Natural Resources Canada
Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8351

Gold mineralization in the Guiana Shield, Guiana and Suriname, South America: a field trip to the 14th biennial Society for Geology Applied to Mineral Deposits (SGA) meeting

M. Bardoux, M. Moroney, and F. Robert

2018

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8351

Gold mineralization in the Guiana Shield, Guiana and Suriname, South America: a field trip to the 14th biennial Society for Geology Applied to Mineral Deposits (SGA) meeting

M. Bardoux[1], M. Moroney[1], and F. Robert[1]

[1] Barrick Gold Corporation, 161 Bay Street, Toronto, Ontario, Canada, M5J 2S1

2018

Permanent link: https://doi.org/10.4095/306546

Recommended citation
Bardoux, M., Moroney, M., and Robert, F., 2018. Gold mineralization in the Guiana Shield, Guiana and Suriname, South America: a field trip to the 14th biennial Society for Geology Applied to Mineral Deposits (SGA) meeting; Geological Survey of Canada, Open File 8351, 28 p. https://doi.org/10.4095/306546

14th Biennial Meeting
Québec City, Canada
August 20-23, 2017

SOCIETY for GEOLOGY APPLIED to MINERAL DEPOSITS

MINERAL RESOURCES TO DISCOVER

EXCURSION GUIDEBOOK FT-03

Gold mineralization in the Guiana Shield, Guiana and Suriname, South America

Marc Bardoux, Marian Moroney and François Robert

SGA QUÉBEC 2017 FIELD TRIPS COMMITTEE

Chair
Michel Houlé

Co-chair
Anne-Aurélie Sappin

Guidebook Publication
Anne-Aurélie Sappin
Michel Houlé
Claude Dion
André Tremblay

SGA QUÉBEC 2017 / FT-03 Guiana guidebook

Cover photo: View overlooking the Pay Caro Pit of the Rosebel mine, Suriname.

Photo: *M. Bardoux (Barrick Gold Corporation)*

Gold mineralization in the Guiana Shield, Guiana and Suriname, South America: a Field Trip to the 14th Biennial Society for Geology Applied to Mineral Deposits (SGA) Meeting

M. Bardoux, M. Moroney, F. Robert

2017

SOCIETY FOR GEOLOGY APPLIED TO MINERAL DEPOSITS (SGA)
FIELD TRIP GUIDEBOOK FT-03

Gold mineralization in the Guiana Shield, Guiana and Suriname, South America

Organized by M. Bardoux[1]

Field trip leaders: M. Bardoux[1], M. Moroney[1], F. Robert[1]

[1] Barrick Gold Corporation, 161 Bay Street, Toronto, Ontario, Canada, M5J 2S1

Field Trip held 13-18 August 2017

Recommended Citation:

Bardoux, M., Moroney, M., and Robert, F., 2018. Gold mineralization in the Guiana Shield, Guiana and Suriname, South America: a field trip to the 14th biennial Society for Geology Applied to Mineral Deposits (SGA) meeting; Geological Survey of Canada, Open File 8351, 28 p. https://doi.org/10.4095/306546

Table of Contents

Foreword

The objective of the “Gold mineralization in the Guiana Shield” field trip is to give participants an overview of the geology and metallogeny of the exceptionally well-endowed Guiana Shield with an emphasis on the geologic setting of gold. This field trip provides an overview of greenstone belts of Guiana and Suriname including three mine visits associated with gold deposits at the Karouni (Guyana), Rosebel (Suriname), and Merian (Suriname) mines and core review of the Montagne d’Or project (French Guiana). A wrap up discussion on gold deposits of the Guiana Shield will take place on the last day.

Programme

Day 1 - Sunday August 13th

- **19:00:** Introduction to the Guiana Shield /Karouni mine at Duke Lodge in Georgetown, Guyana

Day 2 - Monday August 14th

- Tour at the Karouni Mine, Guyana.
- Review of Omai mine highlights

Day 3 - Tuesday August 15th

- Tour at the Rosebel Mine, Suriname.
- Review of Montagne d'Or drilled core (19:30) at Royal Torarica in Paramaribo, Suriname

Day 4 - Wednesday August 16th

- Tour at the Merian Mine, Suriname.
- Group dinner at Garden of Eden (20:30)

Day 5 - Thursday August 17th

- Fly back to Guyana
- Wrap up and visit at the University of Guyana (optional)
- Social events

Day 6 - Friday August 18th

- Fly back to Canada

Safety and Access

Field trip participants should be aware that any geological fieldwork, including field trips, can present significant safety hazards. Foreseeable hazards of a general nature include inclement weather, slips and falls on uneven terrain, falling or rolling rock, insect bites or stings, animal encounters, and flying rock from hammering.

Furthermore, this trip will involve walking over very rough, very unforgiving (angular and sometimes sharp), and often slippery rocks, likely in dusty/misty/rainy conditions, so a considerable degree of agility is required to be able to safely participate in this excursion.

The Leaders have prepared thoroughly the field trip and will take all reasonable care to provide the safety of the participants on its field trips. However, field trip participants are responsible for acting in a manner that is safe for themselves and their co-participants. This responsibility includes using the appropriate personal protective equipment (PPE) such as rain gear, sunscreen, insect repellent, safety glasses, work gloves, hardhat, and sturdy steel-toed boots when necessary or when recommended by field trip leader or mine staff, or upon personal identification of a hazard requiring PPE use. Attending to the safety meetings at each mine site are mandatory. You must stay clear 10 m from rock faces on open pit benches. No stepping over burms will permitted.

You will be exposed to extreme heat and humidity. Make sure you stay hydrated, sun tanned, and covered (hat, long sleeves, insect repellent). If you feel exhausted or ill do not force yourself. Try to find shade and rest. Food is safe. Tap water or rain water is unsafe. If you take medication carry it with you at all times.

Acknowledgements

The authors are greatly indebted to IAMGOLD, Newmont, and Troy Resources for accepting to offer field and core reviews of their respective mine sites and providing feedback on contents of this manuscript. Montagne d'Or is also acknowledged for contributing core as well as an overall review of their setting. Barrick Gold corporation provided support to create this document and offer logistic support to field trip participants.

Chapter 1: Introduction

1.1 Flora and fauna

The Guiana Shield is likely one of the last places where pristine tropical forest still exists (in very remote parts). This forest hosts the largest biodiversity on earth. Its gigantic appearance is highly sensible to human activity that has already caused irreversible damage.

First nations have occupied this territory for millennia in due respect of its capacity to protect and feed themselves. People of the land are constantly battling to preserve its authenticity for generations to come. Like anywhere else, pristine environments are disappearing at an alarming pace thanks to poor licenses to operate.

During this trip please minimize your footprint and admire this splendid and unique landscape.

1.2 Humans

Though there cannot be evidence found of the passage of humans in the tropical forests of the Northern Amazon Basin after the last continental glaciation it is likely that this territory was visited many millennia ago by humans questing food and living off a gigantic and generous fresh water system. Archaeological evidence indicates that the wandering Amerindians migrated to South America from Central America and the Caribbean and lived along many of the coastal lands that were further inland because water levels were significantly higher than today.

1.3 Brief history

1.3.1 Glimpse at Guyana's history

- Christopher Columbus and cohort sailed off the coast of Guyana on his third voyage in 1498. They encountered two major tribes: the Awaraks along the coast and the Caribs in the interior (although the warlike Caribs eventually displaced the peaceful Awaraks).
- In a 1596 voyage to the New World, Sir Walter Raleigh led to subsequent accounts of El Dorado, the city of Gold, which is believed to be in Guyana.
- Discovered by European explorers at the very end of the 16th century, it was the Dutch that began to build permanent settlements in Guyana in 1621, and shortly thereafter African slaves arrived in the new colony.
- Over the next few centuries, Guyana history was punctuated by battles fought and won, possessions lost and regained, as the Spanish, French, Dutch, and British wrangled for centuries to own this land.
- After the last major war between England and Holland in 1803, Guyana is given to England, and its largest settlement is renamed, Georgetown.
- Guyana remained a British colony until it gained its independence in 1966, and remains South America's only English speaking country.
- Omai, the first large gold operation, started in 1990.

1.3.2 Glimpse at Suriname's history

- In 1498, on the same voyage along the coast lines of northern South America, Christopher Columbus sights the coast of Suriname and likely observes some of the traditional house of stilts adapted to extreme rainy conditions and wildlife.
- In 1593, Spanish explorers name the area Suriname, after the country's earliest inhabitants, the Surinen
- 1600-1650: Settlements attempted by Spanish, Dutch, British, and French fail under resistance by Surinen
- 1651: First permanent European settlement by Lord Francis Willoughby at Paramaribo
- 1667: The British cede their part of Suriname to the Dutch in exchange for New Amsterdam (Manhattan)
- 1682: Coffee and sugar cane is worked by African slaves. Slavery was abolished 181 years later (1863). Endured laborers are then brought in from India, Java, and China to work on plantations.
- 1916: Aluminium Company of America (Alcoa) starts bauxite mining that becomes Suriname's main export
- 1954: Suriname gets full autonomy, the Netherlands retains control over its defence and foreign affairs
- 1975: Suriname becomes independent, a third of the population emigrate to Holland.
- 1980 and 1982: Military coups. Executions are followed by economic sanctions (Holland, USA)
- 1986: Guerilla war forces closure of bauxite operations
- 1990: Military coup
- 1992: Peace accord is reached
- 1992 to today: Several coalition parties have been elected. Rosebel Gold mines started in 2000. BHP left Suriname in 2010. Holland recalled its ambassador and interrupted its aid payments in 2012. SurGold started mining Merian in November 2016.

Chapter 2: Geology of the Guiana Shield

2.1 Introduction

The Guiana Shield (recommended spelling following Gibbs and Barron 1993) is nearly 1 million square kilometers in surface area. It defines the northern extension of the Amazon Craton that itself forms the main continental mass of South America (Santos et al. 2008; Fig. 2.1). The core of the Amazon Craton is Neo- to Mesoarchean. Rhyacian (2.30-2.05 Ga) Provinces formed and docked onto it from the north-east side. Younger Orosirian (2.05-1.80 Ga) Provinces formed mainly on its western side. The Andean orogen continues building onto Amazon Craton basement. Its architecture likely influences its evolution and metal systems.

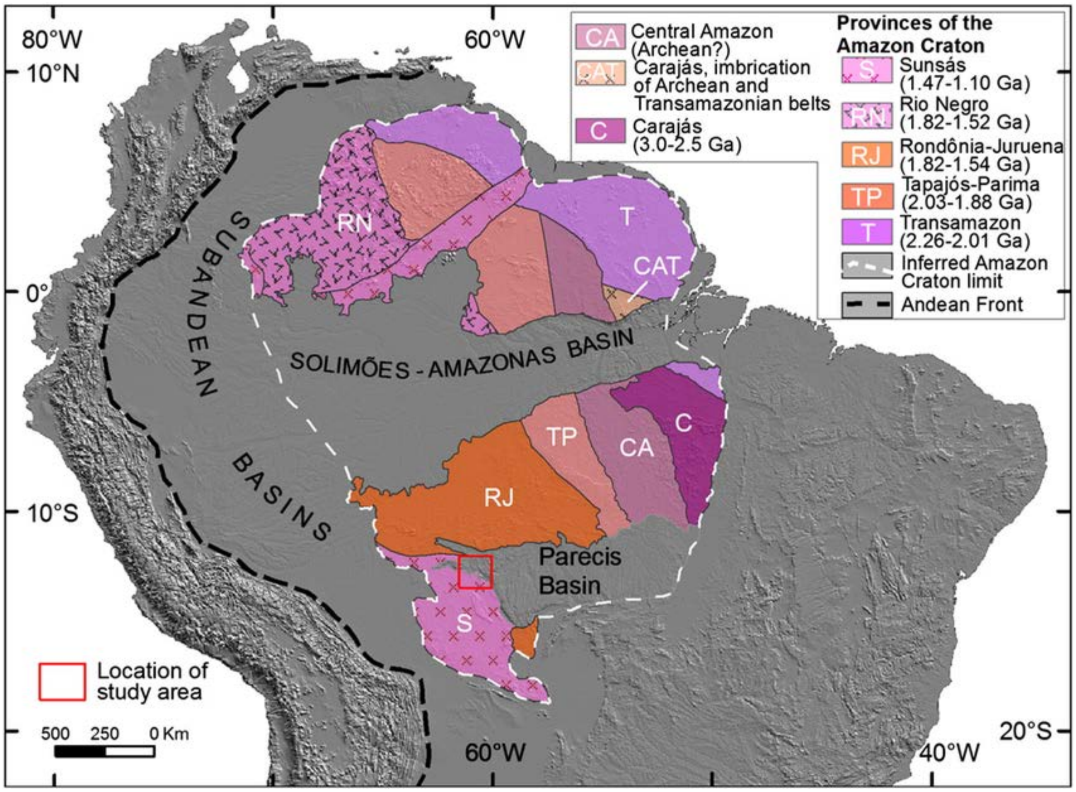


Figure 2.1. Provinces of the Amazon Craton (after Santos et al. 2008). The Takutu rift (indicated as Sunsás North of the Amazonas Basin) separates the Guiana Shield in two halves. This rift was activated in the Mesozoic.

Rocks of the Guiana Shield are best exposed along the Atlantic coast lines and along its beautiful rivers. A lot of white sand covers its low landscape because the water level used to be 100 m higher 10,000 years ago. White sand is great construction material. However, limited infrastructure reaches this vast territory. First nations use boats and love to walk and live in peace.

The Guiana Shield has produced more gold nuggets to the “new world” than any other region of the planet. In the early 16th century, the Spanish were ruling the Caribbean and South American oceans and built huge wealth from these journeys. Today, thousands of persons are working at artisanal operations producing annually hundreds of thousands of ounces of gold from regolith material (alluvials and saprolite). Most of their gold is coarse. In Guyana alone, the alluvial labor force counts more than 20,000 persons (Fig. 2.2). There are thousands more everywhere. Primary gold miners track historical workings that are visible from space.

Very few geologists have worked the Guiana Shield at a regional scale and fewer have been active in it for more than a decade. The ratio of exploration grey matter relative to the total surface area of the Guiana Shield is certainly one of the lowest on earth.

Figure 2.2. Typical alluvial mining operation of the Guiana Shield. Saprolite material mined is often tens of meters thick and soft enough to be hosed down to fresh rock and washed in a sluice box. Coarse gold is the main product of these operations.

In the 1900s large groups of survey geologists from England, Holland, and France paid heroic efforts to break down as many geological components as they could of the impenetrable lands of Guyana, Suriname, and French Guiana. They were literally fighting their way into the unknown and in an environment of beauty and threat. Falling tree branches were there main enemy. Many did not make it back whereas others were told to cut short their efforts in the late 1980's.

In 1993, Gibbs and Barron published the only and remarkable compilation of nearly three decades of limited academic work and government mapping projects with the contribution of many peers (see reference list in Gibbs and Barron 1993). They established significant stratigraphic correlations across Guiana Shield countries (Venezuela, Guyana, Suriname, French Guiana, and Brazil). In Guianese countries many talented geoscientists (Choubert 1974; Mendoza 1974; Ledru et al. 1994; Kroonenberg et al. 2016 to name just a few) led regional mapping efforts to break down the geodynamics of the geological framework of countries they had responsibilities for while defining the mineral inventory (numerous gold anomalies) across the territory.

Since the 1950's, the mineral industry investigated the Guiana Shield looking for the next elephant. It is in the last 30 years that it payed more attention to specific gold camps and realized that volume was there but grade was generally lower than in many popular gold camps of the time (Abitibi, Yilgarn, and Ashanti). An endowment exceeding 100 Moz of gold is now attributed to this vast region. Just in the last few years significant discoveries have been announced and production from surface operations has steadily increased over the last 20 years.

The Guiana Shield comprises Archean, Rhyacian, and Orosirian Provinces that are being slowly defined. Archean rocks are primarily reported in NW Venezuela and NE Brazil. Hints of Archean rocks are being defined in Rhyacian sediments. Rhyacian rocks are primarily documented in the northern Guiana Shield. Orosirian rocks form the majority of the southern Guiana Shield.

