British Columbia Geological Survey
Geological Fieldwork 1997

EPITHERMAL GOLD DEPOSITS OF THE QUEEN CHARLOTTE ISLANDS

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KEYWORDS: Queen Charlotte Islands, Tertiary magmatism, gold, mineral deposits, epithermal veins, hot spring deposits.

INTRODUCTION

The Queen Charlotte Islands (QCI), located off the west coast of British Columbia (Figure 1), host a variety of mineral deposit types including skarns, precious metal veins, hot spring gold, perlite, bentonite, alluvial sands and coal. Since the 1970s most of the mineral exploration effort has been directed towards finding gold-rich deposits on the Islands. Descriptions of many of the mineral occurrences are documented in company assessment reports and have been incorporated into MINFILE, the provincial mineral occurrence database. This information is used in this article, in conjunction with the wealth of geological and geochronological data produced by the Frontier Geoscience Program of the Geological Survey of Canada (Woodsworth, 1991), to reassess the setting and potential of the gold and silver-bearing mineral occurrences.

The structural controls, host rocks and age dates associated with the precious metal occurrences on the Queen Charlotte Islands are interpreted to link almost all of them to Tertiary volcanic and intrusive rocks. This relationship can be used to explain many of their characteristics and to model the different styles of mineralization. There is considerable potential to discover new precious metal deposits on the QCI, particularly if the prospective areas with relatively limited outcrop and dense vegetation cover are reevaluated.

REGIONAL GEOLOGY

The Queen Charlotte Islands are located along the margin of the North American plate which is bounded to the west by the Queen Charlotte dextral transform fault and the Pacific plate (Irving, Souther and Baker, 1992). The oldest reported rocks on the islands are Permian sediments (Hesthammer *et al.*, 1991) which are very restricted in extent. Volcanic rocks of the Late Triassic Karmutsen Formation are a widespread succession of tholeiitic pillow basalts and breccias that are approximately 4 000 metres thick (Sutherland Brown, 1968). Overlying the Karmutsen Formation are Triassic to Early Jurassic sediments and limestones of the Kunga Group, Early Jurassic sediments of the Maude Group and Middle Jurassic sedimentary and volcanic rocks belonging to the Yakoun Group; all these units are regionally extensive. On the other hand, the Early Cretaceous clastic sediments of the Longarm Formation and Cretaceous Queen Charlotte Group sediments and minor mafic volcanic rocks are more restricted in extent. Unnamed Tertiary volcanic and sedimentary rocks occur throughout the Queen Charlotte Islands (Figure 2, Lewis *et al.*, 1991). Tertiary Skonun Formation sediments and the mainly Miocene Masset Formation volcanic flows and pyroclastic rocks are restricted to the northern half of the archipelago. Cenozoic sedimentary rocks are present throughout the Queen Charlotte Basin (Figure 1) that is interpreted to be a Tertiary extensional basin which is now largely below sea level (Yorath and Chase, 1981, Irving, Souther and Baker, 1992). The reader is referred to summary volume for the Frontier Geoscience Program (Woodsworth and Tercier, 1991) for up-to-date descriptions and interpretations of many of the units described above.

The Cretaceous and older rocks are variably deformed and can be subdivided into discrete structural domains separated by major faults. The older rocks are cut by Tertiary plutons and dike swarms and overlain unconformably by Tertiary volcanics and sediments and/or Quaternary sediments (Sutherland Brown, 1968; Hickson, 1991).

The stratigraphy is intruded by the Middle Jurassic San Christoval and Burnaby Island plutonic suites and the Tertiary Kano Plutonic Suite and dikes (Anderson and Reichenbach, 1991). The Burnaby Island Plutonic Suite, which is commonly intensely fractured and hydrothermally altered, is believed to be the source of fluids that formed the numerous iron and base metal skarns that are found proximal to these intrusions (Anderson, 1988). Various company reports show that some Tertiary dikes and intrusions are strongly altered to disseminated pyrite and other minerals and can have zones with anomalous gold, or rarely, copper concentrations.

The Tertiary volcanic rocks and related intrusive rocks formed from Eocene to Miocene time. The analysis of a suite of Tertiary igneous samples using U-Pb isotopic dating by Anderson *et al.* (1995) has distinguished four pulses of Tertiary magmatism - Middle Eocene, Late Eocene, Early Oligocene and Late Oligocene. The age dates show that the locus of magmatism generally migrated northwesterly over time, a point first made by Young (1981). Therefore, erosion has generally exposed increasingly deeper stratigraphic levels and more intrusive rocks in the southern islands of the QCI archipelago.

The Late Tertiary Skonun Formation consists of marine and non-marine sand, sandstone, shale and conglomerate (Sutherland Brown, 1968). In some locations it overlies volcanic rocks of the Masset Formation; however, the deeper, older units are believed to be coeval (Lewis *et al.*, 1991).

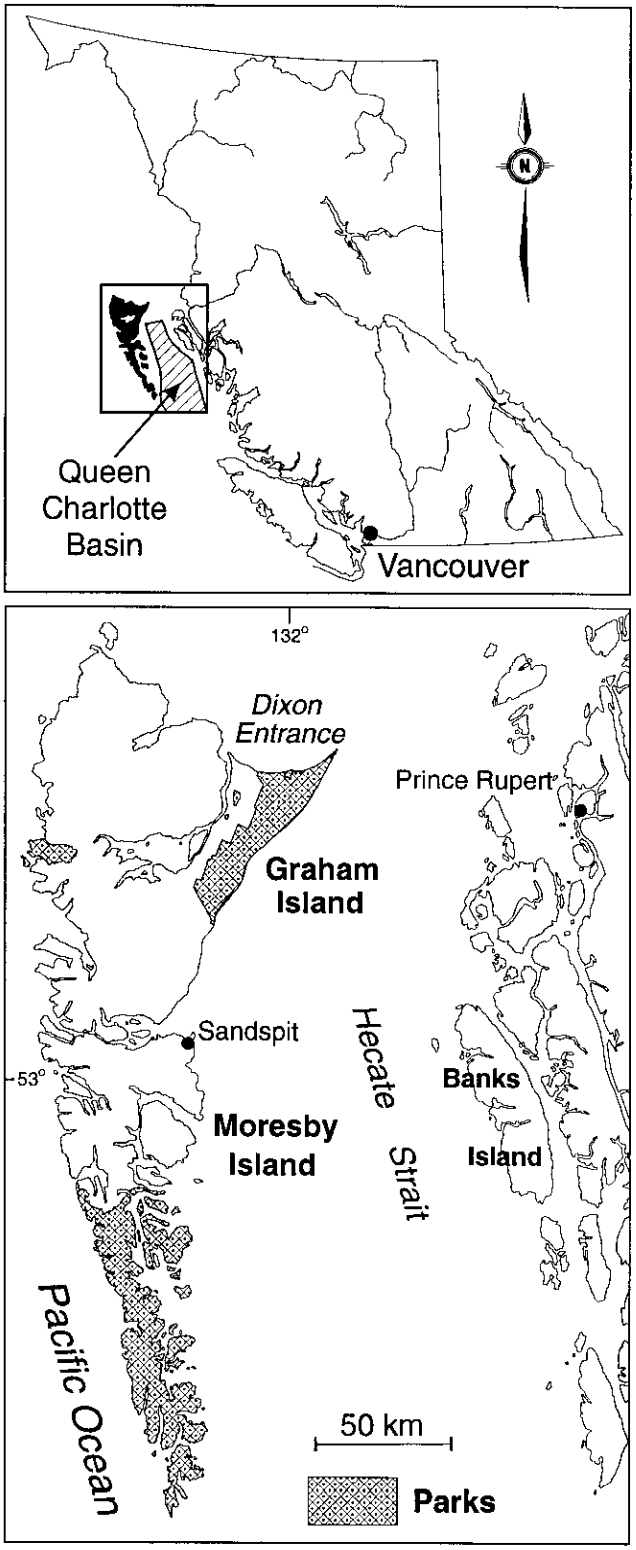

Figure 1. Location of Queen Charlotte Islands.

