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An Epoch-based Metallogenic Scheme for Northern Guyana: A Tool for Mineral Resource Assessment

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Abstract: *The need for mineral resource assessments in Guyana has reached a decisive point in view of the country's Low-carbon Development Strategy (LCDS) within the UN Reduced Emissions from Deforestation and Degradation (REDD+) mechanism. Should the government decide to severely restrict mining in forested lands (which cover over 80% of the country) as part of its LCDS, systematic assessments of the mineral potential of forested lands are needed to provide information on the types and economic value of the undiscovered mineral resources likely to be foregone. An epoch-based metallogenic scheme constitutes an effective first-order tool to help in assessing undiscovered mineral endowment. In this paper, such a scheme is constructed to replace older less satisfactory schemes. The paper reviews existing metallogenic schemes for Guyana to assess their reliability as a tool for mineral resource assessment. A new scheme or conceptual model that uses metallogenic epochs as its building blocks is then proposed for and applied in northern Guyana, where most of the country's mineral wealth is located. Seven metallogenic epochs are suggested for northern Guyana. Known and possible deposit types are discussed within this framework. The advantages of the new model over the older schemes are discussed. An epoch-based metallogenic scheme is shown to provide more refined insights into Guyana's mineral potential.*

Keywords: *Metallogenic epoch, mineral resources assessment, mineral deposit*

1. Introduction

The need for regional-scale mineral resource assessments in Guyana has reached a critical point since the recent announcement by the Government of Guyana of its plans to implement a low-carbon development strategy as part of the Reduced Emissions from Deforestation and Degradation (REDD+) mechanism within the United Nations Framework Convention on Climate Change (UNFCCC). As over 80% of the country is forested, a low carbon development strategy involves a commitment of substantial land space. Should the government decide to restrict mining activity as part of its REDD+ strategy, mineral resource assessments would be urgently required to provide information on the number, types and economic value of the mineral resources that are likely to remain untapped.

In assessing mineral potential, metallogenic schemes provide an essential model for the types of deposits that are likely or unlikely to exist in a chosen area. Current models in Guyana are based on lithostratigraphic units, which are distinguished on the basis of only lithic characteristics and stratigraphic position. These models serve as a useful but limited conceptual tool. As shown in this paper, an epoch-based metallogenic scheme constitutes a more perceptive, reliable and encompassing approach. Epoch-based schemes are based on the idea, as pointed out by Goldfarb et al. (2010), that mineralisation is time-bound and related to specific geodynamic events.

By themselves, metallogenic schemes of any sort are not designed to quantity potential mineral resources. They, however, constitute an important first-order tool to identify and constrain the types of mineralisation that are geologically permissive in a given region.

2. Geological Sketch of Northern Guyana

Rocks in northern Guyana (north of 4° latitude) were formed during three eras: Paleoproterozoic (the overwhelming majority of units), Mesozoic and Cenozoic. Eight major lithotectonic assemblages are recognised (Delor et al., 2003; Gibbs and Barron, 1990; Norcross et al., 2000; Santos et al., 2003). From the oldest to the youngest, these are:

i) the Paleoproterozoic low-grade volcano–sedimentary sequences, known as the Barama-Mazaruni Supergroup (BMS), with a age of 2.25 -1.9 Ga,
ii) the Paleoproterozoic syn- to post-tectonic granitic intrusions of the Granitoid Complex (2.18-1.96 Ga),
iii) the Paleoproterozoic acid/intermediate volcanics (1.99 - 1.92 Ga) and unmetamorphosed sedimentary sequences of the Burro-Burro Group,
iv) the Paleoproterozoic intracratonic sediments of the Roraima Supergroup (1873 ± 3 Ma),
v) the Paleoproterozoic continental mafic intrusives of the Avanavero Suite (1782 ± 3 Ma),

vi) the small number of PAPA (post-Avanavero, pre-Apotoe) dykes of basaltic composition (~1330 – 302 Ma),
vii) the Mesozoic continental mafic intrusives of the Apatoe Suite (198 – 189 Ma), and
viii) the Cenozoic coastal sediments.