ENE-trending aulacogens, in part related to the opening of the Atlantic and the Andean orogeny, have segmented the Guiana Shield in two blocks that are confined between the Amazon and the Orinoco rifts. The Takutu rift splits the Guiana Shield in the middle (Fig. 2.1).

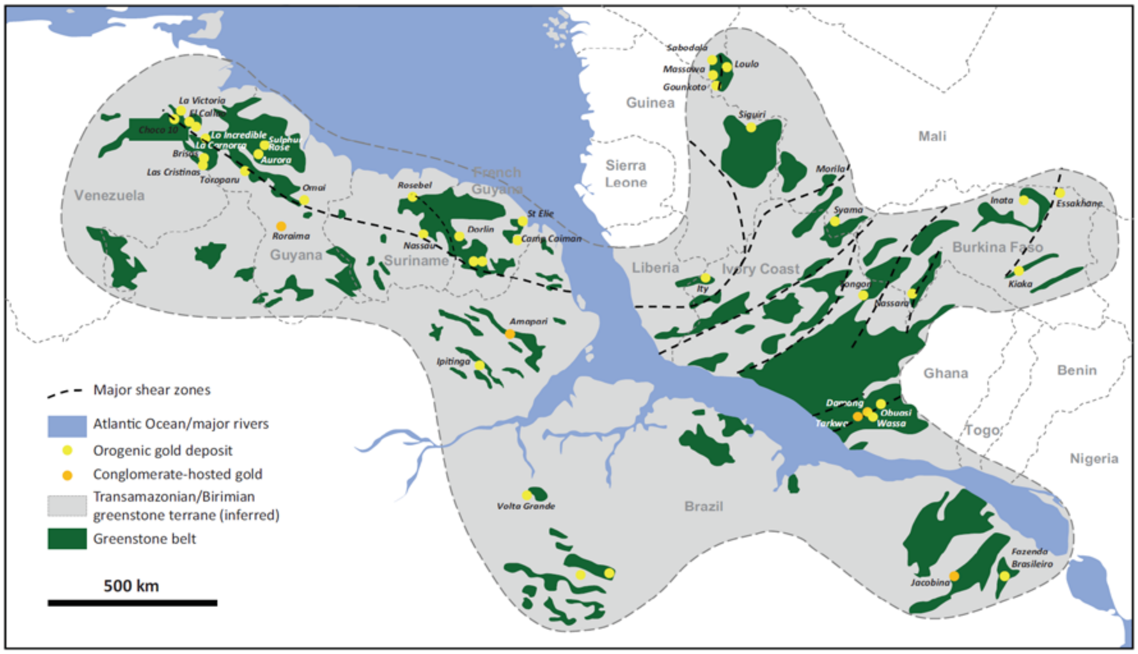


Figure 2.3. Reconstruction of parts of the Rhyacian landmass prior to the dextral opening of the central Atlantic region during the Aptian. The location of greenstone gold deposits and paleoplacer gold is indicated by yellow dots. Note that the geology of the Guiana Shield is bounded to the east by the Archean Man shield. Greenstones of Guyana, Suriname, and French Guiana are nearly continuous for more than 2000 km parallel to the Atlantic coast (modified from Voicu et al. 2001 and Frimmel 2014).

Prior to the opening of the central Atlantic ca. 165 Ma, the geology of the Guiana Shield linked to that of the Leo Shield of the West Africa craton. Due to transform motion during the central Atlantic opening but also because of unclear Rhyacian plate reconstructions the exact fit of the Guiana-Leo shields is still debated (Bardoux and Ernst 2017). The reconstruction proposed in Figure 2.3 is the most published (Frimmel 2014; Goldfarb et al. 2017) and it suggests that most of the Guiana Shield land mass was to the left of the Leo Shield. Under such reconstruction most of the Guiana Shield has few direct links with the many domains defined in the Leo Shield (eg. Ghana links to NE Brazil).

Most geological elements of the northern Guiana Shield are Rhyacian (2.35 to 2.05 Ga; Fig. 2.4). The southern Guiana Shield is less well documented (more remote) and exhibits Mesoarchean components that remain undefined. The best Mesoarchean exposures are found in the Imataca Complex of Venezuela as well as the Amapá region in NE Brazil (Rosa-Costa et al. 2003 and references therein). Archean detrital zircons are reported in southern French Guiana (de Avelar et al. 2003) and Northeastern Suriname (Daoust 2016). The southwestern part of the Guiana Shield is a protracting series of younger Proterozoic tectonometamorphic domains that are younging to the SW towards the base of the Andes.

Since ~1.8 Ga, the Guiana Shield was covered by the very thick Roraima clastic sequence that protected it from erosion until recently. The most easterly inselberg of Roraima sediments is in the middle of Suriname (Kroonenberg et al. 2016).

Large LIP provinces developed ca 2.00 Ga and 1.79 Ga westward of central Suriname and most of them expand westward into Guyana and Venezuela where they are hidden by Roraima sediments.

The total surface area of the Guiana Shield is twice that of the Yilgarn, yet only a strip of approximately 250 km along the Atlantic coastlines is relatively well known.

This guidebook refers to the main stratigraphic terms of the Guiana Shield. By no means it deals with any of them is as much detail as can be found in the literature (Gibbs and Barron 1993; Delor et al. 2003; Kroonenberg et al. 2016; and many references therein).

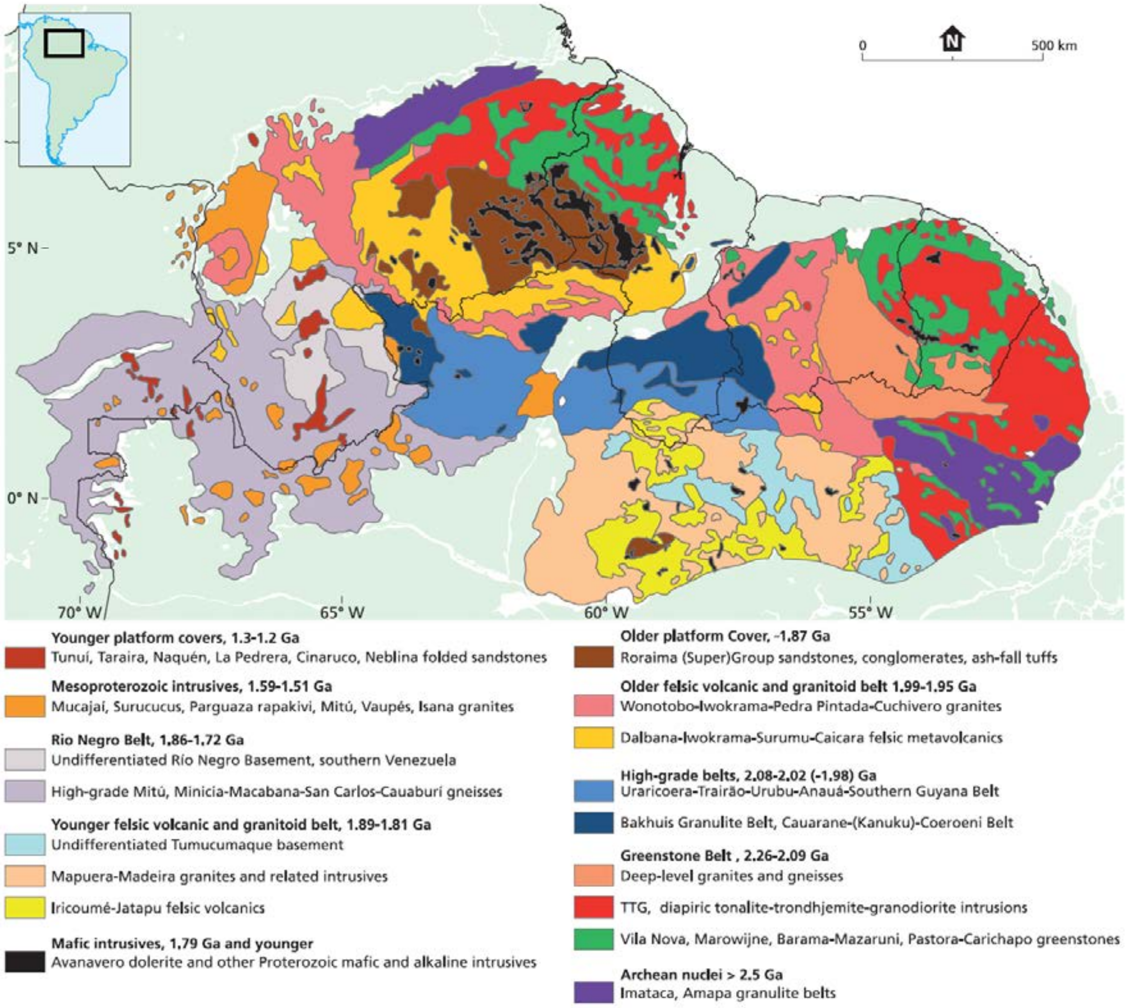


Figure 2.4. Geological framework of the Guiana Shield compiled by Kroonenberg et al. (2016). Rhyacian rocks are green and red.

Essentially there are four sequences of interest in (largely unconstrained) younging **but not continuous** order (spelling changes between countries):

- Paramac(k)a/Barama-Mazaruni (ultramafic to mafic volcanic rocks). Two arc sequences of 2.17 Ga and 2.14 Ga.
- Armina (mafic to intermediate volcanic rocks and volcaniclastic rocks). Roughly 2.16 Ga and younger.
- Rosebel/Orapu or Bonidoro (fluvial or alluvial sediments including polygenic conglomerates). Roughly 2.07 to 2.00 Ga
- Numerous granitic to alkalic intrusive bodies that range in age from 2.16 to 2.10 Ga.

These Rhyacian supracrustal sequences and related intrusive bodies as well as deformation cycles affecting them have been correlated across the Atlantic with identical and coeval rock sequences of the Leo Shield (Milési et al. 1992). The oldest supracrustal rocks of the Guiana Shield were affected by up to three stages of deformation referred to as the Trans-Amazonian Orogeny that peaked around 2.0 Ga. It is debated whether the younger supracrustal rocks may have been affected only by a younger stage of this orogeny or whether the orogeny is a continuum in itself. The orogenic cycles were not systematically protracting. Armina sediments are in profound unconformity onto underlying (strained) arc sequences. The products of the various deformation cycles are usually large faults and megascopic folds. There is much debate on kinematics on many faults. Metamorphism accompanying deformation is usually greenschist facies but locally reaches amphibolite grade.

2.2 The fit between the Leo and Guiana Shields

According to Pangean paleoreconstructions (Scotese 2001), the Guiana Shield was located to the left (current west) of the Leo Shield (Fig. 2.5). Thus, its geological framework is significantly different from that of the greater Leo Shield. Its best fit is (remotely) with that of the Kenieba window of Mali that was located to the right of French Guiana. About 120 Ma, the Leo and Guiana Shields separated along a transcontinental transform margin that separated northwestern Africa from its eastern half. Vestiges of this transform system are preserved inside the continental masses. This gigantic rifting was triggered by the Tristan de Cuna plume. Further drifting split the Rhyacian landmass of the Leo Shield from its coeval parts of southern Africa. Sedimentary basins formed during the Aptian are sites of vast (current and future) hydrocarbon reservoirs on the coastlines of South America and western Africa.

2.3 Mineral systems of the Guiana Shield

The Rhyacian was the second most significant period of gold endowment of the Precambrian (Bardoux 2012). More than 300 Moz of gold have materialized in the Leo Shield and nearly 100 Moz of gold have been reported in the Guiana Shield (Bardoux 2012). Together with gold, several mineral systems have been reported throughout the Guiana Shield. The list of the main commodities is compiled in Table 2.1. Bauxite and gold are the main commodities exploited by standard mining methods. Gold has been and continues to be mined by alluvial methods. Alluvial diamonds are also mined at the base of the unconformable Roraima sequence in Guyana and Venezuela. Sources of diamonds are eluding.

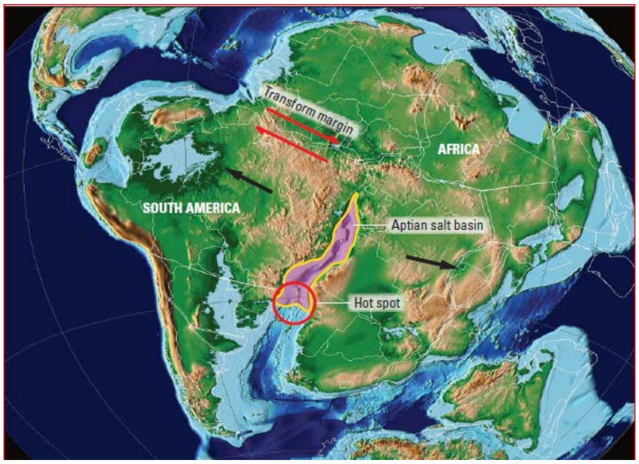


Figure 2.5. Aptian (120 Ma) Pangean reconstruction indicating that the Guiana shield (yellow outline) was located to the current west of the Leo Shield. Most of the Guiana Shield geology best ties up with that of the Kenieba Window. Right lateral drifting along the central Atlantic region separated the two land masses to their current position (modified from Scotese 2001).

Table 2.1. Mineral systems reported from the Guiana Shield.

Commodity	Model Type	Guyana	Suriname	French Guiana
Au	Greenstone	yes	yes	yes
Au	VMS	no	no	yes
Au	Paleoplacer	no	no	yes
Bauxite		yes	yes	yes
Ni-Cu-PGE	Voisey's Bay	yes	no	no
Cu-Pb-Zn (Au)	VMS	yes	no	yes
Cu±Mo-Au	Porphyry	yes	no	no
Nb-Ta-REE	Carbonatite	yes	yes	no
IOCG or IOA	Olympic Dam	no	no	no
Sn-W	Veins	no	yes	yes
Uranium	Athabasca	yes		
Diamonds	Kimberlite/ Placer	No/yes	No/yes	Yes/no

2.4 Gold endowment of the Guiana Shield

Gold has been the commodity of choice in the Guiana Shield for centuries. Gold nuggets were shipped across the Atlantic since the 15th century and have been the object of numerous episodes of European conquests. The fact that large resources of supergene gold are part of local economies indicates that a lot of gold is still mined by alluvial miners (Bardoux 2012). In certain locations, nuggets of several kilograms were discovered. This historical evidence has been a prime motivation for the mining industry to investigate this territory. In general, the perception has been that alluvial mining was the best footprint and therefore an “easy” vector to discovery. In many ways this strategic approach has materialized significant endowment (Fig. 2.6). However, the regolith is complex in many cases and this has led to deceiving results on promising but often “displaced” anomalies. The challenges to find large gold deposits in the Guiana Shield have remained the same for centuries. A lack of factual evidence on the ground will always leave the door open to creative thinking and innovation. The Guiana Shield is the land of golden opportunities making it one of the top ten emerging regions on the planet.

To date the most significant endowment has been in Venezuela but that of Suriname has increased most significantly in the last decade. Both Venezuela and Suriname host Tier 1 deposits (Fig. 2.7). The total production of gold of the Guiana Shield exceeds 1.5 Moz annually. Most of the primary production is from the three deposits that are the focus of this SGA Field Trip FT-03. The forecast is that this production will increase and be sustained for decades (Fig. 2.8).

It took a lot of persistence and talent to unravel the relatively subdued nature of these deposits. As you travel through these regions you will realize that surface conditions are challenging for standard exploration techniques (eg. soil surveys) and mapping takes a lot of skills and patience. Some of the greatest contributors to the new mines were field technicians of local nations backpacking and traversing the jungle in small groups for days along remote and unchartered drainages. Days after days they panned and counted gold grains while having manioc for breakfast, lunch, and dinner. Many of their grade calls off gold specs were very accurate. This trip is, in part, a tribute to their skills and endurance.

During this journey you will see some of the best exposures of geology of this vast territory. In 1993, most of these subjects were under thick cover. Very little direct evidence pointed at their existence.

