# AN OVERVIEW OF SEDIMENTARY-ROCK-HOSTED GOLD MINERALIZATION IN WESTERN WHITE BAY (NTS MAP AREA 12H/15)

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## ABSTRACT

*The area around the Cat Arm road in western White Bay contains a large, low-grade, disseminated gold deposit, hosted by Precambrian granites, which was extensively explored in the 1980s. In the latter stages of this exploration, gold mineralization was discovered in the adjacent sedimentary rocks that unconformably overlie the mineralized granites. This sedimentary-rock-hosted gold mineralization is now important in the context of renewed exploration based upon Carlin-type deposit models.*

*Mineralization is hosted by rocks of the Lower Cambrian Labrador Group (Bradore and Forteau formations), close to the basal unconformity upon Precambrian granites. A major fault zone brings massive dolostones assigned to the Petit Jardin Formation of the Upper Cambrian Port au Port Group over the Labrador Group rocks, and fault-bounded slivers of (probably Ordovician) limestones (St. George Group) also occur within this composite fault zone. There is little sign of alteration or mineralization in these hanging-wall dolostones and limestones, and only local, minor gold enrichment. Below the fault zones, gold mineralization occurs in quartzites of the Bradore Formation, and in basal limestones and calcareous phyllites of the overlying Forteau Formation. Mineralization in the quartzites is, in places, continuous with that in altered granites beneath the basal unconformity, but elsewhere is separated from the granites by barren rocks. The gold mineralization is everywhere associated with fine-grained disseminated pyrite and rarer pyritic veinlets, and is accompanied by sympathetic arsenic enrichment. Calcareous host rocks are possibly silicified, but mineralized quartzites show no obvious alteration. Magnetite in "calcareous ironstones" at the Bradore–Forteau formational boundary has been variably replaced by pyrite, and these rocks typically contain the best gold grades. Detailed description and recognition of geological and mineralogical relationships are severely hampered by intense fracturing and poor core recovery. Future petrographic and geochemical studies are planned to assess the links between granitoid-hosted and sedimentary-rock-hosted gold mineralization, and to further evaluate both in the context of Carlin-type deposit models.*

## INTRODUCTION

The western White Bay area (Figure 1) is well known for its gold mineralization, particularly in Silurian rocks, and was the site of one of the earliest gold-mining ventures in Newfoundland (e.g., Snelgrove, 1935; Saunders, 1991). In the early 1980s, disseminated gold mineralization was discovered in Precambrian granites along the Cat Arm hydroelectric access road. This was systematically explored for several years, and a large but low-grade subeconomic resource was outlined (e.g., McKenzie, 1987a; Poole, 1991a; Saunders and Tuach, 1991). Gold mineralization was subsequently discovered in deformed Cambro-Ordovician sedimentary rocks that sit unconformably upon these granites. Two zones of such mineralization yielded Au grades that were generally better than those reported from the gran-

ite-hosted mineralization, but these were not fully evaluated when exploration terminated in 1991.

After a ten-year hiatus, gold exploration recently resumed, with a regional program directed at disseminated gold deposits, hosted by carbonate rocks and related sedimentary rocks. Deposits of this type, commonly labelled "Carlin-type", are important sources of gold on a global basis (e.g., Arehart, 1996; Hofstra and Cline, 2000) and represent attractive targets. In this context, the known examples of sedimentary-rock-hosted gold mineralization are important indicators, and merit more detailed examination. This report provides an overview of gold mineralization in the area along the Cat Arm road (Figures 1 and 2), with emphasis upon two prospects hosted by Cambro-Ordovician sedimentary rocks. It is based upon company assessment
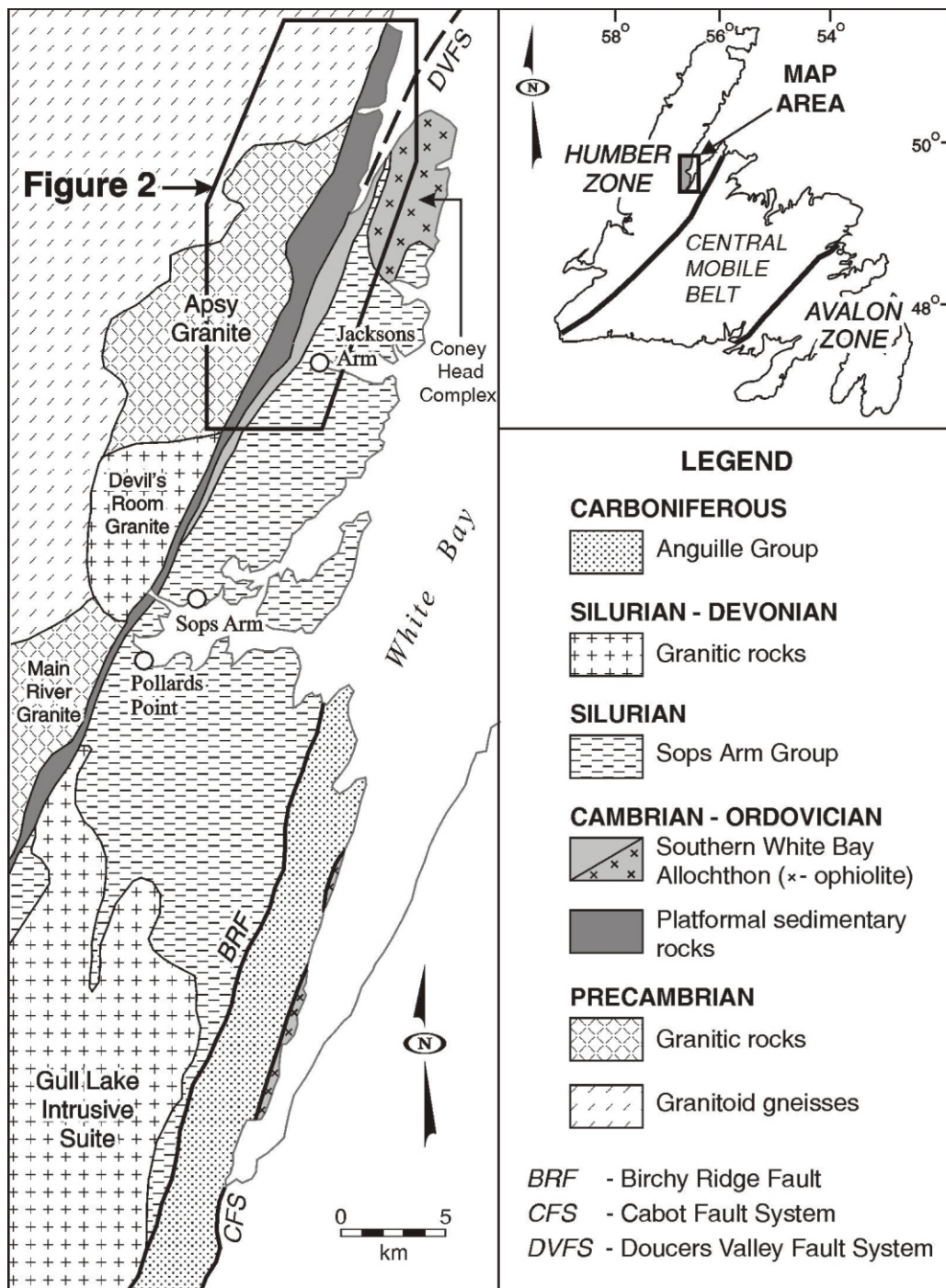
**Figure 1.** *Generalized geology of the western White Bay area, showing the main geological packages (after Smyth and Schillereff, 1982) and the location of the current study area (Figure 2).*

reports, supplemented by examination of key drillholes during the 2003 field season. As no new petrographic or geochemical data are yet available, its contents are preliminary, and mostly dependent upon the previous observations. A companion report (Kerr and Knight, *this volume*) discusses the regional geology of Cambrian and Ordovician rocks in western White Bay, and presents revised interpretations of stratigraphy and structure that are also important in the context of deposit geology.
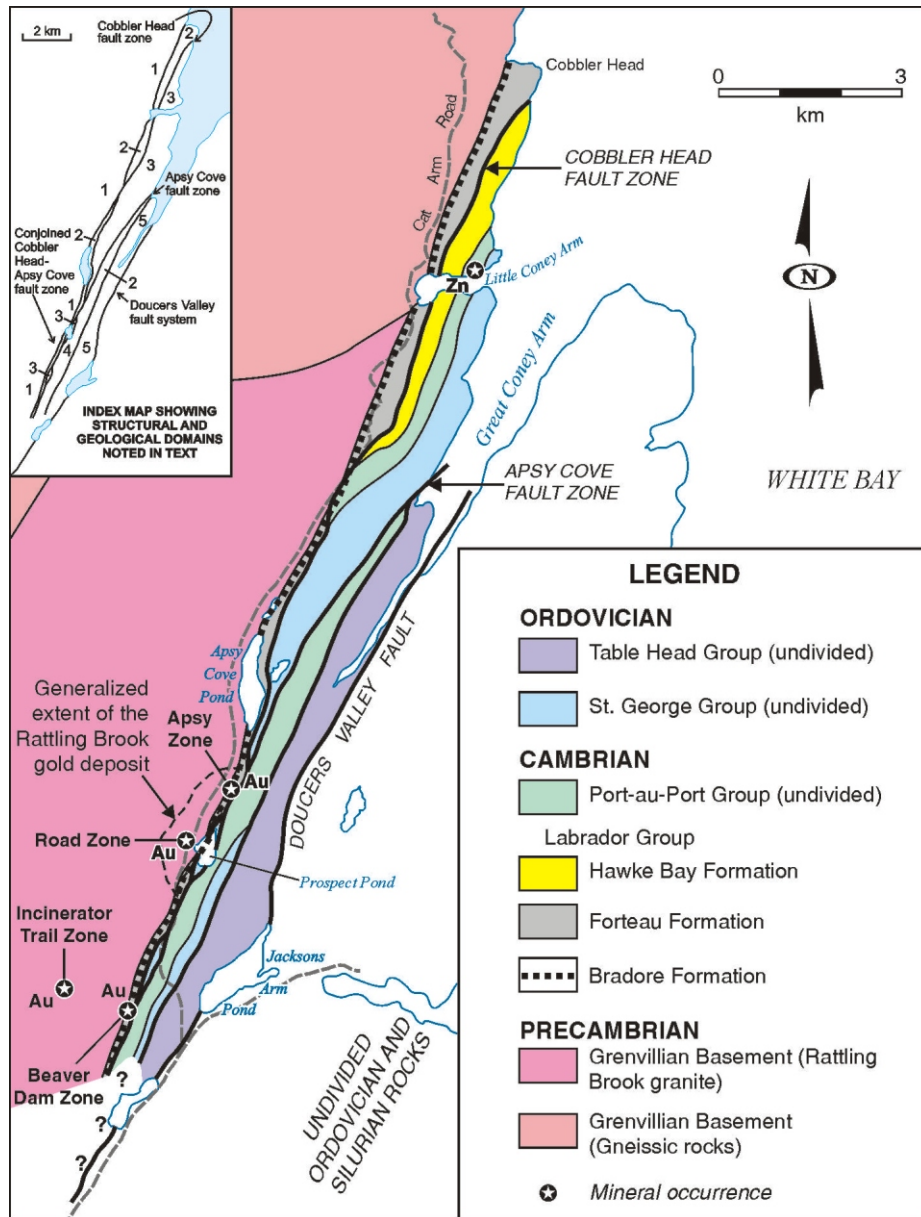
**Figure 2.** *Simplified geology of Cambrian and Ordovician rocks in western White Bay, showing the locations of the main zones of gold mineralization discussed in this report. Simplified after Kerr and Knight (*this volume*).*

## GEOLOGICAL AND METALLOGENIC FRAMEWORK

### GENERAL GEOLOGY

Rocks ranging from the middle Proterozoic to Carboniferous occur in western White Bay where the geology is very complex. Smyth and Schillereff (1982) described six main "packages" of rocks (Figure 1), which are discussed in decreasing order of age below.

