-D2 disseminated Py	+0.6						
SPR3-106.5m	Pre-D2 disseminated Py	-4.9						
SPR3-107.1m	Pre-D2 disseminated Py	-2.5						
SPR3-108.1m	Syn-to late-D2 Qtz-Py-galena vein	-8.0					Qtz +12.7	
SPR3-108.6m	Syn-to late-D2 Qtz-Py-galena vein	-4.7					Qtz +12.8	
SPR3-110.5m	Pre-D2 disseminated Py	+0.9						
SPR3-112.0m	Pre-D2 disseminated Py		-2.3	-0.3	+14.6	+13.4		
SPR3-118.7m	Pre-D2 disseminated Py	+1.0						
SPR3-119.8m	D2-related chlorite							Chl –46
LOULOUIE								
ADV6-124.6m	Syn-to late-D2 disseminated Py in albitized granite	+0.9	-2.4	+0.3	+14.9	+13.7		
ADV6-128,0m	Syn-to late-D2 Qtz-Cb-Py-Chl vein in albitized granite	+0.8	-2.9		+12			
ADV6-134.2m	Syn-to late-D2 Qtz-Py vein in albitized granite	+0.2						
ADV6-135.1m	Syn-to late-D2 Qtz-Py vein in albitized granite	+0.0						
ADV6-147.9m	Syn-to late-D2 disseminated Py in albitized granite	+0.6	-1.8	-1.5	+11.8	+12.6		
ADV6-160.6m	Syn-to late-D2 disseminated Py in schist	-4.3						
ADV6-186.4m	Syn-to late-D2 Cb		+0.9	+0.8	+11.2	+10.9		

Table 5.- Carbon, oxygen, sulphur, and hydrogen isotopic data from different gold deposits in French Guiana.

Tabl. 5.- Données isotopiques en carbone, oxygène, soufre et hydrogène des principaux gisements aurifères de Guyane.

Sample Number	Facies	$\delta^{34}S$ Py (‰)	$\delta^{13}C$ Cal (‰)	$\delta^{13}C$ Dol-Ank (‰)	$\delta^{18}O$ Cal (‰)	$\delta^{18}O$ Dol-Ank (‰)	$\delta^{18}O$ Silicates (‰)	δD Silicates (‰)
ADIEU VAT								
ADV2-119.9m	Pre- to syn-D2 disseminated Py	-1.2						
ADV2-121.0m	Pre- to syn-D2 disseminated Py	-0.7						
ADV2-166.1m	Syn-to late-D2 Qtz-Py vein	+0.0						
ADV3-166.2m	Syn-to late-D2 Qtz-Py vein	-0.2						
CHANGEMENT								
CHT1-63.5m	Syn-to late-D2 Qtz-Py vein							Chl –59
CHT4-91.3m	Syn-to late-D2 Qtz-Py vein	+0.0						
CHT5-101.2m	Syn-to late-D2 Qtz-Cb-Py vein	+1.9	-2.2	-2.1	+12.9	+14.8		
CHT5-127,5m	Syn-D2 disseminated Py	+1.3	-2.6	-2.5	+11.9	+13.7		
CHT6-57,2m	Pre- to syn-D2 disseminated Py	+1.8						
CHT6-75.5m	Syn-D2 disseminated Py	+1.3						
CHT7-100,4m	Pre- to syn-D2 disseminated Py	-0.1	-2.1	-2.2	+13.8	+15.5		
CHT8-95,2m	Pre- to syn-D2 disseminated Py	+0.5						
CHT8-122.7m	Syn-D2 disseminated Py	-1.1						
YAOU A								
C2-49.7m	D2-related disseminated Py in albitized granite	-1.9	-3.1	-3.3	+12.3	+10.2		
C2-52.4m	D2-related disseminated Py in albitized granite	-3.8						
	Py vein	-4.6	-2.9	-2.4	+11.8	+10.3		
C2-53.3m	D2-related disseminated Py in albitized granite	-4	-3.1	-3	+11.6	+10.3		
C2-100.6m	D2-related disseminated Py in albitized granite	-2.2	-3.6	-3.4	+12.1	+10.7		
C44-45.7m	D2-related disseminated Py in albitized granite	-4.1	-3.5	-3.4	+12.1	+10.8		
C44-97.1m	D2-related disseminated Py in albitized granite	-3.1	-3.5	-3.2	+10.9	+11.7		
C44-99.9m	D2-related disseminated Py in albitized granite	-3.6	-3.5	-3	+11.2	+13.2		
C44-129.7m	D2-related albitized granite						Ab +11.1	
YAOU B								
C18-46.0m	D2-related disseminated Py	-4.4						
	D2-related Qtz-Py vein	+1.1	-1.1	-1.2	+13.4	+12.4		
C18-61.3m	D2-related Qtz-Cb-Py vein	-0.8	-1.5		+13.5			
C18-68.9m	D2-related Qtz-Cb-Py veinlet	+2.1	-1.1		+13.9			
C18-69.2m	D2-related Qtz-Cb-Py veinlet	+0.3	-1.3	-1.1	+13.8	+12.5		Chl -50
C26-55.6m	D2-related disseminated Py	-1.5						
	Late-D2 unfolded Qtz-Cb-Py vein	-1.5	-3.2	-3.3	+12.4	+11	Qtz +13.0	
	Late-D2 unfolded albite-Qtz-Cb		-2.4		+11.7		Ab +12.0	
C26-59.1m	D2-related albitized granitic vein						Ab +11.5	
C35-117.1m	Syn-D2 folded Qtz-Cb-Py vein	-0.5	-1.2		+13.6			
	Syn-D2 disseminated Py	-0.7						
C35-117.2m	D2-related Qtz-Py-Cb veinlet	+1	-0.5		+13.7			
	Late-D2 unfolded Qtz-Py-Cb vein	-1.1	-0.7	-0.2	+13.7	+12.6		
C35-118.8m	D2-related facies	+1.4	-1.1		+13.1			
C35-136.0m	Syn-D2 folded Qtz-Py-Cb veinlet	+1.4	-1.3		+13.5		Qtz +15.0	
	Late-D2 unfolded Qtz-Py-Cb vein	+1	-1.6	-1.5	+12.7	+12.8		
	Late-D2 unfolded Qtz-Py-Cb vein	+1.2						
	Syn-D2 folded Qtz-Py-Cb veinlet	+1.2						
	Late-D2 unfolded Qtz-Py-Cb vein	+0.8						
C58-249.4m	Syn-D2 folded Qtz-Cb-Py veinlet	+1.2	-2.5	-2.5	+11.7	+13.5		
C58-251.6m	Syn-D2 folded Qtz-Cb-Py veinlet	-1						
	Late-D2 unfolded Qtz-Cb-Py vein	-1.3	-2.1		+11.7			
C58-254.0m	Syn-D2 folded Py veinlet	-2.1	-2.6		+11.7			
C58-254.5m	Pre- to syn-D2 disseminated Py	-2.1	-2.4	-2.0	+11.9	+13.9		Chl -52
	Syn-D2 folded Qtz-Cb-Py vein		-2.3		+11.8			
C58-257.2m	Syn-D2 folded Qtz-Cb-Py vein	-2.2	-2.3		+11.8			
C58-257.4m	Syn-D2 folded Qtz-Cb-Py vein	-1.4	-2.6		+11.9			
C58-259.9m	Syn-D2 folded Qtz-Cb-Py vein	-1.4	-2.4		+11.7		Qtz +12.7	
C58-260.7m	Syn-D2 folded Qtz-Cb-Py vein	-2	-2.4	-2.6	+11.7	+13.8	Qtz +18.1	
C58-263.8m	Late-D2 unfolded Qtz-Cb-Py vein	-0.9	-1	-1	+13.1	+11.7	Qtz +14.0	
	D2-related disseminated Py	-1.3						

