# Geology and Mineral Potential of the Southern Alexander Terrane and western Coast Plutonic Complex near Klemtu, Northwestern British Columbia

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*KEYWORDS:* Alexander terrane, Grenville Channel fault, Coast Mountains, Coast Plutonic Complex

## INTRODUCTION

Although the northern coastal area of British Columbia contains a significant number of tracts with high mineral potential assessments (Categories 1 and 2 out of 10; BC Mineral Potential Assessment Program; Kilby, 1995; see also Mineral Resources Assessment – Mineral Potential, on Mapplace.ca), mineral exploration has been at low levels, as indicated by the small number of assessment reports and recorded mineral showings. Just as it has received comparatively little exploration interest, this area also has not seen systematic public geological mapping since the original Geological Survey of Canada work in the 1960s (Roddick, 1970; Hutchison, 1982).

This report covers the second of a planned 3-year program study of the bedrock geology and mineral potential of the British Columbia North Coast area (Figure 1). The North Coast bedrock mapping and mineral deposit study is part of a cooperative, Natural Resources Canada (NRCan)-led endeavour, the *Edges Multiple Metals – NW Canadian Cordillera (British Columbia and Yukon) Project*. The Edges Project aims to increase our understanding of the far travelled lithotectonic terranes that make up the outer, accreted margin of the Canadian Cordillera and assess their metallic mineral potential (for a detailed project description see http://gsc.nrcan.gc.ca/gem/min/edges_e.php). Edges is a contribution to the GEM Program (Geo-mapping for Energy and Mineral), a federal program that was initiated in 2008, to enhance public geoscience knowledge of northern Canada in order to stimulate economic activity in the energy and mineral sectors. The Edges project is a collaboration between the Geological Survey of Canada, British Columbia Geological Survey, and Yukon Geological Survey and involves the United States Geological Survey and Canadian and American academic contributors.

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The northern coastal area of British Columbia is underlain in part by rocks of the southern Alexander terrane, a large composite crustal fragment that underlies most of southeastern Alaska and extends farther north into part of the St. Elias Range on the Yukon-Alaskan border, (Figure 1; Wheeler *et al.*, 1991). The Alexander terrane as a whole has attracted considerable exploration interest because of the volcanogenic massive sulphide deposits that it hosts, including Niblack and others on southern Prince of Wales Island, just north of the British Columbia-Alaska border, as well as a trend of Triassic deposits, notably Windy Craggy and the Greens Creek mine (Figure 1). In 2009, the first year of the North Coast project, geological mapping began on and near Porcher Island, at the northern end of Alexander terrane rocks along the north coast, in order to take advantage of proximity to the much better known stratigraphy in southeastern Alaska, and to nearby volcanogenic mineral deposits. Mapping in 2010 focused on the southern end of the terrane near Klemtu. In 2011, sparse exposures of pre-plutonic stratified rocks in the intervening region will be documented.

## PREVIOUS WORK

The northern coastal region of British Columbia was first mapped systematically as part of Geological Survey of Canada regional coverage of the entire Coast Mountains batholith and enclosed metamorphic rocks. The Porcher Island – Grenville Channel area was covered as part of the Prince Rupert – Skeena sheet (Hutchison, 1982) and the Douglas Channel – Hecate Strait sheet (Roddick, 1970), and the area around Klemtu as part of the Laredo Sound sheet (Baer, 1973), all at a scale of 1:250 000. The focus of these studies was on the plutonic rather than supracrustal rocks; in addition, modern tools for the analysis of metamorphosed volcanic and sedimentary sequences, including uranium-lead geochronology and trace element geochemistry, were not available at that time. Recent geological work in the northern coastal region of British Columbia has focused on understanding the structural and igneous history of the

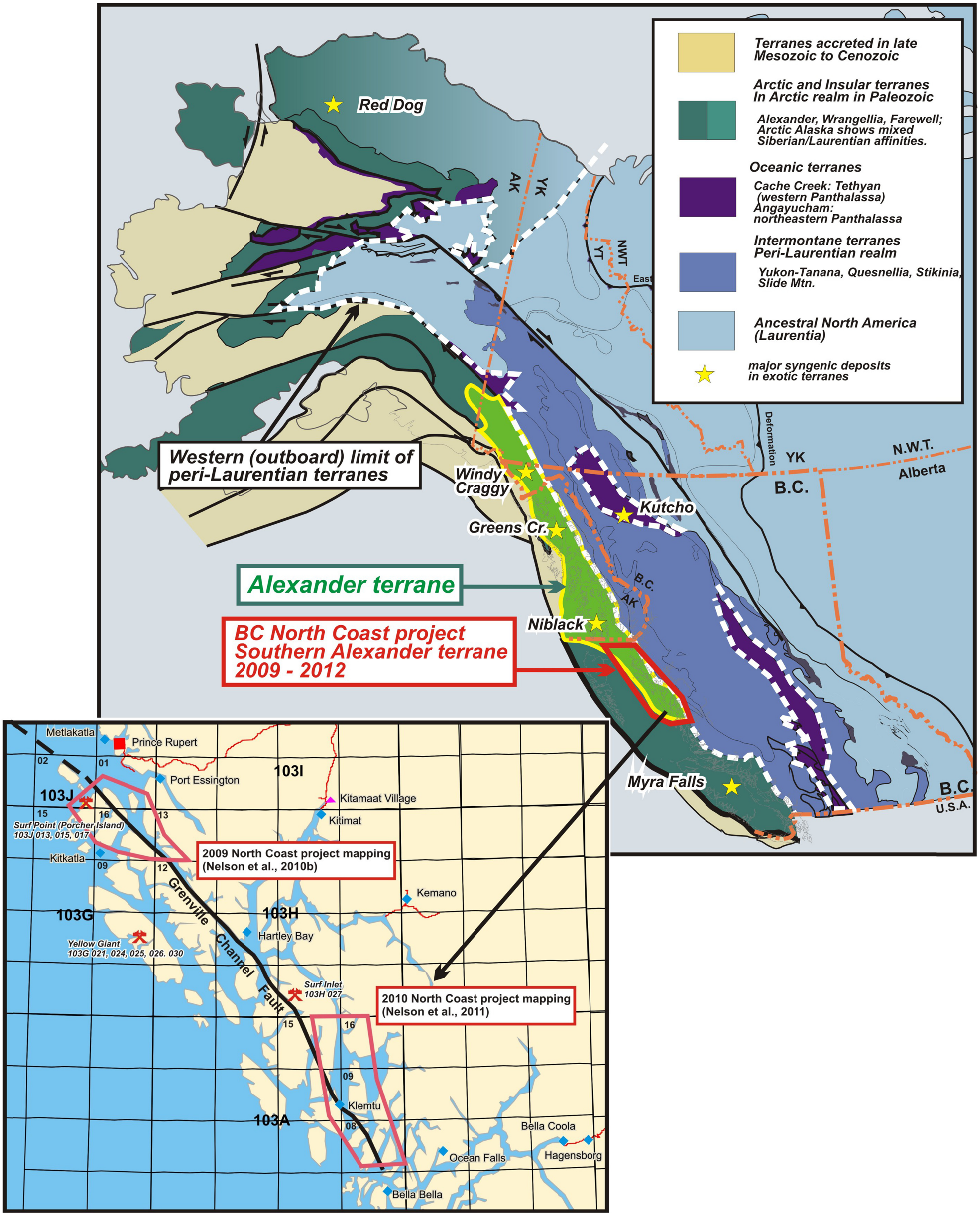


**Figure 1.** Location of the North Coast project in the context of northern Cordilleran terranes and in terms of local geography. Inset shows 2009 and 2010 field map footprints. Also shown on inset: trace of Grenville Channel fault, and location of major gold deposits.

Coast Mountains orogen. Within the North Coast project area, Porcher Island and Grenville Channel have been visited by researchers in the course of much broader structural studies and plutonic syntheses (Chardon *et al.*, 1999; Chardon, 2003; Butler *et al.*, 2006; Gehrels *et al.*, 2009). Detailed geology, in particular the pre-batholithic stratified rocks of the Alexander terrane, have not been thoroughly investigated. The sole exception to this is the ongoing, mostly unpublished, regional geologic work of George Gehrels, part of which is summarized in Gehrels (2001) and Gehrels and Boghossian (2000).

## REGIONAL GEOLOGICAL SETTING

The Alexander terrane (Wheeler *et al.*, 1991), which forms the principal focus of this project, is flanked by variably metamorphosed and deformed metasedimentary-metavolcanic rock units that comprise the Banks Island assemblage to the west, and the Gravina belt and the Yukon-Tanana terrane to the east (Figure 2). With the exception of the Banks Island assemblage, which has only been recognized along the outer coast of northern British Columbia, these terranes continue northward into adjacent portions of southeastern Alaska, where equivalents have been described by Gehrels and Saleeby (1987; 1996), Rubin and Saleeby (1992), Saleeby (2000), and Gehrels (2001).

### *Alexander terrane*

The Alexander terrane in southeastern Alaska and northern coastal British Columbia consists of a broad range of volcanic, sedimentary, and plutonic rocks and their metamorphic equivalents that are primarily of early Paleozoic age, overlain in places by thin younger sequences (Figure 3). In southeastern Alaska, these rocks have undergone limited post-Paleozoic metamorphism, deformation, and plutonism. Farther to the southeast, in northern coastal British Columbia, Cretaceous plutons become more widespread and the degree of Mesozoic deformation and metamorphism increases. In spite of these younger overprinting events, it is possible to correlate geologic units of southeastern Alaska with those of northwestern coastal British Columbia, and as such we use the nomenclature established in southeastern Alaska wherever possible. The following unit descriptions are taken from the well-preserved portion of the Alexander terrane in southern southeastern Alaska as decribed in Eberlein *et al.* (1983), Gehrels and Saleeby (1987) and Gehrels *et al.* (1996).