1. Precambrian orthogneisses and granites underly higher ground in the west, and are part of the southeastern Long Range Inlier, in turn part of the Grenville Province of the Canadian Shield. The gneisses date back to ca. 1500 Ma, and there were two discrete periods of granitoid magmatism, at 1032 to 1022 Ma, and 1000 to 980 Ma (Heaman *et al.*, 2002). The gneisses and granites are intruded by Neoproterozoic diabase dykes (Long Range dykes) dated at ca. 615 Ma (Bostock *et al.*, 1983). The Precambrian Apsy Granite

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(Figure 1) is the host rock for the large disseminated gold deposit generally known as the Rattling Brook deposit (e.g., McKenzie, 1987a; Poole, 1991a; Saunders and Tuach, 1988, 1991).

2. Cambrian and Ordovician sedimentary rocks form a narrow, linear belt on the western shore of White Bay, and represent autochthonous and parautochthonous cover rocks to the Precambrian. Their basal unconformity is well-preserved in the west, but they are mostly steeply dipping to vertical in attitude, and locally are strongly deformed (Lock, 1969, 1972; Smyth and Schillereff, 1982; Kerr and Knight, *this volume*). The sedimentary rocks are cut by diabase dykes. The eastern boundary of these rocks is a major fault zone termed the Doucers Valley fault system (Figure 1). There are also at least two important structures within the sedimentary sequence that probably originated as west-directed thrust faults (Kerr and Knight, *this volume*). Previous exploration in these sedimentary rocks has mostly concentrated on high-purity limestone (e.g., Howse, 1995), but they also host disseminated gold mineralization close to their unconformable contact with the Apsy Granite, adjacent to the Rattling Brook deposit. These prospects are the main focus of this report.

3. A tract of sedimentary and igneous rocks of Cambrian and Ordovician age, including units of mélange, lies east of the Doucers Valley fault system, and structurally overlies the authochthonous sedimentary rocks described above. These were termed the Southern White Bay allochthon by Smyth and Schillereff (1982), and include several fault-bounded "slices", separated by mélanges. The highest structural slice includes gabbro, trondhjemite and tonalite of the Coney Head complex, interpreted to be of ophiolitic affinity (Williams, 1977; Dunning, 1987). The Southern White Bay allochthon is a composite Taconic Allochthon akin to those of the Humber Arm–Bonne Bay region (Smyth and Schillereff, 1982). However, in western White Bay, later deformation has rotated the allochthon from an original subhorizontal attitude to its present subvertical attitude. A few, small gold occurrences are known in the Southern White Bay allochthon (e.g., Saunders, 1991), but it has not been widely explored.

4. Silurian rocks are represented by the Sops Arm Group (Lock, 1969; Smyth and Schillereff, 1982), which comprises subaerial felsic volcanic rocks and shallow-marine to terrestrial sedimentary rocks. These are most commonly in fault contact with the rocks of the Southern White Bay allochthon, but locally preserve an unconformable relationship, suggesting that they were originally deposited upon it. These rocks contain numerous gold occurrences, which are generally associated with quartz veins, and described as mesothermal and structurally controlled. Stratabound Pb mineralization also occurs in brecciated dolostones of the Sops Arm Group (e.g., Tuach, 1987; Saunders, 1991). The Sops Arm Group was most recently explored for gold in the late 1980s, but is now attracting renewed attention.

5. Two major Silurian and Devonian plutonic suites intrude all older rocks described above, and are termed the Gull Lake Intrusive Suite and the Devil's Room Granite (Smyth and Schillereff, 1982; Figure 1). The two may have originally been contiguous, but displaced by post-Devonian dextral motions along the Doucer's Valley fault system. The Gull Lake body has a poorly constrained age of ca. 400 Ma (Erdmer, 1986). The Devil's Room Granite was recently dated at ca. 425 Ma (Heaman *et al.*, 2002); this age supersedes the earlier estimate of $400 \pm 2$ Ma given by Erdmer (1986). The granites host minor fluorite and molybdenite mineralization (e.g., Saunders, 1991), and they have been implicated in the genesis of various styles of gold mineralization (Tuach, 1987a; Saunders and Tuach, 1991).

6. Carboniferous clastic sedimentary rocks of the Anguille and Deer Lake groups are the youngest rocks in the area (Hyde, 1979). These are dominated by sandstones, conglomerates and slates. Conglomerates of the Deer Lake Group are separated from the older rocks described above by a spectacular unconformity. However, the Southern White Bay allochthon, the Sops Arm Group and younger plutonic rocks have locally been thrust over the Carboniferous, indicating post-Carboniferous deformation. Carboniferous rocks host minor Cu–Ag mineralization south of the project area (Tuach, 1987a).

Including Precambrian events, western White Bay area has undergone at least five orogenic episodes over 1300 Ma. The Middle Ordovician Taconic Orogeny is believed to have caused initial emplacement of the Southern White Bay allochthon over autochthonous Precambrian and Cambro-Ordovician rocks (Smyth and Schillereff, 1982). The Silurian Salinic Orogeny and/or the Devonian Acadian Orogeny affected Silurian and older rocks and probably created much of the present geological architecture; these events were accompanied and followed by granitic plutonism. Carboniferous or post-Carboniferous events (Variscan Orogeny) caused tight folding in the Anguille Group (Hyde, 1979), and also caused local thrusting of older rocks over the Carboniferous sequence (Smyth and Schillereff, 1982). The major north–northeast-trending fault systems that transect the area are interpreted to have had mostly transcurrent post-Silurian motions, but it is likely that they had a complex and protracted earlier history, including Ordovician and Siluro-

Devonian motions. The Doucers Valley fault system has long been recognized as a major structure within the Newfoundland Appalachians, and it has been described as a long-lived structure that is both spatially and genetically associated with several styles of mineralization over a long period of time (Tuach, 1987a).

## GEOLOGY, STRATIGRAPHY AND STRUCTURE

The area of interest is a narrow strip of rugged terrain between the Precambrian Long Range Inlier and the Doucers Valley fault system (Figure 1). It was previously mapped by Lock (1969) and Smyth and Schillereff (1982), and was partially remapped in 2003. A partial reinterpretation of the geology is illustrated in Figure 2, and the salient points are summarized below. Further details about the geology, stratigraphy and structure are provided by Kerr and Knight (*this volume*).

The oldest rocks in the area are Precambrian gneisses and granites of the Long Range Inlier, which mostly lie east of the Cat Arm road. North of Little Coney Arm, these consist of banded granitoid gneisses, cut by deformed Long Range dykes. Elsewhere, they are various "facies" of the ca. 1000 Ma Apsy Granite, most of which consists of coarse-grained, K-feldspar megacrystic granodiorite and monzogranite, variably affected by penetrative deformation and cataclasis of uncertain age. In areas containing disseminated gold mineralization, the Apsy Granite is affected by multiple episodes of alteration, discussed in more detail later. Exploration company reports (e.g., McKenzie, 1987a; Poole, 1991a) commonly refer to the Apsy Granite as the "Rattling Brook granite". The sub-Cambrian unconformity is beautifully preserved on the coast and along the Cat Arm road, and dips moderately to the east.

Most of the area is underlain by Cambrian and Ordovician sedimentary rocks, which mostly dip steeply to the east, and generally also face in that direction. These have long been recognized as general correlatives of the western Newfoundland platformal sequence. Kerr and Knight (*this volume*) now suggest that virtually the entire basal Cambrian to Middle Ordovician stratigraphy is present, and is intact in the north. From both stratigraphic and structural perspectives, the area is subdivided into five domains, bounded by the basal unconformity, two major structures that are termed the Cobbler Head fault zone and the Apsy Cove fault zone, and an unnamed fault (Figure 2, inset). Domain 1 consists of Precambrian basement rocks. Domain 2 is underlain by Cambrian siliciclastic rocks, including quartzites of the Bradore Formation and phyllites derived from shales of the Forteau Formation. The Bradore Formation and the underlying unconformity are preserved in the west, but the Forteau Formation rocks are complexly deformed, and probably imbricated within the Cobbler Head fault zone. Domain

3, best seen in the north, contains a well-preserved sequence including the upper part of the Labrador Group (Hawke Bay Formation), the Port au Port Group (March Point, Petit Jardin and Berry Head formations), and the St. George Group (Watts Bight, Boat Harbour, Catoche and possibly Aguathuna formations). The older formations are excised southward along the Cobbler Head fault zone, such that the Catoche Formation is eventually juxtaposed against the Forteau Formation (Figure 2). Domain 3 itself pinches out southward, where the Cobbler Head fault zone and Apsy Cove fault zone coalesce, but is interpreted to be preserved as small fault-bounded slivers. Domain 4 occurs southeast of the Apsy Cove fault zone, which brings dolostones of the Cambrian Port au Port Group over the Ordovician St. George Group. Domain 5 lies east of a third fault zone, presently of uncertain character, and contains a monotonous sequence of massive limestones tentatively interpreted to represent the Middle Ordovician Table Head Group. The fault zones illustrated in Figure 2 are important structures that probably originated early in structural evolution, and it is suggested that both the Cobbler Head fault zone and Apsy Cove fault zone were initially thrust faults. The latter is a well-developed ductile shear zone where it emerges on the coast. However, there is abundant evidence for later shearing or transpression with a dextral sense of motion, and the region along Great Coney Arm is affected by brittle deformation, fracturing and tectonic brecciation. Thus, early structures have in many cases become loci for later ductile and brittle deformation, and this is certainly true of the area around the known gold prospects (Figure 2), where drilling reveals numerous individual fault zones (*see* later discussion).