Legend: Py: pyrite, Po: pyrrhotite, Cb: carbonates, Cal: calcite, Dol: dolomite, Qtz: quartz, Bi: biotite, Chl: chlorite, Ms: muscovite, Tur: tourmaline.

isotopic fractionation between fluid and pyrite is less than 0.5 (Ohmoto, 1972); thus, pyrite $\delta^{34}S$ can be considered representative of the fluid. The $\delta^{34}S$ values of pyrite from all the deposits are given in Table 5 and Figure 10 and discussed below.

Stratabound type (type 1)

At Dorlin, pyrite $\delta^{34}S$ values range from –2.9 to +2.2‰, with no significant difference between the pre-D1 chlorite and tourmaline haloes (+0.3 to +2.1‰) associated with the stratabound deposit and the post-D1 to syn-D2 muscovite+quartz+sulphide veins (–2.9 to +2.2‰).

Sulphide-facies type gold-bearing conglomerates (type 2)

At Espérance, where the Upper Detrital Unit hosts mineralization, pyrite $\delta^{34}S$ values are very close to 0‰.

Au-Fe-Cu mesothermal type (type 3) related to brittle faults and hosted by the Paramaca Formation

At Yaou B in the southern greenstone belt, one of the most representative gold deposits of the discordant polymorph mineralization hosted by the Paramaca Formation, closer attention was paid to the different ore facies, but no significant variations were recognized. Early disseminated sulphides (equivalent of Dorlin), deformed quartz-carbonate veins and their haloes, and undeformed quartz-carbonate veins and their haloes exhibit a similar range of $\delta^{34}S$ values from -4.4 to +2.1‰.

At Changement and Adieu-Vat, in the northern greenstone belt, pyrite $\delta^{34}S$ values range from -1.2 to +1.9‰ and are comparable to those at Yaou B.

Au-Fe-Cu mesothermal type (type 3) hosted by late granitoids along D2 shear zones

Sulphides from disseminations and veins in albite granite sills at Yaou A present a range of values from -4.6 to -1.9‰, slightly different from those at Yaou B.

At Loulouie, pyrite $\delta^{34}S$ values are very homogeneous and close to 0‰.

At Saint-Pierre, where mineralization is hosted by quartz veins and a granite sill, pyrite $\delta^{34}S$ values are lower than in other ore deposits, down to –8‰.

With the possible exception of Saint-Pierre, $\delta^{34}S$ values of pyrite and therefore of mineralizing fluids vary overall from –5 to +3‰; they are homogeneous and very close to 0‰. These results, common in Archean and Proterozoic volcanic- and sedimentary-associated sulphide deposits (Taylor, 1987), indicate a prevailing magmatic component for sulphur of hydrothermal fluids. Nevertheless, they do not exclude a possible slight contribution by sulphur derived from the reduction of seawater sulphates (Taylor, 1987). Magmatic sulphur can originate from either magmatic fluid or sulphides leached from the host volcanic rocks. No evidence has been found for either possibility. The relatively constant isotopic signature of sulphides, regardless of the type of ore facies (disseminated or vein) or host rock, indicates a common source for the sulphur component, but may also indicate reworking of early mineralization.