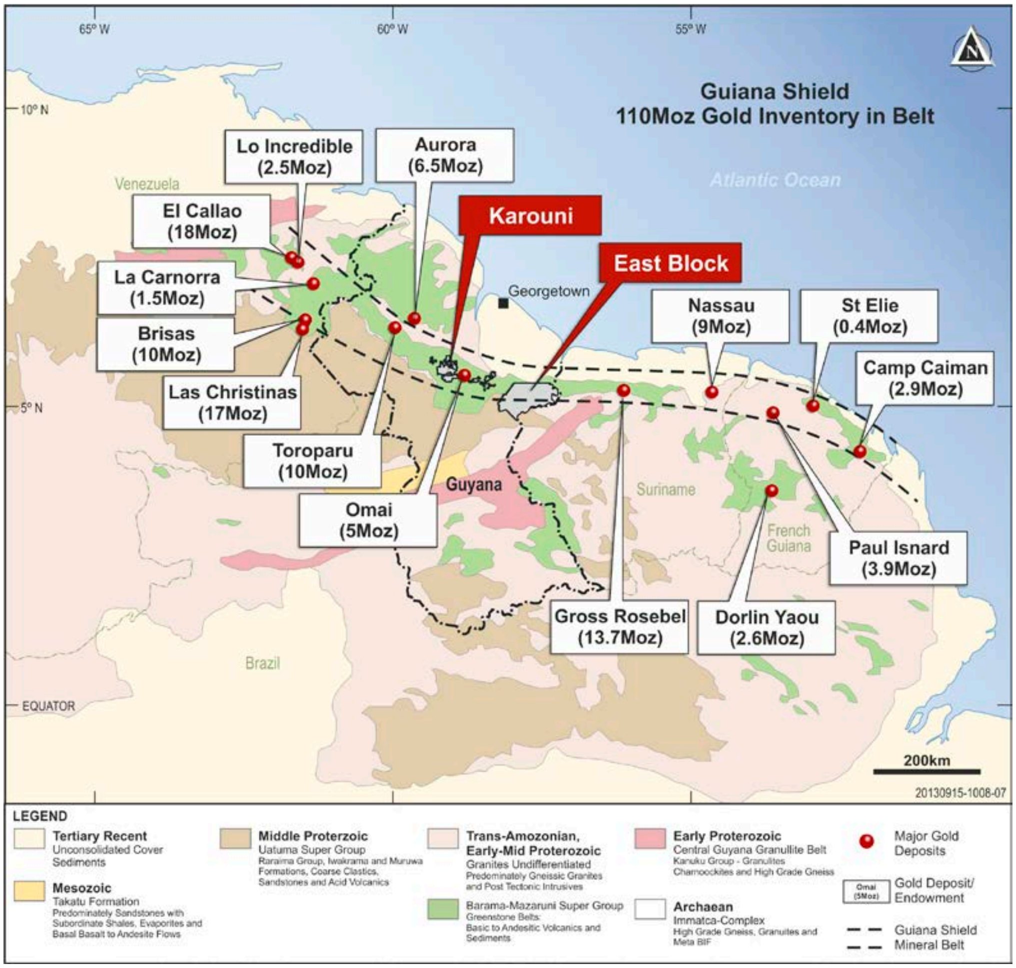


Figure 2.6. Main gold deposits of the northern Guiana Shield in Rhyacian supracrustal sequences. More than 100 Moz of endowment has been defined from 14 sites (source Troy resources, modified after Voicu et al. 2001).

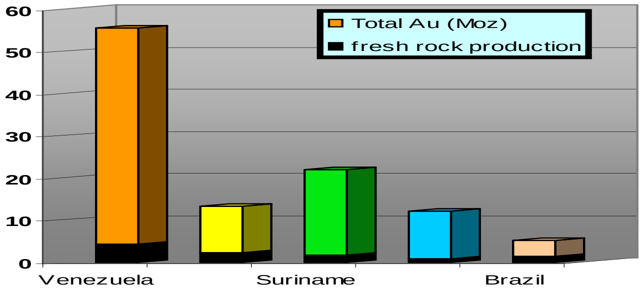


Figure 2.7. Endowment of the northern Guiana Shield from west to east.

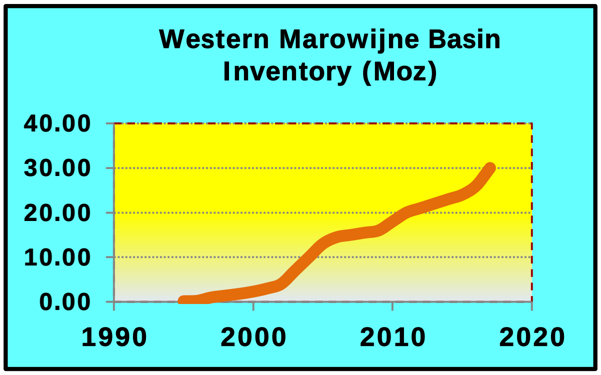


Figure 2.8. Endowment of the northern Guiana Shield by size (Bardoux 2012).

Chapter 3: Geology of the Karouni mine, Guyana

3.1 Geology of Guyana

The sub-continental mantle lithosphere of Guyana may be Archean (Begg et al. 2013) but direct evidence is scattered. In a highly simplified way, Guyana's geology can be roughly divided in a northern and southern part. They were separated by the ENE trending Takutu aulacogen that formed during central Atlantic rifting ca. 120 Ma (Figs. 2.6, 3.1). The trend of the aulacogen may not be fortuitous as it is nearly perpendicular to all orogenic fronts that protracted for more than 1.7 Ga on the SW margin of the Amazon craton (Sunsás to Andean orogenies).

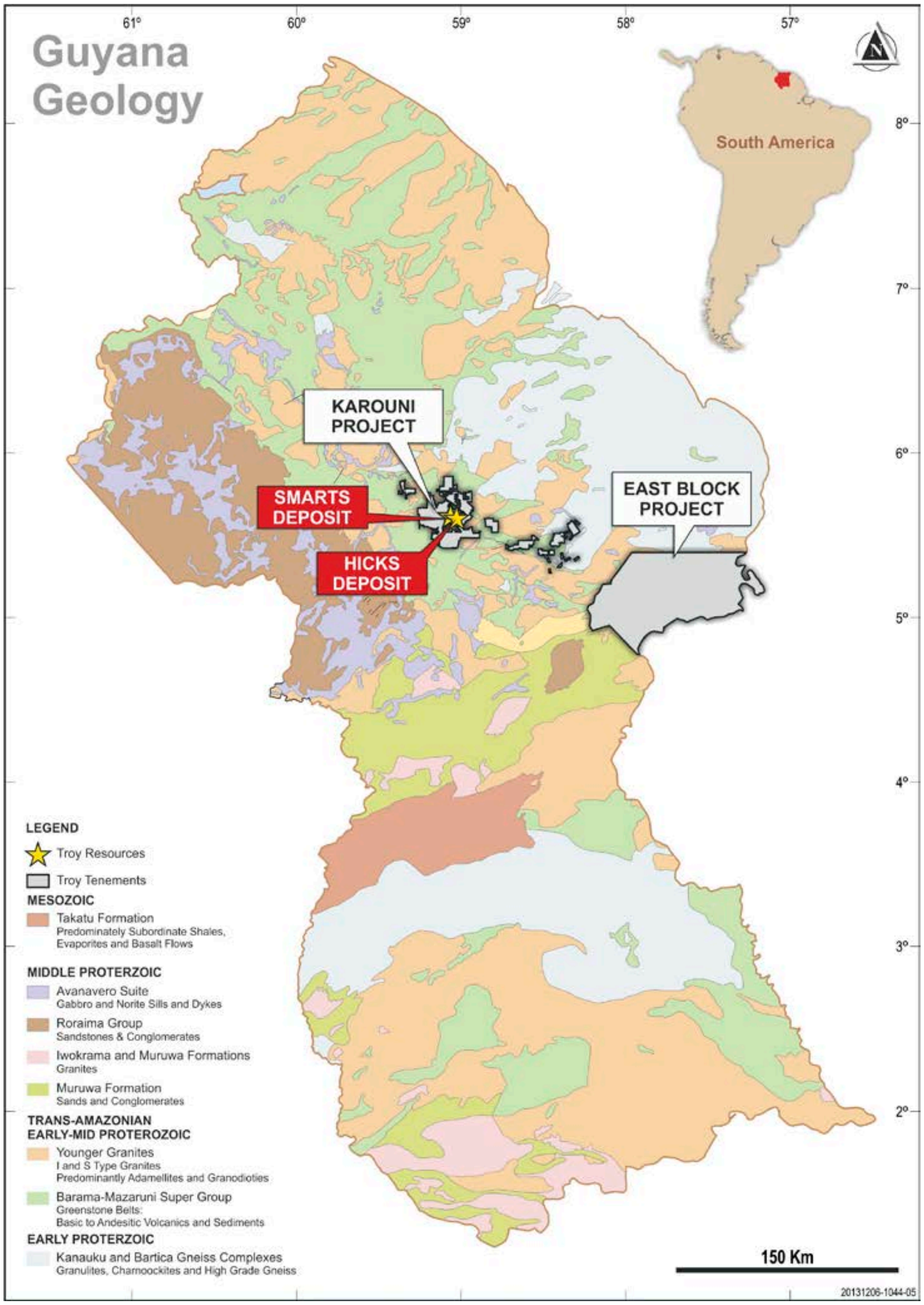


Figure 3.1. Geological map of Guyana showing the location of the Karouni mine in the eastern part of the Cuyuni Basin (source Troy resources, modified after Guiana Geological and Mines Commission (GGMC).

Northern Guiana comprises the largest volumes of Rhyacian supracrustal sequences of the entire Guiana Shield (Gibbs and Barron 1993; Voicu et al. 2001; Fig. 3.1). These supracrustal rocks referred to as the Barama-Mazaruni SuperGroup are essentially divided in three principal sequences starting at the bottom with mafic to intermediate arc metavolcanic rocks that are unconformably capped by metaclastic rocks (volcanic to basement sourced). Local unconformable fluvial sediments (cross bedded quartzose sandstones and polymict conglomerates containing boulders of felsic intrusions) are defining the youngest stage of the geodynamic evolution of this region. Rare ultramafic rocks are encountered in the NW part of the country. Numerous intrusive bodies have pierced supracrustal sequences before or during deformation. Geochronological data is scarce (see Omai section).

Guyana has produced more than 9 Moz in the last 25 years. It ramped up its annual production to 700 Koz in the last three years. More than half is from alluvial operations (Schwertfeger, pers. comm. 2017).

3.2 Omai mine

Mining at Omai had been recorded as early as the 1880`s. The German mining syndicate was active at the site for more than a decade at the turn of the 20th century. By 1911, more than 115,000 oz of gold had been produced. About a century after its discovery, Omai became the largest gold mine of the Guiana Shield from 1990 to 2002. This very nice operation produced 3.7 Moz at an average grade of 1.5 g/t Au. Much gold remains in the ground today under a thick flat sill (Fig. 3.2).

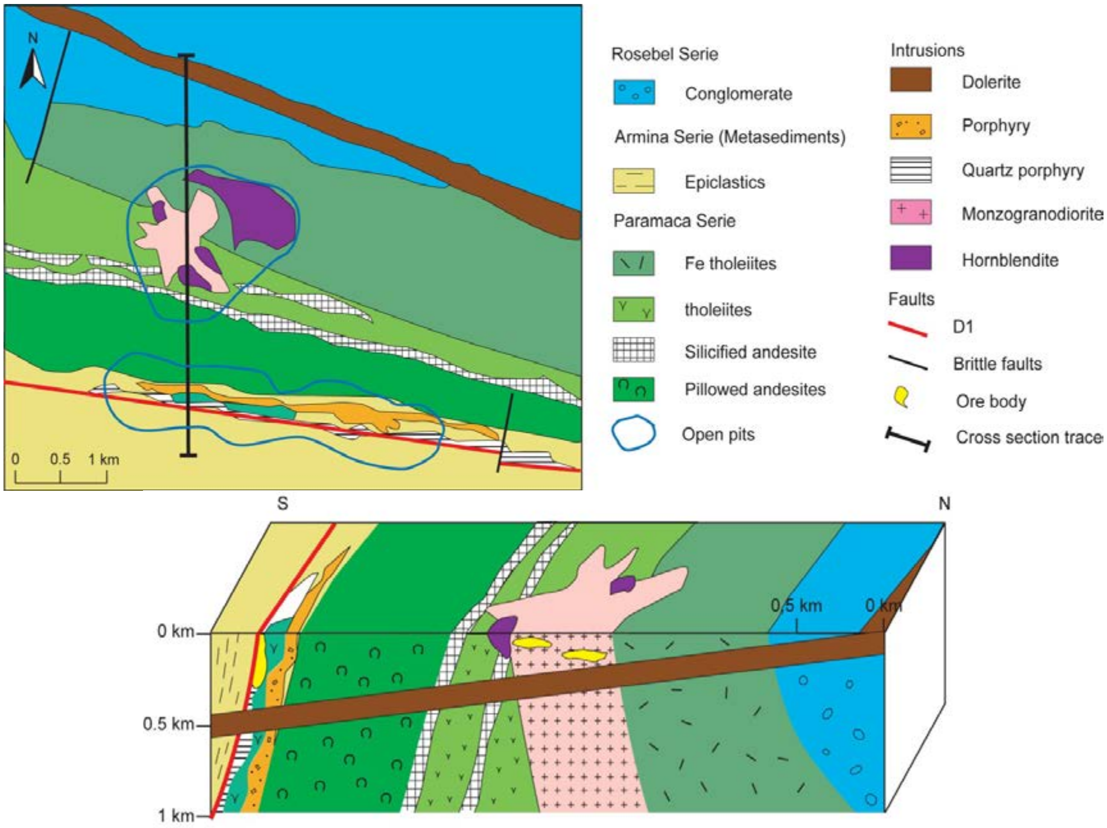


Figure 3.2. Simplified surface geology and block diagram of Omai, Guyana (Bardoux 2012).

Gold was mined from two open pits on extensional and shear lode veins that formed in small shallow crustal felsic bodies that intruded tilted mafic and felsic magmatic rocks in proximity to the regional Wenot Shear Zone (Voicu et al. 1999a). Proximal to the shear zone, felsic bodies took deformation in a brittle way. The largest of the felsic bodies, the epizonal Fennell monzodiorite stock dated at 2094 ± 6 Ma (400 m across, Norcross 1997), hosted the most significant resources. Ladder veins in the stock were nearly flat due to vertical stretching and relatively high local strain that led to boudinaging the carrot shaped body (Fig. 3.2). This process is very reminiscent of that described by Robert and Brown (1986) at the Sigma mine in the Abitibi. The metallic paragenesis comprised Au-Ag-Te-W-Bi-Pb-Zn-Cu-Hg and Mo assemblages. The dominant alteration consists of carbonates-silica-sericite-chlorite-albite-tourmaline-rutile and epidote. Pyrite and pyrrhotite are the main sulfide phases with less abundant sphalerite and chalcopyrite. Scheelite was abundant in veins. Gold appears relatively early in the ore paragenesis although the main gold mineralization is associated with sulfide and telluride deposition during later stages of vein formation. Three distinct generations of tellurides occur at Omai; rare melonite is associated with gold and rutile and chalcopyrite is common in altered metabasalts. Other tellurides (mainly tellurobismuthite) occur as inclusions in pyrite or replacements of pyrite. Temperature values of the vein-forming minerals at Omai are calculated to have cooled from 220°C to 170°C in three stages with increasing sulfur and tellurium fugacities. Stable pH values between 4.0 and 5.4 indicate gradual transition from oxidizing to reducing conditions. Isotopic compositions of the hydrothermal fluids are supportive of a shallow crustal emplacement and a significant input of surface water (Voicu et al. 1999b). Possible mechanisms of metal deposition include H2S loss from the fluid due to wall rock sulfidation reactions or to phase immiscibility, fluid cooling, and interations of mineralizing fluids with reducing wallrocks.

Mineralization in the Fennell stock extends under an 80 thick sill of Avanavero age (Fig. 3.2). Titanite and rutile give a Pb-Pb isochron age of 1999 ± 6 Ma that was believed to reflect a late-stage Trans-Amazonian thermal event that provided a young age limit to Au mineralization (Norcross 1997). Similar ages were obtained recently at Rosebel and suggest that this thermal regime may be related to large LIPs events.