The oldest rocks recognized in the Alexander terrane consist of Late Proterozoic to Cambrian metavolcanic and metasedimenary assemblages of the Wales Group (Figure 3; Gehrels and Saleeby, 1987). Metavolcanic components range from mafic to felsic in composition, with lithic units ranging from metres to hundreds of metres in thickness. Relict textures indicate that protoliths of these rocks were pillowed flows, flow breccias, tuffaceous breccias, and tuffs. Metasedimentary units, similar in abundance to the metavolcanic rocks, consist of volcanic clast-rich metagreywacke, pelitc phyllite or schist, and marble. These assemblages are intruded by bodies of complexly interlayered gabbro, diorite, tonalite, and granodiorite, with layering commonly on a metre to decimetre scale. All rocks of the Wales Group have a strong foliation and lineation that are deformed by outcrop-scale open folds. Metamorphism ranges from greenschist facies (actinolite-chlorite-epidote assemblages) to amphibolite facies (amphibole-biotite-muscovite and rare garnet).

Rocks of the Wales Group in southeastern Alaska are overlain by a less deformed, Early Ordovician to Late Silurian suite of greenschist or lower metamorphic grade volcanic and sedimentary rocks referred to as the Descon Formation. Protoliths of these rocks are similar to those in the Wales Group. Dioritic to granitic plutons that are coeval (and probably cogenetic) with volcanic rocks of the Descon Formation are widespread.

Lower Paleozoic strata are overlain unconformably by a variety of Devonian strata that commonly include a basal clastic sequence (conglomerates and sandstones, including redbeds) of the Karheen Formation, mafic volcanic rocks of the Coronados Volcanics and St. Joseph Islands Volcanics, and limestones of the Wadlegh Formation (Eberlein and Churkin, 1970). The basal conglomerate is interpreted to represent a major phase of uplift and erosion, the Klakas orogeny, as it overlies and contains clasts of a wide variety of older rocks (Gehrels and Saleeby, 1987). Younger, local unconformities are represented by conglomerates in the Late Devonian Port Refugio Formation. The Port Refugio Formation also includes fossiliferous and locally dolomitic limestone, radiolarian chert, mafic and felsic volcanic rocks, and volcaniclastic turbidites. The variability of facies and the presence of locally-derived conglomerates and bimodal volcanic sequences in these formations suggest that they were deposited in rift basins.

Younger strata in the Alexander terrane include fine to medium grained clastic rocks, carbonate, minor basalt of Carboniferous and Permian age, and Triassic basal conglomerate overlain by bimodal volcanic rocks, carbonate, and volcaniclastic strata. The Upper Jurassic to Upper Cretaceous Gravina belt, described separately below, overlies the Alexander terrane.

### *VMS potential of the Alexander terrane*

The Niblack prospect on southern Prince of Wales Island (Figure 1) is a copper-zinc-gold-silver-rich Kuroko-type volcanogenic massive sulphide deposit, with 2.6 million tonnes of indicated mineral resource grading 1.18 per cent copper, 2.33 grams per tonne gold, 2.19 per cent zinc and 33.18 grams per tonne silver; and 1.7 million tonnes of inferred mineral resource grading 1.55 per cent copper, 2.08 grams per tonne gold, 3.17 per cent zinc and 32.56 grams per tonne silver, as of July 2009 (http://www.heatherdaleresources.com/hdr/Projects.asp).

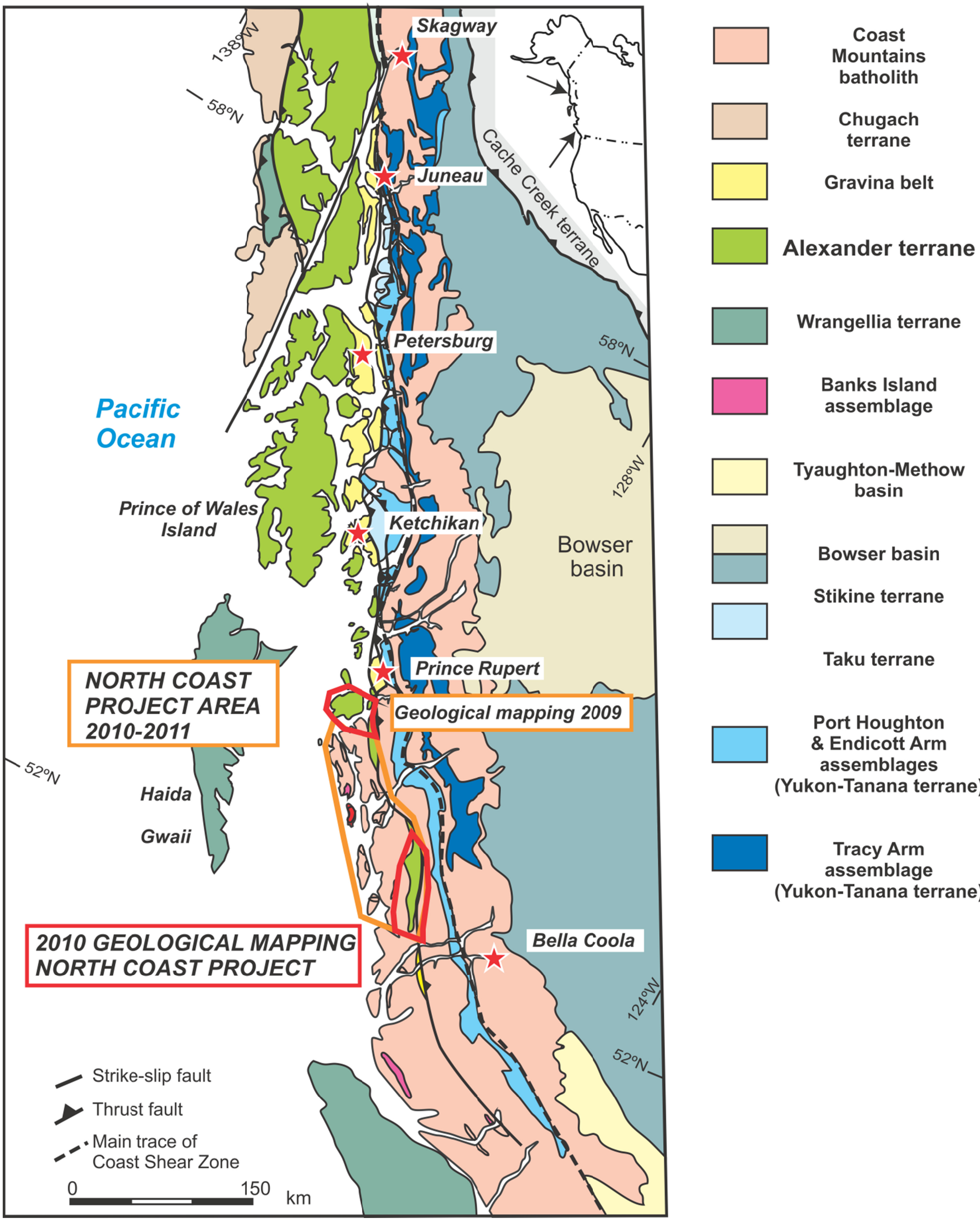


**Figure 2.** Regional geology and terrane map of northern coastal British Columbia and southeastern Alaska; G.E. Gehrels, 2009.