The more negative values, found in granite sills at Saint Pierre and Yaou A, could be attributed to a slight oxidation of the mineralizing fluids compared to other deposits, such as those found in Archean shallow gold deposits in western Australia, Zimbabwe, or Guyana (Tremlow, 1984; Gebre-Mariam *et al*., 1993; Hagemann *et al*., 1994; McCuaig and Kerrich, 1994; Lafrance *et al*., 1999), as barite is not totally absent.

Oxygen and carbon isotopes of carbonates

Stratabound type (type 1)

Carbonate data from the stratabound-type Dorlin deposit have been discussed in Lerouge *et al.* (1999). Calcite, analyzed in the outer chlorite halo (M1) and in the inner tourmaline halo (M2), showed a significant trend in isotopic evolution, from $\delta^{18}O$ = +11‰ and $\delta^{13}C$ = -5‰ (M1) to $\delta^{18}O$ = +15‰ and $\delta^{13}C$ = -1.6‰ (M2). The theoretical thermal evolution model of Rye and Williams (1981) has been applied successfully to the data (Lerouge *et al.*, 1999), assuming an initial fluid composition of +4‰ in oxygen (based on silicate data) and –3 ± 2‰ in carbon (assuming mixing of marine and magmatic components). It indicated cooling of the carbonates as well as significant changes in carbon isotopic composition relative to the thermal trend, with a magmatic component dominant in the outer chlorite zone and a marine component dominant in the inner tourmaline zone. Results obtained at Dorlin could be compared to those from Loulo in Mali, despite a partial ^{18}O and ^{13}C depletion of carbonates at Dorlin. This depletion could be due to an ^{18}O- and ^{13}C-depleted fluid and/or a higher formation temperature.

Au-Fe-Cu mesothermal type (type 3)

Calcite and dolomite or ankerite from Au-Fe-Cu mesothermal ore deposits show comparable large ranges of $\delta^{18}O$ and $\delta^{13}C$ values: $\delta^{18}O$ = +10.9 to +15.7‰ and $\delta^{13}C$ = -3.6 to +0.9‰ for calcite, and $\delta^{18}O$ = +10.2 to +15.5‰ and $\delta^{13}C$ = -3.4 to +0.8‰ for dolomite or ankerite, with 75% of $\delta^{18}O$ values less than +13.5‰ and of $\delta^{13}C$ values more than -3.5‰. The heterogeneity of the calcite-dolomite fractionation indicates a lack of equilibrium between the two carbonates; this confirms earlier textural observations.

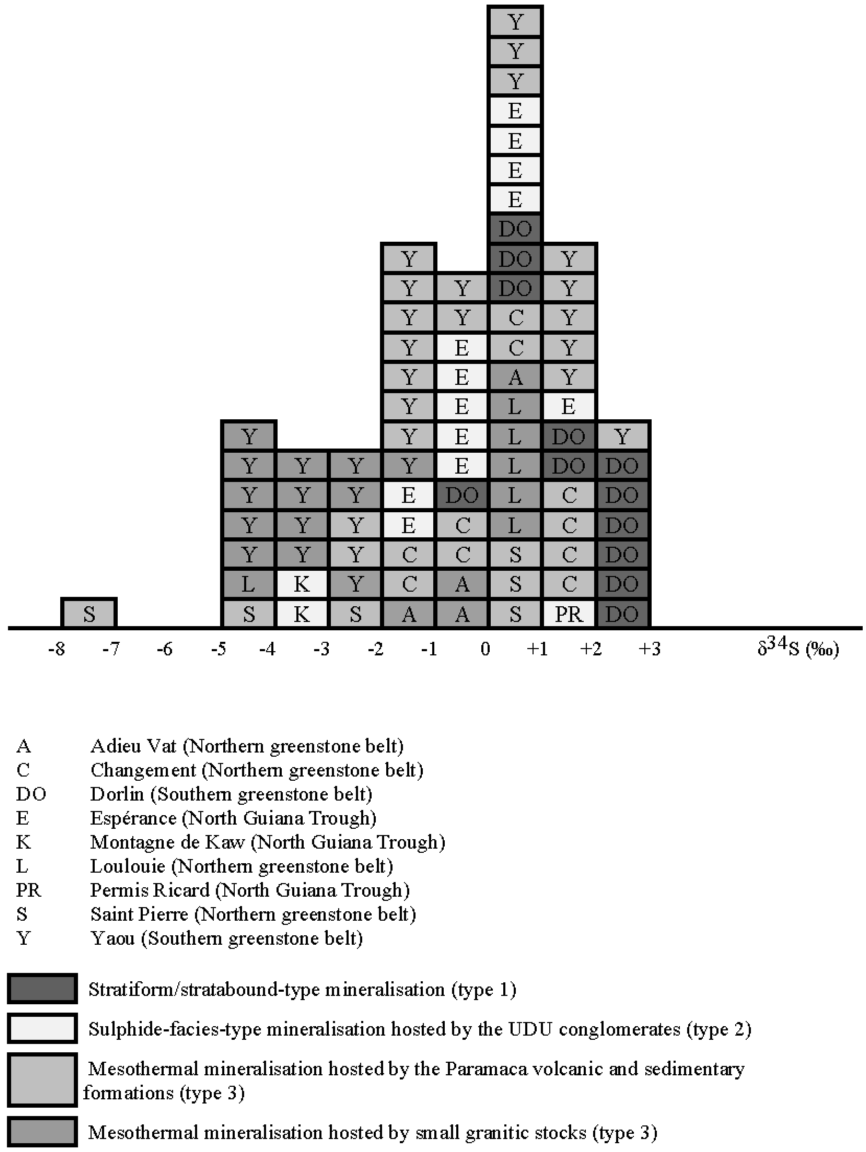


Fig. 10.- Histogram of pyrite $\delta^{34}S$ from several sulphide-gold ore deposits in French Guiana.