3.3 Karouni mine

Karouni is located 40 km west of Omai and in the same general structural corridor (Fig. 3.1). An extended abstract by Tedeschi et al. (2017) is reviewing key components of this region. Mike will present results of his PhD the evening of Aug. 13.

3.3.1 Geology

Karouni currently hosts an estimated 0.8 Moz of gold but more is expected to be found as these are early days of exploration in a complex stratigraphic and structural framework and very challenging regolith conditions.

Karouni like Omai is located at the SE end of the Cuyuni Basin (Bardoux 2012). It is located at the crossings of numerous regional structures readily visible on aeromagnetic data (Fig 3.3). It resides in a regional scale sigmoidal bend centred around the NW-SE trending Karouni monzo-granite that appears to occupy the core of a megascopic anticline (see SGA abstract of Tedeschi et al., 2017). Three phases of deformation have built around this rigid body that has, in part, dictated the discrete structural patterns around itself.

The Rhyacian stratigraphy at Karouni is part of the Barama-Mazaruni Group and comprises from bottom to top: high Cr-Mg basalts with Ti rich phases; amygdaloidal basalts; fragmental mafic volcanic rocks and conglomerates; volcaniclastic rocks and unconformable greywacke and carbonaceous shales. The stratigraphic succession on the NE side of the Karouni intrusion are younging NE. Older high strain zones are oriented NW-SE and they are superimposed by younger E-W and N-S structures that are readily visible in the regional magnetic data.

The bulk of the gold mineralization is hosted along the sulphidized and albitized selvedges of N-S trending quartz-carbonate veins in high Ti basalts and porphyritic bodies. Abundant rutile and tellurides occur with Au.

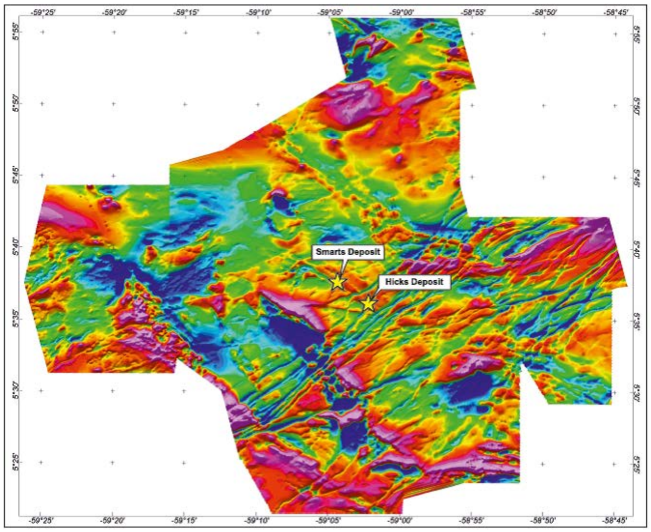


Figure 3.3. Total aeromagnetics of the Karouni region.

Primary gold is exposed at several localities of the Karouni Project, the most notable being the Hicks, Smarts, and Larken Zones along the northern extremity of the Project where the White Sand Formation cover was removed by erosion. This White sand, however, covers the central and south portions of the project tenements. Airborne geophysics indicates that the Barama-Mazaruni greenstones and associated syntectonic intrusives persist at shallow depth beneath this cover (Fig 3.3).

3.3.2 Hicks deposit

The Hicks deposit is the southernmost deposit defined to date along the Omai – Hicks – Smarts – Whitehall (Kaburi) Corridor (Fig. 3.3). Gold is hosted by a northwest trending, sub-vertical to steeply SW dipping shear zone some 2,900 m in strike length and up to 6 0m wide in places with average grade of 2 g/t Au. The shear zone formed within basalts and andesites of the footwall greenstone succession along the northeast limb of a shallowly northwest plunging anticline. Gold also occurs at the contacts of porphyry-granite intrusions. The shear zone is comprised of semi-continuous zones of quartz lenses and quartz-carbonate veining that is often brecciated.

Numerous, moderately well-defined gold-rich lenses, up to 15 m wide, occur within the shear zone and are characterized by greater density of quartz veining, quartz flooding, shearing, chloritization, seritisation, and pyritisation. Visible gold and the majority of gold values typically occur within and along margins of quartz veins, in silicified granitic dykes, and in adjacent, pyritic, often highly strained meta-andesite. Pyrite is common at up to 3% by volume, with local, trace amounts of molybdenite, galena, and sphalerite, associated with auriferous quartz veins. Mineralization is variously accompanied by silica, sericite, chlorite, carbonate, pyrite, and tourmaline alteration, while fuchsite is developed within porphyry intrusives in contact with high magnesian basalts as well as along shear zones.

In general, the northwest trending mineralized shear zone has developed within a steeply inclined sequence of metamorphosed andesitic to basaltic volcanic rocks, adjacent to the northwest margin of the Eldorado (granodiorite) batholith. The volcanic stratigraphy is cut by multiple andesitic to felsic intrusive phases that precede and post-date the introduction of gold.

In 2013, Troy Infill core drilling at the Hicks Deposit focused on the higher grade central and southern parts of the deposit to increase the drilling density from 100 m by 100 m spacing to 50 m by 50 m spacing. Significant assay intervals were obtained (Fig. 3.4).

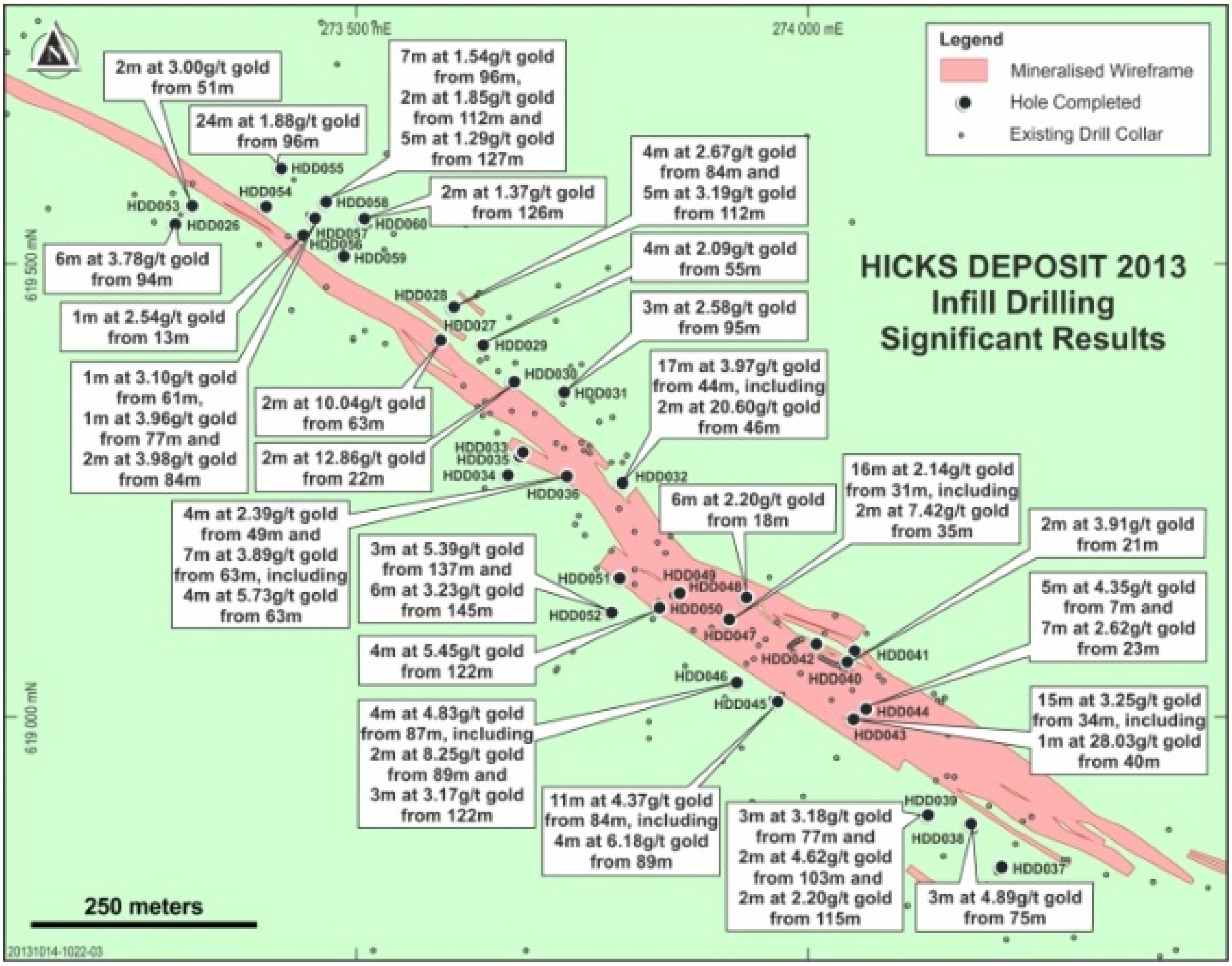


Figure 3.4. Best intercepts of the Hick deposit in 2013 (source Troy Resources).

3.3.3 Smarts deposit

The Smarts Deposit was discovered in January 2011 when Azimuth used RC drilling to follow-up earlier encouraging trench results around local workings known as ‘Smarts Pit’ 4 km to the NW of the Hicks Zone. Gold is hosted by a northwest trending, sub-vertical to steeply southwest dipping shear zone, that has been observed in drill holes for some 2,800 m of strike length and up to 200 m wide in places with average grade mineralization of approximately 4.5 g/t Au which was encouraging.

Exploration has identified extensive gold mineralization at the Smarts Deposit. Gold is hosted by a northwest trending, sub-vertical to steeply southwest dipping shear zone, 2,800 m in strike length and up to 60 m wide. The shear zone has developed within basalts and andesites comprising the footwall greenstone succession along the northeast limb of a shallowly northwest plunging anticline. Auriferous mineralization is also noted at the contacts of porphyry-granite intrusives. The shear zone consists of semi-continuous zones of quartz lenses and quartz-carbonate veining or brecciation.

Numerous, moderately well-defined gold-rich lenses, up to 15 m wide, occur within the shear zone and are characterized by anomalous quartz veining, quartz flooding, shearing, chloritization, seritisation, and pyritisation. Visible gold and the majority of gold values typically occur within and along margins of quartz veins, in silicified granitic dykes, and in adjacent, pyritic, often sheared meta-andesite. Pyrite is common at up to 3% by volume associated with auriferous quartz veins. Mineralization is variously accompanied by silica-sericite-chlorite-carbonate-pyrite-tourmaline alteration.

In general, the northwest trending mineralized shear zone has developed within a steeply inclined sequence of metamorphosed andesitic to basaltic volcanic rocks, adjacent to the northwest margin of the Eldorado (granodiorite) Batholith. The volcanic stratigraphy is cut by a multiple series of andesitic to felsic intrusive phases that precede and post-date the introduction of gold.

Chapter 4: Geology of the Rosebel mine, Suriname

4.1 Geology of Suriname

The sub-continental mantle lithosphere of Suriname may be Archean in age (Begg et al. 2013). Indirect evidence may be deducted from the presence of enigmatic BIF cobbles in unconformable volcaniclastic rocks capping intermediate volcanic rocks in the NE part of the country near Rosebel (Bardoux 1994).

Five large domains are defined across Suriname (Fig. 4.1). They are in younging order from NE to SW: 1) Rhyacian supracrustal rocks of the Marowijne Basin (2145 Ma volcanic rocks to 2127 Ma? wackes to 2115 Ma arenites-conglomerates); 2) Eastern biotite or pyroxene migmatitic granites of 2100 to 2090 Ma and gneissic remnants of Rhyacian supracrustal rocks; 3) NW trending Coeroni Gneiss complex (exhumed ca. 1.97 Ga); 4) the NE trending Bakhuis Granulite high (exhumed ca. 2.07-2.06 Ga); and 5) Western muscovite granites of 1985 Ma (1950 Ma) and gabbroic-ultramafic bodies intruding ignimbrites that are also intruding the Coeroni and Bakhuis gneiss complexes. The five Rhyacian to Osirian domains were eroded and unconformably capped by ca. 1.8 Ga Roraima sediments that were intruded by thick NE trending Avanavero tholeiitic dikes and sills dated at 1782 Ma (Santos et al. 2003). Roraima sediments have a preserved paleosol at their base. They were likely derived from SW sources. The grabben related alkaline Käyser olivine dolerite forms a NW trending dyke swarm transecting the Coeroni complex. Tentatively dated at 1.5 Ga it is unique in the Guiana Shield and younger than Avanavero dikes.

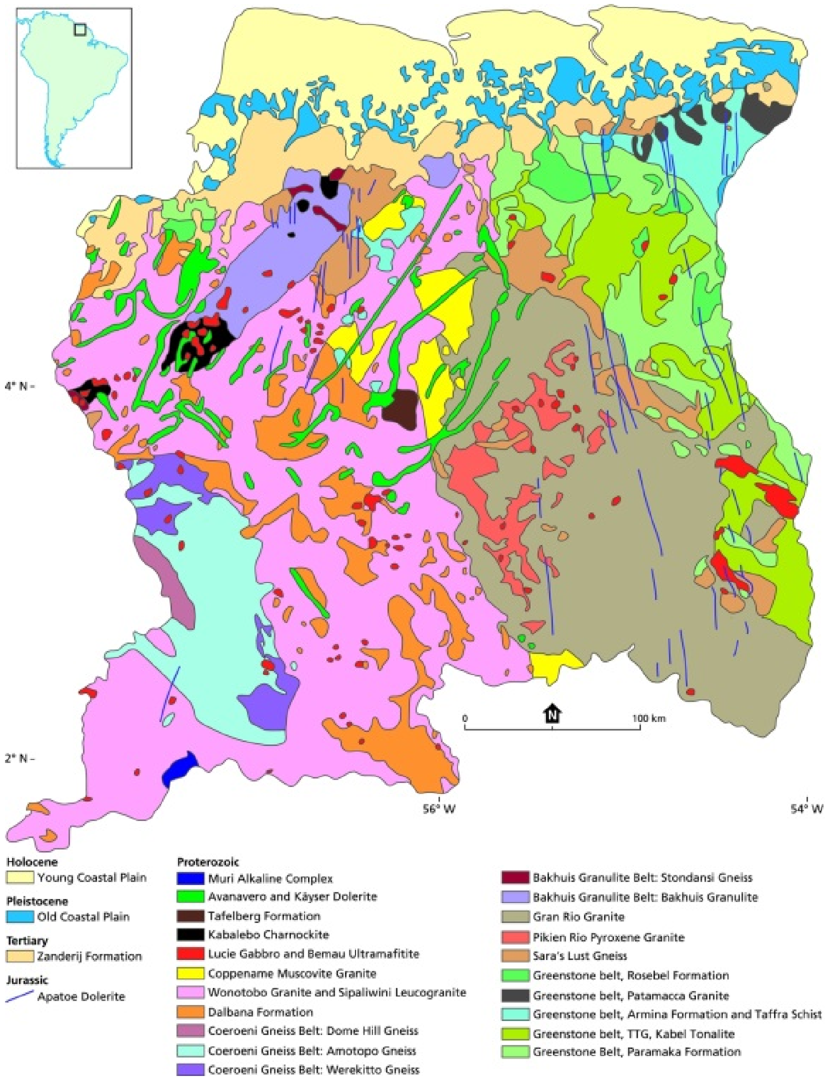


Figure 4.1. Geological map of Suriname (Kroonenberg et al. 2016).

Rhyacian supracrustal rocks of NE Suriname comprise in aging order, mafic volcanic rocks unconformably capped by metawackes unconformably overlain by arenites and conglomerates. The overall basin sequence is younging to the N-NE. ***Gold in Suriname is almost exclusively related to metawacke (Rosebel, Merian) and some of it is in metavolcanic rocks (Saramacca).*** The eastern granite domain is likely the deeper crustal equivalent of the Rhyacian supracrustal rocks. Rafts of mafic volcanic rocks, quartzites, iron formations are commonly reported. The western granites are nearly 100 Ma younger than the eastern granites and therefore the boundary between granite populations is considered a major N-S trending geotectonic boundary. The Coeroni complex is domal with granulites in the core and amphibolites outside. Gneissic rocks are of sedimentary (pelites, quartzite, psammite, marble) and volcanic (amphibolite, ultramafic rocks) protoliths that were likely Rhyacian supracrustal rocks. Granulites of the Bakhuis complex are considered ultrahigh temperature (UHT) equivalents to those of the Coeroni complex. Overall western Suriname is unique in the Guiana Shield as the large domal Coeroni Gneiss complex is surrounded by products of 4 LIPs events nearly separated by 90 Ma ending with the Avanavero events at 1790 Ma. The Coeroni complex also appears to be the triple point of large uplifted lower crust blocks defining a nearly radiating pattern.