The area of most economic interest lies in the south, where the Cobbler Head and Apsy Cove fault zones locally coalesce, and several slivers of Ordovician (?) carbonate rocks are trapped between them. This is a zone of great complexity, and the map shown in Figure 2 is undoubtedly a gross oversimplification. There are four principal zones of gold mineralization (Figure 2; Poole, 1991a). The Road Zone is entirely hosted by the Apsy Granite, west of the sub-Cambrian unconformity. The Apsy Zone, a short distance to the north, is mostly in granite, but also includes a zone within the sedimentary rocks. Farther south, the Incinerator Trail Zone is hosted by the Apsy Granite, and the Beaver Dam Zone is msotly hosted by sedimentary rocks above the unconformity. There was only limited drilling in the granites at the Beaver Dam Zone, and the extent of gold mineralization beneath the unconformity is uncertain.

## EXPLORATION HISTORY

The history of mineral exploration in the area is reviewed by McKenzie (1987a), Poole (1991a) and, most

recently, in a report published online by Kermode Resources (Wilton, 2003). The following provides only a generalized summary.

Well-known Newfoundland prospector Clyde Childs is credited with the initial discovery of gold in 1982 in an outcrop of rusty, altered granite by the Cat Arm road. Labrador Mining and Exploration acquired the mineral rights, and conducted some basic sampling and localized geophysical surveys in 1983 (Bruneau, 1984). This was followed by a more focused program including trenching, with values of 8.4 ppm Au and 4 ppm Au over lateral distances of 2 to 3 m at the Road Zone. Regional exploration work established that disseminated Au mineralization was extensive, albeit discontinuous and sporadic (French, 1985; Avison and French, 1985). Results were sufficiently attractive for BP-Selco to option the property and embark upon a drilling program in 1986, partly through a joint venture with Varna Resources.

Systematic exploration work was conducted in 1986 and 1987 by BP-Selco. The results are summarized by McKenzie (1987a), and detailed in comprehensive assessment reports (McKenzie, 1986, 1987b; Holmes and Hoffman, 1987). Both soil geochemistry and induced-polarization (IP) surveys proved effective in defining mineralized zones and targeting drillholes. Mineralization proved to be extensive in the subsurface, although grades were generally low (0.5 to 3 ppm Au). The best intersection in the granites was 4.4 ppm Au over about 5 m. Later work partly defined mineralization in adjacent quartzites and carbonate rocks at the Apsy Zone. Some high-grade surface mineralization and float were discovered (over 40 ppm Au locally), and there were interesting drill intersections, containing over 10 ppm Au. The Incinerator Trail Zone was located and drilled, and mineralization was also discovered in sedimentary rocks at the Beaver Dam Zone. Renewed work in 1990 focused on the Beaver Dam Zone, and also on further investigation of the Apsy Zone (Poole, 1991a, b). Several intersections of note were obtained in both areas, with values of 5 to 7 ppm Au over 2 to 3 m, but exploration efforts were again suspended, this time for a decade. The mineral rights passed to Noranda Mining and Exploration, but no work was conducted under their tenure, and the entire area eventually came open for staking.

The mineral rights were then acquired by South Coast Ventures Inc., whose prospecting efforts focused on areas underlain by sedimentary rocks rather than granites, with Carlin-type models in mind. A subsequent agreement with Kermode Resources led to more detailed work, including relogging of drill core, and a more ambitious field program commenced in 2003. Results from post-2000 exploration work remain confidential, but some details have been placed in the public domain online (*www.kermode.com*), including the geological review by Wilton (2003). Additional drilling was conducted at the Beaver Dam Zone in the winter of 2004, and initial results (Kermode Resources, press release, January 12, 2004) indicate mineralization similar to that previously described by BP Resources.

# GOLD MINERALIZATION

Most previous descriptions of mineralization (e.g., Tuach and French, 1986; Tuach, 1987b; McKenzie, 1987a; Saunders and Tuach, 1988, 1991) emphasize the granitoid-hosted environment, and the treatment of this below is drawn from these sources. Mineralization in the sedimentary rocks is described by Holmes and Hoffman (1987) and by Poole (1991a, b). Field work in 2003 emphasized the Apsy and Beaver Dam zones, from which key drillholes were examined in detail.

## ROAD ZONE AND APSY ZONE (Granitoid-hosted Mineralization)

Taken together, the Road Zone and the Apsy Zone define a large area of low-grade disseminated mineralization hosted by variably altered "facies" of the Precambrian Apsy Granite. Mineralization is exposed intermittently along the Cat Arm road for about 1 km, and was intersected in most of the drillholes collared west of the unconformity. Drilling in the late 1980s explored to depths of approximately 200 m in the area west of the Cat Arm road. Mineralization is similar in both areas, and is dominated by disseminated pyrite and minor arsenopyrite. The sulphides are in most areas associated with a complex network of fractures and thin veinlets that also contain quartz and lesser amounts of carbonate, mostly ankerite [$CaFe(CO_3)_2$]. Locally, these veinlets are thicker and more numerous, and the rocks are sulphide-rich, but typical mineralization contains only a few percent sulphides. Larger quartz veins within the mineralized zones are reported to be barren (McKenzie, 1987a). Although altered granite is the dominant host, mineralization also occurs in "pretectonic" mafic dykes, which are strongly sericitized and pyritized. McKenzie (1987a) and Saunders and Tuach (1988, 1991) both refer to possible structural controls by both shallow-dipping mylonitic-cataclastic zones and east–west-trending faults. McKenzie (1987a) identified the main fracture directions as 010° to 030° (i.e., parallel to strike in the adjoining sedimentary rocks) and 050° to 070°, with subordinate sets at ~ 090° and 150°. The extent of mineralization, and its general continuity and consistency, are impressive, but the general range of grades is only 0.5 to 2 ppm Au, with local enrichment up to 4 ppm Au. These low average gold grades represent the most significant obstacle to further exploration and development.

BP-Selco geologists divided altered and mineralized granites, into four "types" or "facies", labelled A, B, C and D, in which the sequence denotes increasing alteration (McKenzie, 1987a). Type-A granites are essentially unaltered, whereas weakly altered type-B granites display secondary K-feldspar growth, but retain mostly pristine igneous plagioclase and mafic silicates. More strongly altered type-C granites display more pronounced potassic alteration, coupled with sericitization and epidotization of the plagioclase and mafic silicates, and minor pyritization. The most strongly altered and mineralized type-D granites are essentially composed of quartz and alkali feldspar, are pervasively cut by quartz–carbonate veinlets, and contain obvious disseminated and veinlet-style sulphides. This simple classification remains the most effective in the field because some more subtle features described below are indistinguishable to the naked eye. In some cases, increasing alteration is associated with replacement of igneous magnetite by sulphides, but McKenzie (1987a) notes that magnetic susceptibility measurements on drill core were essentially uncorrelated with the gold grades.

Saunders and Tuach (1988, 1991) linked physical and mineralogical changes to geochemical patterns, and established the timing of alteration events. They demonstrated that the intense potassic alteration that characterizes the sequence from type-A to types-C and -D (*see above*) is an early large-scale metasomatic event. This "stage 1" potassium metasomatism was accompanied by enrichment in Rb, Th, and light REE, and depletion in CaO, $Al_2O_3$, MgO, MnO, Sr and Zn; it is generally not associated with Au enrichment where present alone. In type-C and type-D granites, stage 1 is overprinted by more localized effects spatially associated with vein and fracture systems. This later (stage 2) alteration is associated with fine-grained albite, quartz, ankerite and sericite, and its most obvious geochemical effect is enrichment in $Na_2O$, and depletion of the other elements. Sulphide deposition, and associated Au mineralization, is inferred to have accompanied stage 2. Saunders and Tuach (1991) concluded that both alteration episodes were linked to a single long-lived hydrothermal system, which they inferred to be Late Silurian or younger in age. This conclusion reflects their view that gold mineralization throughout the White Bay area, including occurrences in Silurian rocks, formed in a single episode. There is no direct evidence for the timing of mineralization, other than the fact that it must be post-Cambrian (*see below*).

Mineralogical studies by Saunders and Tuach (1988) confirmed the presence of pyrite and arsenopyrite, and also minor pyrrhotite and galena, which generally form inclusions in pyrite. Gold was observed only rarely, as clusters of small grains ranging from <1 µm to around 15 µm in diameter. They also reported extremely fine-grained (<1 µm) specks of Au–Ag telluride, Pb–Au telluride and Pb telluride within pyrite. Unpublished work by BP-Selco came to similar conclusions, and also identified minor sphalerite and tennantite. It is not known if "invisible" (refractory) gold is present in the pyrite or arsenopyrite, but metallurgical test results reported by BP-Selco suggest that this is possible.

## INCINERATOR TRAIL ZONE (Granitoid-hosted Mineralization)

The Incinerator Trail Zone is poorly exposed, but was well defined by coincident IP chargeability anomalies and Au+As anomalies in soils. It was tested by only four drillholes and its geometry, extent and characteristics are poorly known (Poole, 1991a). Mineralization is hosted mostly by altered Apsy Granite, mostly of types-C and -D, surrounded by less-altered granites, but is also present in strongly altered and sheared mafic dykes. The ca. 080° trend of the Incinerator Trail Zone suggests that it is structurally controlled, and the mineralization generally resembles that described above from the Road Zone (Poole, 1991a). The grades are also similar; the best intersection was 1.8 ppm Au over 4 m in hole RB-37, which appears to be mostly hosted by an altered dyke.