Fig. 10.- Histogramme des compositions isotopiques $\delta^{34}S$ des pyrites de plusieurs gisements à or-sulfures de Guyane.

+quartz assemblages at Dorlin has shown that deposition temperature was about 200 to 300°C (Lerouge *et al.*, 1999).

Au-Fe-Cu mesothermal type (type 3)

The few oxygen compositions of quartz from different quartz+ carbonates veins at Yaou B and Saint-Pierre range from +12.7 to +15‰, with a high value of +18.1‰. They are characteristic of mesothermal quartz veins (Golding *et al.*, 1989; Groves and Foster, 1991; Ronde (de) *et al.*, 1992).

The few hydrogen compositions of hydrated minerals (chlorite and muscovite) obtained at Yaou B, Changement, and Saint-Pierre are homogeneous, ranging from -59 to -46‰.

Fluid compositions and origins

The $\delta^{18}O$ and δD values of hydrothermal fluids were calculated for each deposit for which data were available, assuming temperatures estimated from the isotopic thermometry in the stratabound Dorlin deposit, essentially from the chlorite thermometer in the mesothermal ore deposits, and from the muscovite-biotite thermometer at Yaou B. Results are summarized in Table 6 and plotted in Figures 11 and 12.

Oxygen data are relatively comparable to those obtained on calcite in similar contexts, such as at Saint Elie in French Guiana (Lafrance *et al.*, 1999) and Omai in Guyana (Voicu *et al.*, 1999). Carbon data are relatively homogeneous (Fig. 10) and comparable to global $\delta^{13}C$ variations for Archean gold deposits (Golding *et al.*, 1989; Groves and Foster, 1991; Ronde (de) *et al.*, 1992).

Oxygen and hydrogen isotopes of silicates

Stratabound type (type 1)

Oxygen compositions of tourmaline and chlorite at Dorlin are very similar to those of some VMS (Slack *et al.*, 1984) in which seawater is a dominant component. Oxygen thermometry applied to chlorite+quartz and tourmaline

Stratabound type (type 1)

Calculated $\delta^{18}O$ and δD values of hydrothermal fluids at Dorlin are respectively -1 to +4‰ and -3 to -13‰ (Lerouge *et al.*, 1999), indicating a dominant contribution from seawater to the hydrothermal fluids.

Au-Fe-Cu mesothermal type (type 3)

The range of fluid isotopic compositions, obtained from a variety of minerals in the different Au-Fe-Cu mesothermal deposits, is very homogeneous, with $\delta^{18}O$ ranging from +6.4 to +12.0‰ and δD ranging from -34 to -16‰. In part, these values are consistent with a metamorphic signature of unknown origin, *i.e.* fluids of dehydration, magmatic fluids, seawater-derived fluids, meteoric waters, basin fluids, etc., re-equilibrated with the metamorphic environment. Conclusions are consistent with isotopic data from the Saint Elie mesothermal gold deposit in northern Guiana (Lafrance *et al.*, 1999). However, the highest δD values (up to -16‰) found at Saint-Pierre may indicate a contribution from D-rich waters, such as seawater.

Ore deposit	$\delta^{18}O$	Used minerals	δD	Used minerals
Changement	+9.3 to +11.5 ‰	calcite	-34 to -25 ‰	chlorite
Loulouie	+6.4 to +11.5 ‰	calcite		
Saint-Pierre	+8.2 to +9.6 ‰	quartz	-25 to -16 ‰	chlorite
	+11.4 to +12.0 ‰	calcite		
Yaou A	+11.1 to +12.0	albite		
	+10.9 to +12.0	calcite		
Yaou B	+7.7 to 11.7 ‰, Excepted value of +14.8 ‰ obtained from quartz of the sample C58-260.7 m	quartz	-32 to -25 ‰	muscovite
	+7.9 to 11.6 ‰	calcite		

Table 6.- Oxygen isotopic compositions of the hydrothermal fluids have been estimated from those of minerals, using the quartz-water and albite-water fractionations of Zheng (1993) and the calcite-water fractionation of O'Neil *et al.* (1969). Hydrogen compositions of the hydrothermal fluids have been estimated from those of hydrated minerals, using the chlorite-water fractionation of Graham *et al.* (1987) and the muscovite-water fractionation of Suzuoki and Epstein (1976).

Tabl. 6.- Les compositions isotopiques en oxygène des fluides hydrothermaux ont été estimées d'après les compositions des minéraux, en utilisant les fractionnements de Zheng (1993) quartz-eau et albite-eau et les fractionnements calcite-eau de O'Neil et al. *(1969). Les compositions isotopiques en hydrogène des fluides hydrothermaux ont été estimées d'après les compositions des minéraux hydratés, en utilisant les fractionnements chlorite-eau de Graham* et al. *(1987) et les fractionnements muscovite-eau de Suzuoki et Epstein (1976).*

Discussion and conclusions

Gold deposits: markers of geological evolution

The relative chronology of the various types of gold deposits in the tectono-metamorphic evolution of the greenstone belts of French Guiana indicates two stages of gold concentration, corresponding to the two geodynamic stages defined by Vanderhaeghe *et al.* (1998).