Figure 1 shows a geological map of Guyana. The most significant tectonic event in northern Guyana was the Trans-Amazonian tectono-thermal episode (2.2-1.9 Ga) encompassing the entire Guiana Shield. Its main manifestations are regional metamorphism, magmatic emplacements, regional deformation, and gold mineralisation (Gibbs and Barron, 1993).

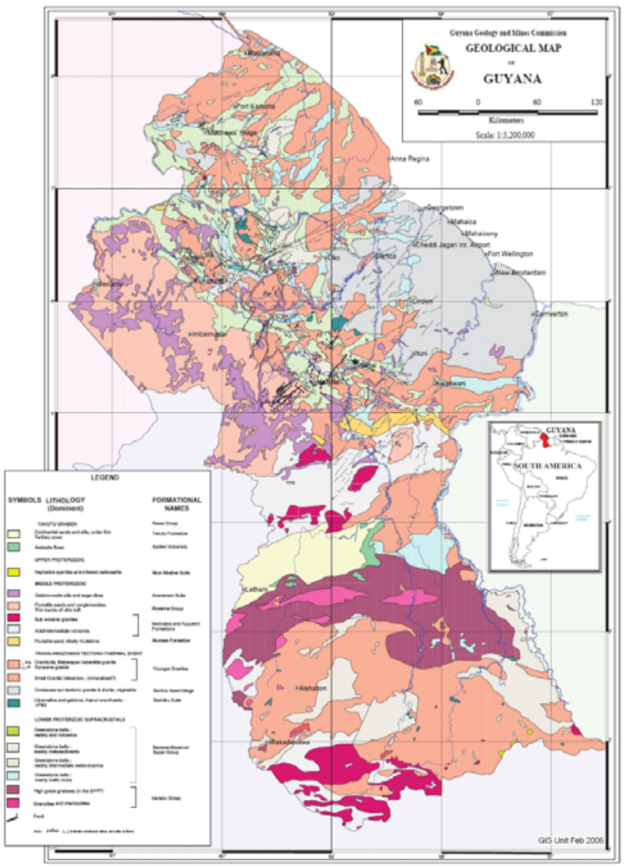

Figure 1. A Geological map of Guyana

3. Assessment of Current Metallogenic Schemes

The most-referenced metallogenic scheme of Guyana is that proposed by Walrond (1980). Walrond identified seven distinct metallogenic provinces based on the demonstrated presence of specific mineralisation within them or on the permissiveness of their geology to host particular mineralisation. His metallogenic provinces are underpinned by large stratigraphic divisions, such as the Barama-Mazaruni Supergroup and the Roraima Supergroup. Within each province, he pinpointed smaller units such as zones and ore districts based on specific deposit types. The work by Walrond remains an important synopsis of mineral potential in the Guiana Shield.

A later work by Voicu (1999) likewise favours a lithostratigraphic-based framework and identifies six metallogenic provinces. As one of his provinces, Voicu delimits a mafic/ultramafic metallogenic province, with the unsatisfactory outcome (typical for such schemes) that rocks of the Avanavero and Apatoe Suites, which were formed under difference tectonic regimes and over 1.4 billion years apart, are lumped together.

The use of major stratigraphic or lithologic divisions as the basic unit for a metallogenic scheme carries the downside that deposits of different styles, ages of formation, and tectono-magmatic regimes may be placed in one province. As Petrascheck (1965) warns, many regional tectonic units, especially orogens, are formed during several tectonic epochs and, as a result, contain several structural elements of different ages. Recognising that large stratigraphic units (such as a supergroup or complex) can be affected by several tectonic episodes allows for a more refined assessment of the possible mineralisation events within such units. Following Petrascheck's (1965) advice, this paper recommends that in Guyana the concept of a province be restricted to these tectonic epochs or time intervals.

To illustrate the jeopardy that lithostratigraphic-based metallogenic schemes in Guyana can pose for resource assessment, we point to two examples. The first concerns the empirical evidence that Guyana's orogenic or greenstone-hosted gold deposits (and, in fact, those in the entire Guiana Shield) are far lower in number, grade and size than those in Canada's Archean greenstone belts. The historic practice, therefore, of assessing Guyana's gold potential based mainly on the lithostratigraphic similarities between the greenstone belts of the two countries has produced over-optimistic estimates.