4.1.1 Ultramafic rocks

Ultramafic rocks are rare in the Guiana Shield. Two generations of ultramafic rocks are identified in eastern Suriname. The older Bemau complex in the Saramacca area as well as in SE Suriname are considered part of the Paramaka Formation. These rocks dated at ca. 2147 Ma (Pb-Zr evaporation, Delor et al. 2003) are interpreted as being the feeder pipes of Paramaka pillowed basalts. Locally these ultramafic rocks are significantly serpentinized. The significant gold intercepts recently announced by Iamgold at Saramacca are, in part, hosted in these rocks.

Small gabbro and ultramafic intrusions of the Lucie gabbro suite occur in western and central Suriname and are dated at 1987 Ma. Some of these rock types may be represented by cumulate textured leucogabbros in the charnockitic parts of the Bakhuis granulite horst of western Suriname.

4.1.2 Avanavero LIPs

Fifty meters to 1 km wide and up to 100 km long Avanavero dolerites are reported in western Suriname. The majority of these dikes are trending NE. Many extend west into Guyana and Venezuela and form sills in the Roraima sediments.

Dikes of the same age are reported in West Africa (Jessell et al. 2015) as well as in Sarmatia (Bogdanova et al. 2013). They represent an excellent reference for the paleoreconstruction of Nuna ca. 1.8 Ga. They also help reconstructing the position of the Leo and Guiana Shields at the same time.

4.1.3 Carbonatites

Alkalic complexes are also rare in the Guiana Shield. The Muri alkaline complex is a unique occurrence in the Guyana shield. Located on the SW border of Suriname with Brazil, it consists of two bodies of nepheline syenite and a carbonatite. Nadeau (2014) dated it at 1090 Ma. Rivers around this REE rich setting have a pH of 8.5 (Kroonenberg et al. 2016). Interestingly significant carbonatite complexes of the same age occur in the Superior Lake and Kapuskasing regions of Canada.

4.1.4 Geochronology

Many new U–Pb and Pb–Pb zircon ages and geochemical data have been obtained in Suriname, and much new data are also available from French Guiana (Table 4.1). This has led to a considerable revision of the geological evolution of this region (Kroonenberg et al. 2016).

4.1.5 Middle Rhyacian arc magmatism

The evolution of Rhyacian geology, between 2.18 and 2.09 Ga, comprises ocean floor magmatism, arc magmatism, clastis sedimentation, metamorphism, anatexis, and plutonism in the Marowijne Basin and the adjacent older granites and gneisses. The basin closed progressively and relatively slowly on itself over a period exceeding 100 Ma.

Subduction led to arc formations between 2.18 and 2.09 Ga. Intra arc collisions took place during this period at different times in different places. Arcs were slowly eroded while docking on an unclear continental mass. Archean detrital zircons in clastic rocks covering the arcs suggest that some of these landmasses were older than considered to date.

4.1.6 On Trans-Amazonian orogenesis

Not all cycles of deformation across the Guiana Shield are likely the same in style and age. Perhaps many of these cycles relate to the collision between the Guiana and Leo Shields but nothing is less certain going back in time. Thus, it appears that gold in the Guiana Shield may have various sources and various habits and these settings cannot be connected under a single tectonic continuum model.

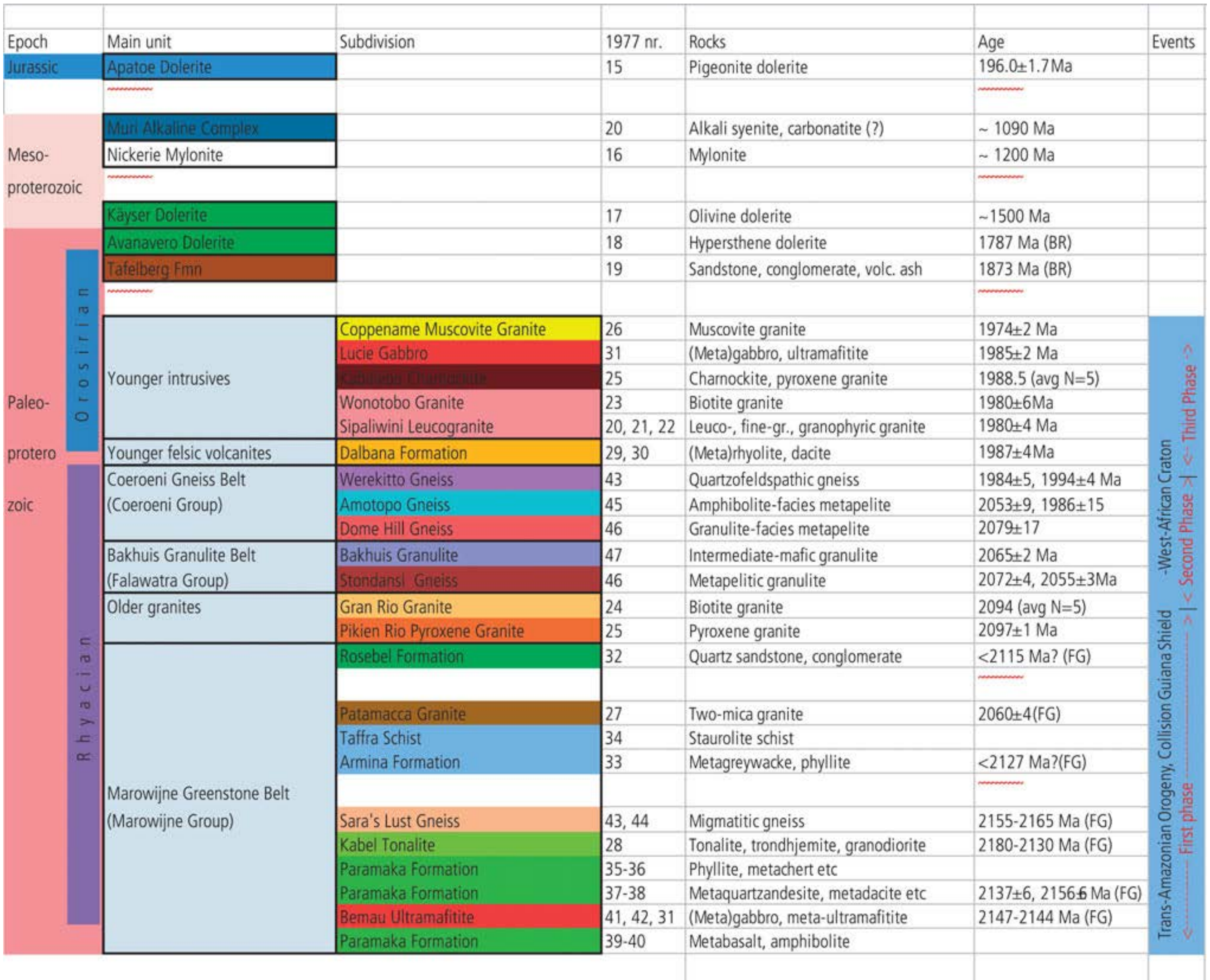
4.1.7 Late Rhyacian to Osirian LIPs and rifting

The second phase encompasses the evolution of the Bakhuis Granulite Belt and Coeroeni Gneiss Belt through rift-type basin formation, volcanism, sedimentation and, between 2.07 and 2.05 Ga, high-grade metamorphism. The third phase, between 1.99 and 1.95 Ga, is characterized by renewed high-grade metamorphism in the Bakhuis and Coeroeni belts along an anticlockwise cooling path, and ignimbritic volcanism and extensive and varied intrusive magmatism in the western half of the country. An alternative scenario is also discussed, implying an origin of the Coeroeni Gneiss Belt as an active continental margin, recording northwards subduction and finally collision between a magmatic arc in the south and an older northern continent. The Grenvillian collision between Laurentia and Amazonia around 1.2–1.0 Ga caused widespread mylonitisation and mica age resetting in the basement.

4.2 Gold deposits of Suriname

Mesothermal and alluvial gold of Suriname is principally found in Rhyacian supracrustal rocks of the greater Marowijne basin area that covers more than 100 thousand square kilometers in surface area (Bardoux and Ernst 2017). In 2013, the primary and alluvial gold production of Suriname exceeded 800 koz (Kioe-A-Sen et al. 2016) nearly half was from the Rosebel Mine. From an endowment of less than 250 koz in 1995, Suriname now totals more than 10 Moz of reserves and nearly twice as much in inferred resources and has become the fastest emerging gold setting of South America. This phenomenal success, in part, built on persistence and visionary exploration of many that are no longer directly involved in the process of production. Today's results represent the culmination of decades of exploration. Suffice to say that the two large gold deposits of Suriname were not meeting most criteria searched or expected by many gold companies until relatively recently. The gold endowment in metawackes lacks significant volumes of magmatic rocks and is associated with relatively low strain (Bardoux and Ernst 2017).

Table 4.1. Recent geochronological data from Suriname and French Guiana (Kroonenberg et al. 2016).



Epoch		Main unit	Subdivision	1977 nr.	Rocks	Age	Events
Jurassic		Apatoe Dolerite		15	Pigeonite dolerite	196.0±1.7Ma	
Meso-proterozoic		Muri Alkaline Complex		20	Alkali syenite, carbonatite (?)	~ 1090 Ma	
		Nickerie Mylonite		16	Mylonite	~ 1200 Ma	
		Käyser Dolerite		17	Olivine dolerite	~1500 Ma	
Paleo-proterozoic	Orosirian	Avanavero Dolerite		18	Hypersthene dolerite	1787 Ma (BR)	
		Tafelberg Fmn		19	Sandstone, conglomerate, volc. ash	1873 Ma (BR)	
		Younger intrusives	Coppename Muscovite Granite	26	Muscovite granite	1974±2 Ma	Trans-Amazonian Orogeny, Collision Guiana Shield -West-African Craton <------ First phase ------>| <- Second Phase ->| <- Third Phase ->
			Lucie Gabbro	31	(Meta)gabbro, ultramafitite	1985±2 Ma	
			Kabalebo Charnockite	25	Charnockite, pyroxene granite	1988.5 (avg N=5)	
			Wonotobo Granite	23	Biotite granite	1980±6Ma	
			Sipaliwini Leucogranite	20, 21, 22	Leuco-, fine-gr., granophyric granite	1980±4 Ma	
		Younger felsic volcanites	Dalbana Formation	29, 30	(Meta)rhyolite, dacite	1987±4Ma	
	Rhyacian	Coeroeni Gneiss Belt (Coeroeni Group)	Werekitto Gneiss	43	Quartzofeldspathic gneiss	1984±5, 1994±4 Ma	
			Amotopo Gneiss	45	Amphibolite-facies metapelite	2053±9, 1986±15	
			Dome Hill Gneiss	46	Granulite-facies metapelite	2079±17	
		Bakhuis Granulite Belt (Falawatra Group)	Bakhuis Granulite	47	Intermediate-mafic granulite	2065±2 Ma	
			Stondansi Gneiss	46	Metapelitic granulite	2072±4, 2055±3Ma	
		Older granites	Gran Rio Granite	24	Biotite granite	2094 (avg N=5)	
			Pikien Rio Pyroxene Granite	25	Pyroxene granite	2097±1 Ma	
		Marowijne Greenstone Belt (Marowijne Group)	Rosebel Formation	32	Quartz sandstone, conglomerate	<2115 Ma? (FG)	
			Patamacca Granite	27	Two-mica granite	2060±4(FG)	
			Taffra Schist	34	Staurolite schist		
			Armina Formation	33	Metagreywacke, phyllite	<2127 Ma?(FG)	
			Sara's Lust Gneiss	43, 44	Migmatitic gneiss	2155-2165 Ma (FG)	
			Kabel Tonalite	28	Tonalite, trondhjemite, granodiorite	2180-2130 Ma (FG)	
			Paramaka Formation	35-36	Phyllite, metachert etc		
			Paramaka Formation	37-38	Metaquartzandesite, metadacite etc	2137±6, 2156±6 Ma (FG)	
			Bemau Ultramafitite	41, 42, 31	(Meta)gabbro, meta-ultramafitite	2147-2144 Ma (FG)	
			Paramaka Formation	39-40	Metabasalt, amphibolite		

4.3 Geology of Rosebel region

The Gross Rosebel region has been explored for decades. In 1951, Noranda had estimated that 50 thousand ounces of gold were potentially present in the area. Many companies revisited Gross Rosebel but it was detailed trench mapping in 1994 (Fig. 4.2) that showed that drill orientation had to be realigned (Bardoux 1994, Wasel et al. 1998).

Figure 4.2. Exploration geologist Mitch Wasel (far left) and technicians Wallace and Edmundo staying in shape playing the hacky sack at the Bigi Asanjamoni exploration camp in May 1994. Mitch pushed hard to show Rosebel was a prospect of prime choice. One of the keys was to implement trenches in the dry season and measure every single vein orientation in 3D and optimize the drill orientation from this data set.

The Rosebel gold district is hosted between two arcs in the western part of the Marowijne basin (Daoust 2016, Bardoux and Ernst 2017). The majority of the deposit is vein hosted at greenschist facies. Host rocks have undergone two principal phases of low to medium strain deformation with discrete high strain partitioning (Bardoux 1994; Daoust et al. 2011). The structural architecture is remarkably expressed in aeromagnetic data where the NW regional fabric predominates and numerous bends and flexures reflect the clear rheological contrasts between metamagmatic and metasedimentary sequences (Fig. 4.3). The carbonate alteration footprint of the deposits is extensive (Daoust 2016). Its potassic footprint may be significant as well.

4.4 Rosebel mine

Rosebel Gold Mines operations started in 2000. Total production to date has been in excess of 4.6 Moz. Recent exploration successes suggest that more endowment will be added to this camp.

4.4.1 Geology

Economic gold ore is hosted in mafic to felsic metavolcanic rocks as well as two metasedimentary successions that are classified in younging order as turbiditic and arenitic depositional sequences. Overall these sedimentary rocks are maturing upward. The detailed lithostratigraphic characterization and the geochemistry enable the correlation of the local rock types with the Paramaka, Armina, and Rosebel formations respectively. Further discrimination of the metavolcanic rocks identified fore-arc tholeiitic basalts in the south, and back-arc calc-alkaline andesites and rhyolites in the north (Daoust 2016). Some high-K (shoshonitic) rhyodacitic tuffs are interlayered in upper clastic rocks with Zr contents reaching 300 ppm. Rosebel is thus hosted in a back-arc setting. The entire sequence defines a regional syncline plunging shallowly to the NW with a slight inversion on its southern flank against the Brinks granite that had pierced tholeiitic basalts prior to regional strain (Fig. 4.4). The sedimentary basin seems to bridge between the two magmatic settings. Geochronology suggests that this basin took a long time to form (Daoust 2016).