In stage 1 of crustal growth by "magmatic accretion", the earliest formation of a gold stock is associated with regional-scale hydrothermal fluid circulation in the southern Paleoproterozoic greenstone belt. Regional alteration is marked by intense tourmalinization associated with carbonates, chlorite, and sulphides and affecting volcaniclastic and lava sequences ("stratabound") of the Paramaca Formation. The low-grade disseminated gold mineralization of the Dorlin deposit, hosted by tourmalinite, is an example of the earliest gold stock. The local presence of chert indicates subaquatic conditions of deposition, i.e. at or near the seafloor. Formation temperatures are estimated to have been about 200 to 300°C. Isotopic data indicate a marked contribution by marine waters mixed with a magmatic component. These data are comparable to data from major tourmalinites around the world (Slack, 1982, 1996; Slack *et al.*, 1984, 1993; Plimer, 1988; Dommanget *et al.*, 1985, 1993; Fouillac *et al.*, 1993). These gold-bearing tourmalinites were locally modified under upper–middle crust conditions during emplacement of crosscutting mesothermal-orogenic quartz veins.

In stage 2 of "crustal recycling and tectonic accretion", gold was emplaced during all increments of D2 transcurrent tectonics responsible for the progressive deformation of the North Guiana Trough, from its creation through its burial and final exhumation. This stage is characterized by a great variety of syntectonic mineralization of (1) "gold-bearing conglomerate" type and (2) "mesothermal-orogenic" type (Table 4):

(1) The "gold-bearing conglomerate" type is represented by several deposits that marked the progressive burial and exhumation of the rocks: (i) a gold-oxides "Banket" type "paleoplacer", hosted in monogenic, quartz-pebble conglomerates that have undergone little change, representing the earlier sedimentary stage; (ii) a "debris-flow" type, which may represent both a paleoplacer and/or syndiagenetic stage; (iii) an epigenetic type of D2-related disseminated sulphides hosted in polygenic conglomerates, marker of the changes that affected the conglomerates in the upper–middle crust during D2 tectonic accretion; and (iv) an epigenetic type of mesothermal quartz stockworks that cut both monogenic and polygenic conglomerates and are also excellent markers of the changes undergone by the conglomerates in the upper–middle crust during the D2 tectonic accretion stage. Similar conclusions have been reached for other gold-bearing conglomerate deposits elsewhere: Tarkwa in Ghana (Hirdes *et al.*, 1988; Milesi *et al.*, 1991; Klemd *et al.*, 1993) and Jacobina in Brazil (Milesi *et al.*, 2002).

That earlier mesothermal ore deposits have been reworked is suggested by (a) the presence of hydrothermally altered pebbles (tourmalinite, fuschsite-bearing pebbles) with anomalous geochemical signatures of felsic affinities (Li, Nb, and K_2O) and (b) the abundance of quartz pebbles with mylonitic, cataclastic textures. Such pebbles have been described in the gold-bearing conglomerates of Jacobina in Brazil (Milesi *et al.*, 2002).

The mineralogical association of the various facies-type of gold deposits hosted by the UDU conglomerates is a marker of the tectono-metamorphic P-T path of the North Guiana Trough (e.g. burial and subsequent exhumation) and, in some ore deposits, of the multistage emplacement of

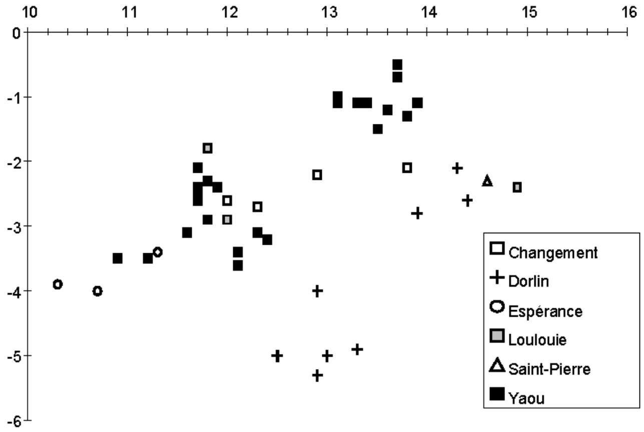


Fig. 11.- $\delta^{13}C$-$\delta^{18}O$ diagram representing isotopic composition of hydrothermal carbonates from different gold deposits in French Guiana.

Fig. 11.- Compositions isotopiques $\delta^{13}C$-$\delta^{18}O$ des carbonates hydrothermaux de différents gisements aurifères de Guyane.

hydrothermal fluids. Thus, minerals such as garnet, amphibole, biotite, kyanite, andalusite, and chloritoid suggest medium-grade conditions for the metamorphic peak (up to amphibolite facies). For example, at Espérance, the stability of mesothermal quartz veins with a garnet+ biotite±amphibole hydrothermal halo indicates that an earlier generation of quartz veins formed in conditions of amphibolite-facies metamorphism. On the other hand, the presence of chlorite veins not in equilibrium with the rock indicates that these veins correspond to a second generation of veins formed under lower metamorphic conditions, at temperatures estimated at about 300°C. Sulphur isotopes on pyrite from sulphide-bearing facies-type deposits (Espérance, Permis Ricard, and Montagne de Kaw) suggest a magmatic origin for the sulphur.

(2) The "mesothermal-orogenic" type, associated with D2 shear zones and their related granitoid magmatism, is represented by (i) an emergent type of Au-As mesothermal ore deposit, (ii) a dominant Au-Fe-Cu type associated with brittle-ductile fault zones, and (iii) abundant ore deposits related to granitoids.