The second example concerns the belief, now widely rejected, that potential exists for paleoplacer uranium mineralisation in the Paleoproterozoic Roraima intracratonic sequence (1873 ± 3 Ma) because of its lithostratigraphic similarities to South Africa's Archean Witwatersrand deposits and Canada's Elliot Lake deposits. Such deposits are now considered unlikely to have formed in the oxygen-rich atmosphere that prevailed globally after 2.4 Ga, long before the formation of the younger Roraima sequence (Cox et al., 1993).

The current metallogenic schemes in Guyana, based as they are on large lithostratigraphic and lithodemic components, are therefore imprecise tools for mineral resource assessments.

Given these considerations, this study sees an advantage in using tectono-metallogenic epochs as the building block to construct a metallogenic scheme for Guyana. A metallogenic epoch is commonly interpreted as the time interval that was favourable for the formation of particular economic mineral, or during which a particular style of mineralisation was most intense, as a result of a major tectonic event or regime. As noted by Goldfarb et al. (2010), there is a temporal pattern to ore deposits, reflecting the complex interplay of geodynamic and other factors. The authors further state that a particular ore deposit type will tend to have a time-bound nature and rocks formed or deformed during a certain time may be permissive for a given deposit type, whereas of rocks of less favorable ages would possess less potential.

Using an epoch-based approach, we are first tasked with demarcating periods with distinctive tectonic, magmatic and sedimentary activity and then assessing the potential within each period for particular deposit types. Very few examples of such work exist for other parts of the Guiana shield, one of which by Klien and Rosta-Costa (2011) identifies five metallogenic epochs in the eastern Guiana shield in Brazil.

4. Proposed Epoch-Based Metallogenic Scheme

The successful use of epochs to construct a metallogenic scheme presupposes that geochronological and other data are available to fix the timing and tectonic setting of mineralisation. Little of such data exists for local deposits. Epochs for northern Guyana are therefore mainly delimited based on ore deposit models, crustal-scale temporal patterns of mineralisation, and information from better-studied areas especially in the Guiana shield, such as in studies by Delor et al. (2003).

This study identifies three (3) broad tectono-magmatic periods, each encompassing several metallogenic epochs. The periods are defined relative to the Trans-Amazonian (TA) orogeny, which affected rocks of the Guiana Shield between 2.2 and 1.9 Ga. The three periods are: (1) early-Transamazonian (2) late-Transamazonian, and (3) post-Transamazonian. Within these periods, seven metallogenic epochs are proposed for northern Guyana. Epochs are recognised based on tectono-magmatic events and on the actual or potential mineralisation associated with them.

The early-Transamazonian period (2.26-2.08 Ga across the Guiana shield) witnessed the progressive consumption of juvenile oceanic crust during the convergence of the Amazonian and African blocks (Delor et al., 2003a, b). This major subduction process was marked by Tonalite-Trondjhemite-Granodiorite magmatism (TTG) and the formation of volcano-sedimentary greenstone belts across the shield. The belts in Guyana are known as the Barama-Mazaruni Supergroup (BMS). They show a typical greenstone stratigraphic succession with basic/ultrabasic volcanic formations at the bottom, felsic/ intermediate volcanics in the middle, with clastic/ chemical sedimentary rocks at the top (Gibbs and Barron, 1993).

The metallogenic scheme proposed in this paper considers the entire early-TA period as one metallogenic epoch (labeled Epoch 1). In this tectono-magmatic regime, mineralisation is likely to be associated with such lithologies as the felsic submarine volcanics and chemical sediments.

The late-TA period encompasses two epochs in the proposed scheme (Epochs 2 and 3). On the scale of the Guiana shield, Epoch 2 is marked by the formation of granulite-facies metamorphism and emplacement of granites as a result of continental sinistral shearing around 2.0 Ga (Delor et al., 2003a,b). This late TA period is widely acknowledged as the period of most intense epigenetic gold mineralisation in the Guiana Shield (Gibbs and Barron, 1993). Emplacement of gold at Omai (~100 mt Au), Guyana, for example occurred 2001 ± 2 Ma (Norcross et al., 1999).