## BEAVER DAM ZONE (Sedimentary-Rock-hosted Mineralization)

### Review

The Beaver Dam Zone is located in the southern part of the area, on the southeast side of a small stream valley, and is accessible by a small road (Figures 2 and 3). The area lies very close to the sub-Cambrian unconformity, and the Bradore Formation quartzites are exposed in the stream valley. However, the outcrops along the access road are mostly beige to grey dolostones, which are here assigned to the Petit Jardin Formation of the Cambrian Port au Port Group (Figures 2 and 3). Prospecting in the stream valley during 1987 located pyritic quartzite, containing up to 35 ppm Au, which proved to be coincident with a Au–As enrichment in soils and an IP chargeability anomaly (Poole, 1991b). The best drill intersection was in hole RB-48, which returned 3.5 m of 5.5 ppm Au, including 2 m of 7.5 ppm Au (Poole, 1991b). Interesting gold mineralization was also intersected in RB-49 (1 m of 6.2 ppm Au) and RB-51 (2.1 m of 7.3 ppm Au), and lower grade mineralization occurred in four other drillholes (RB-53, 59, 62 and 63). Detailed descriptions, core logs and complete assay data are provided by Poole (1991b). The mineralized sections from RB-48 and RB-51 are unavailable, but remaining material is stored at the Department of Mines and Energy Core Library in Pasadena. In 2003, holes RB-48, 51, 53, 56 and 62 were examined and sampled.
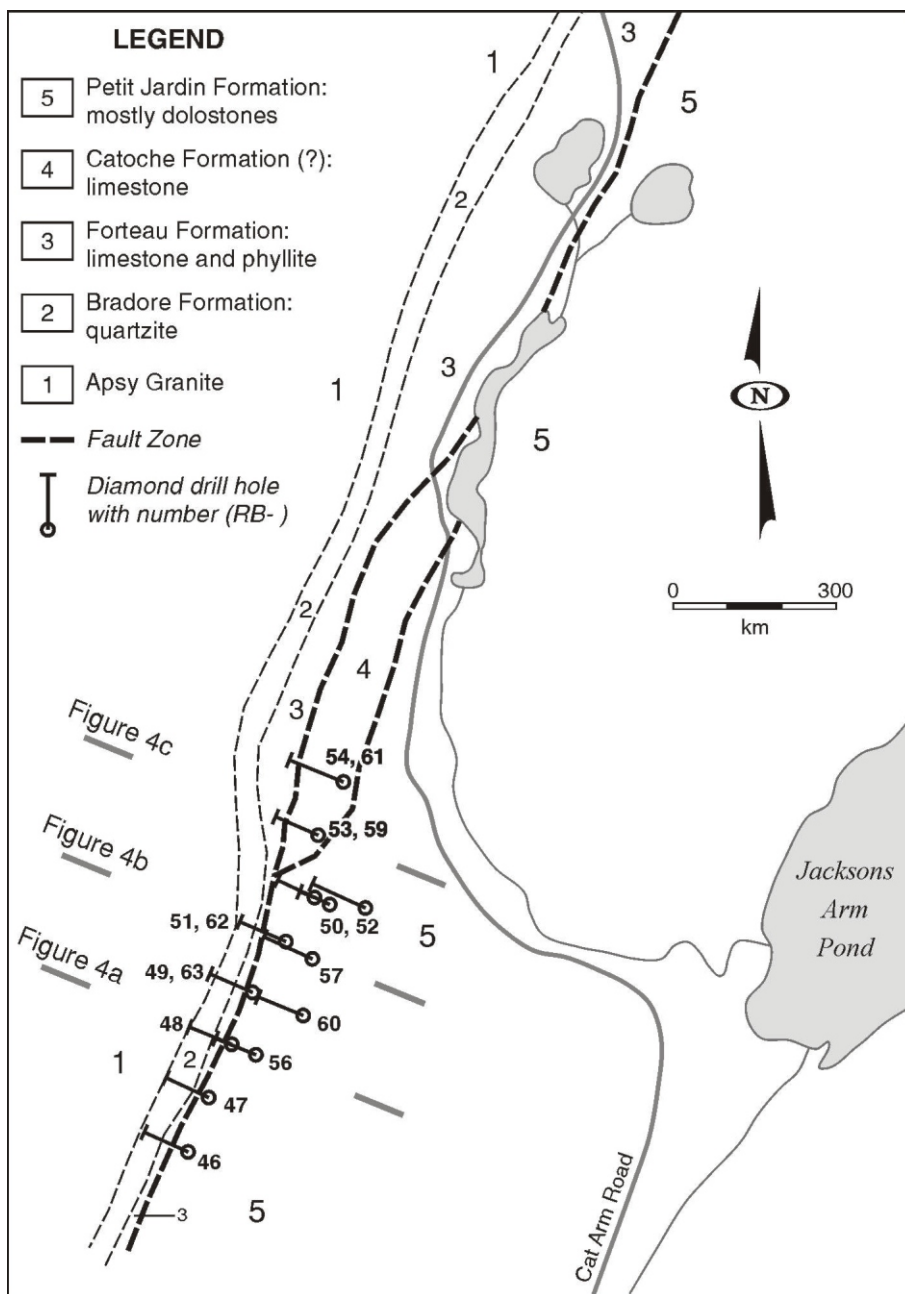
**Figure 3.** S*urface geology and drillhole locations for the Beaver Dam Zone area. Geology modified after Poole (1991b) based upon observations in 2003.*

### Surface and Subsurface Geology

The surface geology and drillhole locations are depicted in Figure 3, and cross-sections are depicted in Figure 4. Detailed mapping of the area has not yet been conducted. Outcrops in the west consist of the Apsy Granite, variably affected by type-C or type-D alteration. Bradore Formation quartzites are exposed in a small stream valley, in close proximity to the granites, suggesting that the basal unconformity is preserved. Poole (1991b) shows the Forteau Formation as a unit some 150 m wide, but all holes were collared in massive carbonate rocks, generally dolostones. In most of the drillholes, the Forteau Formation is represented only by a thin unit of limestones that sits above Bradore Formation quartzites, and overlying calcareous phyllites are only present in the north (Figure 4). In the south, the Forteau Formation is a narrow strip, structurally beneath a fault (Figure 3). Bradore Formation quartzites range from 4 m to over 30 m in thickness and pass downward into the underlying granite. All drillholes contain zones of intense fracturing and
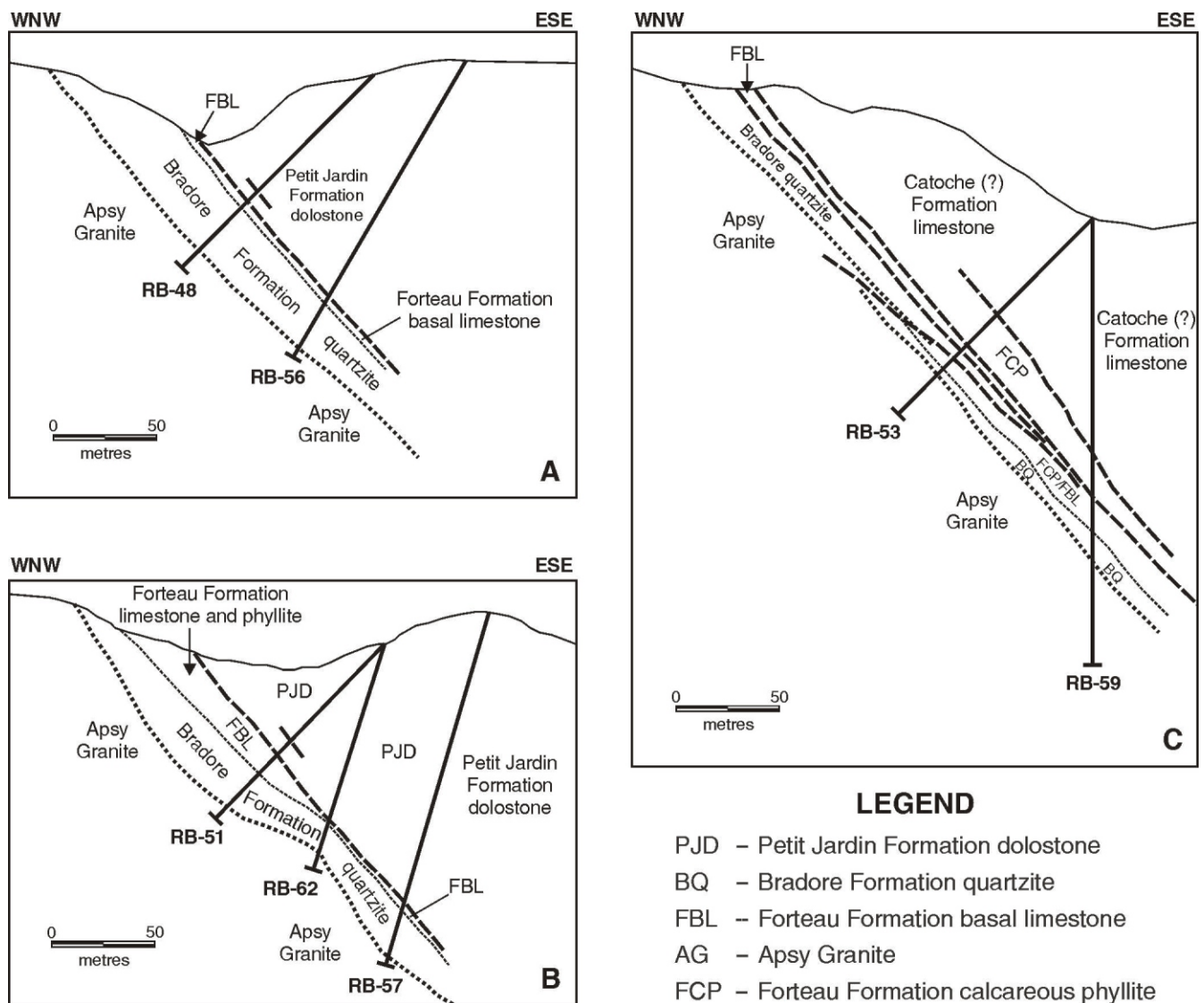
**Figure 4.** *Cross-sections through the Beaver Dam Zone, illustrating the arrangement of various geological units in the sub-surface. Modified after Poole (1991b) based upon observations in 2003.* See *Figure 3 for section locations.*

poor core recovery, indicating the presence of numerous small faults, and greatly complicating the identification and correlation of rock types.

The four drillholes in the south of the area (Figure 4a, b) contain an upper sequence of massive white, grey and beige dolostones that are locally laminated or stylolitic, but generally featureless and recrystallized. This material is locally fractured, and hematite staining is common in the fractured zones. Locally, red clay-like gouge zones occur. The dolostones were assigned to the Hawke Bay Formation by Poole (1991b), but are here assigned to the Petit Jardin Formation of the Port au Port Group. One hole in the north of the area (RB-53; Figure 4c) contains an upper carbonate sequence of very different character, including massive

white limestones that are "decorated" by hematitic fracture patterns, and burrowed (i.e., bioturbated) limestones. These rocks are suspected to represent the Ordovician Catoche Formation, which probably forms a fault-bounded sliver, possibly extending northward to similar outcrops exposed on the Cat Arm road (Figure 3). Based on drill logs (Poole, 1991b) it is suspected that holes RB-59 and RB-61 encountered similar carbonate rocks.