Mesothermal ore deposits, related to brittle-ductile fault zones and granitoids, show relatively uniform P-T conditions of emplacement, whether the host rocks are Paramaca volcanic and sedimentary sequences or small, late-D2 granites. Thermometry and the mineral assemblage white mica+carbonates+chlorite+albite±biotite indicate low-grade metamorphism (greenschist facies), with temperatures of about 400°C. The emplacement of ore in hypovolcanic dykes suggests low pressures of about 1 to 2 kbar. Isotopic data obtained at Changement, Yaou, Saint-Pierre, Adieu-Vat, and Loulouie reveal a magmatic origin for sulphur and partly for carbon and a metamorphic signature for oxygen and hydrogen. Potential sources of metamorphic fluids are surface-derived waters (marine or meteoric waters) and/or deep-seated fluids (dehydration metamorphic fluids or magmatic fluids). Sulphur and carbon isotopes indicate a magmatic component. Some data from Changement and Yaou B are quite similar to data from the Saint Elie mesothermal gold deposit in northern French Guiana (Lafrance *et al*., 1999); other data from Saint Pierre are more comparable to data from the Omai deposit in Guyana (Voicu *et al*., 1999), where oxygen and hydrogen data provide evidence of surface-derived waters, near seawater. According to Lafrance *et al.* (1999), the crustal continuum model for Archean lode-gold deposits of Groves (1993) might be applicable to the Paleoproterozoic greenstone belts of French Guiana and the Guiana Shield. Hydrothermal mineral assemblages vary with level of emplacement into the crust, probably also with the distance to granite intrusives and with host rocks. Taking into account the observations of Lafrance *et al*. (1999) and Voicu *et al*. (1999) in the Guiana Shield and synthesis work on Archean mesothermal gold deposits (Groves *et al*., 1998), the studied deposits mentioned above are located at the brittle-ductile limit and also at the limit of the biotite grade.

Consequently, we do not follow the model for "orogenic" deposits of Stüwe (1998), accepted by Voicu *et al*. (2001), that involves - within an orogenic framework starting with low-grade metamorphic terranes and ending with high-grade metamorphic terranes and with external heating and moderate denudation -, "mineralizing fluids derived from metamorphism at depths that travel upward in low-rank metamorphic rocks and precipitate as "postmetamorphic" gold-bearing quartz veining". According to Voicu *et al.* (2001), this interpretation is in agreement with the fact "that most gold deposits of the Guiana Shield show overlapping ages with the high-grade metamorphic terranes and late-emplacement time compared to the host low-grade metamorphic rocks".

This model does not adequately take into account various observations such as:

- the absence in French Guiana of high-grade terranes, equivalent to the granulites of Suriname (whose age range is not 2.02 to 1.95 Ga as proposed by Voicu *et al*. (2001), but rather 2.07 to 2.05 Ga (Roever *et al*., 2003), coeval with late granitoids of Guiana;

- an earlier gold stock emplaced in volcano-sedimentary basins, related to pre-D1 hydrothermal and volcanic activity (e.g. Dorlin district);

- during D2 transcurrent tectonics, emplacement in the upper–middle crust of "orogenic" gold-bearing quartz-sulphide veins in various geometric traps related to shear zones, folds, or rheological barriers and responsible for "changes" to the Dorlin stratiform/statabound deposit, to paleoplacers in the UDU conglomerates, and to some granitoids.

Isotopic data provide some indications of crustal levels and sources:

- At Dorlin, formed in the subsurface, hydrothermal fluids consist of a dominant marine component mixed with magmatic fluids (Lerouge *et al.*, 1999);

- At Omai, formed in subgreenschist conditions (Voicu *et al.*, 1999), and probably at Saint-Pierre, isotopic data suggest a mixing of metamorphic fluids (deep-seated fluids) and surface-derived waters, near seawater;

- At Saint-Elie (Lafrance *et al.*, 1999), Adieu-Vat, Changement, Loulouie, Saint-Pierre, and Yaou B, all formed in upper greenschist conditions, hydrothermal fluids have a metamorphic signature.

Surface-derived waters have not been identified at increased depths of burial, either because they did not reach such depths or because they equilibrated with metamorphic rocks. The extensive albitization in granites and carbonation in mafic to intermediate volcanic rocks also argue in favour of the involvement of seawater-derived fluids.

Consequently, we propose a model involving mixing, throughout the entire Transamazonian Orogeny (from at least pre-D1 to late-D2), of magmatic fluids and surface-derived waters, re-equilibrated with their host metamorphic rocks during terrane burial.

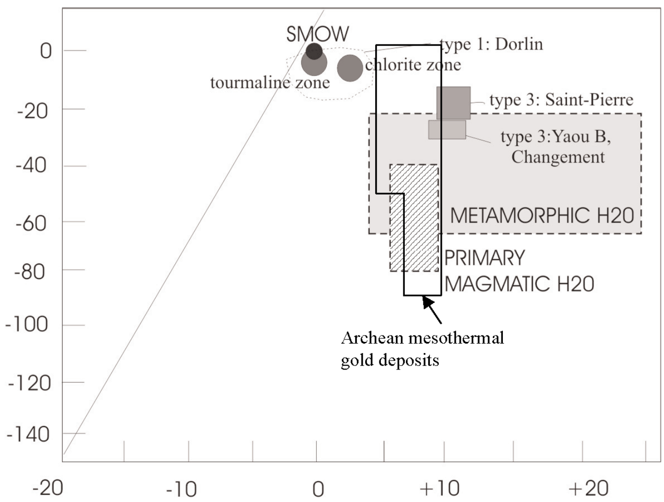


Fig. 12.- δ18O-δD diagram in which are plotted fields of hydrothermal fluids calculated in the different ore deposits of French Guiana. Main known reservoirs are also indicated: primary magmatic and metamorphic waters (after Taylor, 1987) and Archean mesothermal fluids (Hagemann *et al.*, 1994).