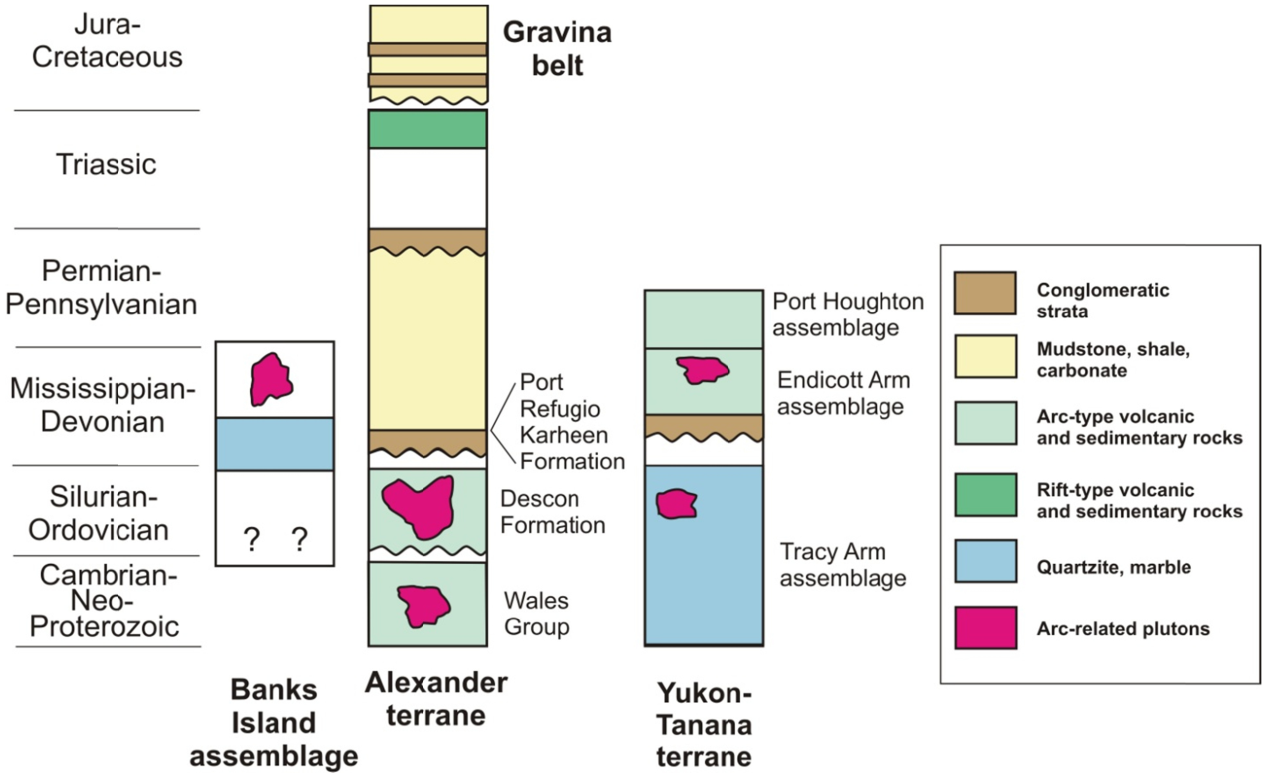


**Figure 3.** Stratigraphic columns for major terranes of southeastern Alaska and coastal northwestern British Columbia.

It is currently optioned by Heatherdale Resources Inc., an affiliate of Hunter Dickinson Inc., from Niblack Mineral Development Inc. It is located within a tightly folded pyroclastic rhyolite unit, the Lookout rhyolite, that lies above a mixed felsic to mafic volcanic sequence and below a section of mafic volcanic rocks, all of which have been assigned to the informal Moira Sound unit by Ayuso *et al.* (2005) and Slack *et al.* (2005). Although it has been regarded as hosted by the Wales Group (Gehrels *et al.*, 1996), a recent Ordovician U-Pb zircon date of *ca.* 478 Ma has been obtained from the Lookout rhyolite (Karl *et al.*, 2009). Ayuso *et al.* (2005) and Slack *et al.* (2005), as well as Gehrels *et al.* (1983), point out that volcanogenic deposits are known both in this unit and within the Wales Group and that both Neoproterozoic and Ordovician volcanic sequences are prospective for syngenetic base metal mineralization.

## *Other terranes and assemblages*

### Banks Island assemblage

The Banks Island assemblage (Figures 2, 3) has been recognized as a distinct unit of possible continental margin affinity, based on the predominance of interlayered quartzites (meta-quartz arenites) and marbles, which are rare in the generally more primitive Paleozoic arc-related assemblages of the Alexander terrane (Gehrels and Boghossian, 2000). These rocks are exposed on the southern shore of Banks Island, on western Porcher Island, and on the outer islands as far south as Klemtu. The dominant lithic components are strongly deformed and regionally metamorphosed metaclastic quartzites that commonly occur in centimetre-scale bands (Figure 4), marble layers with thicknesses of several centimetres to several tens of metres, and pelitic phyllite/schist. These rocks everywhere have a well-developed foliation and display outcrop-scale isoclinal folds. Pelitic components have been metamorphosed to biotite phyllite or schist, and garnet is present in some regions.

**Figure 4.** Banks Island assemblage on southern Digby Island, showing typical lithology of quartz siltstone laminae in carbonate.

The age of the Banks Island assemblage is constrained by the following relationships:

1) detrital zircons recovered from two quartzites are as young as ~415 Ma (Silurian-Devonian boundary; G. Gehrels, unpublished data),
2) an orthogneiss on Aristazabal Island that has undergone the regional deformation and amphibolite-facies metamorphism along with the adjacent marble and metabasite has yielded a U-Pb age of 357 Ma (Early Mississippian), and
3) plutons of Late Jurassic age are emplaced into these rocks (Gehrels *et al.*, 2009) and at least locally intrude across the regional foliation and folds.

These constraints suggest that at least some portions of the Banks Island assemblage accumulated during mid-Paleozoic time.

### Yukon-Tanana terrane

East of the Alexander terrane are metavolcanic and metasedimentary rocks of the Yukon-Tanana terrane that underlie the western margin of the Coast Mountains, along the length of southeastern Alaska and northern coastal British Columbia (Figure 2). In general, these rocks form a panel that dips eastward and youngs westward, suggesting an overall inverted stratigraphy. Using the nomenclature defined in southeastern Alaska (Gehrels *et al.*, 1992), the Yukon-Tanana terrane includes the following units (Figure 3):

1) Tracy Arm assemblage: This package contains marbles, quartzites, pelitic schists, and orthogneisses, which are commonly high in metamorphic grade and migmatitic. The age of this unit is constrained as Devonian or older based on ages from the overlying Endicott Arm assemblage.
2) Endicott Arm assemblage: This unit has a distinctive basal conglomerate containing clasts derived from the Tracy Arm assemblage. Overlying strata include greenschist to amphibolite facies felsic to mafic metavolcanic rocks, pelitic schists, and minor marble. Available faunal and U-Pb geochronologic constraints suggest that most strata are Devonian-Mississippian in age.
3) Port Houghton assemblage: These strata gradationally overlie the Endicott Arm assemblage and consist of greenschist to amphibolite facies metaturbidites, pelitic schist, and metabasalt. Available faunal constraints suggest that most strata are late Paleozoic in age.

In northwestern British Columbia, the Ecstall belt (Alldrick, 2001; Alldrick *et al.*, 2001; see also Gareau and Woodsworth, 2000) with its enclosed Devonian volcanogenic deposits, is also assigned to the Yukon-Tanana terrane. The host units are equivalent to the middle, Endicott Arm assemblage of southeastern Alaska.

### Gravina belt

Rocks of the Alexander terrane are overlain by Upper Jurassic to Upper Cretaceous (Oxfordian to Cenomanian) turbidites and subordinate mafic volcanic rocks of the Gravina belt. These rocks can be traced, generally along the inboard margin of the Alexander terrane, for the length of southeastern Alaska (Berg *et al.*, 1972) and into northern coastal British Columbia (Figure 2). On Tongass Island in southeastern Alaska, and on the mainland east of Port Simpson (Lax Kw'alaams) rocks assigned to the Gravina belt also overlie a sequence of metavolcanic and metasedimentary rocks that have been assigned to the Yukon-Tanana terrane (Gehrels, 2001).

## *Plutons of the western Coast Plutonic Complex*

Tonalitic to granodioritic plutons of the Coast Plutonic Complex, or Coast Mountains batholith, occur as isolated bodies in northern and western portions of northern coastal British Columbia, and increase in extent southeastward to form huge continuous bodies of plutonic rock (Gehrels *et al.*, 2009; Figure 2). Compositionally, most are tonalite and granodiorite, with subordinate diorite and minor gabbro and leucogranodiorite. A large majority of plutons have hornblende abundances exceeding those of biotite, are rich in titanite, and some plutonic suites contain euhedral epidote that is interpreted to be magmatic in origin.

According to a recent comprehensive geochronological summary (Gehrels *et al.*, 2009), plutonic U-Pb ages record a history of eastward migration of emplacement across the Coast Mountains. The westernmost plutons are 160-140 Ma (Late Jurassic) tonalites and granodiorites. Early Cretaceous (120-100 Ma) tonalites and granodiorites occur directly east of the Late Jurassic bodies. A nearly continuous band of 100-85 Ma plutons (*e.g.* Ecstall pluton of Hutchison, 1982) underlies the western margin of the Coast Mountains, succeeded eastward by mainly tonalitic sills of *ca.* 70-60 Ma (latest Cretaceous-earliest Tertiary) age, and the central and eastern portions of the Coast Mountains are underlain by huge 60-50 Ma (Eocene) granodiorite bodies.

The emplacement depth of plutons also increases eastward across the Coast Mountains as shown by hornblende barometric studies conducted by Butler *et al.* (2001). This work suggests that westernmost Late Jurassic bodies were emplaced at depths of ~15 km, whereas Early Cretaceous plutons were slightly deeper, ~20 km, and farther east, mid-Cretaceous plutons of the Ecstall belt were emplaced at significantly greater depths, perhaps 25-30 km. This increase in depth of emplacement correlates well with the eastward increase in metamorphic grade.

## SUMMARY OF PORCHER ISLAND – NORTHERN GRENVILLE CHANNEL GEOLOGY

The 2009 map area, comprising the vicinity of Porcher Island, northwestern Pitt Island and Grenville Channel, is underlain by metamorphosed supracrustal and plutonic rocks, intruded by late synkinematic Cretaceous plutons and cut by an array of northwest-striking sinistral faults that divide the geology of Porcher Island into a series of panels (Nelson *et al.*, 2010a, b). Some faults mark major lithologic breaks, whereas others repeat similar sequences. The Grenville Channel fault (GCF) is the master fault; from it the Salt Lagoon and Useless fault splays cross Porcher Island. The northern continuation of GCF in Telegraph Passage may be an older, dextral structure (J. Angen, personal communication, 2010).

Detailed field mapping, supported by U-Pb geochronology (Gehrels and Boghossian, 2000; Butler *et al.*, 2006; J.B. Mahoney, unpublished data, 2010; G. Gehrels, unpublished data, 2010) has allowed positive identification of many units in the mapped area, and tentative assignment of others. Because they are based on more complete geochronological data, unit ages and assignments shown on the open file map of the area (Nelson *et al.*, 2010b) supercede those in Nelson *et al.* (2010a). Most important, field identification in 2009 of possible Wales Group equivalents on Porcher Island (Nelson *et al.,* 2010a) was refuted by subsequent Ordovician U-Pb ages. The main metavolcanic sequence, which comprises most of the Alexander terrane in this area, is correlated with the Ordovician Descon Formation (*s.l.*) of southeast Alaska. In particular, it resembles the rhyolite-bearing Moira Sound unit, which hosts the Niblack volcanogenic massive sulphide deposit. Clastic rocks on Kennedy Island and near Baron Point on the mainland are correlated with the Early Devonian Karheen Formation.