TERTIARY MAGMATIC SUITE

Tertiary Intrusive Suite

Kano Plutonic Suite

The Kano Plutonic Suite (KPS), a series of small monzodiorite, diorite and granite stocks, crop out on the east and west coasts of Moresby Island and the west coast of Graham Island (Figure 3). These Late Eocene to Oligocene epizonal plutons are seriate to porphyritic, homogeneous, and commonly contain miarolitic cavities (Anderson and Reichenbach, 1991). Some KPS intrusions exhibit hypabyssal textures and intrude Tertiary volcanic rocks, both characteristics of a relatively high level of emplacement.

Tertiary Dike Swarms

Numerous Tertiary dikes are found throughout the QCI (Sutherland-Brown, 1968); they are typically steeply dipping to vertical, vary from less than a metre to 20 metres in thickness, and can form composite dikes up to 100 metres wide (Souther and Jessop, 1991). Columnar jointing perpendicular to flow contacts occurs in many dikes while others exhibit marginal flow banding. The dikes are often concentrated in broad regional swarms that are from 10-20 kilometres across and up to 40 kilometres long. Within a swarm, the dikes display a dominant trend with relatively minor variation. Souther and Jessop (1991) identified seven major swarms called informally the Rennell Sound, Selwyn Inlet, Tasu Sound, Lyell Island, Bigsby Inlet, Burnaby Island and Carpenter Bay dike swarms. New mapping indicates a north-northwesterly trending sheeted dike swarm near Redtop Mountain, that cuts across the east-trending Selwyn Inlet dike swarm, is related to the Tasu Dike swarm (Anderson *et al.*, 1995). Towards the centre of some swarms, dikes coalesce into sheeted complexes with associated KPS plutons. The best examples of these "central igneous complexes" are at Carpenter Bay, Lyell Island and southern Louise Island (Souther and Jessop, 1991).

The dikes are frequently aphanitic to weakly phyric. Most are basaltic to andesitic in composition, but there are some dacites and rhyolites. Detailed mapping by Souther and Jessop (1991) established that the dikes comprise from 1 to 7% of the rock exposed across a transect of a particular dike swarm. The dikes have experienced relatively little deformation - minor offsets on faults or possibly minor post-emplacement tilting. The dike swarms formed during periods of extension and strike north, northwesterly, northeasterly and easterly. Souther and Jessop (1991) describe alteration associated with dikes in the Renell Sound, Bigsby Inlet, Selwyn, Lyell Island, Burnaby Island and Carpenter Bay swarms. Some dikes

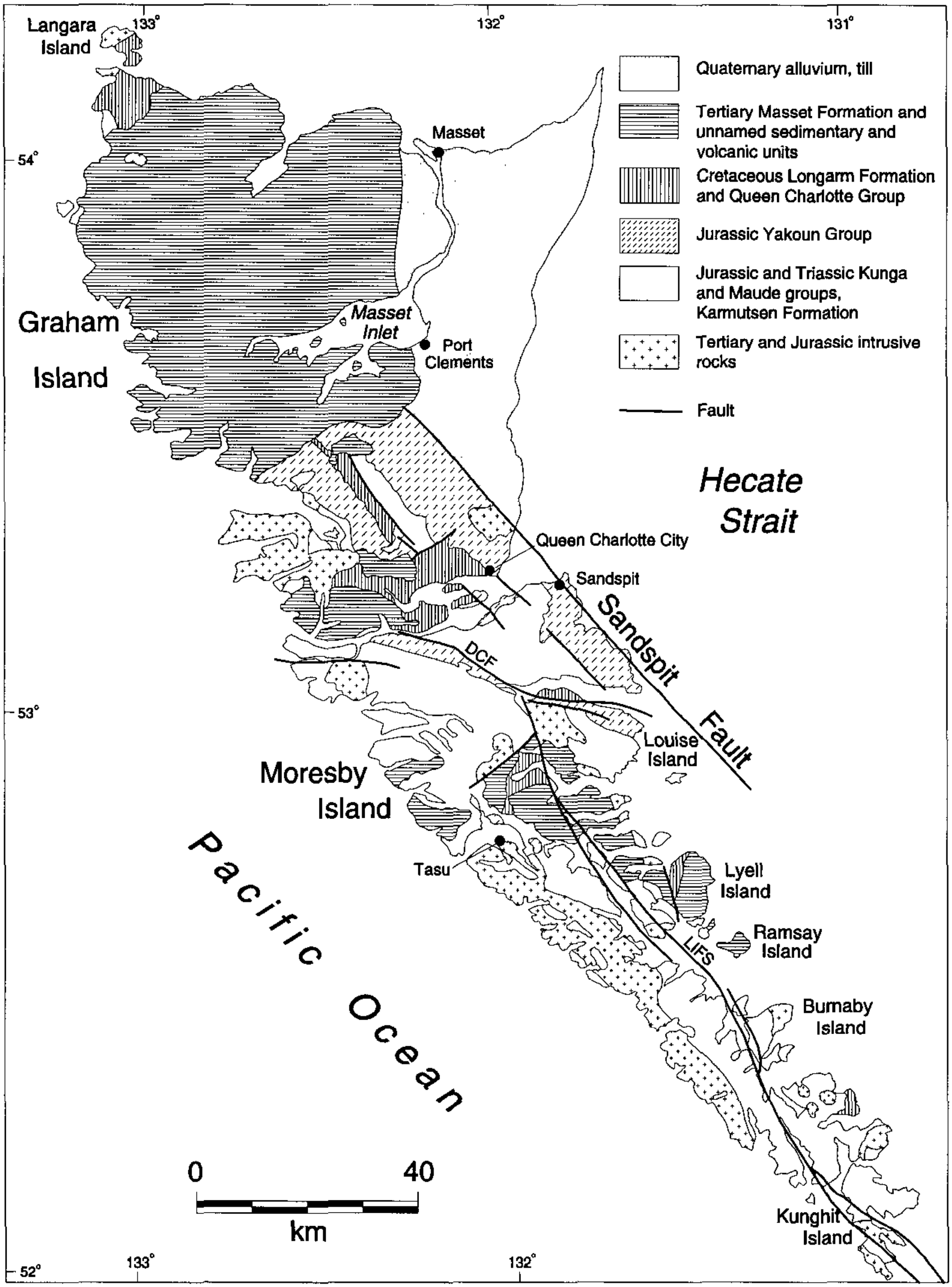

Figure 2. Simplified geology map of the Queen Charlotte Islands, from Lewis *et al.* (1991). DCF- Dawson Cove fault, LIFS - Louscoone Inlet fault system.