Fig. 12.- Diagramme δ18O-δD reportant les champs des fluides hydrothermaux calculés de différents gisements aurifères de Guyane. Les principaux réservoirs connus sont également indiqués : eaux primaires magmatiques et métamorphiques (d'après Taylor, 1987) et fluides archéens mésothermaux (Hagemann et al.*, 1994).*

Comparison with the West African Shield

Dorlin, the only stratabound ore deposit in French Guiana, has many characteristics in common with the tourmalinite-hosted ore deposit of Loulo in Mali (Milesi *et al.*, 1992; Dommanget *et al.*, 1993) and the Bambadji district of Senegal. This provides evidence for an earliest gold stock associated with widespread hydrothermal events in the Paleoproterozoic orogeneses of Guiana and West Africa.

In Guiana as in West Africa, D2 transcurrent tectonics controls a wide variety of syntectonic "gold-bearing conglomerate" and "mesothermal-orogenic" types of deposits.

The different facies of "gold-bearing conglomerates" are markers of the changes undergone by the conglomerates in the upper–middle crust during burial and exhumation. Some are equivalents to the deposits of Ghana. Examples include (i) the "gold-oxides paleoplacers", hosted by monogenic quartz-pebble conglomerates, which are comparable to the "Au-Banket" type conglomerates; (ii) the "gold-rich debris flows", which share some similarities with the Kawere conglomerates that contain erratic gold values and some reworked diamonds; and (iii) the mesothermal quartz stockworks, which are also identified in Tarkwa where some quartz-pyrite veins cut the main reef.

In French Guiana as in West Africa, the "mesothermal-orogenic" type of ore deposit is the most common. Some facies in Guiana are equivalent to those of West Africa. The main differences have to do with their relative importance. Thus, the Au-As mesothermal type, characterized by predominantly structurally controlled sulphide dissemination, is found in Guiana only at Montagne de Kaw, whereas it is well represented in West Africa in the Ashanti and Bibiani belts of Ghana (Milesi *et al.*, 1989, 1992; Oberthür *et al.*, 1994, 1998; Klemd *et al.*, 1996) and their extension in the Aféma (Côte d'Ivoire) and in Mali (Milesi *et al.*, 1989). Gold-iron-copper mesothermal deposits related to brittle-fault zones in French Guiana (Changement, Yaou B) share similarities with the mesothermal quartz-carbonate-gold vein-type deposits related to shear zones in West Africa, such as Poura (Burkina Faso), Sabodala (Senegal), Sanoukou and Diabarou (Mali), or Banora (Guinea) (Milesi *et al.*, 1989, 1992). Granitoid-related mesothermal gold deposits emplaced along brittle-ductile shear zones have similar characteristics in French Guiana (Adieu-Vat, Loulouie, Saint-Pierre, Yaou A: Milesi *et al.*, 1995) and in West Africa (Ashanti Belt: Yao and Robb, 2000; Larafella: Bamba *et al.*, 1997; Béziat *et al.*, 1998). In French Guiana as in West Africa, we can discuss the role of these granitoids, which constitute metallotects: "passive" rheological bodies during episodes of D2 deformation or direct implication in the