Pre-Cretaceous plutonic bodies include the Ordovician McMicking and Hunt Inlet plutons, the Early Mississippian (?) Swede Point pluton, and a Devonian pluton in Porcher Inlet. Southwest of the metamorphosed supracrustal units, two metamorphosed igneous complexes, the Ogden Channel and Billy Bay complexes, are recognised. The Billy Bay complex is an intrusive equivalent of the Descon volcanic sequence. At this point, no conclusive age determination on the Ogden Channel complex has been made.

## LOCAL GEOLOGY – 2010 MAPPING NEAR KLEMTU

The 2010 map area is located 100 km southeast of the 2009 map area, in eastern Laredo Sound (103A) map sheet. It extends from Return Channel in the south to Graham Reach, on the eastern side of Princess Royal Island, in the north (Figure 1). As shown in Figure 5, most of this area is underlain by large plutons, with deformed and metamorphosed older stratified rocks of the Alexander terrane exposed in narrow pendants between them. The southern projection of the Grenville Channel fault passes through Klemtu Pass at Klemtu, then crosses Finlayson Channel and continues south through Jackson and Oscar passages and into southern Mathieson Channel.

Because of difficult access to the island interiors and extensive forest cover, most of the observations that form the basis of our mapping were made along shorelines. These were supplemented with logging road traverses, helicopter spot checking and limited traverses, together with image analysis of 5-metre resolution SPOT-5 satellite data captured between 2004 and 2006.

The geology in Figure 5 is based on a 1:50 000-scale open file map in preparation that will be available in early 2011 (Nelson *et al.*, 2011).

### *Stratified Units*

#### Mathieson Channel Formation

Strong lithologic similarities between layered metasedimentary and metavolcanic pendants in the Alexander terrane scattered throughout the 2010 map area have led to their inclusion within a single map unit, herein named the Mathieson Channel Formation. Because the original depositional relationships and stratigraphic continuity of units is disrupted by strike-slip faults, several generations of intrusive rocks and repeated by isoclinal folding, no simple stratigraphic section can be constructed, and true thicknesses of the stratigraphic layers are uncertain due to folding and structural repetition. However, overall stratigraphy of the Mathieson Channel Formation is based on consistent internal lithologic features and contact relationships that are documented in the layered units throughout the area. Figure 6 shows an interpretive stratigraphic section of the formation, measured along the eastern shoreline of Pooley Island. It includes the following provisional stratigraphic members:

1) Clastic-carbonate member
Calcareous siliciclastic rocks and calcarenite make up the most widespread and abundant map unit.

2) Marble member
Clastic-poor carbonates grade into the main clastic-carbonate member. They form mappable bodies in the Graham Reach area.

3) Conglomerate-greywacke member
Coarse clastic units are locally important on eastern Pooley Island where they are interlayered with the clastic-carbonate member. They also occur at a few other sites in the area.

4) Andesite-gabbro member
Andesite sills and flows (?) are restricted to part of the eastern shore of Graham Reach.

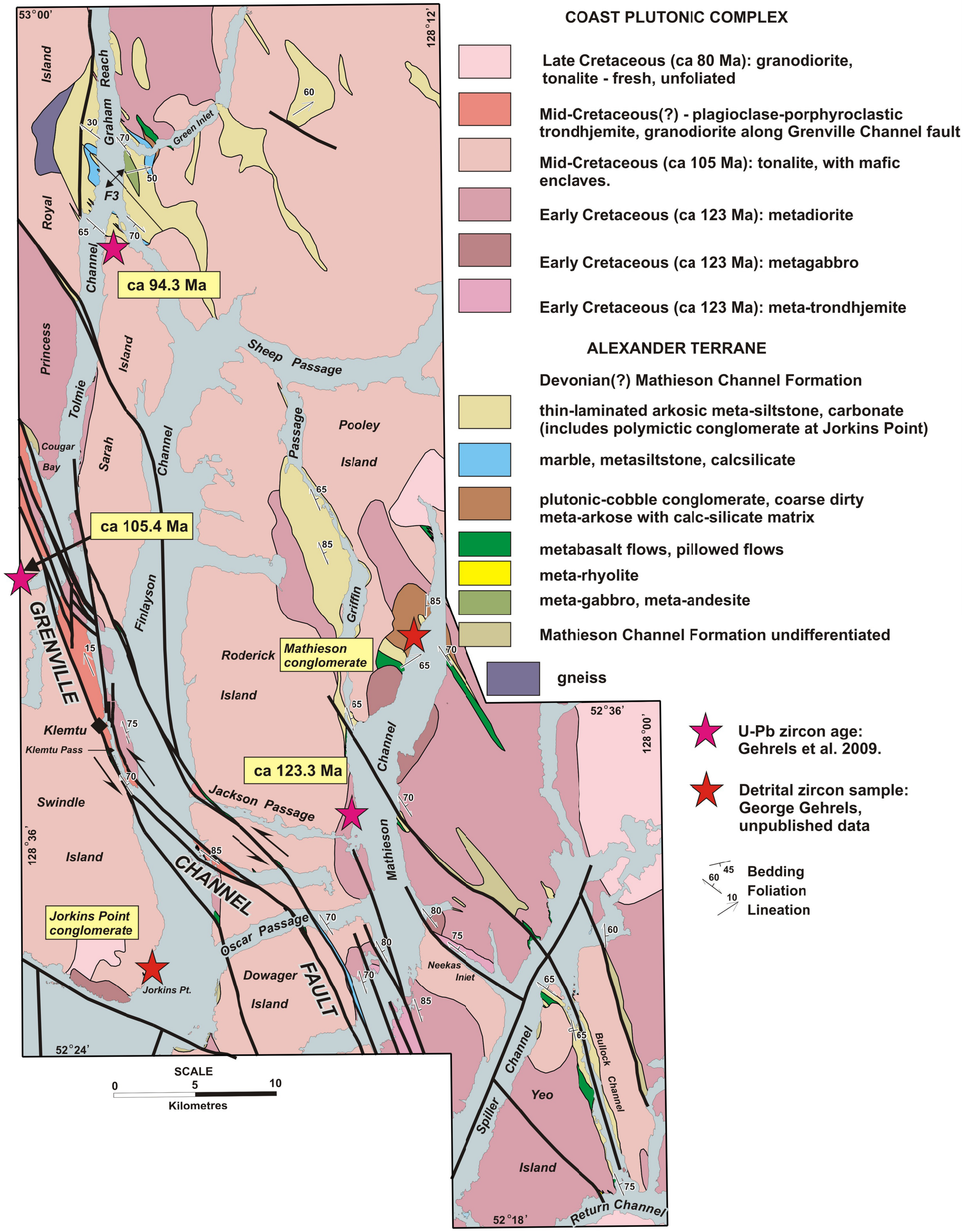


**Figure 5.** Geology of northeastern Laredo Sound map area (103A). Geological mapping 2010 (J. Nelson, L. Diakow, S. Karl, J.B. Mahoney, G.E. Gehrels, M. Pecha and C. van Staal. Some contacts from Baer, 1973).

5) Volcanic member: Dominated by basalts and volumetrically minor rhyolites, this sequence tends to occur west of, and possibly stratigraphically beneath, the clastic and carbonate members.

Interfingering and transitional relationships are observed between all of these units; thus the Mathieson Channel Formation is inferred to represent the varied fill of a single basin. Observations that support inferred depositional relationships between the various units are described below.