The Rosebel district comprises eight discrete gold deposits grouped along two discrete regional structures along the edges of the syncline (Bardoux 1994; Daoust et al. 2011; Cardin-Tremblay et al. 2015; Fig. 4.3). These deposits will be described in more detail during the field trip. The northernmost structure is a sub-vertical WNW–ESE shear zone showing evidence of dextral strike–slip followed by normal faulting. Veins are mainly in its footwall. The southern structure is an east–west trending reverse fault along which gold deposits are mainly in the footwall. Gold mineralization is in quartz vein arrays formed along pre-existing structural heterogeneities, such as stratigraphic contacts and fold hinges. Four main vein types are recognized in the district: shear veins (up to several meters thick), north–south tension veins, stacks of north-dipping tension veins, and anticline-hosted tension veins. Mineralized quartz-carbonate-tourmaline veins exhibit wallrock alteration comprising sericite, chlorite, carbonate, tourmaline, pyrite, pyrrhotite, and accessory sphalerite and plagioclase (Cardin-Tremblay et al. 2015). The presence of a WNW–ESE dextral strike–slip structure, an east–west reverse fault, and north–south tension veins are consistent with the formation of a Riedel system during a dextral simple shear event (Daoust et al. 2011). All vein sets cut deformed sedimentary rocks that were deposited in a pull-apart basin, which together with their planar geometries, indicates a late-Transamazonian orogen timing for gold mineralization. Daoust et al. (2011) indicates that gold deposition occurred late in the structural history of the belt, and is considered part of a late regional metallogenic event with respect to the geotectonic evolution of the Guiana Shield. Extensive dating of other orogenic gold deposits in the Guiana Shield has revealed ages between 2.02 and 1.96 Ga for gold mineralization, which is broadly coeval with the onset of late-Transamazonian calc-alkaline volcanism and plutonism (2.05–1.88 Ga) in the southern Guiana Shield.

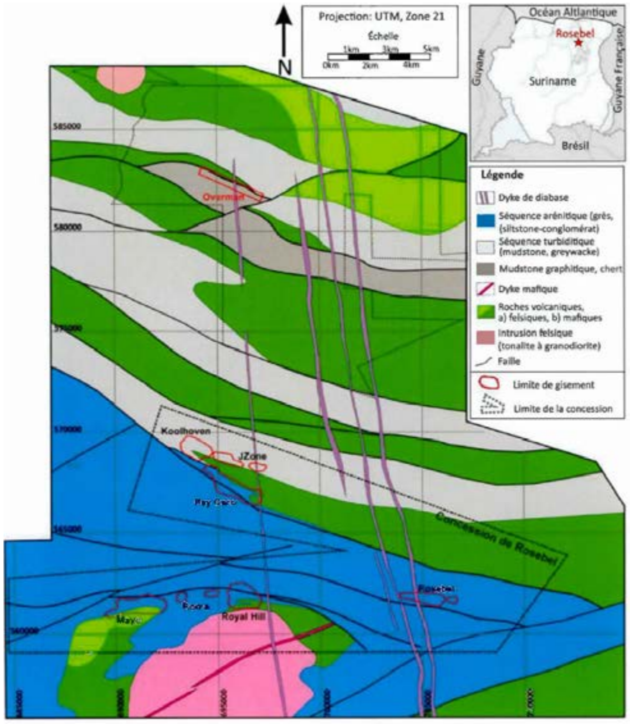


Figure 2.1
Carte géologique de la région du district minéralisé de Rosebel produite dans le cadre du doctorat et basée sur la cartographie dans les fosses, la cartographie d'exploration, les cartes géophysiques et 600000 mètres de forage distribués dans les huit gisements. Voir l'annexe A pour la carte géologique détaillée de la propriété avec les principales mesures structurales et la localisation des échantillons (lithogéochimie et datations).

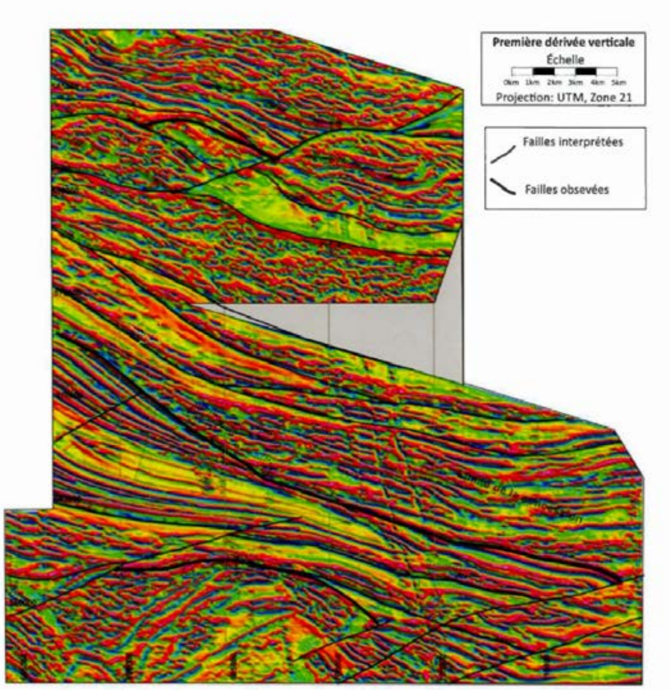


Figure 5.1b
Relevé aéromagnétique (IGRF - 1ère dérivée verticale) du district minéralisé de Rosebel. Les principaux éléments structuraux interprétés comme des failles sont soulignés en noir et les traits les plus gras représentent les failles qui ont aussi été observées sur le terrain.

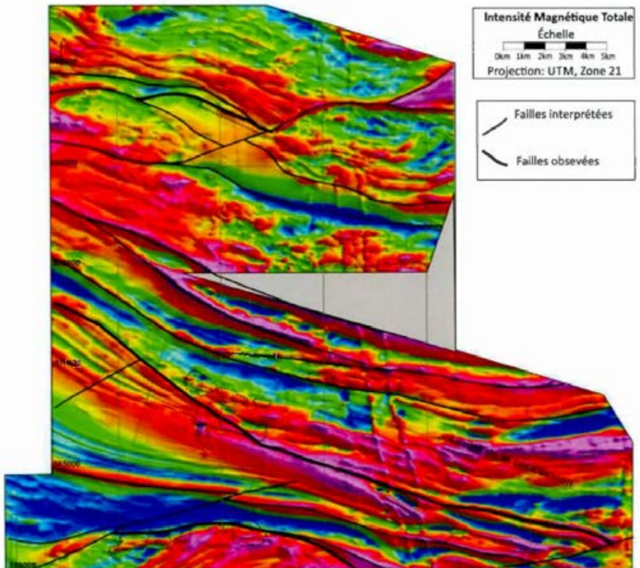


Figure 5.1a
Relevé aéromagnétique (IGRF - intensité magnétique totale) du district minéralisé de Rosebel. Les principaux éléments structuraux interprétés comme des failles sont soulignés en noir et les traits les plus gras représentent les failles qui ont aussi été observées sur le terrain. Les linéaments montrant une orientation nord-sud représentent des dykes de diabase tardifs.

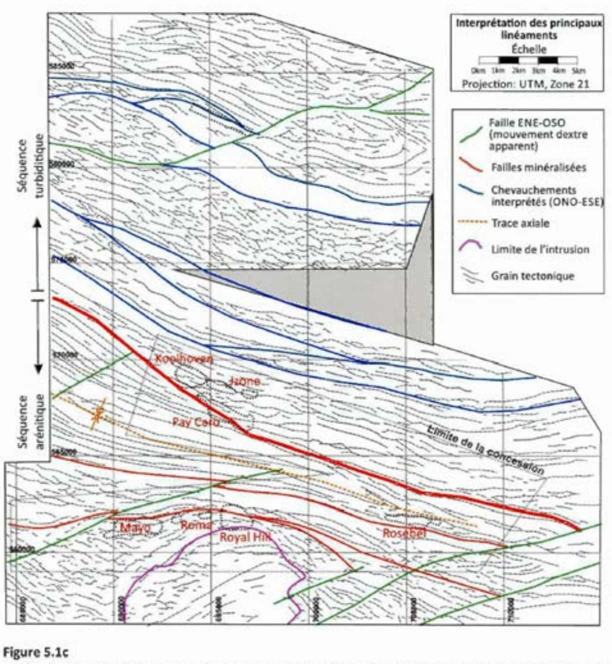


Figure 5.1c
Interprétation des linéaments géophysiques de la région du district minéralisé de Rosebel. Les principaux linéaments sont séparés en trois ensembles de failles : en rouge les structures minéralisées (E-O à ONO-ESE), en bleu des chevauchements et en vert des failles montrant un mouvement apparent tardif dextre (OSO-ENE).

Figure 4.3. Geological and geophysical expressions of the Rosebel district. (Cadrin-Tremblay et al. 2015).

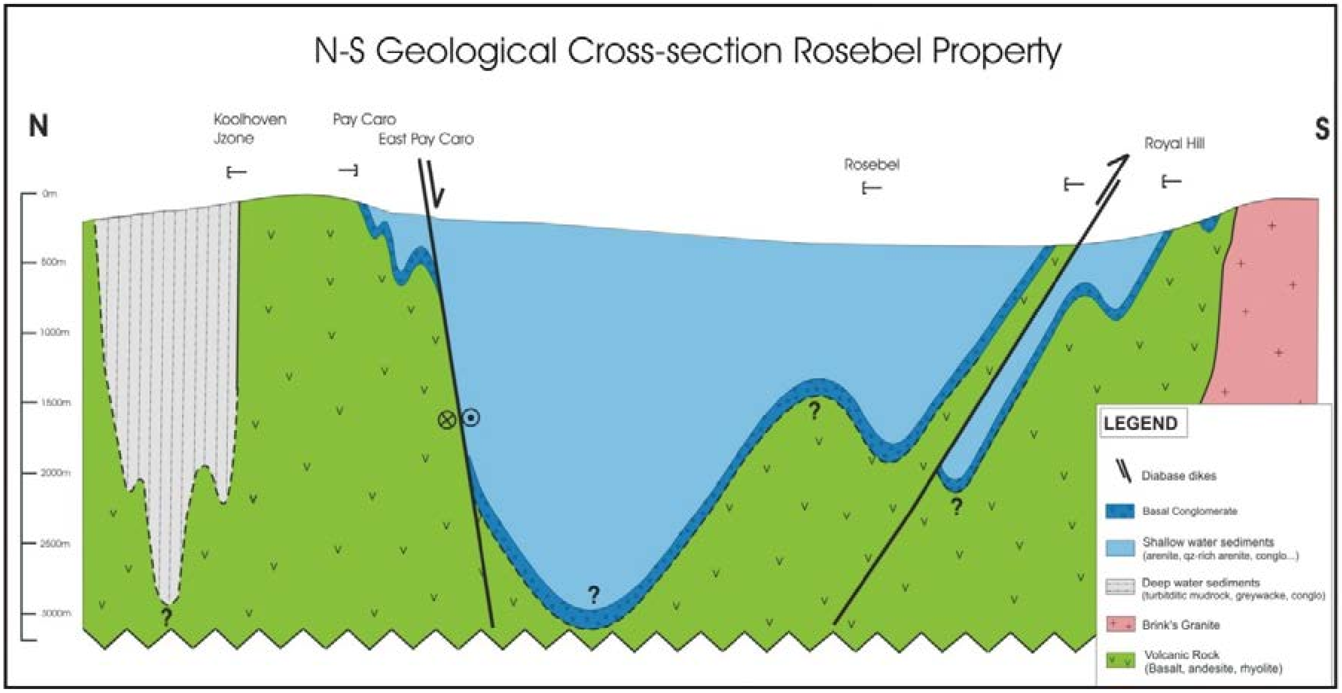


Figure 4.4. Rosebel syncline bounded by faults. The main deposits are on the north and south edges (domains) of the syncline where higher strain has developed. Veins are mainly in footwalls of faults (modified from Daoust 2016).

4.4.2 Geochronology

Key age determinations have been obtained at Rosebel and they help refine the geodynamic framework of the district (Daoust 2016). A summary is presented in Table 4.2. Felsic volcanic rocks are dated and are coeval to the Brinks tonalite at ca 2164 Ma. Seven populations of zircons are reported from clastic sediments with peaks at 2202 Ma, 2178 Ma, 2164 Ma (local source such as Brinks tonalite), 2143 Ma (most common), 2116 Ma, 2092 Ma, and 2074 Ma. Most of these populations correspond to different arc sources. At Montagne d'Or, volcanic rocks hosting the Au-VMS setting are dated at 2143 Ma (Guiraud et al. 2017). At Omai, the monzodiorite is dated at 2094 Ma (Norcross 1997). At least three small populations of older zircons are reported from metaclastic rocks and peak at 3021 Ma, 2720 Ma, 2600 Ma, and 2488 Ma. Sources of such old zircons are unknown (Table 4.2 and Fig 4.5). Zircons of nearly similar ages have been documented in southern French Guiana (de Avelar et al. 2003). Notice the very young population of zircons of ca. 2070 Ma that is 100 Ma younger than the oldest arcs. Gold at Rosebel is propably as young as 2.0 Ga (Daoust 2016) like at Omai (Voicu et al. 2001) and St-Elie (Lafrance et al. 1999).

Table 4.2. Summary of most geochronological results obtained at Rosebel (modified from Daoust 2016). Metatonalite and metarhyolite in the southern domain are coeval ca 2164 Ma. Andesite of the northern domain are possibly younger and most likely of the next detrital zircons ages of 2145 Ma, 2124 Ma or 2094 Ma. Six populations of Rhyacian zircons are detected through the metasediments and are probably sources from surrounding arc components. Notice the very young population of zircons of ca. 2070 Ma that are nearly 100 Ma younger than volcanic arcs and evidence of a long period of erosion after arc formation. Arcs were deformed prior to clastic sedimentation.

Sample		Nb Analyses	Geochron data		Populations of detrital zircons					
Description	Number		Age	Error						
Tonalite	09Rose05	6	2165,3	+2,5/-1,8						
Rhyolite	09Rose07	5	2164,6	+1,5/-1,4						
Mineralized meta-arenite	09Rose04	60	2145	6				2,145	2,164	2,178
Barren meta-arenite	09Rose01	60	2071	11	2,071	2,094	2,124	2,147	2,169	
Barren Rosebel metaconglomerate	09Rose03	66	2088	5		2,088	2,119	2,141		
Mineralized Rosebel metaconglomerate	09Rose06	60	2076	6	2,076		2,114	2,148	2,163	
Armina metaconglomerate	09Rose08	59	2094	9		2,094	2,108	2,132	2,160	2,202
			Average		2,074	2,092	2,116	2,143	2,164	2,190

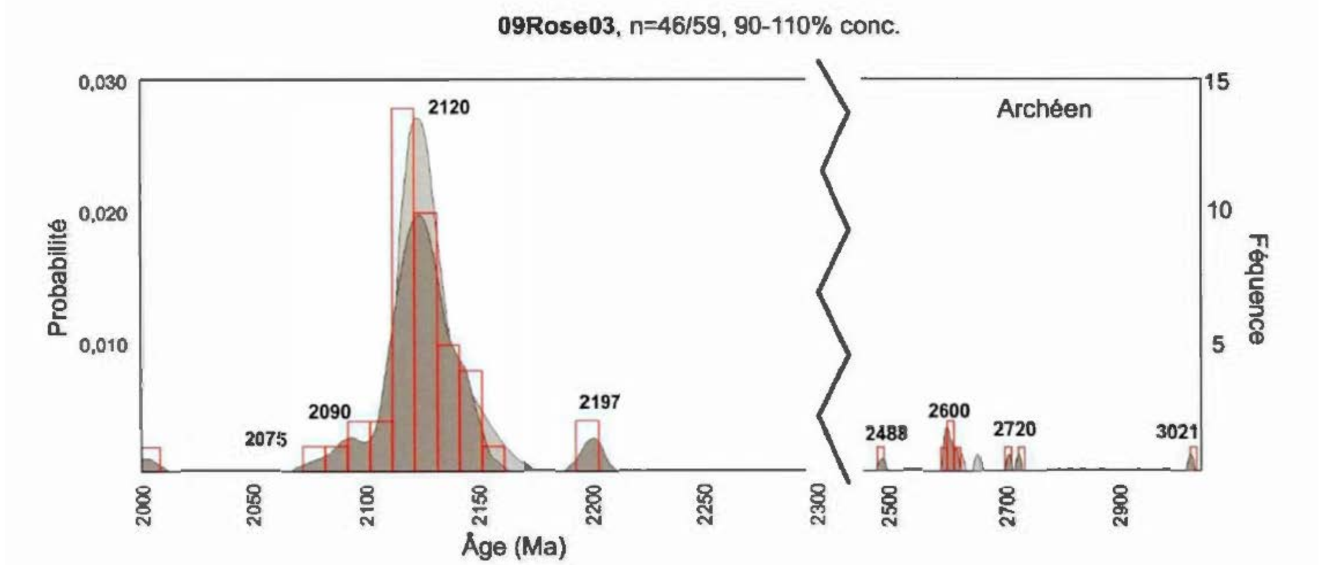


Figure 4.5. Metasediment of the Royall Hill area in the southern domain are yielding two maxima populations at 2119 ± 2 Ma and 2142 ± 3 Ma. This sample also yielded the oldest zircons of the region at 3021 Ma. These zircons are of unknown source (from Daoust 2016). Notice the very young zircon population of zircons ca 2.0 Ga. The metasediments were deformed and mineralized after this event. Similar ages of mineralization are proposed at Omai (Voicu et al. 2001) and St-Elie (Lafrance et al. 1999).