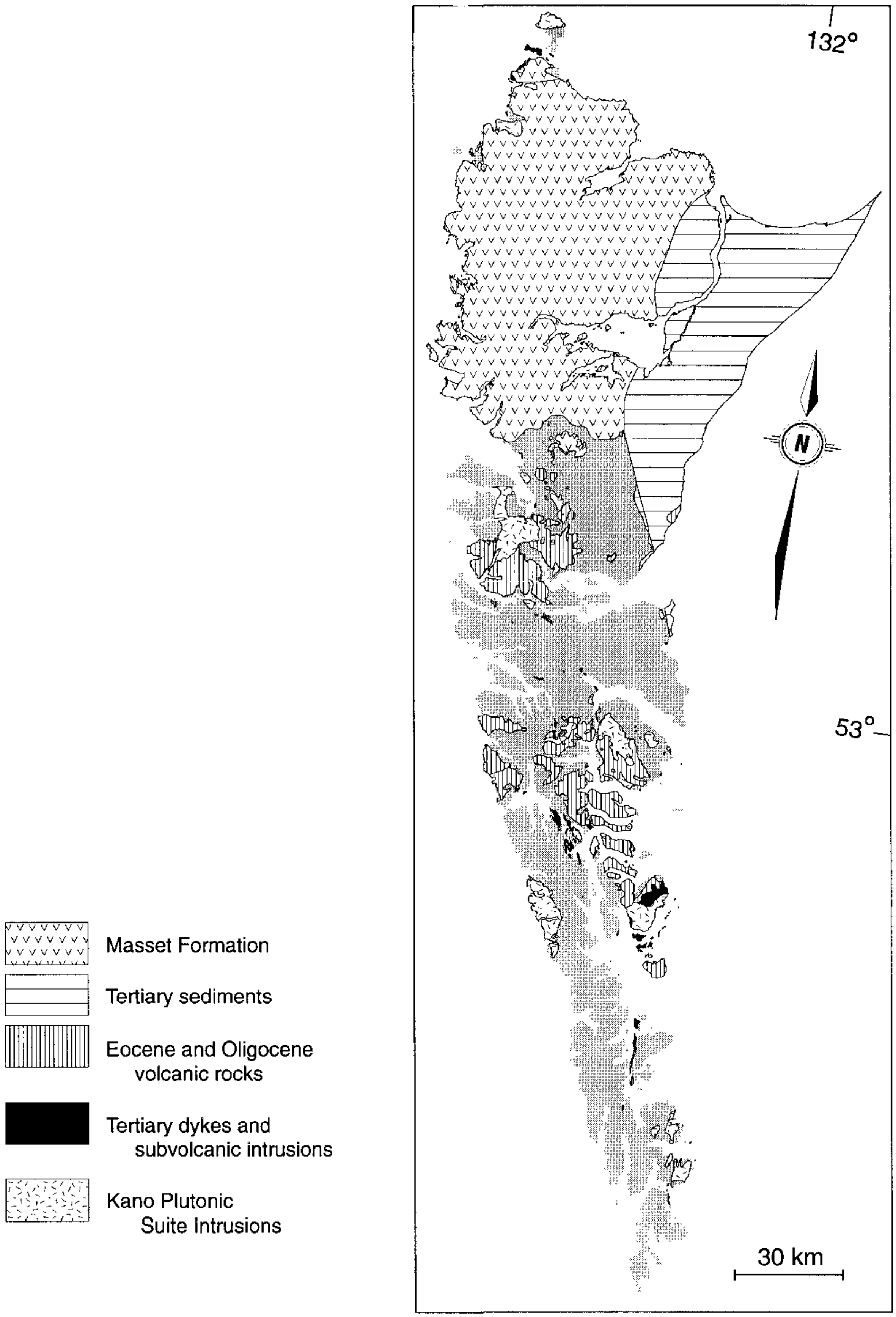

Figure 3. Tertiary Geology of the Queen Charlotte Islands.

are altered to a variety of minerals including disseminated pyrite, quartz, zeolites and carbonates.

The composition and spatial distribution, as well as a number of age dates link the dike swarms to Tertiary volcanism and the KPS (Anderson and Reichenbach, 1991; Souther and Jessop, 1991). As such, the KPS stocks and, in some cases, dikes represent the subvolcanic intrusions which lay beneath Tertiary volcanic accumulations that have been largely eroded.

Tertiary Volcanic Rocks

A mixed suite of Tertiary mafic and felsic volcanics occurs throughout the northern two-thirds of the Queen Charlotte Islands, with the greatest volume on Graham Island (Sutherland Brown, 1968). These volcanic rocks consist of columnar basalt flows, mafic breccias, felsic lava flows and pyroclastic rocks and are cut by intimately related hypabyssal intrusions (Sutherland Brown, 1968; Souther, 1991, 1993). The volcanics are predominantly subaerial in character; submarine textures have only been noted locally. The flows are subhorizontal and believed to be largely undeformed, although some post-emplacement tilting may have taken place (Hickson, 1991). While Sutherland Brown identified three different facies, a regional Tertiary volcanic stratigraphy has not been developed due to numerous local variations (Souther, 1993; Hickson, personal communication, 1997).

Earlier workers included all the Tertiary volcanic rocks in the Masset Formation (Sutherland-Brown, 1968 and Cameron and Hamilton, 1988). More recently Hickson (1991) restricted the Masset Formation to aphyric to sparsely phyric, calc-alkaline volcanics and associated epiclastic sediments found on Graham Island. These volcanics are estimated to be about 3 000 metres thick. K-Ar and a few U-Pb age dates indicate that older Tertiary volcanic rocks are essentially coeval with the KPS and dike swarms (Anderson *et al.*,1995). The Masset Formation, as defined by Hickson, is currently interpreted to be Miocene in age (25 to 20 Ma) based on a large number of K-Ar dates.

Within the pre-Tertiary rocks of the Queen Charlotte Islands, only the western part of Moresby Island south of Bigsby Inlet is relatively free of Tertiary dikes and intrusions (Souther and Jessop, 1991). This suggests that the Tertiary volcanic rocks were originally considerably more extensive on Moresby Island than at present. Hickson (1991) believes that a significant portion of the western Masset Formation has been displaced north along the Queen Charlotte Fault to Alaska. Mafic volcanic rocks cropping out on islands on the eastern side of Hecate Strait have been equated by some with QCI Tertiary volcanic rocks because they are an equivalent age and have similar geochemistry and composition (Woodsworth, 1991). Possible Tertiary volcanic rocks have also been identified in drilling in Hecate Strait (Hyndman and Hamilton, 1991).

Several styles of volcanism are interpreted for the Tertiary volcanic units of the QCI based on their morphology, textures, distribution, relationship to structures and geochemistry. Jessop and Souther (1991) envisioned central volcanoes along a continental margin arc, like the Cascades, spaced approximately 30-50 kilometres apart. In an interesting extension to their model, Jessop and Souther (1991) integrated the dike swarms and "central intrusive complexes" into a three-dimensional model which suggested that the dikes extended possibly ten times as far laterally as vertically. In contrast, based on mapping on Graham Island, Hickson (1991) suggests that Masset volcanic centres were large, low profile shield volcanoes on the order of 20-30 kilometres in diameter and almost contiguous.