In the south, the upper dolostone sequence passes downward into a zone of intense fracturing and brecciation, which represents an important fault (Figure 4a, b). The matrix to brecciated dolostones is hematitic, and discrete fracture zones are filled with red clay. It is suggested that the fault zone was subjected to weathering and groundwater

effects during the Carboniferous, as seen in nearby outcrops (Tuach, 1987b; Kerr and Knight, *this volume*). This fault is considered to be the conjoined Apsy Cove fault zone and Cobbler Head fault zone (Figures 2 and 3). Below this fault zone, there is a thin sequence of variably textured limestones interpreted to represent the basal carbonate unit of the Forteau Formation. These limestones locally appear to be silicified and/or brecciated, and may locally be interbedded with quartzites, but detailed examination is generally difficult due to fracturing and poor recovery. They pass downward into a rock type referred to as "calcareous ironstone" (Poole, 1991b), which appears to have carbonate-rich and quartz–magnetite-rich layers on a scale of millimetres to centimetres. This is underlain by grey quartzites, which are also magnetite-bearing, notably in the upper part of the interval. The blue quartz grains that typify many surface outcrops are prominent throughout, and the matrix is hematitic. Coarser grained quartzites, locally conglomeratic and/or arkosic, occur toward the base. Schistose zones are developed within the quartzites in some holes, but the contact with underlying granite is generally not strongly deformed.

The one hole examined in the north (RB-53) also contained a prominent fault zone at the base of suspected Catoche Formation, beneath which are laminated rocks that resemble Forteau Formation calcareous phyllites seen elsewhere, such as at the Apsy Zone (*see* later discussion). These rocks in turn pass downward into intensely fractured zones, suggesting that their lower contact is also a fault. These fault zones are interpreted to represent the Cobbler Head fault zone, rather than the Apsy Cove fault zone, which must be located east of the drill collar (Figure 3). More massive limestones, underlain by quartzites, occur in the lower part of RB-53. This sequence is repeated downhole, suggesting disruption by smaller faults. As in the south, "calcareous ironstones" occur at the contact between Forteau Formation limestones and underlying Bradore Formation. The granitoid rocks at the bottom of RB-53 contain altered diabase dykes, some of which are mineralized.

### Gold Mineralization

The distribution of gold mineralization in the Beaver Dam Zone is not entirely controlled by stratigraphy or rock type, but it is influenced by such features. Figure 5 shows gold abundance versus depth for four key drillholes, using the data from Poole (1991b). Mineralization is present in the Forteau Formation carbonate rocks, Bradore Formation quartzites, and also within altered granite beneath the unconformity. Some minor Au enrichment (<0.3 ppm) is observed in the upper dolostones in hole RB-49, but elsewhere these rocks are barren. The strongest Au enrichment is generally within the calcareous, magnetite-rich rocks that

occur at the transition between Bradore Formation and Forteau Formation, as in holes RB-48 and RB-51 (Figure 5). According to Poole (1991b), the highest gold assays commonly correspond with "calcareous ironstones", in which magnetite is variably replaced by pyrite. Thus, the stratigraphy exerts some influence upon the deposition of gold. There is a strong correlation between gold and arsenic, and arsenic profiles are essentially identical in shape to the gold profiles (Figure 6a). The strong gold–arsenic correlation was noted for the granitoid-hosted mineralization (e.g., McKenzie, 1987a; Tuach and Saunders, 1991), and is also evident for the sedimentary-rock-hosted mineralization, in which As/Au ratios are typically $10^3$ to $10^4$ across a wide range of Au contents (Figure 6b).

In drill core, the auriferous zones are mostly characterized by fine-grained disseminated pyrite. Generally, the strong fracturing and poor core recovery hamper attempts at detailed textural description. Arsenopyrite is noted by Poole (1991b) but was rarely visible to the author; however, arsenic data (Figure 6b) certainly suggest its presence and (assuming that all arsenic is in arsenopyrite, with ~ 46 wt% As) some high-grade samples contain up to 2% arsenopyrite. Sulphide-bearing veinlets are rarer, but were noted locally. Pyritic limestones are possibly partly silicified, but there is little or no sign of alteration in mineralized quartzites. Mineralization hosted by granitoid rocks in the lowermost section of drillhole RB-53 resembles its counterparts in the Road Zone and western parts of the Apsy Zone (*see* previous descriptions).

### APSY ZONE (Sedimentary-Rock-hosted Mineralization)

### Review

Granitoid-hosted mineralization at the Apsy Zone was explored and drilled in 1986 and 1987, and progressively traced to the north. This necessitated drilling through the adjacent sedimentary rocks, where low-grade gold mineralization was encountered in pyritic quartzites in drillhole RB-20 (Holmes and Hoffmann, 1987). Subsequent drillholes demonstrated the presence of gold in other parts of the quartzite, and also in overlying limestones and calcareous phyllites. The best result obtained in 1987 was 2.5 ppm over 6.5 m, including a shorter interval that gave 3.2 ppm Au over 2 m (Holmes and Hoffman, 1987). A second phase of drilling was conducted in 1991, and encountered better grades. Drillhole RB-42 returned the most gold, with 8.6 ppm Au over 0.6 m, but the best result was from drillhole RB-44, which gave 4.1 ppm Au over 3 m (Poole, 1991b). It was noted that the northern strike extension and downdip extension both remained untested (Poole, 1991b), but no further work was conducted. During 2003, drillholes RB-20,
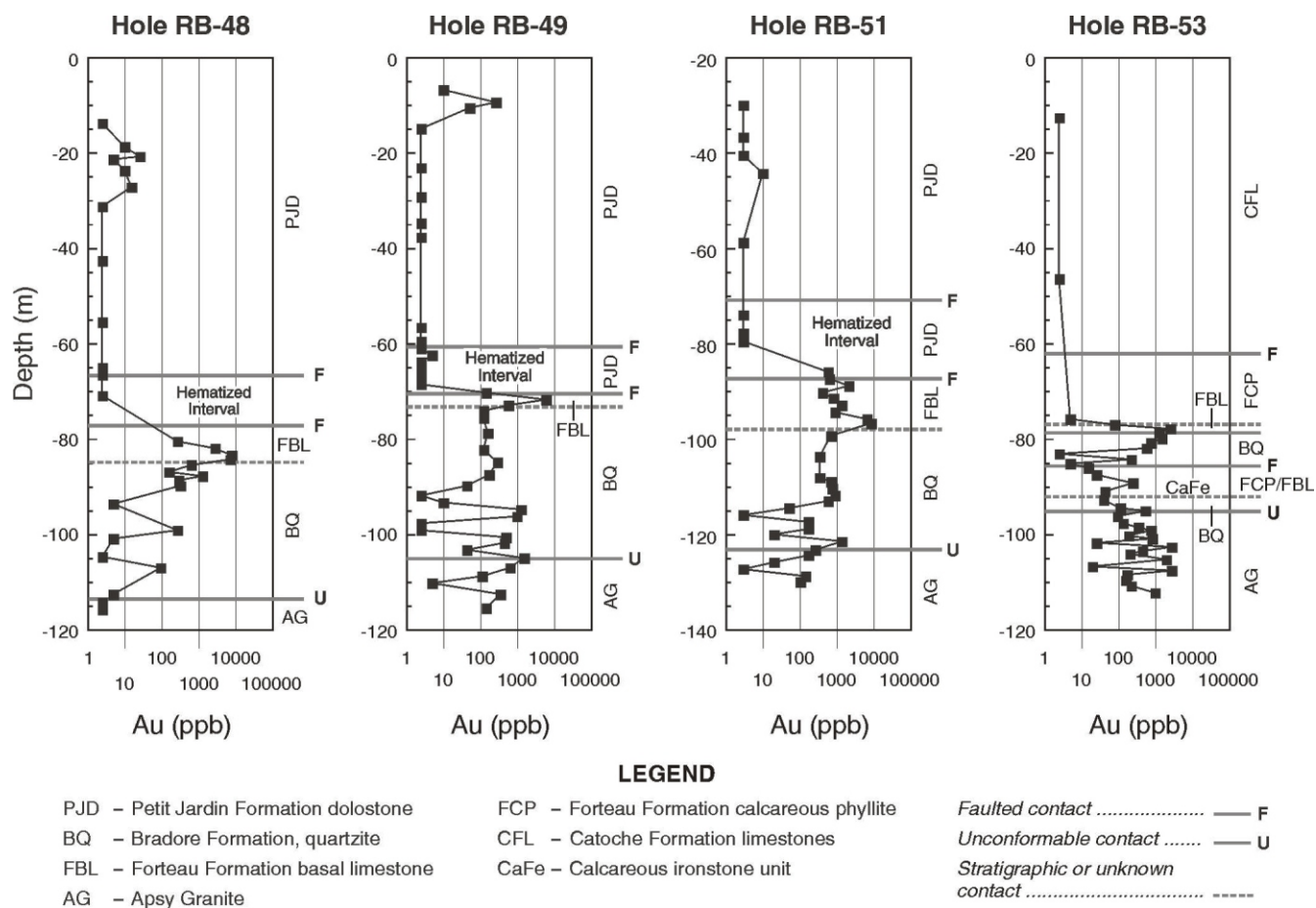
**Figure 5.** *Distribution of gold with depth in representative drillholes from the Beaver Dam Zone, showing the relationship between mineralization, geological units and structures.*

23, 28, 29, 30, 31, 38, 40, 43, 44 and 55 were examined and sampled. As in the case of the Beaver Dam Zone, the highest grade intersections (RB-44 and RB-42) are not present in the Pasadena Core Library.

### Surface and Subsurface Geology

The Apsy Zone occupies a steep-sided valley between the Cat Arm road and the hydroelectric power line. The surface geology and drillhole locations are depicted in Figure 7, and three cross-sections are depicted in Figure 8. Detailed mapping of the area has yet to be conducted by the author.