Eburnian of West Africa (Milesi et al., 1989, 1992; Feybesse et Milesi, 1994; Ledru et al., 1991b, 1994; Ledru, 1995; Feybesse et al., 1999a, 1999b, 2001; Billa et al., 1999; Lescuyer, 2001 Lescuyer, 2002, unpub., Delor and Milesi, 2002, unpub.	**Transamazonian of Guiana** (Jegouzo et al., 1990; Ledru et al., 1991a, 1994; Egal et al., 1994, 1995; Milesi et al., 1995; Vanderhaeghe et al., 1998; Delor et al, 2001, 2003, this volume)
First magmatic accretion with production of juvenile lithosphere and opening of flysch-type sedimentary basins. - 2.25-2.17 Ga (East) and 2.25-2.085 Ga (West): Greenstone belt of Ghana (tholeiitic volcanism et bimodal), oceanic plateaux, continent/oceanic arc subduction. *No ore deposits* - 2.15 Ga: production of juvenile continental crust, granodiorite and monzonite (partial melting of basic juvenile crust and/or Archean). *No ore deposits.* - 2.15-2.085 Ga: Break of a composite continental crust: flysch-type sedimentary basins (foreland basins) with felsic to andesitic volcaniclastic interbeds (lava and hyaloclastites). First hydrothermal synsedimentary preconcentration of gold (Au-B*) along talus in turbidites, (305 t Au in the Loulo-Bambadji district), emplacement of Mn deposits, Fe deposits (Falémé) and one Ag-Zn VMS (Perkoa).	**Paleoproterozoic accretion and production of juvenile crust:** - 2.21 Ga: "Ile de Cayenne" trondjhemitic/gabbroic formations and 2.18-2.16 Ga TTG melts. *No ore deposits* - 2,15 - 2.13 Ga: Greenstone belts including the stratiform/stratabound in tourmalinised volcaniclastic rocks (<30 t Au at Dorlin); Armina flysch-type. *No ore deposits* - 2.15 - 2.13 Ga: granodiorite, tonalite and TTG association dated (Central Guiana Complex, CGC. *No ore deposits*
Stage 1 of tectonic accretion: (D1: 2.115-2.093 Ga) - convergence of composite lithospheric micro-plates, tectonic collision at the boundary of Man Archean shield, tangential tectonic, formation of a first «composite» lithotectonic stack, - Crustal thickening and high-grade metamorphism (anatexie, HP 12 Kb). - syn-D1 plutonism (2.115-2.095 Ga): calcalkaline granites. **emplacement of the Au-B stock in basins, controlled by pre- to syn-D1 sedimentary tectonics (tectonic distal of the Archean-Paleoproterozoic convergent margin)*	**Stage 1 of tectonic accretion:** first deformation and metamorphism (D1: 2.15-2.13 Ga ?): thrusting locally developed (South) and/ or deformation related to the emplacement of granitic batholiths. *No ore deposits*
Second magmatic accretion (2.09-2.07 Ga): - Younger volcanic belts: bimodal volcanism locally continental including ignimbrites and adakites). *Oceanic hydrothermalism*: rare disseminated sulphides et feeder-zones (Kiniero). *Continental hydrothermalism:* "modern-style" mineralisations related to calcalkaline/adakitic volcanism: magnetite-bearing skarns, Cu-Au or Cu-Mo-Au disseminated/stockweorks sulphides (Ity, 2.097 Ga; Gaoua, ~ 13 t Au), Au-pyrite in felsic sub aquatic dykes (Angovia, 2.103 Ga), disseminated mineralisations related to subvolcanic bodies hosted by earlier flysch-type sediments (Sadiola-Yatela).	*No evidence of this event. No ore deposits*
Stage 2 of tectonic accretion: transcurrent tectonics (D2-D3: 2.1-1.95 Ga) and final compressive events: - Opening and closure of syntectonic basins (forelands) (2.13-2.097 Ga) with gold-oxydes-bearing quartz pebble conglomerates (Tarkwa district: ~1 260 t Au, 2.104 to 2.097 Ga), - "Orogenic" mesothermal Au-Quartz veins controlled by shear-zones, faults and folds (***~6 500*** t Au including ~ 2 600 t Au in the Au-As Ashanti Belt (including 1 600 t Au in the Obuasi deposit), - Late tectonic-magmatic stage: granitoids, brittle tectonic, erosion and denudation (2.06-1.95 Ga ?). *Continental hydrothermalism:* "modern-style" mineralisations related to calcalkaline/adakitic volcanism: **Fe ox-Cu-Au** (Falémé district, 2.08/2.07 Ga), - Late- D2 meta-kimberlites of Akwatia (origin of alluvial diamonds of SW Ghana), cut by late "orogenic" quartz ± Au veins.	**Stage 2 of tectonic accretion:** transcurrent tectonics (D2 : 2,115 Ga à post 2,083 Ga): - Opening and closure of syntectonic basin (foreland), the "North Guiana Trough" (NGT) (2.115 ± 0.004 Ga –2.08 Ga); Upper Detrital Unit (UDU) with gold-oxydes-bearing conglomerates. - "Orogenic" mesothermal Au-Quartz veins controlled by shear-zones, faults and folds (1,988-1,9 Ga): origin of the alluvial /eluvial deposits that constitutes large part of historical production (195 t Au); Primary ores constitutes a resources of 750 t Au on all the Guianas, including up to 200 t Au in French Guiana. - 2.105-2.09 Ga: Mg-K type granites and anatexites (South and West Guiana), - 2.08-2.06 Ga: late leucogranite (North Guiana) - alluvial diamonds (Kaw district), possible equivalent of those of Akwatia.

Table 7.- Gold deposits throughout the evolution of the West Africa and Guiana Paleoproterozoic provinces.

Tabl. 7.- Place des minéralisations aurifères dans l'évolution des Provinces paléoprotérozoïques d'Afrique de l'Ouest et de Guyane.

genesis of the deposits, as thermal and/or fluid sources comparable to the Cu-Au porphyries of modern chains.

In Guiana as in West Africa, the mesothermal deposits and the gold-bearing tourmalinites exhibit composite mineralogical and geochemical signatures of (a) mafic affinity, with Co-Ni minerals preferentially present in the earliest stages of the gold-bearing shear zones, where they are associated with chalcopyrite, and (b) felsic affinity, with Mo-Bi minerals and tellurides, which appears to be particularly abundant in Guiana compared to West Africa.

The main differences between the two regions are the absence in Guiana of (i) terranes of the second magmatic accretion (Table 7), which are represented in West Africa by younger bimodal volcanic belts with locally continental volcanism including ignimbrites and adakites and related ore deposits (continental and oceanic), and (ii) "modern-style" continental hydrothermal deposits related to calc-alkalic and/or adakitic volcanism, such as the Fe ox-Cu-Au deposits of the Falémé district (Senegal), Au-pyrite haloes (>30 km) in silicified ignimbrites (Mauritania), magnetite-bearing skarns or Cu-Au or Cu-Mo-Au disseminated or stockwork sulphides.

The ore deposit types identified in the Guiana Shield are comparable to those of West Africa and were emplaced during a similar period of geotectonic evolution (pre-D1 Au-B, then D2-related gold-bearing conglomerates and "orogenic" lodes, Table 7), likely implying a relatively similar evolution of the geodynamic settings and the metallogenic mechanisms at the scale of the chain.

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