Tertiary Magmatic Suite Geochemistry

Initial petrographic and geochemical work on the Tertiary volcanic rocks by Sutherland Brown (1968) identified alkali basalts and sodic rhyolites. More recent work has identified a mixed parentage for the Tertiary igneous suite, which appears to be the product of both calc-alkaline and tholeiitic magmatism (Souther and Jessop, 1991). The Masset Formation has an orogenic, calc-alkaline to tholeiitic signature according to Hickson (1991). On the other hand, Hamilton and Dostal (1993) examined analyses from all the Tertiary rocks on the QCI and suggested the basalts are depleted oceanic tholeiites to variably enriched tholeiites which are often found in rifted continental margins and within-plate settings. They believe the dacites and rhyolites formed by fractional crystallization.

TERTIARY TECTONIC SETTING

During the Eocene to Miocene period in the Queen Charlotte Islands region, western North America was converging with the Farallon Plate to the west. Some workers believe the Tertiary magmatic rocks formed in a volcanic arc related to this convergence (Souther, 1991), possibly as part of the Pemberton Volcanic belt which extends from the Chilliwack Batholith in southern British Columbia to the QCI (Souther and Yorath, 1991). This arc is now represented by widely spaced epizonal plutons and deeply eroded volcanic piles.

A more complex interpretation of plate movements during the Eocene to Miocene period is tied to migration of the Farallon-Pacific-North American plate triple junction, which was close to the QCI during that time. One possibility is that the triple junction was north of the QCI until Early Miocene. This would result in back arc extension in the QCI Basin and an eastward shift in the Farallon-Pacific spreading axis with production of tholeiitic igneous rocks (Souther and Jessop, 1991). Alternatively, Hyndman and Hamilton (1991) suggested the Tertiary volcanism could result from oblique plate extension which would produce transcurrent movement along the continent margin and orthogonal extension inland.

QCI MINERAL OCCURENCES

More than 140 mineral occurrences are documented in the Queen Charlotte Islands in the provincial MINFILE database, including skarns, precious metal veins, perlite, bentonite, alluvial sands and coal.. Iron and copper skarns containing magnetite, chalcopyrite, pyrite and pyrrhotite are the most abundant mineral deposit type (Figure 4). The skarns are hosted mainly by Kunga Formation limestones and Karmutsen Formation mafic volcanics (Sutherland Brown, 1968: Ray and Webster, 1997). They are related, and found proximal, to intrusions of the Late Jurassic Burnaby Island Plutonic Suite (Anderson, 1988). The only major mineral production in the QCI has been from these skarns. Between 1914 and 1983 the Tasu mine produced 20.8 Mt containing 12.2 Mt of iron, 59 866 tonnes of copper, 50 394 kilograms of silver and 1 339 kilograms of gold, while the Jessie deposit produced 3.9 Mt containing 2.1 Mt of iron (MINFILE). The skarns have attracted little exploration attention in recent years.

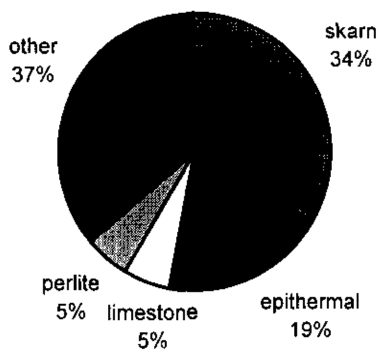

Figure 4. Relative abundances of the more common deposit types on the Queen Charlotte Islands.

A variety of epithermal precious metal occurrences, commonly associated with faults and/or Tertiary dikes, are the next most abundant style of mineralization on the QCI. Most of them have been found in the last thirty years. Higher grade mineralization is typically confined to quartz veinlets, veins and stockworks, while some alteration zones contain approximately one or more grams per tonne gold over tens of metres. Disseminations and occasional veinlets of fine grained pyrite and arsenopyrite are found in almost all the veins and often occur in the associated wallrock alteration zones. Many occurrences have associated broad zones of silicification and/or clay alteration with geochemically anomalous gold and arsenic values.

These precious metal occurrences are both epithermal hot springs and veins. The differences between these two styles of mineralization relate primarily to the original depth of emplacement in the earth's crust. Hot spring gold occurrences formed near, or at the surface, while epithermal gold-silver veins formed at up to a kilometre below the surface (Panteleyev, 1991). Epithermal and hot spring deposits can generally be distinguished from each other by their mineralogy, form, alteration, geochemistry and Au:Ag ratios. These precious metal deposit types continue to attract exploration attention and are discussed in more detail below.

There are a number of other mineral deposit types on the QCI (Table 1), including possible mesothermal gold-bearing quartz veins, volcanic redbed copper (basaltic copper) occurrences hosted by Triassic volcanic rocks, placer gold and heavy mineral accumulations, coal and a variety of industrial mineral deposits (Sutherland Brown, 1968). The Early Bird was the first lode mine in British Columbia and produced 171 tonnes grading 51 g/t gold and 7.3 g/t silver. Along with the Haida Gold and Highgrade occurrences, the Early Bird is interpreted to be a mesothermal gold-bearing quartz vein. These veins may

Table 1. Number of occurrences of different deposit types in the MINFILE database for the Queen Charlotte Islands.

Deposit Type	No. of Deposits	Deposit Type	No. of Deposits
iron skarn	25	porphyry (?)	2
copper skarn	23	polymetallic veins Ag-Pb-	1
garnet skarn	1	porphyry Cu±Mo±Au	1
epithermal hot spring Au-Ag	17	carbonate-hosted disseminated	1
epithermal Au-Ag: low	7	oil shale	2
epithermal Au-Ag - unassigned	4	bitumen, tar seeps	2
epithermal manganese	1	peat	1
limestone	8	bentonite	1
perlite	8	sedimentary kaolin	1
coal	7	diatomite	1
volcanic redbed copper (basaltic	5	agate	1
marine placer	5	hot spring	1
gold-quartz veins	2	unclassified	16

Table 2. MINFILE occurrences of the Queen Charlotte Islands of presumed Tertiary age. The status of the occurrence is classified as follows: S - showing, P - prospect, DP - developed prospect and PP - past producer. Some host lithologies could not be determined and this is indicated by the abbreviation N/D.