Outcrops along the road are dominantly altered and mineralized granite, generally showing type-C and type-D alteration according to the classification of McKenzie (1987a). A small outcrop of Bradore Formation quartzites is located immediately across the road from the mineralized granite; the quartzite contains minor disseminated pyrite, and more extensive staining related to sulphides on fracture surfaces. This quartzite outcrop contains 0.88 ppm Au and

2000 ppm As (Holmes and Hoffman, 1987), and is the only location where mineralization in sedimentary rocks may easily be seen on surface. The valley is occupied by calcareous phyllites assigned to the Forteau Formation, which sit structurally above Bradore Formation quartzites (Figures 7 and 8). The cliffs and higher ground to the east of the valley are formed by more massive carbonate rocks, which were previously assigned to the Hawke Bay Formation (Holmes and Hoffman, 1987; Poole, 1991b), but are here mostly assigned to the Cambrian Port au Port Group. Poole (1991b) believed that the sequence was largely intact, but the contact between upper carbonate rocks and phyllites is here interpreted as tectonic, representing the conjoined Cobbler Head and Apsy Cove fault zones. Northward, these two fault zones are interpreted to diverge, and grey, bioturbated limestones of the Catoche Formation are in contact with Forteau Formation calcareous phyllites to the west, and dolostones to the east (Figure 2). Southward, massive grey limestones reappear just north of Prospect Pond, and are interpreted as a fault-bounded sliver of Catoche Formation (Figures 2 and 7). A northwest–southeast-trending fault is
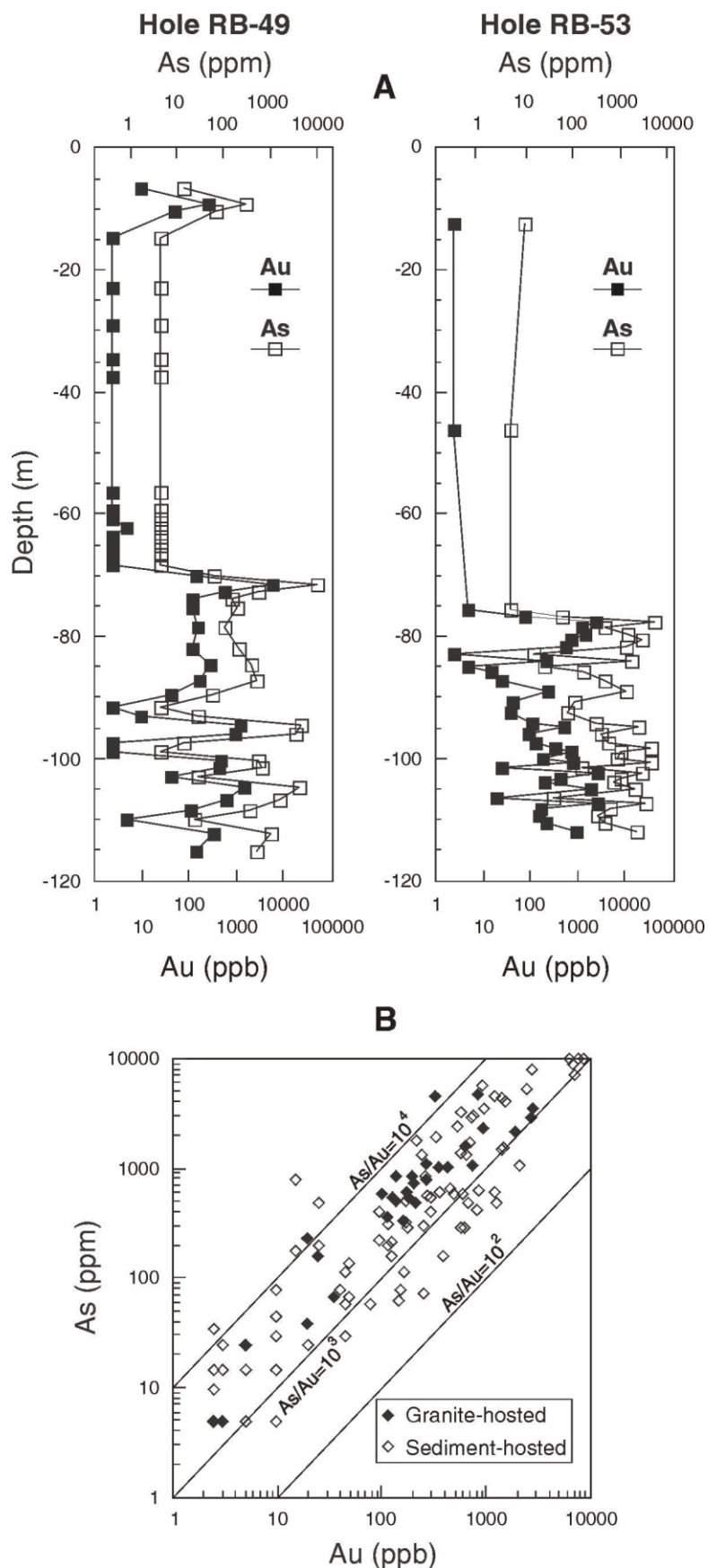
33

**Figure 6.** *Gold–arsenic correlations at the Beaver Dam Zone. (a) Profiles for holes RB-53 and RB-49, illustrating sympathetic behaviour. (b) Scatter diagram illustrating gold–arsenic correlation for the Beaver Dam Zone, using data from the four drillholes indicated in Figure 5.*

present in the centre of the zone, and causes a dextral offset of some 75 m, but it is not clear if this affects the major faults (Figure 7).

Most Apsy Zone drillholes were collared within calcareous phyllites of the Forteau Forma-tion, and only six holes were collared in the more massive carbonate rocks to the east (Figure 7). Hole RB-55, at the north end of the prospect, and holes RB-40, 42, and 43, in the centre, all pene-trated an upper sequence of massive pale-grey to beige dolostones (Figure 8a, b). These strongly resemble rocks observed in the upper sections of most holes at the Beaver Dam Zone (*see above*) and are similarly assigned to the Petit Jardin For-mation of the Port au Port Group. A thick sequence of equivalent dolostones is also exposed in Rattling Brook gorge, immediately southeast of the Apsy Zone (Figure 7). However, hole RB-44 intersected a different upper sequence of mas-sive grey limestones that show only local dolomi-tization. The lowermost interval of these lime-stones exhibits a strong, locally mylonitic, folia-tion (Figure 8c). Drill logs for hole RB-45 sug-gest that its upper section is similarly dominated by limestones (Poole, 1991b). These grey lime-stones are considered to represent a small fault-bounded sliver of Catoche Formation (?) trapped within the composite fault zones, as indicated by regional patterns, and similar relationships at the Beaver Dam Zone (*see above*).

The contact between the massive carbon-ate rocks and the underlying calcareous phyllites is invariably marked by strong deformation and intense fracturing, suggesting that it is an impor-tant fault zone (Figures 7 and 8). The underlying Forteau Formation phyllites have a banded appearance defined by alternating dark chloritic or micaceous seams and light-coloured carbon-ate-rich bands. This lamination is contorted, indi-cating folding, and rootless fold closures are locally visible. Deformed quartz veins and dark
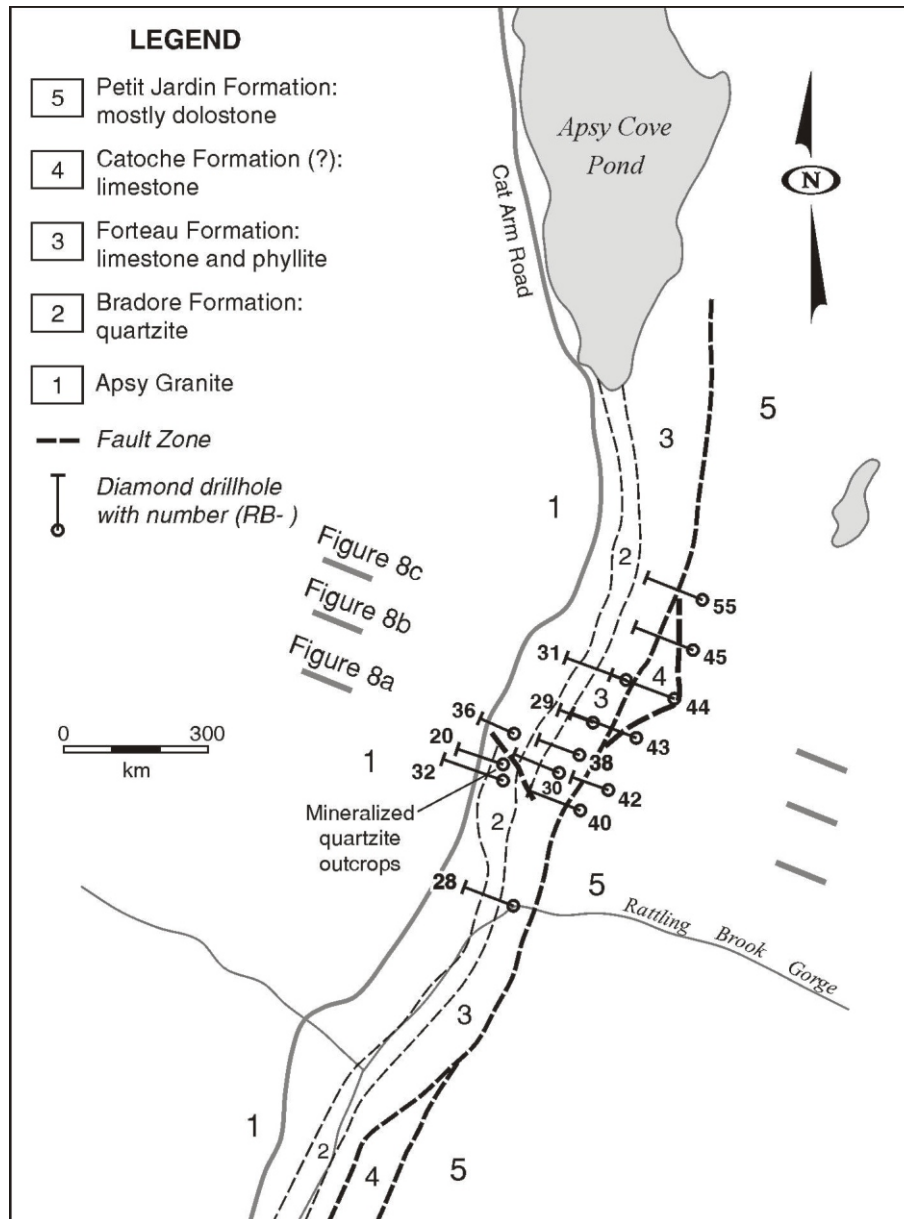
**Figure 7.** *Surface geology and drillhole locations for the Apsy Zone area. Geology modified after Poole (1991b) based upon observations in 2003.*

dolomitic bands are also common; the latter could represent either relict beds or originally discordant veins. The core has a brownish cast that likely indicates widespread disseminat- ed sulphides, but these are extremely fine grained and diffi- cult to see. Where visible, they appear to be more abundant in darker (argillaceous) bands. In every hole, the Forteau Formation phyllites commonly include discrete zones of intense fracturing that likely represent smaller faults, not indicated in Figure 8. The most intense fracturing is seen toward the base of the phyllitic interval.