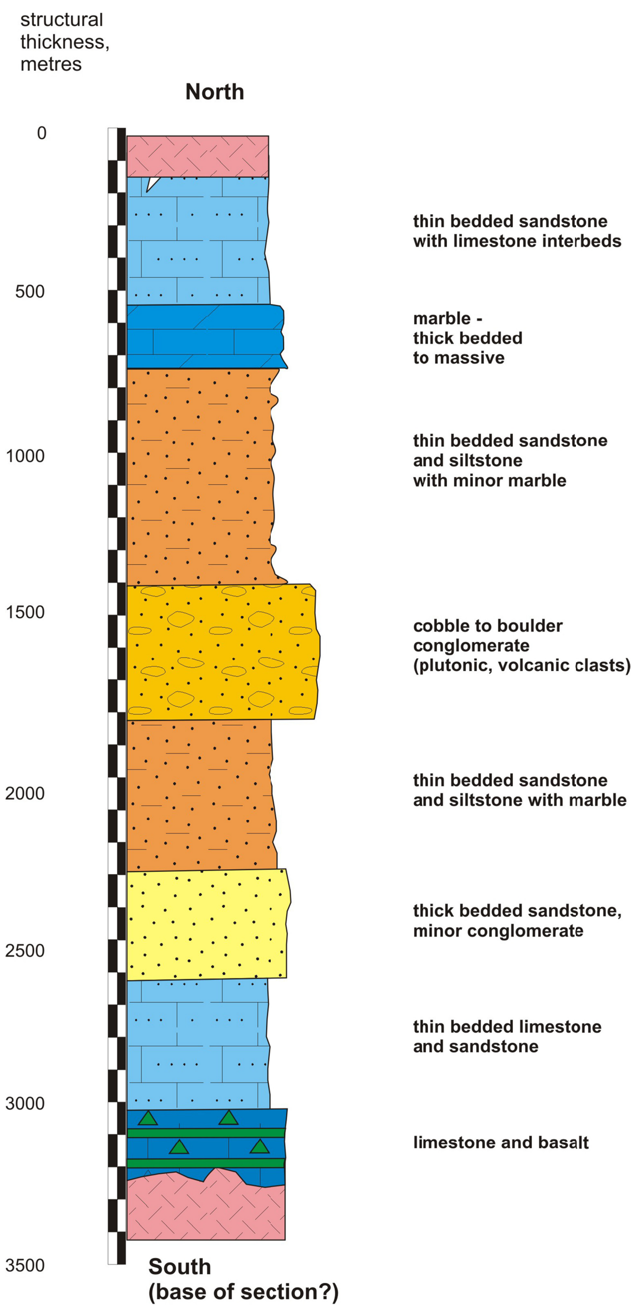


**Figure 6.** Structural-stratigraphic section of Mathieson Channel Formation on east shoreline of Pooley Island.

## Clastic-carbonate member

This unit typifies exposures in of the Alexander terrane in the map area. It comprises metasiltstones and lesser metasandstones and metagreywackes, which in places alternate on a millimetre to decimetre scale with impure carbonates and calcsilicates. The regular, thin parallel layering and lamination in this unit are distinctive (Figure 7a). The main clastic components, as determined petrographically, are quartz and plagioclase, with significant orthoclase in some samples. Grains are equant, and form polygonal, fine-grained aggregates. In the metasiltstones, quartzofeldspathic laminae of millimetre to centimetre thickness have biotite-rich partings. Trace detrital minerals include titanite, apatite and zircon. Metagreywacke alternates with "purer", less biotite-rich clastic intervals. Some of the thicker bedded sandy sequences are distinguished by rusty orange weathering, and pinkish or reddish colours in outcrops (Figure 7b). The quartz-feldspar metasiltstone layers contain abundant, finely distributed reddish brown ($Fe^{+3}$-rich) biotite and pyrite or pyrrhotite. These phases formed in equilibrium


**Figure 7a.** Clastic-carbonate member of the Mathieson Channel Formation. Thinly layered metasiltstone in impure marble (meta-calcarenite), characteristic of finer grained facies of Mathieson Channel Formation (10JN07-01; 543688E, 5871816N).


**Figure 7b.** Clastic-carbonate member of the Mathieson Channel Formation. Redbeds, Sarah Head (10JN05-10; 533126E, 5859204N).

with calcic plagioclase, hornblende, and diopside in amphibolite facies metamorphism. They indicate original Fe-rich composition of the otherwise well-sorted arkosic protolith. We consider it likely that these were redbeds that contained authigenic matrix hematite. Inferred arkosic protoliths, supported by a sample from the mountains east of Graham Reach that contains fine laminae of pure granular apatite, suggest a plutonic provenance for the clastic-carbonate member.

Although sedimentary structures are rarely preserved in this unit, graded beds were observed in relatively coarse, thick-bedded sandstones in Bullock and along Spiller channels (Figure 7c). Possible siltstone cross-laminations were also noted in carbonate at several localities, including Sarah Head at the northern tip of Sarah Island (Figure 7d). Given the degree of deformation, these delicate laminations may not be primary depositional features.

Carbonate layers are generally impure, ranging from calcite-rich meta-calcarenite to pale green, diopside-rich


**Figure 7c.** Clastic-carbonate member of the Mathieson Channel Formation. Sandstone sequence in Bullock Channel. Thickest bed shows grading, and contains grit-size plutonic clasts (10JN12-05; 564040E, 5801153N).

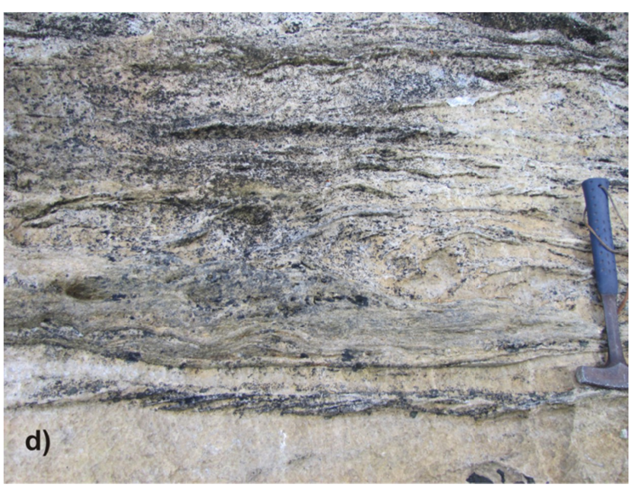


**Figure 7d.** Clastic-carbonate member of the Mathieson Channel Formation. Delicate crossbeds of quartz-feldspar in impure marble, Sarah Head (10JN05-10; 533126E, 5859204N).

calcsilicate. Very dirty marbles, dense with tiny irregular clasts, may have contained fossil hash; but deformation and recrystallization prevent a positive identification of any possible biogenic material in them.

Dark meta-argillites form a relatively minor component of the unit, found mainly along Bullock Channel near the southern terminus of the Alexander terrane. In general, argillaceous rocks appear to increase relative to pure carbonates toward the southern end of the belt, which may represent the deepest part of the basin.

### Conglomerate-greywacke member

A sequence of thick-bedded conglomerate and greywacke is exposed for over 2 km along the eastern shore of Pooley Island next to Mathieson Channel. The true thickness of this unit is difficult to determine because deformation has produced variable bedding attitudes (Figure 6). The conglomerate beds consist of elongate, rounded, but poorly sorted plutonic and subordinate volcanic clasts (Figures 8a, b), and vary from matrix to clast-supported deposits. Individual clasts range in size from 1 to over 40 cm in diameter; average size is in the 10 cm range. Grading and erosive bases of beds are seen in some places (Figure 8a). Elsewhere in this exposure, conglomerates take the form of trains of clasts concentrated in a poorly sorted matrix composed of angular, sand-size lithic and mineral grains.

The intrusive clasts are medium grained equigranular to porphyritic in texture, consistent with fairly shallow depths of emplacement. None contain a foliation developed prior to incorporation in the clastic deposit. Most were deformed after lithification and exhibit varying degrees of flattening. Clast compositions include tonalites and also plagioclase-phyric granodiorites. The volcanic clasts are mostly basalt, less commonly dacite and/or rhyolite. Abundant diopside in the conglomerate matrix attests to an original micritic matrix.

Conglomerates at Pooley Island extend eastward across Mathieson Channel to a locality where multiple thin beds are intercalated with clastic-carbonate layers. Elsewhere, the northern extent of the conglomerate member includes minor occurrences in Griffin Passage and Green Inlet.

Transitional contacts are observed between the conglomerate-greywacke member and the overall finer-grained and more thinly layered clastic-carbonate member. On eastern Pooley Island, the two members are interbedded on a metre scale, and in one case a granitoid cobble lies within carbonate. In Griffin Passage, intrusive clasts occur in a carbonate matrix, in a metre-thick bed interlayered with more typical carbonate and in sandstone-siltstone (Figure 8c). The extreme size and compositional contrast between igneous clasts and calcarenitic matrix suggest these could be lag deposits. These observations document that the coarse, high-energy conglomerate-greywacke unit is integral to the Mathieson Channel Formation. It does not rest unconformably upon


**Figure 8a.** Conglomerate-greywacke member. East Pooley Island conglomerate with erosive base (10JN11-04; 552198E, 5832156N).


**Figure 8b.** Conglomerate-greywacke member. Granitoid and dark green mafic volcanic clasts (10SK04-2; 553101E, 5833771N).

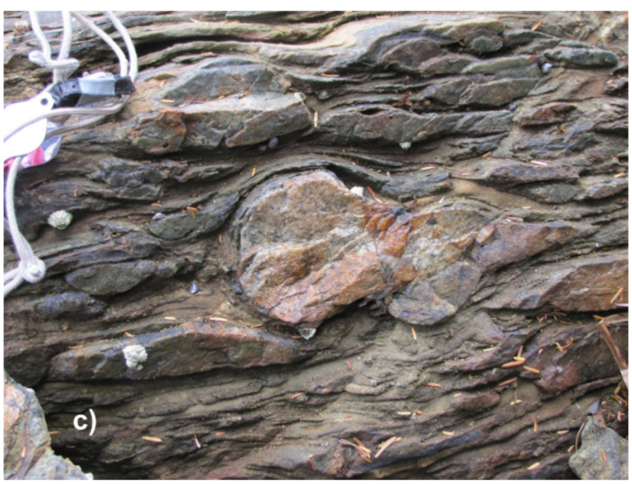


**Figure 8c.** Conglomerate-greywacke member. Conglomerate clasts in carbonate matrix, Griffin Passage (10JN18-01; 544781E, 5842872N).

it, and thus does not represent a basal conglomerate.

### Marble member

Pure or nearly pure marble forms mappable layers in the Mathieson Channel Formation. Intervals of pure bedded marbles, thickest along Graham Reach, pass gradationally into more clastic-rich variants. Thin, discontinuous marble units also occur along faults that transect Jackson and Oscar passages. Marble layers vary considerably in thickness, due in part to plastic flow during deformation that produced tight folds. They weather buff yellow-tan with white coarsely crystalline fresh surfaces One of them, at Quarry Point (MINFILE 103A 007), was previously mined for use at the Swanson Bay pulp mill, 11 km to the north.

### Andesite-gabbro member

Dark green meta-igneous rocks occur along the east shore of Graham Reach south of Green Inlet. Some appear to be metamorphosed dikes and/or sills of andesitic composition with fine to coarse-grained textures. Locally there are fragmental or pseudofragmental textures, and some intrusives contain coarse grained gabbro clasts in a highly deformed matrix. This unit may be entirely intrusive and thus not part of the supracrustal succession.