	Name	MINFILE No.	Status	Deposit Type	Host Lithology
1	April	103B 064	P	hot spring Au-Ag	Tertiary volcanics
2	Gumbo	103F 001	S	hot spring Au-Ag	Yakoun Group
3	Point	103F 002	S	hot spring Au-Ag	Tertiary Masset, rhyolite tuffs
4	Courte	103F 003	S	hot spring Au-Ag	Yakoun volcanics
5	Needles	103F 006	S	hot spring Au-Ag	Yakoun volcanics and sediments
6	Stib	103F 009	S	hot spring Au-Ag	Yakoun volcanics and sediments
7	Marie Lake	103F 010	S	hot spring Au-Ag	Kano intrusives
8	Marie Lake	103F 011	S	hot spring Au-Ag	Tertiary Masset felsic pyroclastics
9	Dome	103F 027	S	hot spring Au-Ag	Masset Formation
10	Specogna (Cinola)	103F 034	DP	hot spring Au-Ag	Skonun and Skidegate Formation
11	Inconspicuous 4	103F 043	S	hot spring Au-Ag	Masset - andesite and
12	Inconspicuous 6	103F 044	S	hot spring Au-Ag	Masset Formation
13	Bateaux (B & D)	103F 049	S	hot spring Au-Ag	Tertiary volcanics?
14	Marino	103G 008	S	hot spring Au-Ag	N/D
15	Bella	103G 028	S	hot spring Au-Ag	Tertiary volcanics?
16	SHG	103C 007	S	hot spring Au-Ag?	Kunga limestone
17	Ellen	103B 012	PP	hot spring Au-Ag?	Karmutsen Formation
18	Carpenter	103B 056	S	epithermal Au-Ag	Yakoun Group
19	Crescent	103B 062	S	epithermal Au-Ag	Yakoun volcanics
20	Colinear Creek	103B 068	S	epithermal Au-Ag	N/D
21	Security (AB)	103F 028	S	epithermal Au-Ag	Karmutsen Formation
22	Security (Overproof)	103F 029	S	epithermal Au-Ag	Yakoun Group, Karmutsen
23	Security (B)	103F 033	S	epithermal Au-Ag	fault breccia
24	Seven	103F 045	S	epithermal Au-Ag	Yakoun volcanics
25	Cumshewa (L.1223)	103G 009	S	epithermal Au-Ag	Yakoun Group
26	Locke	103B 066	S	unassigned epithermal	Kunga Group, Karmutsen
27	Bateaux (C)	103F 042	S	unassigned epithermal	Karmutsen volcanics
28	Bateaux (A)	103F 050	S	unassigned epithermal	N/D
29	Baxter Creek (Snow)	103G 005	S	unassigned epithermal?	N/D
30	Shag Rock	103K 001	P	epithermal Mn	Masset Formation
31	Alder Gold	103B 007	S	carbonate-hosted Au-Ag	Kunga, Yakoun, Kartmutsen
32	Brendar	103F 032	S	porphyry	West Kano pluton
33	Raspberry Cove	103B 055	S	porphyry Cu±Mo±Au	Kano Pluton
34	Blackwater Creek	103F 024	S	bentonite	Tertiary Masset, rhyolite
35	Yakoun River	103F 025	S	diatomite	Skonun sediments
36	Cape Ball	103G 003	S	agate	N/D
37	Ironside Mountain	103F 019	S	perlite	Tertiary Masset, rhyolite
38	Coates Creek	103F 020	S	perlite	Tertiary Masset, rhyolite
39	Skelu Bay	103F 021	S	perlite	Tertiary Masset, rhyolite
40	Blackwater Perlite	103F 022	S	perlite	Tertiary Masset, rhyolite
41	Canoe Creek	103F 023	S	perlite	Tertiary Masset, rhyolite
42	Ship Kieta Island	103F 036	S	perlite	Tertiary Masset volcanics
43	Juskatla Inlet	103F 037	S	perlite	Tertiary Masset volcanics
44	Florence Creek	103F 053	S	perlite	Tertiary Masset volcanics
45	Skonum Point	103K 002	P	coal	N/D
46	Ramsay Island	103B 005	S	bitumen	Tertiary volcanics
47	Tian Point	103F 048	S	bitumen	N/D

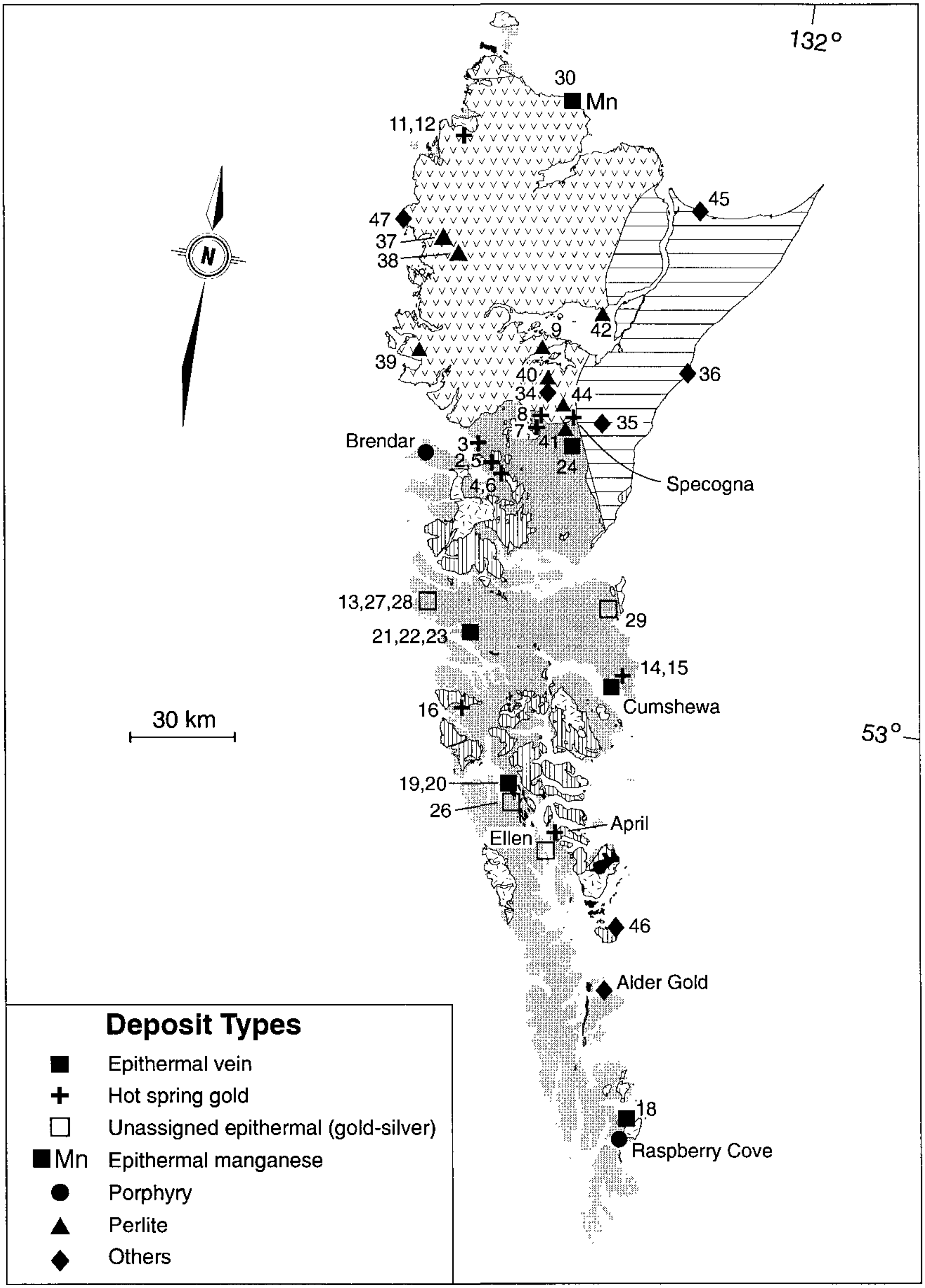

Figure 5. Tertiary Mineral Occurrences on the Queen Charlotte Islands. See Figure 3 for geological legend. See Table 2 for names of numbered mineral occurrences.

be Tertiary or older. Although polymetallic veins constitute more than 20% of the known mineral occurrences in British Columbia, the QCI has only one known example, the Southeaster. It was developed with underground workings in the 1920s and 1930s and produced 459 tonnes grading 2.8 g/t gold and 1.8 g/t silver with minor copper and lead (MINFILE).