Chapter 5: Geology of the Merian mine, Suriname

5.1 Merian geology

The Merian district is another area that has been known for its gold anomalism for a long time. Its alluvial mining footprint has developed for decades and was nearly 100 km^2 at the time of thorough exploration by Surgold starting in 2004. The project is now in production (Fig. 5.1). The area of soil anomalism is in an area of high magnetic background. Magnetite is mostly detrital.

Figure. 5.1. Merian mine site in NE Suriname. June 2017.

The Merian district is located in the central portion of the Marowijne basin. Its framework consists of a series of contractional features that are generally trending NW-SE. The style of deformation is not that of a classic "cordilleran type" (Sener et al. 2005) but rather that of an inverted tectonic style whereby growth faults of the time of sedimentation were likely reactivated under compressional conditions in a thick skin style (Bardoux 2012; Fig. 5.2).

The geology around Merian consists of conglomeratic sandstones, wackes, siltstones, and carbonaceous mudstones altogether affected by a regional anticline trending S40E and plunging 20° to 40° to the SE. The SE-plunging anticline is clearly defined on aeromagnetic data and has been confirmed by field mapping and oriented drill core interpretation (Figs. 5.3, 5.4). This resulted in the definition of folds of various scales as well as zones of discrete high strain and faults. No igneous rocks have been reported in the Merian district. The grade of metamorphism is greenschist. Conspicuous oblong porphyroblasts form distinct macroscopic features in the metasediments and are subparallel to the penetrative regional fabric. Porphyroblasts are primarily pseudomorphosed to calcite-chlorite assemblages.

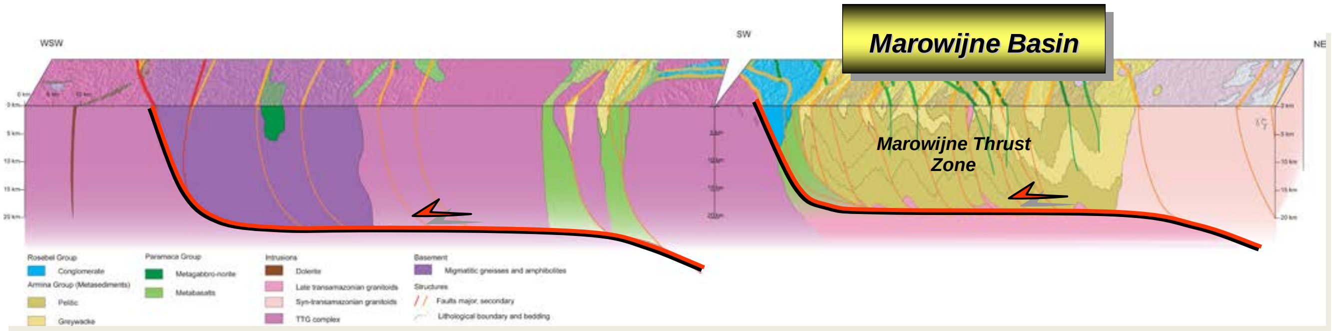


Figure 5.2. Regional block diagram of the central Marowijne Basin region and interpreted thick skin style deformation caused by the inversion of normal faults (Bardoux 2012).

5.2 Merian mine

Merian mine reserves are 4.8 Moz and resources total 1.9 Moz. The average grade of the deposit is 1.1 g/t Au. Roots of the system are being delineated (Figs 5.5, 5.6).

The current model combines a fold and shoot with discrete shear ore bodies. It is proposed that a main shear zone (reverse fault) "blows out" at: 1) fold hinges/axial planes; 2) favorable lithologic units; and 3) structural intersections.

The main structural features delineated in Figure 5.5 consists of: 1) gray breccia core with halo of deformed veining and 2) fold axes. Lithologic packages cannot be effectively modeled because single stratigraphic units are too thin to be singled out. Few of these units have, however, been used to decipher the principal elements of the structural framework.

Most vein (array) intercepts are metric in width but in some instances breccia veins blow out to tens of meters (Fig. 5.5).

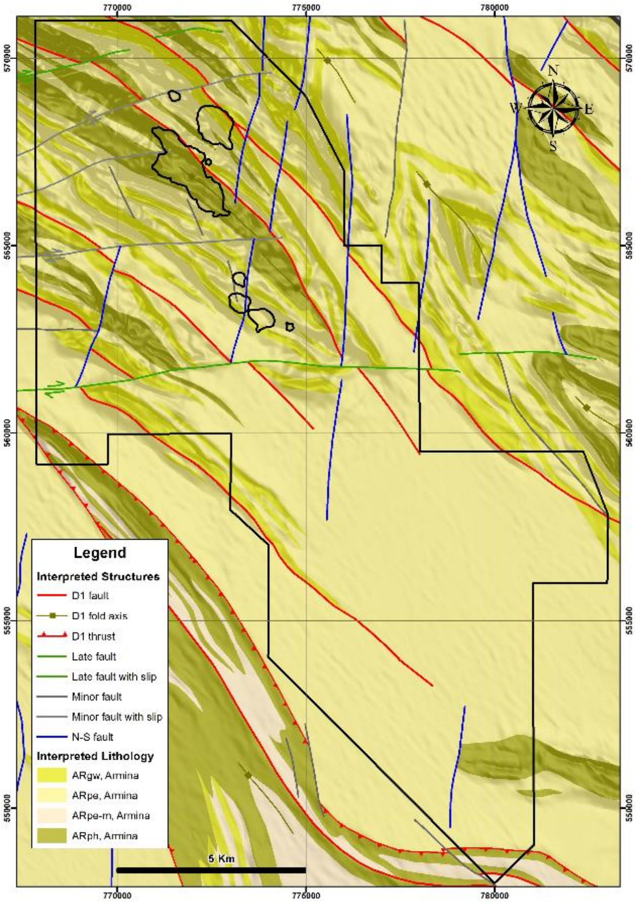


Figure 5.3. Geology interpretation of aeromagnetic data illustrating the regional fold pattern affecting the Armina metasediments. Discrete fold closures and faults are delineated (Anderson et al. 2015). Black polygons are ore bodies.

Figure 5.4. Typical upright fold style observed in metasediments. Veins tend to cluster around fold hinges and are likely connected by discrete shear veins. Metawacke of the Armina Formation affected by upright folding (photo Bardoux 2005).

5.2.1 Gold mineralization

Gold-bearing veins are syn- to post-metamorphic. Quartz veins that are either sheeted (shear), comb textured (tension) or brecciated (hydrostatic). Veins are cemented with quartz, ankerite, calcite, chlorite, albite, and white micas with pyrite and pyrrhotite in vein selvedges. Pyrrhotite content increases near higher grade zones where white micas are also more abundant.

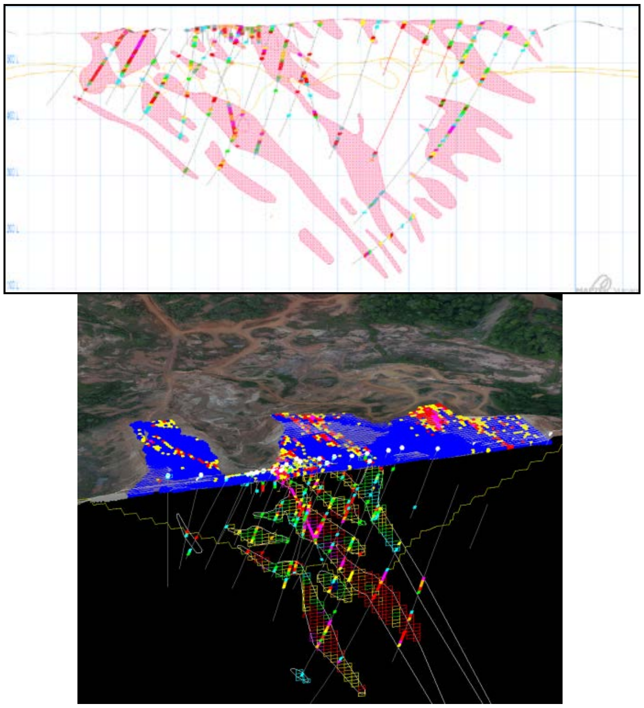


Figure 5.5. Typical cross section and 3D projection of gold shapes at Merian. Looking west (Anderson et al. 2015).

5.2.2 Reserves-resources

Surgold`s Merian operations started in September 2016. The open pit reserves are 4.8 Moz (127 Mt @ 1.2 g/t Au) and resources are 1.9 Moz (61 Mt @ 1.0 g/t Au). The deposit consists currently of two principal bodies of mineralization referred to as Merian II and Maraba separated by less than 1 km (Fig. 5.6). Mineralization styles between the two deposits are similar except that veins are bigger at Merian II. Overall the main bodies of mineralization at Merian II are dipping at approximately 50° to the NNE. Both deposits are open at depth. Very good intersections have been encountered at vertical depths exceeding 400 m below surface at Merian II.

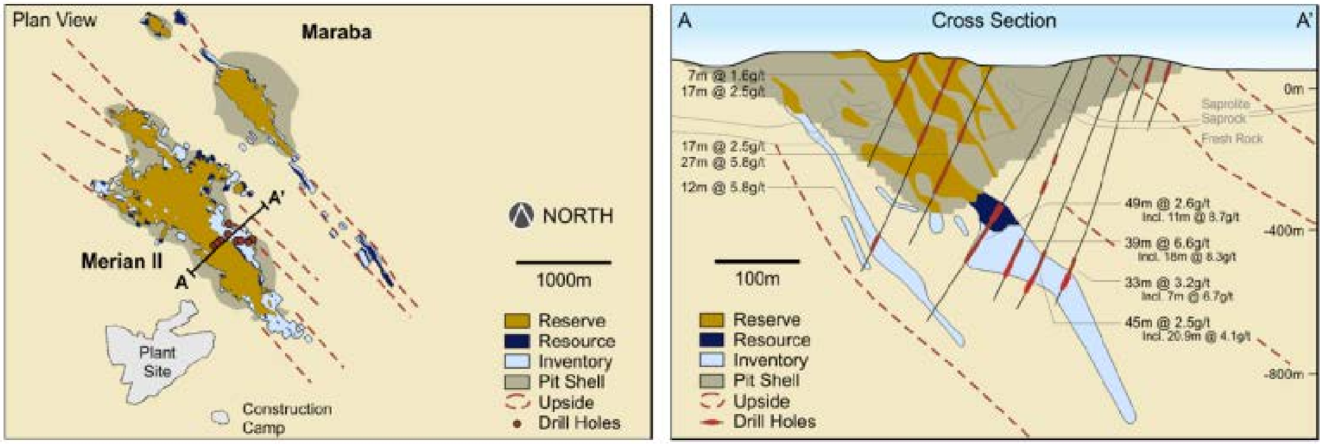


Figure 5.6. Plan view and cross section of the Marian II deposit. The main ore body extends 500 m below surface and is anticipated to extend to greater depths (Source Newmont press release).

Chapter 6: Geology of French Guiana

6.1 Geology

The geological framework of French Guiana is somewhat simpler than that of Suriname. It links to Rhyacian supracrustal rocks of NE Suriname and splits in two parallel belts of the same general composition and stratigraphic order as those described in NE Suriname (terminology and spelling changes slightly). From the Marowijne Basin in NE Suriname, the northern belt of French Guiana crosses the entire French territory from west to east for nearly 400 km and extends further into NE Brazil. The southern belt also extends across the middle of the territory from west to east and carries on for several hundred kilometers to the Brazilian Amapà region. Large batholithic masses separate the two belts with a few supracrustal pendants hanging between TTG batholiths (2.15-2.13 Ga in the north; 2.18-2.16 Ga in the north and south). Granitic bodies of 2.11 to 2.08 Ga are considered late tectonic (post-arc). South of the southern belt, gneissic supracrustal rocks and TTGs resemble those of the Eastern granite domain of Suriname. Detrital zircons of 3.19-2.77 Ga in meta-arenites in SE French Guiana as well as local εNdi of -6.0 to +1.0 are indicative of Archean relicts nearby (de Avelar et al. 2003). Further to the SE, in the Amapá region, Rosa-Costa et al. (2003) clearly dated Archean supracrustal rocks that are nearly coeval with those of the Superior and Yilgarn. NNE trending dykes are associated with the ca. 1.78 Ga Avanavero swarm whereas NNW dikes are related to the Atlantic break-up.

Rhyacian supracrustal rocks of French Guiana are organized in the same general order as those of Suriname and Guyana with a few more specific details based on more detailed mapping and geochronology (see details in Delor et al. 2003, Figs. 6.1, 6.2). Supracrustal sequences start with 2.26-2.20 Ga juvenile crust (Ile de Cayenne) followed by metavolcanic arc units (2 arc suites of 2.16 Ga and 2.14 Ga) that are unconformably capped by mixed metaclastic rocks altogether capped locally by meta-arenite (fluviatile) sequences on the top of the stratigraphic sequence. The fluviatile metasediments are more abundant in the northern belt than in the southern belt. This likely relates to preservation as the southern half of French Guiana is more deeply exposed (gneissic). Fluvial clastic rocks in the northern belt clearly delineate the trace of a 500 km long structure called the North Guyana Trough (Ledru et al. 1994; Voicu et al. 2001). At least two phases of deformation are identified in most supracrustal rocks. The latest phase is believed to have been dextral and was pierced by syn-tectonic metaluminous monzogranites dated between 2.08-2.06 Ga.

6.2 Gold mining in French Guiana

Like in Suriname and Guyana, alluvial mining has been producing a lot of gold in French Guiana. Since 1990, up to 1.9 Moz have been officially recorded with a peak of 135 koz declared in 2001 (Fig. 6.3).

Ever since the metallogeny of French Guiana was compared to that of West Africa (Milési et al. 1991) many companies investigated most anomalies with significant investments. Camp Caiman was the first resource of significance defined in 2002 (Bardoux 2012; Fig. 6.4).

However, being located in an environmentally sensitive region it was forbidden to develop. Since then, exploration activity has largely focused on prospects developed in the 1990s. Montagne d'Or is one of those successfully assembled in recent years.

6.3 Montagne d'or project

The Montagne d'or project is located in the western part of the northern Belt on the trace of the Northern Guiana Trough and on the SE edge of the Marowijne basin. The only gold-rich VMS of the Guiana Shield to date (Bardoux 1995; Franklin et al. 2000; Guiraud et al. 2017), the Montagne d'Or project just received a favorable feasibility assessment indicating that reserves of the project are 2.7 Moz at an average grade of 1.58 g/t Au.

A detailed account of the geological setting is offered by Guiraud et al. (2017). A review of the project and representative core will be available on Aug 15 after our group dinner.

Figure 6.1. Geology of French Guiana (Delor et al. 2003).