### Volcanic member

Mappable bodies of metabasalt, in places containing carbonate pods, occur in southwestern Bullock Channel, along Spiller Channel, in Mathieson Channel, on the south end of Sarah Island, in northern Graham Reach and in Green Inlet. There are also metabasic mylonites along the Grenville Channel fault and its splays. In the least deformed exposures, pillows and pillow breccias are distinguishable (Figure 9a), as well as layers of angular scoria in carbonate matrix. Microscopically, some of the otherwise mafic (hornblende-calcic plagioclase-rich) metabasalts also contain biotite and/or potassium feldspar. These minerals suggest unusually potassium-rich, alkalic compositions.

Small occurrences of metarhyolite accompany the basalt at a few localities, at both ends of the Bullock Channel exposures, and along Spiller Channel. In Return Channel and into the south end of Bullock Channel, off-white weathered, coherent rhyolite shows delicate flow-banding (Figure 9b). At the north end of Bullock Channel and in one outcrop along Spiller Channel, rhyolite breccias occur, consisting of angular white fragments in darker matrix.

Along Bullock Channel, there are gradational contacts between the volcanic and clastic-carbonate members of the Mathieson Channel Formation. The base of the clastic member there contains fine grained tuffaceous layers; and some siltstones are anomalously rich in orthoclase compared to siltstones elsewhere. It is likely that the abundant potassium feldspar is locally derived from rhyolitic sources, as may be the case at the southern end of Bullock Channel. This volcanic to fine


**Figure 9a.** Volcanic member. Pillow basalt, Spiller Channel; note preservation of protolith features in amphibolite grade metamorphism (10SK02-8; 560835E, 5814316N).


**Figure 9b.** Volcanic member. Flow-banded metarhyolite (10JN12-01; 564086E, 5796866N).

volcaniclastic to clastic transition appears to young northeastward. Overall, volcanic rocks are most abundant in the more westerly exposures of the Mathieson Channel Formation. For this reason, we tentatively regard it as a northeast-facing sequence, with a volcanic-rich base succeeded by clastic and carbonate members in the upper section.

The rhyolite flow in Return Channel is presumed to occupy a low stratigraphic position within the Mathieson Channel Formation and was sampled for U-Pb zircon geochronology to determine its eruptive age which would place a lower stratigraphic age constraint on the formation.

## DEPOSITIONAL ENVIRONMENT, AGE, DETRITAL ZIRCON CHARACTER AND POSSIBLE CORRELATIONS

The Mathieson Channel Formation was deposited in marine conditions, as shown by the prevalence of limestone. Its along-strike homogeneity and interlayered and gradational contact relationships between all of the members suggest deposition within a single marine basin. Depths did not generally exceed the carbonate compensation depth. Possible redbed protoliths within the sequence are also an indication of shallow-water deposition. Conglomerates are most abundant in the type area on Pooley Island and nearby; overall conglomerate forms less than 5 per cent of an overall sequence of arenaceous clastics interlayered with carbonates. The local occurrences of coarse, poorly sorted conglomerate and more widespread but thin intervals of greywacke indicate periodic mass flow deposition, perhaps related to basin-margin faulting. Their restricted occurrence argues against deposition in a large-scale submarine fan, as does the inferred general shallow depth of water. The presence of small-scale bimodal volcanism is consistent with a rift origin for the basin. Overall, a rifted, epeiric sea in a subtropical, arid setting, into which ephemeral streams locally discharged high loads of coarse sediment is envisaged. Sandy and silty fractions may have been re-deposited by tidal currents or storm surges that alternated with background carbonate deposition.

In some regards, the Mathieson Channel Formation resembles the sandstone-conglomerate unit on Kennedy Island in northern Grenville Channel (Nelson *et al.*, 2010a) which, in turn, has been correlated with the Karheen Formation of southeastern Alaska. The Karheen Formation was named for a succession of conglomerate, sandstone, siltstone, shale and minor limestone exposed on Prince of Wales Island (Eberlein and Churkin, 1970, Gehrels and Saleeby, 1987). Conodont and brachiopod biostratigraphy indicate the formation is middle Early Devonian (Pragian) in age. The formation overlies Silurian and older rocks, and is interpreted as part of a subaerial to shallow marine clastic wedge that coarsens and thickens to the southeast (Eberlein and Churkin, 1970; Gehrels and Saleeby, 1987). Detrital zircon geochronology from the Karheen Formation includes a *ca.* 420-450 Ma dominant population, apparently derived from Late Ordovician and Silurian plutonic rocks of the southern Alexander terrane, and a diverse, much less abundant Middle Proterozoic to Late Archean population of unknown cratonic derivation (Gehrels *et al.*, 1996).

Like the Karheen Formation, the cobble population from conglomerate in the Mathieson Channel Formation is dominated by shallowly emplaced (unfoliated, medium grained to porphyritic) granitoids, and sandstone compositions are similarly arkosic with disseminated biotite. However, the great thickness and extent of boulder-rich facies and large-scale crossbedding that characterize the Karheen Formation are not present in the Mathieson Channel Formation. Instead, the fairly minor, local conglomerates in the latter are interpreted as mass-flow deposits, some with erosive bases. Further, the Karheen Formation does not contain regular intervals of carbonate or the monotonously thin-bedded siltstones that are so common in this unit. Overall, the Mathieson Channel Formation is finer grained and more calcareous than the Karheen Formation, features that may reflect smaller scale uplift in a less active basin.

At present, a single detrital zircon sample has been analysed from the conglomerate-sandstone member of the Mathieson Channel Formation on Pooley Island ; it shows a unimodal peak at about 420 Ma (Gehrels and Boghossian, 2000; Gehrels, unpublished data, 2010). This is somewhat younger than typical Ordovician-Silurian populations in the Karheen Formation of southeast Alaska (Gehrels and Boghossian, 2000) and gives an earliest Devonian maximum age for the unit. Like the Karheen, the signature reflects a plutonic source terrane younger than the mainly Ordovician volcanism of the Descon Formation.

Given the probable Devonian age of the Mathieson Channel Formation and its mode of origin in a shallow, marine basin bounded in part by local scarps, it could represent a separate basin analogous to the rift basins in which the Karheen Formation probably accumulated. Another possible correlative in the Alexander terrane of southeast Alaska is the Late Devonian Port Refugio Formation, defined by Eberlein and Churkin (1970). It consists of greywacke, conglomerate, thinly-bedded siltstone and shale, limestone, basalt in the form of lava flows, both pillowed and brecciated, and tuff and minor rhyolite.

### *Jorkins Point conglomerate*

An unusual quartzite-cobble conglomerate outcrops on the headland 2 km northeast of Jorkins Point on southern Swindle Island. It is described separately here because it represents a pericontinental source completely unlike the plutonic-volcanic sources of the Mathieson Channel Formation. At its southernmost exposure, it is poorly sorted and immature, consisting of angular centimetre to decimetre-size fragments of impure quartzite, along with a few clasts of metasiltstone and diopside-rich, carbonate-altered metavolcanics in a dirty, diopsidic calcsilicate matrix (Figure 10a) Farther north along the shoreline, the conglomerate becomes more polymictic with increasing quantities of volcanic and siltstone clasts, and better sorted; cobbles are more rounded (Figure 10b). The most southerly exposure has the aspect of a nearly single-sourced fanglomerate, while its continuation to the north indicates farther transport and mixing of lithologic types. Texturally, the local occurrence of conglomerate and the abrupt variation in degree of maturity resemble base-of-scarp deposits in rift basins, for instance along the Eskay rift in northwestern British Columbia (Alldrick *et al.*, 2005). The next exposure to the south of the conglomerate, across a septum of tonalite and diorite, is a thin-layered calcsilicate-metasiltstone unit that resembles the quartz-plagioclase (±orthoclase) arenitic siltstones in the Mathieson Channel Formation.

Microscopically, the quartzite clasts are dominated by coarse grained, interlocking quartz, but they also contain minor quantities of plagioclase, orthoclase, diopside, titanite, hornblende and tiny zircon grains.


**Figure 10a.** Jorkins Point conglomerate. Chaotic, poorly sorted conglomerate of mostly quartzite clasts in calcsilicate matrix (10JN02-01; 535273E, 5810889N).

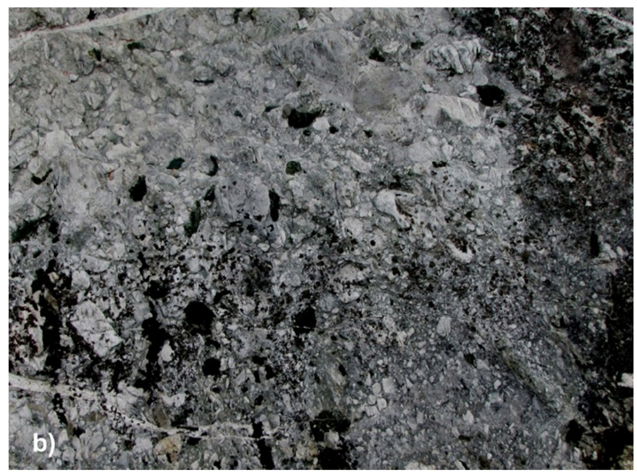


**Figure 10b.** Jorkins Point conglomerate. Polymictic conglomerate with more clast rounding and sorting. FOV 2 metres. (10JN02-01a; 535255E, 5811050N).

Siltstone clasts are finely laminated and contain varying proportions of fine grained quartz, plagioclase, and orthoclase, and mafic laminations in which hornblende, titanite and diopside dominate. These have a strong resemblance to siltstones that are widespread in the Mathieson Channel Formation. The presence of orthoclase in them is particularly noteworthy, in that it is of somewhat restricted occurrence within the Mathieson Channel Formation.