TERTIARY MINERAL OCCURRENCES

Over 40 mineral occurrences on the Queen Charlotte Islands are interpreted to be have formed at the same time as the Tertiary volcanism (Table 2, Figure 5). Their ages are inferred from the geology of the occurrences, the age of the host rock, the association with Tertiary structures and the absence of any younger igneous events. Champigny and Sinclair (1982) obtained two K-Ar age dates of 14 Ma for silicified and sericitized porphyrytitic rhyolite from the Specogna (also called Cinola or Babe) deposit. They interpret the dates as the minimum age of the emplacement of the rhyolite and the timing of the mineralization. Since there are no other published dates from mineral occurrences, it is fortunate that there are numerous dates on the associated Tertiary magmatic suite that provide quantitative constraints on the age of mineralization. The following discussion focuses on the precious metal occurrences, but includes a brief discussion of several porphyry occurrences.

Information concerning the Tertiary precious metal occurrences are available in company reports filed with the provincial government for assessment credits and distributed on microfiche. Several articles and one thesis have been published on the Specogna deposit which provide more complete descriptions of this deposit (Champigny and Sinclair, 1980; Champigny, 1981; Christie; 1988; Tolbert and Froc, 1988). It is worth noting that many of the occurrences have high Au:Ag ratios, hence exploration geologists frequently reported only the gold values from bedrock samples described in these reports.

Hot Spring Au Occurrences

The following description of hot spring precious metal deposits is drawn largely from work by Panteleyev (1991, 1996). For more information, the reader is referred to articles by Sillitoe (1993), White (1981) and Lehrman (1986). Hot spring deposits consist of chalcedonic silica and fine-grained quartz in veins, stockworks and breccias which commonly show evidence of multiple periods of fracturing and deposition. The mineralization is gold or electrum, often microscopic, which occurs with very fine grained, disseminated pyrite and marcasite. Stibnite, realgar and/or cinnabar can occur with the mineralization. The wallrocks are commonly strongly silicified with argillic or, less commonly, advanced argillic assemblages. Propylitic alteration occurs distal from, or deeper than the argillic assemblage. Hot spring deposits have relatively Hedenquist and Reid (1985) used Au:Ag ratios of more than 1 to 10 to separate hot spring deposits from epithermal veins.

Hot spring deposits form at the top of epithermal systems due to boiling of hydrothermal fluids at shallow depths and in hot springs at surface. The hydrothermal fluids tend to follow faults or fractures, hydrothermal breccias and permeable stratigraphic units. The deeper hydrothermal fluid systems can be developed along active, high-angle faults and volcanic and subvolcanic intrusion-related structures. While individual veins can contain high grade, bonanza gold over narrow widths, these deposits are currently more attractive as lower grade, bulk tonnage targets which typically contain more than 10 Mt grading 1 to 2 g/t gold.

The Point, Courte, Stib, Marie Lake (Rockhound and Prospector showings), Specogna, Inconspicuous (4 and 6), Bateau (B & D), Marino, Bella, April and Dome can be classified as hot spring occurrences (Figure 5, Table 2). The majority of these occurrences are located on Graham Island and a few are found at the northern end of Moresby Island. The April mineralization is located on northern Lyell Island and inside South Moresby National Park. It is hosted by Tertiary pyroclastic rocks and significantly farther south than the other hot spring occurrences.

The Specogna is the only hot spring gold deposit on the QCI with calculated reserves. Current reserves are 31 Mt grading 2.05 g/t gold with a 1.2 g/t gold cut-off (News Release, May 12, 1997, Misty Mountain Gold Limited). Exploration in the late 1980s and early 1990s defined reserves of 40.7 Mt grading 1.65 g/t Au with a cutoff of 1.1 g/t Au (Tolbert and Froc, 1988). A bulk sample weighing 2.4 t shipped to the Tacoma smelter in 1975 contained 116.5 g/t gold, 52.1 g/t silver, trace quantities of copper lead and zinc and anomalous amounts of arsenic and bismuth (MINFILE). Within the larger deposit there are some veins which grade over 10 g/t gold. For descriptions of this deposit the reader is referred to Christie (1988) and Tolbert and Froc (1988).

A number of the hot spring occurrences are hosted by Tertiary volcanic or intrusive rocks and the Specogna deposit occurs in the Miocene to Pliocene Skonun Formation (Table 2). Given the inferred Tertiary age of the mineralization and shallow depths of emplacement required to form these deposits (usually less than a kilometre, Panteleyev, 1991), these strata are at the erosion level expected to host this style of mineralization. However, there are other hot spring gold occurrences which are hosted by Middle Jurassic Yakoun Group sediments or volcanics or the underlying Kunga Group limestone or sediments. The Bateau (B&D) occurrence is even cited as occurring in the Karmutsen Formation (Pattison, 1981), but this is likely incorrect as the company report cites felsic volcanics intercalated with the basalts. Felsic volcanics are common in the Tertiary sequence, but not found in the Karmutsen Formation (Sutherland Brown, 1968). These older host rocks could reflect the fact that the mineralization sometimes formed in areas with few or no Tertiary volcanic rocks.

The Specogna deposit and other hot spring occurrences in the QCI exhibit similarities in mineralogy, alteration, relationship to felsic volcanic activity and chemistry to the active geothermal system at Steamboat Springs in Nevada (White, 1981). For example, at Steamboat Springs the contemporaneous felsic volcanism is spatially restricted, strongly controlled by structures, and there are no extrusive igneous rocks in direct association with the top of the hot spring system. Stibnite occurs in veinlets and cavities to depths of 45 metres at Steamboat Springs and there is an absence of base metal sulphides. Gold, arsenic, antimony, mercury and thallium are anomalous in the upper parts of the of the Nevada geothermal system (drilling was to depths of 558 metres), while silver favours middle and deeper parts. Mercury is only found within 15 metres of surface.

Epithermal Vein Au-Ag Occurences

The other style of precious metal mineralization on the QCI that has attracted considerable exploration interest comprises gold and silver-bearing epithermal veins, stockworks and breccias. The Carpenter, Crescent, Colinear Creek, Security (AB), Security (Overproof), Security (B), Seven and Cumshewa (L. 1223) are classified as epithermal gold-silver occurrences based on MINFILE descriptions and assessment reports (Figure 5). All except for the Seven are located on Moresby Island, extending from near the southern tip to the northwest corner. The Seven is located south of Specogna on Graham island. The Cumshewa is the only occurrence with past mining activity. It was discovered in 1907 and 1,800 feet of underground development had been completed by 1913 (Sutherland Brown, 1968). Apparently a small quantity of hand-picked ore was shipped. Five MINFILE occurrences exhibit epithermal characteristics and are judged to be Tertiary age; however, they are poorly described and have not been assigned to specific deposit type (Table 2).