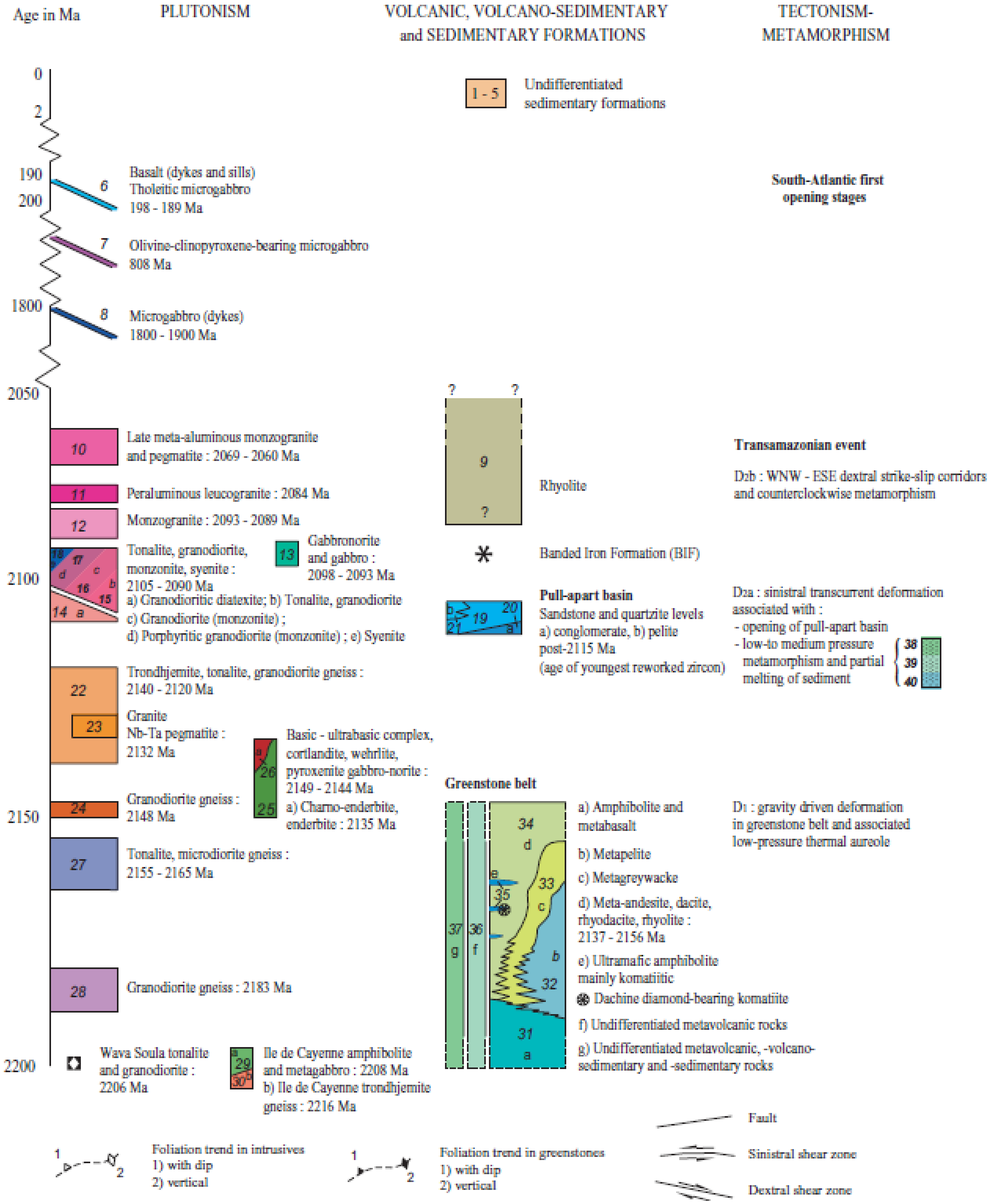


Figure 6.2. Legend of Figure 6.1 (Delor et al. 2003).

.

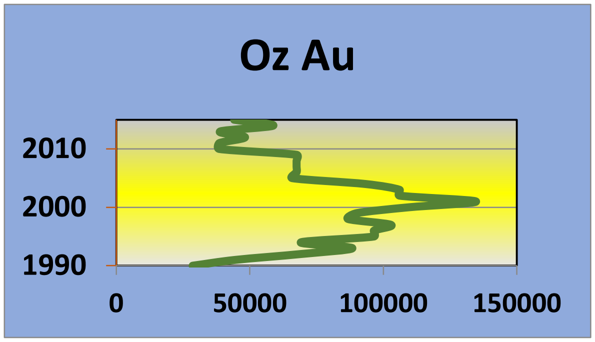


Figure 6.3. Annual (artisanal) gold production of French Guiana since 1990. Numerous subjects have been explored but many were abandoned due to unclear policies and social unrest.

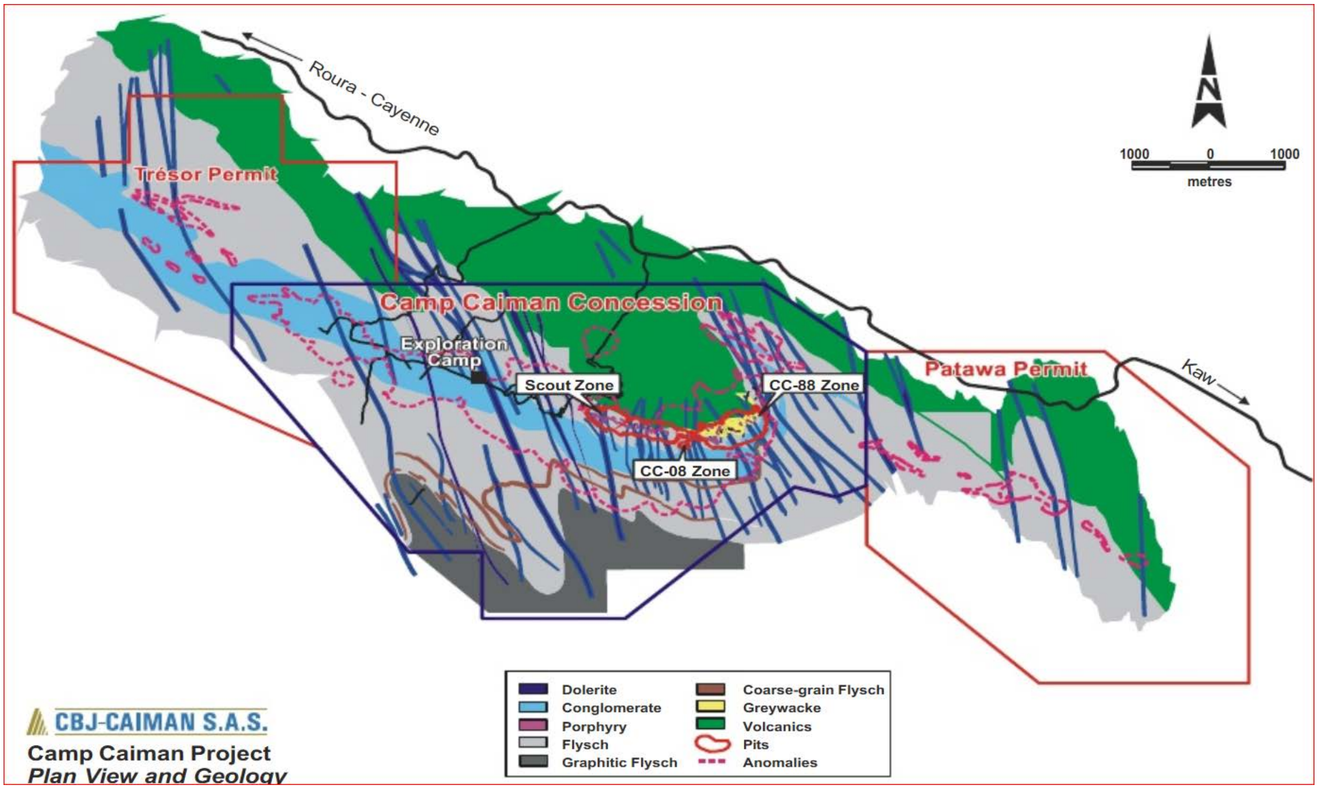


Figure 6.4. Geological map of Camp Caiman (Bardoux 2012). Notice the interbedded relationships between the quartz pebble conglomerates and Armina type metasediments. Mineralization at Camp caiman is primarily along the andesite-sediment contact and strongly controlled by discrete fold closures that are generally plunging to the SE. Notice also the size and number of soil anomalies that coincide with the pebble conglomerate. NS trending dolerite dikes related to opening of the Atlantic.

References

Anderson S, Wilson J, Radjkomear S, Schmidt K, Mashburn D (2015) Geology of the Merian gold deposits, Suriname, South America. New Gen Gold presentation

Bardoux M (1994) Structural elements of the Gross Rosebel concession. Unpublished report to Golden Star Resources, 34p.

Bardoux M (1995) Structural elements of Paul Isnard. Unpublished report to Golden Star Resources, 38p.

Bardoux M (2005) Structrual elements of Merian. Unpublished report to Newmont, 22p.

Bardoux M (2012) Gold in the early Paleoproterozoic Birrimian Shield. Abstract at SIMEXMIN conference, Brazil.

Bardoux M, Ernst R (2017) From LIPs to gold in Rhyacian metawackes. Proceeding of the 14th Biennial SGA Meeting, 20-23 August 2017, Québec City, Canada: In press.

Begg GC, Griffin WL, O'Reilly SY, Hronsky JMA (2013) Ore deposits and lithosphere evolution in the early Earth. Mineral Mag 77: 676.

Bogdanova SV, Gintov OB, Kurlovich DM, Lubnina NV, Nilsson MKM, Orlyuk MI, Pashkevich IK, Shumlyanskyy LV, Starostenko VI (2013) Late Paleoproterozoic mafic dyking in the Ukrainian Shield of Volgo-Sarmatia caused by rotation during the assembly of supercontinent Columbia. Lithos 174: 196-216.

Cardin-Tremblay V et al. (2015) Geology and mineralization at Rosebel. Internal 43-101 report.

Choubert B (1974) Le Précambrien des Guyanes. BRGM, Mémoire 81, 213p.

Daoust C (2016) Caractérisation stratigraphique, structurale et géochimique du district de Rosebel (Suriname) dans le cadre de l'évolution géodynamique du Bouclier Guyanais. PhD thesis, Université du Québec à Montréal.

Daoust C, Voicu G, Gibson H, Gauthier M (2011) Geological setting of the Paleoproterozoic Rosebel gold district, Guiana Shield, Suriname. J South Am Earth Sci 32: 222-245.

de Avelar VG, Lafon J-M, Delor C, Guerrot C, Lahondère D (2003) Archean crustal remnants in the Southeasternmost part of the Guyana Shield: Pb-Pb and Sm-Nd geochronological evidence for Mesoarchean versus Neoarchean signatures. Géol de la France 2-3-4: 83-99.

Delor C, Lahondère D, Egal E, Lafon J-M, Cocherie A, Guerrot C, de Avelar VG (2003) Transamazonian cristal growth and reworking as revealed by the 1:500,000 scale geological map of French Guiana. Géol de la France 2-3-4: 5-57.

Franklin J, Bertoni C, Boudrie M, Bout J-P, Costelloe D, Lillié F, Millo L, Sauvage J-F (2000) The Paul Isnard gold-copper occurrence, French Guiana: the first volcanogenic massive sulphide occurrence in the Guiana Shield? In: Sherlock R, Logan MAV (eds) VMS deposits of Latin America. Geological Association of Canada, Special Publication 2, pp. 509-542.

Frimmel HE (2014) Giant Mesoarchean crustal gold-enrichment episode: possible causes and consequences for exploration. Society of Economic Geologists, Special Publication 18, pp. 209-234.

Gibbs AK, Barron CN (1993) Geology of the Guiana Shield. Oxford University Press, 246p.

Goldfarb RJ, André-Mayer A-S, Jowitt SM, Mudd GM (2017) West Africa: the world's premier Paleoproterozoic gold province. Econ Geol 112: 123-143.

Guiraud J, Tremblay A, Jébrak M, Lefrançois R (2017) The Rhyacian "Montagne d'Or" auriferous volcanogenic massive sulphide deposit, French Guiana, South America: stratigraphy and geochronology. Proceeding of the 14th Biennial SGA Meeting, 20-23 August 2017, Québec City, Canada, 237-240.

Jessell M, Santoul J, Baratoux L, Youbi N, Ernst RE, Metelka V, Miller J, Perrouty S (2015) An updated map of West African mafic dykes. J Afr Earth Sci 112: 440-450.

Kioe-A-Sen NME, van Bergen MJ, Wong TE, Kroonenberg SB (2016) Gold deposits of Suriname: geological context, production and economic significance. Neth J Geosci 95: 429-445.

Kroonenberg SB, de Roever EWF, Fraga LM, Reis NJ, Faraco T, Lafon J-M, Cordani U, Wong TE (2016) Paleoproterozoic evolution of the Guiana Shield in Suriname: A revised model. Neth J Geosci 95: 1-32.

Lafrance J, Bardoux M, Voicu G, Stevenson R, Machado N (1999) Geological and metallogenic environments of gold deposits of the Guiana Shield: a comparative study between St-Elie (French Guiana) and Omai (Guyana). Explor Min Geol 8: 117-135.

Ledru P, Johan V, Milési JP, Tegyev M (1994) Evidence for a 2.0 Ga continental accretion in the circum-Atlantic provinces. Precam Res 69: 169-191.

Mendoza V (1974) Evolucion tectonica del Escudo de Guayana. Segundo congreso Latinoamericano de Geologia, Caracas, V. III: 2237-2270.

Milési JP, Ledru P, Ankrah P, Johan V, Marcoux E, Vinchon Ch. (1991) The metallogenic relationship between Birimian and Tarkwaian gold deposits in Ghan. Miner Deposita 26: 228-238.

Milési JP, Ledru P, Feybesse J-L, Dommanget A, Marcoux E (1992) Early Proterozoic ore deposits and tectonics of the Birimian orogenic belt, West Africa. Precam Res 58: 305-344.

Nadeau S (2014) Guyana geological timescale, Guyana. Geological and Mining Commission, 1p.

Norcross CE (1997) U-Pb geochronology of the Omai intrusion-hosted Au quartz veins deposit and host rocks, Guiana Shield, South America. MSc thesis, University of Toronto.

Robert F, Brown AC (1986) Archean gold-quartz veins at the Sigma mine, Abitibi greenstone belt, Quebec. Part 1: Geologic relations and formation of the vein system. Econ Geol 81: 578-592.

Rosa-Costa LT, Ricci PSF, Lafon J-M, Vasquez ML, Carvalho JMA, Klein EL, Macambira EMB (2003) Geology and geochronology of Archean and Paleoproterozoic domains of southwestern Amapá and northwestern Pará, Brazil, southeastern Guiana shield. Géol. de la France 2-3-4: 101-120.

Santos JOS, Potter PE, Reis NJ, Hartmann LA, Fletcher IR, McNaughton NJ (2003) Age, source and regional stratigraphy of the Roraima Supergroup and Roraima-like outliers in northern South America based on U-Pb geochronology. Geol Soc Am Bull 115: 331-348.

Santos JOS, Rizzotto GJ, Potter P, Mcnaughton N, Matos R, Hartmann L, Chemale jr F, Quadros M (2008) Age and autochthonous evolution of the Sunsas Orogen in West Amazon Craton based on mapping and U-Pb geochronology. Precam Res 165: 120-152.

Scotese CR (2001) Atlas of Earth history, Volume 1, Paleogeography, PALEOMAP project, Arlington, Texas, 52 p.

Sener AK, Young C, Groves D, Krapez B, Fletcher IR (2005) Major orogenic gold episode associated with Cordilleran-style tectonics related to the assembly of Paleoproterozoic Australia. Geol 33: 225-228.

Tedeschi M, Hagemann S, Davis J (2017) Lithostratigraphic, structural and hydrothermal evolution of the Rhyacian Karouni orogenic Au deposit, Guyana, South America. Proceeding of the 14th Biennial SGA Meeting, 20-23 August 2017, Québec City, Canada, 273-276.

Voicu G, Bardoux M, Jébrak M, Crépeau R (1999a) Structural, mineralogical, and geochemical studies of the Paleoproterozoic Omai gold deposit, Guyana. Econ Geol 94: 1277-1304.

Voicu G, Bardoux M, Jébrak M (1999b) Tellurides from the Paleoproterozoic Omai gold deposit, Guiana Shield. Can Mineral 37: 559-573.

Voicu G, Bardoux M, Stevenson R (2001) Lithostratigraphy, geochronology and gold metallogeny in the northern Guiana Shield, South America: a review. Ore Geol Rev 18:211-236.

Wasel M, Agnew L, Donald P, Fleming A (1998) Case history of the Gross Rosebel gold project: a review of field technique and geological modeling leading to discovery. Min Eng 49: 64-70.

SOCIETY for GEOLOGY APPLIED to MINERAL DEPOSITS

View overlooking the Pay Caro Pit of the Rosebel mine, Suriname