A detrital zircon sample of quartzite clasts from the conglomerate shows a very broad Precambrian peak between about 900 and 2000 Ma, with lesser peaks to 2600 Ma; no Paleozoic grains were identified (George Gehrels, unpublished data, 2010). The cratonal signature of the Jorkins Point quartzites contrasts markedly with signatures of both autochthonous northwestern North America (Gehrels *et al.*, 1995) or the more inboard, pericratonic Yukon-Tanana terrane (Gehrels and Kapp, 1998; Nelson and Gehrels, 2007). It suggests an exotic origin. However, the resemblance of siltstone clasts to the Mathieson Channel Formation may provide a sedimentological link between the two units. In this case, pericontinental rocks possibly formed part of the basement to the Mathieson Channel basin, and the Jorkins Point conglomerate could have formed along a western scarp. Gehrels *et al.* (1996) argued that the Silurian-Devonian Klakas orogeny involved interaction between the Alexander terrane and an outboard (present coordinates) continental fragment, such as is represented by the Banks Island assemblage (Gehrels and Boghossian, 2000; Figure 2, this paper). The Jorkins Point conglomerate may represent a "missing link" between the two. Ongoing detrital zircon studies (J.B. Mahoney, 2010-11) may shed light on this important potential correlation.

## Intrusive units

As shown on Figure 2, over 90 per cent of the project area is underlain by Cretaceous intrusive rocks of the western Coast Plutonic Complex. In the original mapping of the Laredo Sound area (Baer, 1973), the granitoids were given unit assignments based on composition and degree of foliation. This study benefited from the use of uranium-lead zircon dates from representative sites in the area (Gehrels *et al.*, 2009), as well as an enhanced appreciation for styles of deformation of the plutonic bodies. This has resulted in significant changes in the location of plutonic contacts and interpreted contact relationships.

Uranium-lead ages reported by Gehrels *et al.* (2009) were important in the definition of three main plutonic suites in the study area (Figure 5). The oldest plutonic suite is based on an age of *ca.* 123 Ma from a site north of the east end of Jackson Passage (Figure 5), obtained from a penetratively deformed, amphibolite grade diorite-pyroxenite-gabbro complex. In our mapping, this metaplutonic complex corresponds to most of Baer's unit 2 and some of his unit 3; several small bodies of trondhjemite, shown on his map as unit 5, are also part of the complex. The second plutonic suite ranges in age from *ca.* 104 to *ca.* 94 Ma and is dominated by large homogenous tonalite bodies that comprise much of Sarah and Roderick islands, adjacent to Finlayson Channel. These plutons range from comparatively leucocratic and unfoliated cores (Baer's unit 5) to darker and more foliated margins (Baer's unit 3). The youngest plutonic suite, designated as unit 14a in Baer (1973), have several ages of approximately 82 Ma. One small intrusion was mapped near James Bay, along the western shoreline of Mathieson Channel. This body continues southeast across the channel where a coeval age indicates that it also includes a body previously mapped as Baer's unit 5. These significant changes emphasise the importance of new detailed mapping in concert with U-Pb dating as necessary to the understanding of the Coast Plutonic Complex.

### Early Cretaceous (ca. 123 Ma) mafic intrusive complex

A deformed and metamorphosed, generally mafic plutonic suite outcrops extensively along both sides of Mathieson Channel. Similar bodies also occur northwest of Klemtu and north of Green Inlet. Diorite is the dominant phase, although variants from ultramafite to trondhjemite are present. Where large enough, the gabbro-ultramafite and trondhjemite bodies have been mapped separately from the main, undivided, dominantly dioritic bodies. It should be noted, however, that this suite shows strong variability even at outcrop scale (Figure 11a).

Diorites, which are most abundant throughout these complexes, are typically penetratively foliated to protomylonitic with asymmetric fabrics (Figure 11b). The foliation involves fine grained metamorphic hornblende, accompanied by quartz, calcic plagioclase, and titanite. Primary igneous minerals survive as pseudomorphs and porphyroclasts. Gabbro bodies contain areas of ultramafic cumulates, for instance near the eastern entrance of Jackson Passage. Ultramafites are metamorphosed to coarse grained tremolite/actinolite-clinochlore-biotite assemblages, in one case with bright green picotite (?) grains. Trondhjemites south of southern Mathieson Channel are highly foliated to protomylonitic, with a strong biotite fabric (Figure 11c).

No relationships with angular discordance were observed between phases of this complex and the Mathieson Channel Formation. Foliation involving amphibolite-facies assemblages is strongly developed in both, parallel to their contacts.

A U-Pb age of 123.3 ± 1.4 Ma was reported by Gehrels *et al.* (2009) from this suite, at a location 1.5 km north of the eastern end of Jackson Passage. The sample is from a medium-grained diorite with moderate foliation, which grades compositionally into gabbro and tonalite. The latest phase at this outcrop is a highly foliated trondhjemite/pegmatite dike (Figure 11a).

An unusual body of partly protomylonitic granodiorite in Neekas Inlet is tentatively assigned to this suite, based on its occurrences as a northwest-aligned sliver, and its degree of deformation. In it, coarse igneous microcline grew in equilibrium with plagioclase, and large brown allanite grains are rimmed with epidote. Subsolidus mylonitic fabrics include wispy biotite trains partly overgrown by late muscovite and chlorite, quartz ribboning and extensive development of trains of small neoblasts. Well-formed epidote grains grow across biotite. This body will form part of a U-Pb geochronological study by M. Pecha, aimed at constraining ages of deformation (2010-11).


**Figure 11a.** *Ca.* 123 Ma intrusive complex. U-Pb site north of Jackson Passage; outcrop-scale intrusive complex. Note wall-parallel foliation in crosscutting trondhjemite dike. FOV 1.5 metres.


**Figure 11b.** *Ca.* 123 Ma intrusive complex. Well-foliated metadiorite (10JN20-02; 549391E, 5816174N).


**Figure 11c.** *Ca.* 123 Ma intrusive complex. Protomylonitic trondhjemite (10JN25-06; 551404E, 5808794N).

## *Mid-Cretaceous (ca. 94-105 Ma) tonalite and quartz diorite*

Bodies of tonalite transitional to quartz diorite compositions underlie most of the islands adjacent to Finlayson Channel, forming part of a batholithic mass that dominates the Laredo Sound map area. Baer (1973) designated these rocks as units 3 and 5; however, only relatively minor internal compositional and textural variability are recognized and hence these units are now combined (Figure 5). Distinguishing features of these plutons include uniform off-white color that approaches greyish shades with increasing mafic mineral content, ubiquitous mafic enclaves, and comparatively weak to moderate strain manifested by aligned mafic minerals and enclaves (Figures 12a, b).

Internally, the large tonalite bodies are medium grained, equigranular and have consistent mineralogy dominated by zoned plagioclase, euhedral hornblende and interstial quartz. Aligned biotite aggregates define foliation. Titanite is sparse but ubiquitous. The presence of mafic enclaves distinguishes these tonalite bodies. They typically make up less than 3 per cent of the rock, but particularly in border phases they may constitute more than 40 per cent. Composed of plagioclase and mafic minerals, they are amphibolites with fine- to medium-grained texture, and variably strained. Depending on strain intensity, the enclaves vary from ovoid to lenticular in shape.

Tonalite in Meyers Channel, west of Klemtu has several U-Pb ages averaging about 104 ± 1.5 Ma, and a single age of 94.3 ± 1.4 Ma was obtained at the northern end of the tonalite body on Sarah Island (Gehrels, 2009).


**Figure 12a.** Mid-Cretaceous (94-105 Ma) tonalite suite. Typical tonalite from the mid-Cretaceous suite displays elongate mafic enclaves.

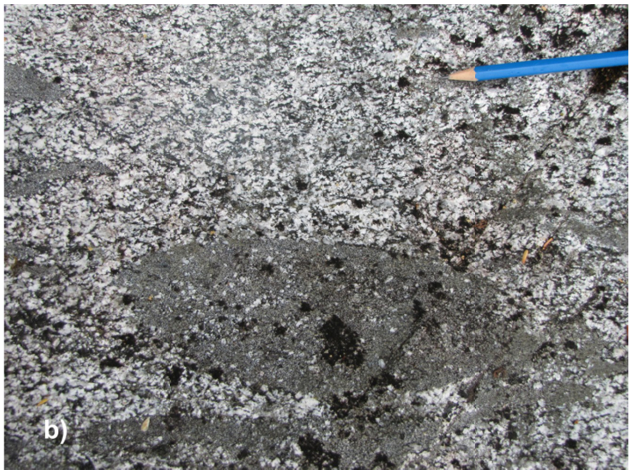


**Figure 12b.** Mid-Cretaceous (94-105 Ma) tonalite suite. Detail of foliated tonalite with mafic enclaves – note plagioclase porphyroblasts in the enclaves, which are compositionally identical to igneous plagioclase in the tonalite (10JN21-01; 534258E, 5820134N).


**Figure 12c.** Mid-Cretaceous (94-105 Ma) tonalite suite. Mid-Cretaceous tonalite with enclaves, showing moderate igneous foliation, cuts and surrounds *ca.* 123 Ma amphibolite facies metadiorite (10JN25-02; 552821E, 5814165N).