The epithermal vein occurrences are hosted by Yakoun Group sediments or volcanics, Karmutsen Formation volcanics, or in one case a fault breccia with fragments of Tertiary volcanics and Karmutsen basalt.

Porphyry Occurrences

Given the presence of relatively numerous Tertiary and Jurassic intrusions with coeval volcanic rocks, the Queen Charlotte Islands have remarkably few porphyry occurrences (Figure 5). The Brendar and Raspberry Cove occurrences are possible examples of porphyry mineralization that are hosted by Tertiary intrusions. There is also a quartz stockwork occurrence with molybdenite, pyrite and chalcopyrite, the Yakulanas, hosted by a middle Jurassic Burnaby Island Plutonic Suite intrusion.

The Tertiary igneous complexes identified by Souther and Jessop (1991) commonly have associated zones of hydrothermal alteration. They noted one such rusty brown weathering zone on southeastern Lyell Island associated with a large plagioclase quartz dacite porphyry unit which contains pyrite as disseminations and along fractures (rarely with bornite) and widespread epidote alteration (Anderson *et al.*, 1992).

The small number of Tertiary porphyry occurrences likely reflects the limited amount of erosion experienced by younger Tertiary rocks on the northern half of Moresby Island and on Graham Island. The preservation of fairly extensive Tertiary volcanic rocks in the QCI despite the relatively thin original accumulations (see below) is congruent with modest amounts of erosion since the Tertiary. As the Tertiary intrusions are small, often aphanitic to weakly porphyritic, and have been emplaced in an extensional environment, they may not have experienced much differentiation before solidification. This could also explain both the small number and limited development of the porphyry occurrences found to date.

There may be potential for intrusive-related gold deposits. For example, on the Bateau property the felsic dikes are reported to consistently carry high gold values (Lickley and Vincent, 1980). This association between anomalous gold values and Tertiary felsic intrusive rocks warrants further investigation.

Carbonate-hosted Au-Ag Occurrences

During the first years after its discovery, Specogna was thought to be a Carlin-type gold deposit because the mineralization is hosted by sediments, has a similar geochemical signature, and is a bulk tonnage, low grade gold deposit (Richards *et al.*, 1976; Champigny and Sinclair, 1982). Subsequent studies have shown that Specogna is a classic hot spring gold deposit (Christie, 1988). However, there are at least two carbonate-hosted gold occurrences on the Queen Charlotte Islands that represent possible Carlin-type deposits. The Alder Gold occurrence has visible gold with minor sphalerite within silicified Kunga Group limestone (Shearer, 1980), while the Locke showing, near Crescent Inlet, has anomalous gold in a jasperoid zone with disseminated pyrite and arsenopyrite. These small occurrences have not been well explored.

The style of mineralization appears to be disseminated pyrite within silicified Mesozoic sediments, primarily limestones, associated with regional and/or local faults. The most common host rocks are flaggy black limestone and limy argillites in the upper part of Kunga Group. These rocks are similar lithologies to the Roberts Mountain Formation, the main host of the Carlin-type deposits in Nevada (Teal and Jackson, 1997). There are other carbonate units in the Mesozoic sequence which could also be attractive host rocks for this style of mineralization (Lewis *et al.*, 1991).

EXPLORATION MODELS

During the 1970s and into the 1980s a number of major companies, including Chevron, City Resources, Energy Reserves, Placer, Noranda, Quintana Minerals and UMEX, and a variety of junior companies and prospectors carried out exploration programs for gold on the Queen Charlotte Islands. The geologists involved in these exploration plays were often using deposit models and exploration methodologies developed in the United States and/or the southwest Pacific to explore for Tertiary epithermal deposits. They were successful in identifying new occurrences (Richards *et al.*, 1979); unfortunately, very little information about the conceptual models employed by these prospectors and geologists was published.

Frederick Felder and geologists at UMEX had developed a model for gold mineralization related to Tertiary dikes. They recognized the importance of a variety of features, including altered hypabyssal dike swarms intruding variably altered Yakoun Formation rocks (referred to by Wilson *et al.*, 1986). The recognition of the importance of this relationship led to one of the exploration projects being called the Golden Dike property (Wilson *et al.*, 1986). Virtually all the companies were using anomalous gold, arsenic, antimony, mercury and silver values in stream sediments and soils to target areas of interest. As well, geologists were searching for silicification and clay alteration.

More recently, information from the Frontier Geoscience Program provides support for the correlation between felsic Tertiary intrusions and gold mineralization. Souther and Jessop (1991) analysed seven major dike swarms to determine a variety of characteristics, including the percentage of felsic dikes. The Carpenter Bay and Burnaby Island swarms contain 7 % felsic dikes, while the Lyell Island, Tasu Sound and Renell Sound swarms contain 8%, 15% and 19% respectively. In contrast the Selwyn Inlet swarm is mostly andesite and the Bigsby Inlet swarm contains only mafic dikes. The two dike swarms with no felsic dikes have no known gold occurrences, while all the other swarms, except Burnaby Inlet, have associated precious metal occurrences. Furthermore, Souther noted during his mapping that the felsic dikes were much more likely to be altered than the mafic dikes (personal communication, 1997).

The association between gold mineralization and felsic intrusions is perhaps the most important key to understanding the setting of these epithermal deposits. Sillitoe (1989) argues for a magmatic connection for gold deposits hosted by volcanic arcs in the western Pacific, which could explain the relationship. On the other hand the association could reflect only a common structural control for the igneous intrusions and precious metal mineralization. A simple schematic model for the epithermal mineralization in the QCI emphasizes the connection to Tertiary magmatism (Figure 6). It is similar to an unpublished conceptual section for the Specogna deposit prepared independently by Misty Mountain Gold Limited (1996).

TERTIARY METALLOGENY

Epithermal gold occurrences are found throughout the QCI and many are intimately related to Tertiary magmatism. This close spatial association suggests they formed at the same time. Descriptions of the deposits clearly demonstrate that many are related to felsic intrusive rocks, a relationship that was identified by exploration geologists in the 1970s and 1980s. Epithermal gold mineralization occurs in hot spring and vein environments and these grade into each other. Minor base metal mineralization occurs with the epithermal veins and several porphyry-style copper occurrences are hosted by the Tertiary Kano Plutonic Suite. The limited number of Tertiary porphyry occurrences in the QCI is believed to reflect both the limited depth of erosion and the style of magmatic activity. Given the anomalous levels of gold in some felsic aphanitic to phyric dikes, the KPS stocks may represent targets for low grade, bulk tonnage, intrusion-related gold deposits.

Since epithermal precious metal occurrences are found throughout the QCI and are related to Eocene to Miocene magmatism, it appears that conditions favourable for this style of mineralization existed for tens of millions of years. The mineralization and alteration are associated with the more differentiated, felsic Tertiary igneous rocks. Therefore, there could be a link between precious metal mineralization and more evolved igneous activity during this extended period, although not all these rocks are mineralized.