Most of the Apsy Zone drillholes also intersected a thin sequence of texturally diverse carbonate rocks at the base of the calcareous phyllites that separates them from underlying quartzites (Figure 7). The features of these carbonate rocks are obscured by intense fracturing and poor core recovery, but they include white, pale-grey and yellowish limestones, and rarer dolostones, which range from well-laminated to essentially massive and structureless. The limestones have a heterogeneous "brecciated" appearance, and locally appear silicified, notably where mineralized. However, some of
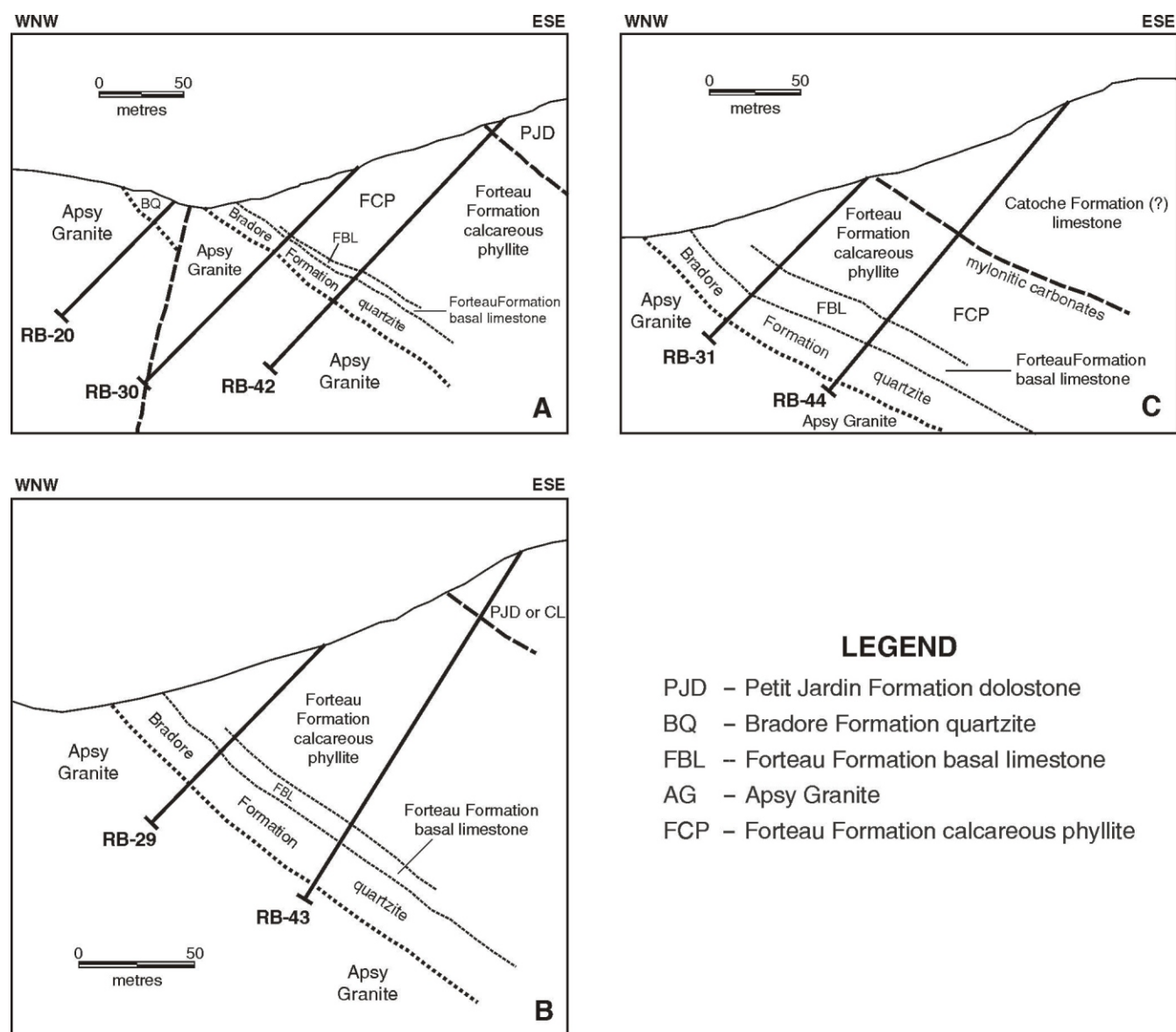
**Figure 8.** *Cross-sections through the Apsy Zone, illustrating the arrangement of various geological units in the subsurface. Modified after Poole (1991b) based upon observations in 2003. See Figure 7 for section locations.*

these more siliceous variants may actually be thin beds of quartzite or calcareous sandstone; it is difficult to know because the core is badly broken. Toward the base of the limestones a few holes, notably RB-29, 31 and 43, contain calcareous sandstones and quartzites that have discrete magnetite-rich bands. These rocks resemble the "calcareous ironstones" described above from the Beaver Dam Zone.

The lowermost sections of all Apsy Zone drillholes consist of Bradore Formation quartzites (Figure 8), which closely resemble those described above from the Beaver Dam Zone. These are typically fine- to medium-grained light to dark-grey rocks that contain prominent blue quartz grains,

and variable amounts of magnetite. The colour variation does not appear systematic, as some holes contain dark-grey material toward their bases, whereas others show the reverse pattern. The quartzites are locally arkosic close to the basal contact, and a thin (<20 cm) basal conglomeratic unit containing quartz pebbles up to 1 cm in diameter occurs in hole RB-20. The contact between quartzites and underlying Apsy Granite is generally well preserved and rarely sheared. Hole RB-20 provides the thickest intersection of altered and mineralized granite beneath the unconformity, but mineralized granites are present in other holes, notably RB-30 and 42 (Figure 8a).

### Gold Mineralization

Gold mineralization at the Apsy Zone is not entirely controlled by stratigraphy or rock type, but it is influenced by these factors. Figure 9 shows Au abundance versus depth for representative drillholes, using data from Holmes and Hoffman (1987) and Poole (1991b). Mineralization is mostly within Forteau Formation basal carbonate rocks, and in various parts of the Bradore Formation quartzites. The Forteau Formation calcareous phyllites show only local weak gold enrichment. In hole RB-55, there is minor gold enrichment (<0.2 ppm Au) in the upper dolostones, but these rocks are barren elsewhere. In holes RB-20, 30 and 42 mineralization in the quartzites appears to be continuous with mineralization in the underlying granites, whereas other holes (RB-29, 31, 44 and 55) contain mineralization in carbonates and/or adjacent quartzites, but lack mineralization in the lower part of the quartzites and/or the granites. As in the case of the Beaver Dam Zone, the strongest gold enrichment is commonly seen at the Forteau–Bradore formational boundary, where it is at least locally associated with replacement of magnetite in the "calcareous ironstones" described by Poole (1991b). Thus, although the mineralization is not stratigraphically controlled, the deposition of gold has been influenced by the stratigraphy.

Mineralization in calcareous phyllites and basal carbonate rocks of the Forteau Formation is associated largely with fine-grained disseminated pyrite, although discrete pyritic veinlets are visible locally. A breccia-like texture is developed in places, and the breccia matrix appears pyritic, albeit extremely fine grained. Elsewhere, as noted above, these brecciated limestones appear variably silicified. A white, soft mineral is present in some of the mineralized carbonate rocks, and may represent clay-mineral alteration of some type. A pink mineral noted in some thin sulphide-bearing veinlets in mineralized quartzites is possibly K-feldspar. The core in gold-bearing intervals is intensely fractured, and textures are difficult to resolve. Poole (1991b) reports visible arsenopyrite from hole RB-44, associated with zones of stronger pyritization. Arsenic data (Figure 10) clearly suggest the presence of arsenopyrite elsewhere. Quartzite-hosted mineralization for the most part also consists of finely disseminated pyrite. Some of the pyrite is locally associated with grains of (presumably detrital) magnetite, and may be replacing these. Discrete sulphide-bearing veinlets are rare in the quartzite, but they were noted in hole RB-40, associated with higher grade intervals. The style of mineralization in the quartzites and the underlying granites is similar in holes where mineralization appears continuous, but discrete sulphide-bearing veinlets are more obvious within the granites. This contrast could reflect a greater porosity within the sedimentary rocks, in which fluids were perhaps more able to percolate along grain boundaries than in the underlying crystalline rocks.

Gold–arsenic correlations are obvious, and the shapes of gold and arsenic profiles for individual drillholes are closely similar, regardless of the host rocks (Figure 10a). However, high As values (>6000 ppm As) occur in the upper dolostones of hole RB-55, accompanied by only minor Au enrichment (Figure 10a). A larger dataset for the Apsy Zone (Figure 10b) indicates that Au–As correlation is not as strong as in the Beaver Dam Zone (Figure 6b), particularly at low Au contents. In particular, samples from sedimentary-rock-hosted mineralization containing <0.5 ppm Au tend to have high As/Au ratios compared to those from granite-hosted mineralization.

## SUMMARY AND DISCUSSION

This preliminary report is intended to be descriptive rather than interpretive. Gold mineralization in the sedimentary rocks is largely associated with fine-grained disseminated pyrite, and understanding of textures and geological relationships is presently hampered by pervasive fracturing and poor core recovery. More detailed descriptions and interpretations will only be possible in the light of petrographic and geochemical studies. Nevertheless, several points can be made on the basis of the present information.

First, the host rocks are structurally complex, and do not represent a stratigraphic sequence. In both areas, an important fault zone is present, that correlates with the conjoined Cobbler Head–Apsy Cove fault zones defined by regional work (Figure 2). At the Beaver Dam Zone, this brings massive dolostones of the Petit Jardin Formation over Bradore Formation quartzites and thin basal carbonate units of the Forteau Formation (Figure 4). The calcareous phyllites of the Forteau Formation are generally absent in this area. At the Apsy Zone, the same fault brings the dolostones over calcareous phyllites of the Forteau Formation (Figure 8). Both areas also contain fault-bounded slivers of (probably Ordovician) limestones, which are trapped betwen the Apsy Cove fault zone and the Cobbler Head fault zone where they locally diverge to form discrete structures. It is important to realize that the geology within the mineralized zones is certainly far more complicated than presently depicted in Figures 3 and 7!