The other significant metallogenic event related to Epoch 3 in the late TA period relates to the acid magmatism across the Guiana Shield between 2.01-1.96 Ga, interpreted to be subduction-related arc magmatism (Delor et al., 2003a, b). In Guyana, this event is marked by the volcanics, volcaniclastics and comagmatic subvolcanic intrusives of the Iwokrama Formation. Likely mineralisation includes, among others, syngenetic massive sulphide deposit.

The post-TA period in northern Guyana is likewise marked by several significant geologic events. Four metallogenic epochs are proposed (Epochs 4, 5, 6 and 7). Epoch 4 encompasses the events during the Orosirian which lead to the formation of the Roraima Supergroup. These involved the deposition and subsequent uplift of sedimentary sequences in the fault-maintained intracratonic basin (see Santos et al., 2003).

Epoch 5 is associated with the events that led to the intrusion to the emplacement of the large mafic dykes, and sills continental tholeiitic magma belonging to the Avanavero Suite, dated at 1794 ± 4 Ma (Norcross et al., 2000). The Avanavero Suite is assumed to mark a major tectonic event at the scale of the shield (De Roever et al., 2003). Choudhuri et al. (1990) postulate that the voluminous intrusions are related to an abortive attempt at continental rifting. Syngenetic magmatic deposits are possible.

Epoch 6 is related to the tectono-magmatic events associated with the opening of the South Atlantic during the Mesozoic. The associated basic magmatism and block faulting provided conductive conditions for deposit formation.

Epoch 7 marks a period of tectonic quiescence during which erosion and weathering were the dominant agents of deposit formation.

Table 1 provides additional details on the deposit types associated with each epoch in Northern Guyana. While in some cases, mineralisation could be directly linked to an event within an epoch, in other cases the link has not been established.

5. Discussion

The proposed epoch-based metallogenic scheme, through

Table 1: A Proposed Epoch-Based Metallogenic Scheme for North Guyana

Periods	Major tectonic and magmatic events	Metallogenic epochs	Main types of mineralisation	Remarks
EARLY-TRANSAMAZONIAN	Progressive consumption of juvenile crust with formation of TTG magmatism and volcano-sedimentary greenstone belts.	**Epoch 1**	(i) Sedimentary Mn, (ii) VMS base metals associated with felsic volcanism, eruptive centres and subvolcanic porphyries. (iii) Magmatic Ni-Cu and PGEs, associated with mafic and ultramafic formations of the BMS. (iv) Algoma Fe/volcanogenic magnetite	(i) Confirmed. Mn mineralisation, in the North-West of Guyana. (ii) No unambiguous VMS mineralisation found. (iii) Confirmed. Occurrences and soil anomalies in the BMS, e.g., PGE at Karemembu. (iv) Confirmed occurrence in the upper Pomeroon.
LATE-TRANSAMAZONIAN		**Epoch 2**	(i) Orogenic Au, associated with late orogenic metamorphic fluids. (ii) Intrusion-related Au, genetically associated with felsic intrusives. (iii) Intrusive-related uranium mineralisation. (iv) Albitite-hosted uranium mineralisation.	(i) Confirmed. Hundreds of Au occurrences and deposits exploited. (ii) Eagle Mt is a possible example. (iii) Speculative. (iv) Confirmed. Indicated resources at Kurupung. Inferred resources elsewhere in Guyana. Timing of mineralisation highly speculative.
	Subduction-related acid magmatism, represented by the Iwokrama formation in northern Guyana.	**Epoch 3**	(i) VMS deposits in felsic volcanics	(i) Speculative
POST-TRANSAMAZONIAN	Block faulting, deposition and uplift associated with the formation of the Roraima Supergroup.	**Epoch 4**	(i) Quartz-pebble conglomeratic Au. (ii) Unconformity-type U, associated with the unconformity between the BMS basement and the overlying Roraima Supergroup.	(i) Exploration results unfavorable to date. (ii) Speculative. Favorable geology, U anomalies. Timing of mineralisation highly speculative.
	Crustal extension as a result of failed continental rifting, associated with the emplacement of the Avanavero suite .	**Epoch 5**	(i) Magmatic Ni-Cu and PGEs associated with differentiated basalts of the Avanavero Suite.	(i) Exploration results unfavorable to date.
	Precursor basic magmatism and block faulting in connection with opening of the South Atlantic (the South Atlantic Event -approx 200 Ma).	**Epoch 6**	(i) Magmatic Ni-Cu and PGEs associated with differentiated basalts of the Apatoe Suite.	(i) Speculative.
	Tectonothermal quiescence.	**Epoch 7**	(i) Supergene/lateritic Mn. (ii) Supergene bauxite. (iii) Lateritic Ni. (iv) Modern placers of diamond and Au	(i) Confirmed. Measured resources. (ii) Confirmed. Proven reserves. (iii) Confirmed. Ni anomalies. (iv) Confirmed.