In contrast to many epithermal deposits which are hosted by roughly coeval volcanic rocks, the hot spring and vein occurrences on the QCI are often hosted by much older Jurassic rocks. This suggests that any Tertiary volcanic cover rocks in the immediate area of the occurrences must have been less than a kilometre thick at the time of mineralization. In fact, the lengthy dike swarms may have extended beyond the associated extrusive rocks, as suggested by Souther and Jessop (1991). Therefore, epithermal mineralization related to these dykes would be hosted by the Tertiary Skonun Formation sediments, like the Specogna deposit, or Cretaceous and older units. Since the Cretaceous rocks are not widely distributed in the QCI, this could explain the abundance of epithermal occurrences hosted by Jurassic rocks.

Geological criteria that can be used to identify prospective areas for hot spring deposits in the QCI are:

- permeable and/or porous host rocks
- Kunga Group or younger host rocks
- proximity to Tertiary structures
- existence of Tertiary intrusive rocks at depth
- large zones of silicification, extensive breccias or quartz stockworks which can form areas of positive relief
- gold occurrences with gold to silver ratios greater than 1:10
- presence of fine-grained pyrite ± marcasite and stibnite
- advanced argillic alteration
- anomalous mercury in rock, soil or stream sediment samples

Prospective areas for epithermal veins are likely to have some of the following characteristics:

- Cretaceous or older host rocks, typically the Jurassic Yakoun Group
- proximity to Tertiary structures
- evidence of Tertiary intrusive activity, particularly felsic dikes directly associated with mineralization
- envelopes of silicification, propylite and other alteration assemblages
- precious metal occurrences with gold to silver ratios of less than 1:10
- pyrite, arsenopyrite and minor base metal sulphides
- presence of quartz veins, veinlets and stockworks

As has been noted, both types of deposits share some characteristics and grade into one another. For example, stibnite occurs in both types, although it is more common in the hot spring gold deposits.

CONCLUSIONS

Tertiary intrusions and related volcanics in the Queen Charlotte Islands formed in an extensional environment which resulted in numerous dike swarms, small stocks and shield volcanoes. In some cases the magmatic suites evolved to felsic end members. Associated with some of the Tertiary magmatic events, particularly those with felsic dikes, are epithermal hot spring and vein gold-silver occurrences and porphyry-style mineralization. The relationships between these styles of mineralization are particularly well displayed in the QCI because the volcanic and intrusive rocks generally become older and more deeply eroded from north to south.

Using a combination of mineral occurrence descriptions and recently published geological data, it has been possible to construct a metallogenic model for the Tertiary gold mineralization on the Queen Charlotte Islands. In addition, there is interesting potential for carbonate-hosted gold deposits of the Carlin-type.

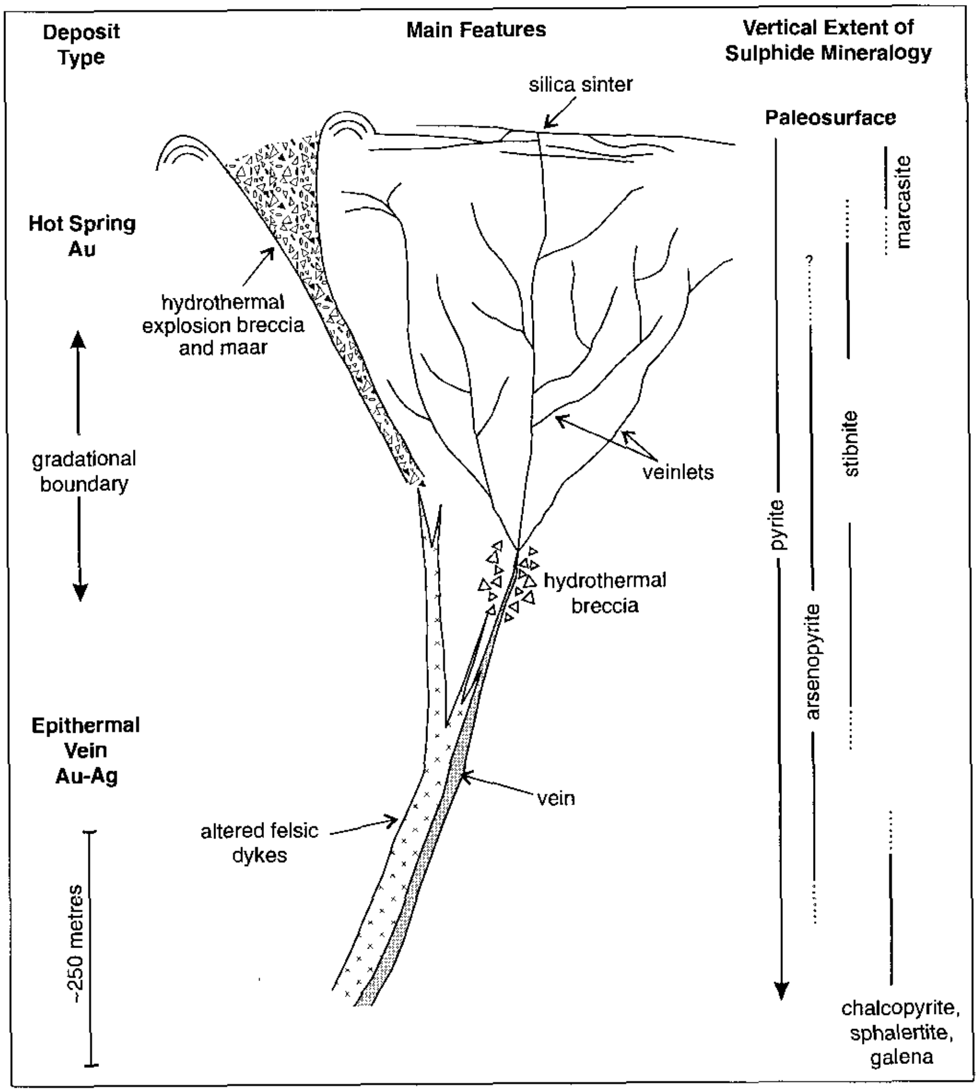

Figure 6. Schematic model of the epithermal precious metal mineralization on the Queen Charlotte Islands. More than one type of mineralization will not necessarily be present at a single locality. Figure modified from Berger and Simon (1983).

ACKNOWLEDGEMENTS

The author's personal knowledge of the Queen Charlotte Islands is limited to visits to the Specogna deposit and Cimodora occurrence. For this reason, discussions with geologists who have worked for industry and government on the QCI proved invaluable in writing this article. Bob Anderson of the Geological Survey of Canada (GSC) provided an insightful overview of the geology of the QCI and details of the plutonic rocks and their ages. Other members of the GSC, Tark Hamilton, Cathie Hickson and Jack Souther, shared their knowledge of the Tertiary volcanic rocks and tectonic setting of the QCI. A number of industry geologists shared their knowledge of specific mineral occurrences on the QCI, including James Christie, Frederick Felder, Barry Price and Joe Shearer.

Mike Fournier drafted the figures and worked to his usual high standards. Special filters provided by Ward Kilby for the digital geology and MINFILE databases expedited the research. The article benefited from reviews by Bob Anderson, Trygve Höy, Bill McMillan and Gerry Ray.

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