Second, gold mineralization is mostly confined to rocks that are structurally below (i.e., west of) these major fault zones. The upper dolostones and limestones are largely barren, containing only a few weakly anomalous zones that have <0.3 ppm Au. Gold mineralization is not entirely controlled by stratigraphy or rock type, and is present in cal-
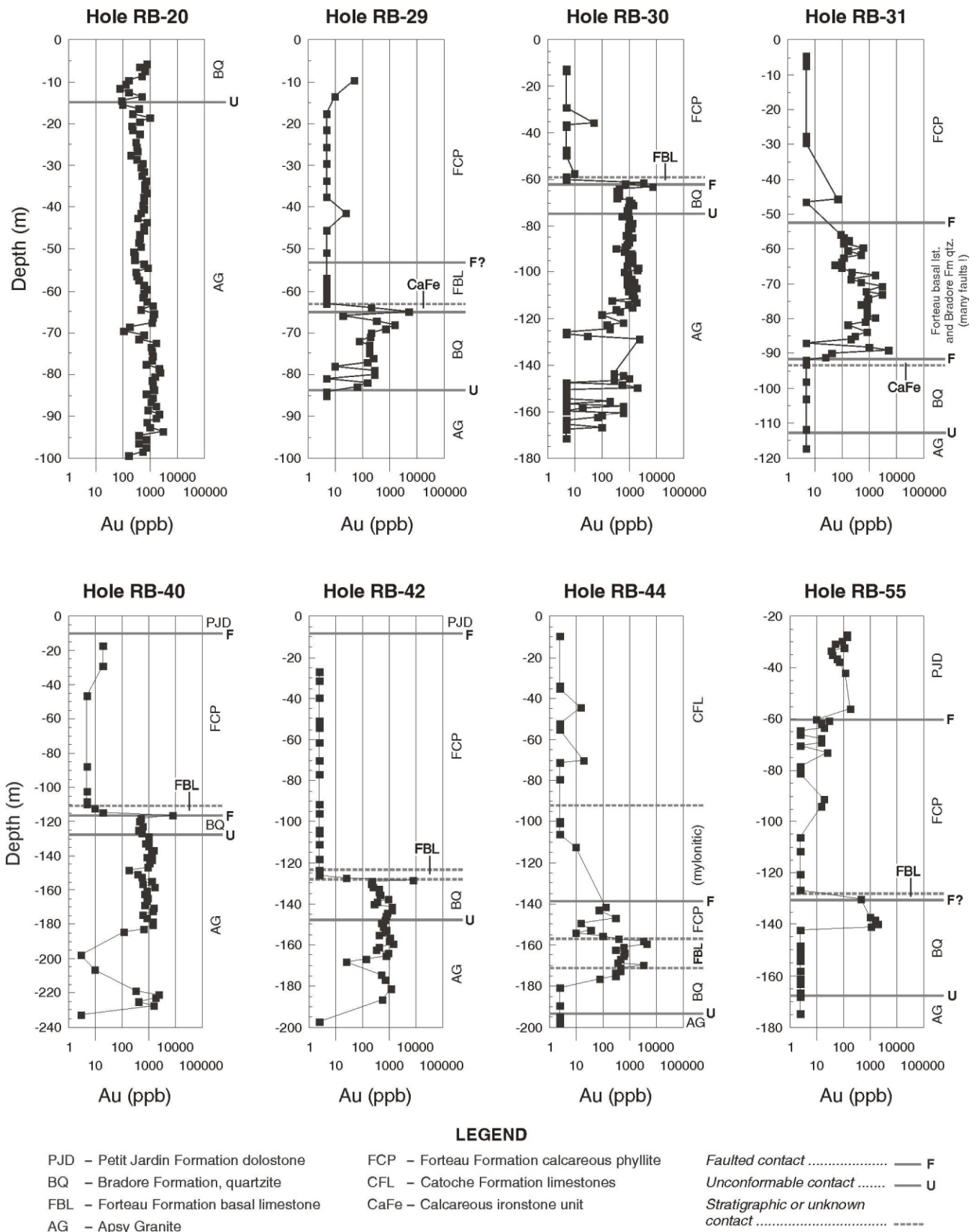
**Figure 9.** *Distribution of gold with depth in representative drillholes from the Apsy Zone, showing the relationship between mineralization, geological units and structures.*
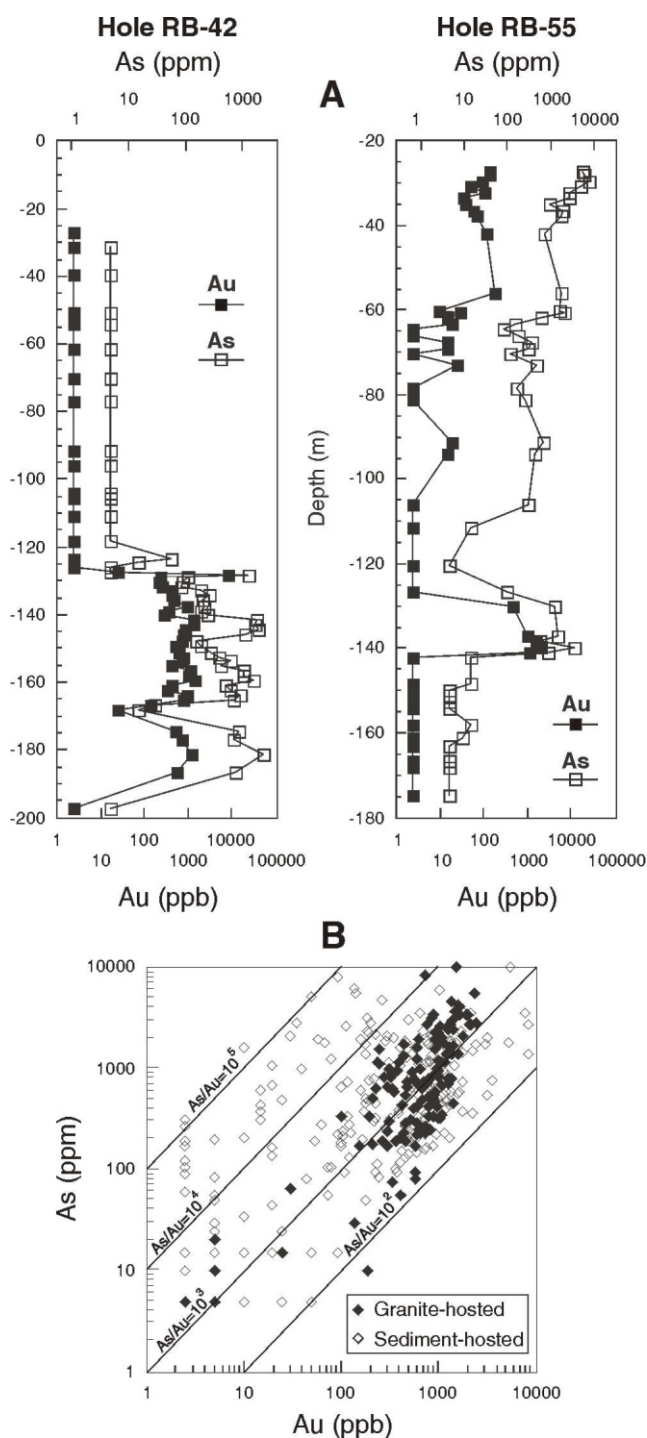
**Figure 10.** *Gold–arsenic correlations at the Beaver Dam Zone. (a) Profiles for holes RB-55 and RB-42, illustrating sympathetic behaviour. (b) Scatter diagram illustrating gold–arsenic correlation for the Beaver Dam Zone, using data from the drillholes indicated in Figure 9.*

careous phyllites, brecciated limestones and quartzites (Figures 5 and 9). This suggests that it is epigenetic, crosscuts lithological boundaries, and may at least, in part, be struc-

turally controlled. Nevertheless, the highest grade mineralization typically occurs at the Forteau–Bradore formational boundary, where Au appears to have been favourably deposited in iron-rich rocks. Poole (1991a, b) suggested that mineralization predated later motions along the fault zones, and this is certainly consistent with the general absence of mineralization to the east of them. An alternative explanation is that the massive recrystallized dolostones that dominate the hanging-wall sequences may have acted as a barrier to the movement of mineralizing fluids, and that mineralization was synchronous with or later than the faulting.

Third, gold mineralization is associated with fine-grained disseminated and veinlet-style pyrite, and generally resembles the mineralization observed in the adjacent granitoid rocks. Mineralization in quartzite and granite is physically continuous in some holes, and gold is strongly associated with arsenic in both environments (Figures 6 and 10), which suggests a genetic link. It is not yet possible to compare the alteration signatures of granitoid-hosted and sedimentary-rock-hosted mineralization, and this is a priority for further research. Given the evidence for potassium metasomatism associated with early alteration stages in the granites (Saunders and Tuach, 1991) similar effects might be anticipated in the sedimentary rocks, but they are not obvious to the naked eye. In the absence of any evidence for separate events or different styles of mineralization, it seems reasonable to assume that the granitoid-hosted and sedimentary-rock-hosted mineralization were produced by a single post-Cambrian hydrothermal system. However, the possibility that older Precambrian gold mineralization has been locally remobilized around younger faults cannot be completely excluded.

Fourth, and perhaps most importantly, the mineralization in the sedimentary rocks remains incompletely explored. Poole (1991b) noted that there was some potential for further work at the Beaver Dam Zone, and recommended more work in the Apsy Zone, which remains open to the north. On a regional scale, the potential host rocks extend for several kilometres (Figure 2) but have been tested only in two restricted areas. Prior to the 2003 program by Kermode Resources, no systematic exploration work had been carried out in the carbonate rocks to the east and north.

The absolute timing of the gold mineralization remains very poorly constrained, and is of significant interest. Tuach and French (1986) initially suggested that it was of late Precambrian age, but the 1987 discovery of gold in the Cambrian quartzites forced revision of this idea. Most subsequent interpretations (Tuach, 1987a; Saunders and Tuach, 1991; Saunders, 1991) suggest that gold mineralization throughout western White Bay, including that in the Sops Arm Group, was formed in a single Silurian or post-Silurian event, involving hydrothermal systems driven by late

granites, such as the Devil's Room Granite (Figure 1). Although mineralization in the Sops Arm Group must be Silurian or younger, there is still no direct evidence linking the Rattling Brook deposit to such an event.  There are also no younger, posttectonic felsic igneous rocks cutting either the Apsy Granite or the sedimentary rocks, although cross-cutting diabase dykes are common in the latter (Kerr and Knight, *this volume*). The evidence for a "younger magmatic connection" thus remains largely circumstantial. Direct dating of the mineralization, perhaps by using Re–Os studies of pyrite and arsenopyrite (e.g., Stein *et al.*, 2000; Arne *et al.*, 2001) would be the best approach, if feasible. The results from such a study could perhaps be linked to regional geochronological studies that might independently constrain deformational events (*see* Kerr and Knight, *this volume*).

Previous metallogenic interpretations suggested broadly mesothermal characteristics, citing high As, high Au/Ag ratios, high $CO_2$ contents in fluid inclusions, and intermediate pH alteration assemblages as evidence (Saunders and Tuach, 1991; Saunders, 1991). Recent exploration activity is driven by different exploration models based upon so-called "Carlin-type" gold deposits, which represent a very important resource of gold in the western United States and elsewhere (e.g., Arehart, 1996; Hofstra and Cline, 2000). A detailed review of Carlin-type gold deposits is well beyond the scope of this report, but some features of mineralization described above are broadly consistent with such classification. These include the impure carbonate host rocks, high Au/Ag and high Au/base-metal ratios, an association with disseminated pyrite, and the strong correlation of gold and arsenic. Wilton (2003) provides a lengthier evaluation of the possible potential of this area for Carlin-type deposits, but notes that several important types of data are presently lacking or of very limited extent. These include information on sulphide and arsenide mineralogy, associated trace-metal enrichment patterns, and the alteration processes in the sedimentary host rocks. Future research planned for this project will endeavour to provide information on these key issues, and further evaluate the applicability of Carlin-type deposit models for future exploration in western White Bay.

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