tentative and vague in several regards, provides a more reliable and useful model for the assessment of mineral potential in northern Guyana. Several examples illustrate this:

i) the relative potential for magmatic Ni-Cu sulphide deposits of the three main mafic/ultramafic complexes in northern Guyana (the mafic/ultramafic metavolcanics of the Rhyacian greenstone belts of Epoch 1, the sills and dykes of the Statherian Avanavero Suite of Epoch 5, and the dykes of the Mesozoic Apatoe Suite of Epoch 6) can be assessed based on the presence of a felsic crust (the common source of sulfur) at the time of their formation. On this criterion alone, the absence of crustal material during the formation of the Guiana greenstone belts makes the metavolcanics less prospective;

ii) the sedimentary manganese deposits (Epoch 1) and supergene/lateritic manganese deposits (Epoch 7), while associated with the same lithostratigraphic unit, are placed in different metallogenic epochs, separated by over two billions years of geologic time. The older deposit is a primary sedimentary deposit, while the second is a secondary deposit formed from the weathering of the first. Current exploration in Guyana focuses on the younger secondary deposits. The older primary deposits, however, constitute a potential resource requiring a separate assessment based on the depositional environments prevalent in the early Transamazonian period;

iii) the Roraima Supergroup as a single lithostratigraphic unit contains potential and discovered mineralisation of different styles and epochs. These include quartz-pebble paleoplacer gold mineralisation (Epoch 4), the unconformity-type uranium deposit (Epoch 4 or later) and diamondiferous kimberlites. To treat the basin as one metallogenic province, as done by previous workers, is an inappropriate model to assess the several genetic styles involved;

iv) the epoch-based approach allows the four classes of uranium mineralisation known or likely in northern Guyana, (the unconformity-type, the intrusive type, the albitite-hosted type and the conglomeratic paleoplacer type) to be placed in a proper temporal sequence based on their ages of formation and tectonic settings. Given that uranium mineralisation occurred during several epochs in northern Guyana, the potential for economic deposits should be considered significant;

v) the fact that volcanogenic massive sulphide (VMS) deposits have been found in great abundance in the Canadian Shield but to an insignificant extent in the Guiana Shield has provoked much debate (as well as frustration) in Guyana. From an epoch-based metallogenic perspective, however, the Paleoproterozoic era, the age of the Guyana's VMS-permisive greenstone belts, is considered one of the six major global periods of VMS formation (Franklin et al., 2005). Lack of known deposits in Guyana, therefore, may not be due to unfavorable geodynamic conditions operating in the crust at the time. This view bolsters the argument that past unsuccessful exploration for VMS deposits was due to poor exploration designs;

vi) the epoch-based approach facilitates an assessment of the impact on deposit formation of tectonic and other events in the Guiana shield, such as the K'mudku Episode (1.3-1.2 Ga), that are not associated with the emplacement of new material in the upper crust and, as such, with no specific lithostratigraphic units. Such events may, however, cause the reactivation of mineralisation processes and structures as well as the formation of deposits of metamorphic origin.

6. Conclusion

As more geochronological, tectonic and mineral exploration data become available for the Guiana Shield and similar areas worldwide, the epoch-based metallogenic model can become a more powerful tool to define temporal patterns of mineralisation in Guyana. As such, the continuation of the recent government project that involved the radiometric dating of rocks in southern and central Guyana has begun to provide invaluable data that can enhance an epoch-based scheme. Land-use decisions (such as the REDD initiative) can then be made on a more informed basis than at present.

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