Contacts between tonalite and rocks from the older mafic complex and Mathieson Channel Formation are exposed on shorelines of Sarah Island in Tolmie Channel, and in southern Mathieson Channel. Most contacts are sharp breaks, presumed to be steep faults; however, in a few localities clear crosscutting relationships can be observed, in which phases of the tonalite suite cut across the transposition foliation in the metamorphic rocks, and the amphibolite fabric in the *ca.* 123 Ma plutons. Tonalite dikes intrude rocks of the older mafic complex and at one locality tonalite engulfs rounded, milled blocks of foliated metadiorite and pyroxenite at its contact with the mafic complex. In southern Mathieson Channel, a weakly foliated, mafic enclave-rich border phase of a large tonalite pluton contains large inclusions of amphibolite-facies metadiorite (Figure 12c).

### *Late Cretaceous (ca. 80 Ma) tonalite*

A tonalite stock north of James Bay, western Mathieson Channel represents the youngest pluton in the study area. This small body comprises the western lobe of a larger pluton, unit 14a, that Baer (1973) extends southeastward across the channel and beyond the study area. Apophyses of the pluton cut obliquely across the general northwest regional structural fabric, and contacts are sharp and intrusive into rocks of the Mathieson Channel Formation and Early Cretaceous plutonic suite. Near the margin of the pluton on the south side of James Bay, angular inclusions with internal foliation occur in undeformed tonalite matrix. Shoreline exposures typically are white; and bold cliffs with sparse jointing pass at higher elevation into clusters of steep-sided knobs supporting only sparse tree cover.

The tonalite body near James Bay overall resembles those comprising the mid-Cretaceous suite; however, mafic enclaves are not present and the pluton lacks features due to regional metamorphism or deformation, unlike parts of the older suite. Internally, the James Bay tonalite is homogeneous and consists of medium-size grains of equigranular plagioclase and quartz, in addition to 10-15 per cent combined mafic minerals (biotite and lesser hornblende). Except for incipient replacement of zoned plagioclase by fine opaques, all minerals are pristine and unstrained. Prismatic titanite is abundant.

The timing for emplacement of these undeformed tonalitic intrusions is inferred from U-Pb dating at the eastern extension of the body that straddles Mathieson Channel, which is 81.7 ± 1.2 Ma (Gehrels *et al.*, 2009). An equivalent U-Pb date was also obtained immediately north from a circular pluton originally assigned to Baer's (1973) unit 5. Elsewhere in the study area, however, because of distinguishing lithologic features and in absence of supporting geochronology, we have reassigned other unit 5 tonalitic plutons to the mid-Cretaceous suite.

White pegmatite and aplite dikes occur regionally, cross-cutting all other rock units. They are probably related to the mid- and Late Cretaceous intrusive suites. Pegmatitic boudins in the Mathieson Channel Formation show that deformation continued during Cretaceous intrusion.

## STRUCTURAL GEOLOGY AND METAMORPHISM

Structural styles and metamorphic grades in the map area are specific to the major rock units. Both the Mathieson Channel Formation and the older (*ca.* 123 Ma) Cretaceous intrusive suite are characterized by penetrative deformation at amphibolite grade: this is characterized by polyphase folding within the layered metamorphic rocks and penetrative foliations in the plutons (Figure 13a). Planar fabrics in the map area strike northwest and deep steeply to the east, an orientation that is common throughout the western Coast Mountains (Rusmore *et al.*,

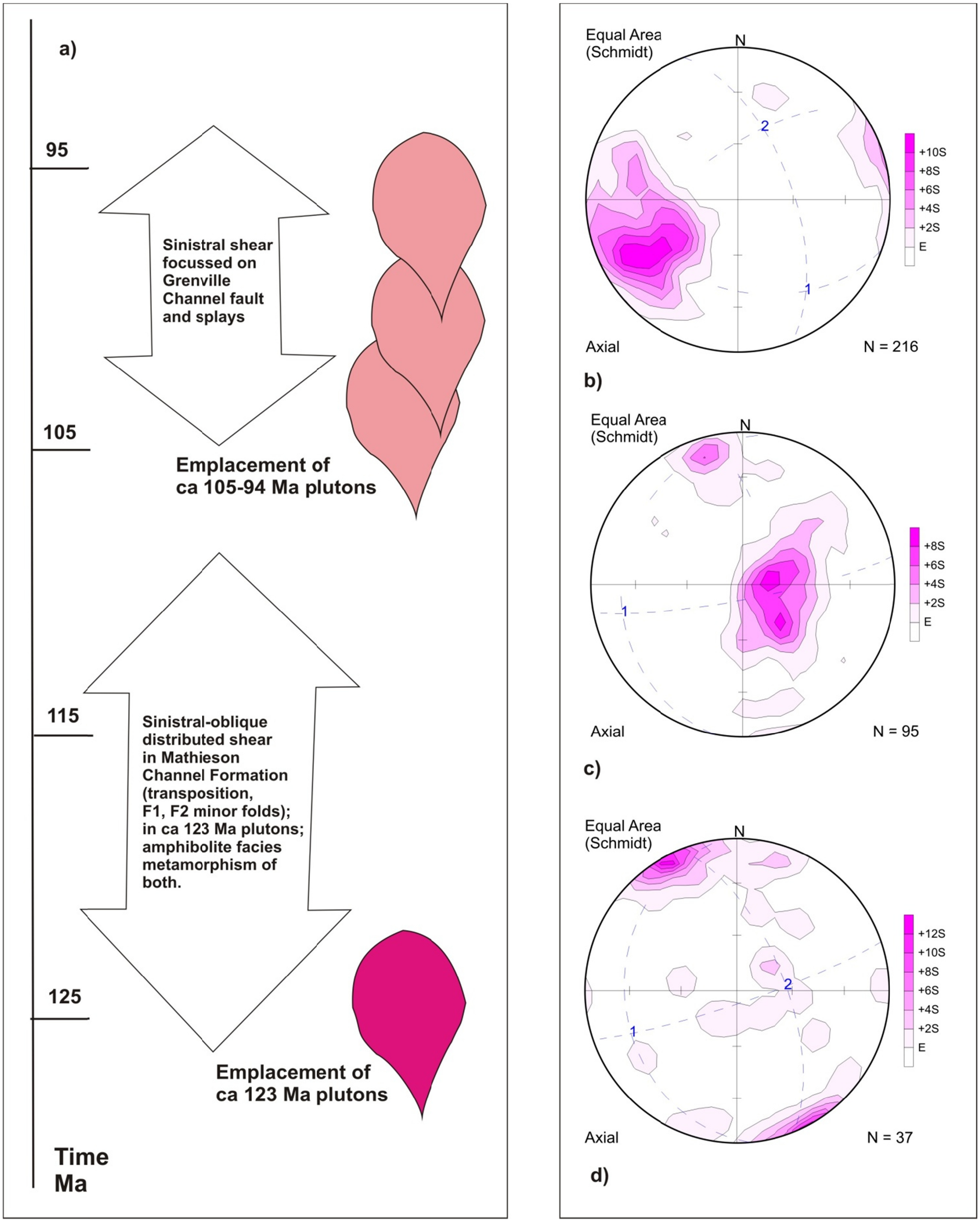


**Figure 13.** a) Cartoon Cretaceous structural history of eastern Laredo Sound map area. b-d) Stereo plots of minor structures in the northeastern Laredo Sound map area; b) Poles to planar structures (bedding, transposition fabrics) in Mathieson Channel Formation; c) Linear minor structures (F1 and F2 rootless and isoclines - L1 and L2 mineral lineations) in Mathieson Channel Formation; d) Linear minor structures (mineral, stretching and mylonitic lineations) in Cretaceous intrusions.

2005; Crawford *et al.*, 2000) as well as on Porcher Island and along northern Grenville Channel (Nelson *et al.*, 2010a). Within the map area, the intensity of deformation increases towards the northeast.

Plutons of the mid-Cretaceous suite are not penetratively deformed, except for local mylonitic fabrics along major fault strands. The northwest-striking Grenville Channel fault passes through the western and south-central part of the map area (Figure 5). Measured kinematic indicators show sinistral displacement, affecting all rock units including the mid-Cretaceous plutons and also younger leucocratic dike phases that were emplaced along fault strands. North-striking faults with minor dextral displacements join the Grenville Channel fault array in southern Tolmie Passage and northern Swindle Island.

### Mathieson Channel Formation

Regional fabric orientations in the Mathieson Channel Formation strike northwesterly, and dip steeply to the northeast (Figure 13b). Transposition fabrics are prevalent throughout the unit. The exceptions to this reflect lithologic control; the thick-bedded conglomerate and sandstone on eastern Pooley Island are deformed into open folds with an axial planar cleavage, and metavolcanic sections devoid of carbonate show preservation of original textures and few outcrop-scale folds. Because of its thinly layered nature and high proportion of marble layers in the Mathieson Channel Formation, small-scale isoclinal folds and rootless isoclines are well-developed within it, recording polyphase folding during progressive deformation (Figure 14a). F1 minor folds are intrafolial and do not appear to refold the transposition fabric, whereas F2 folds clearly involve both layering and fabric. Isoclinal fold axes - both F1 and F2, which are generally coaxial - and also mineral lineations, vary in plunge from gentle to steep and downdip. Steep plunges in the southeastern quadrant are more common than in the northeast (Figure 13c). On ridges southeast of Green Inlet, sheath folds in metasiltstones attest to the large amount of strain accommodated by this unit, particularly in its northeastern extent (Figure 14b).

Sinistral asymmetries are observed in “tails” on conglomerate clasts and boudins throughout the area (Figure 14c). Rootless isoclines show sinistral asymmetry in many cases. Strain in these rocks appears to have been dominantly pure shear, with northeast-southwest shortening and overall southwesterly vergence. In addition, a sinistral reverse component of motion is shown by the predominantly southeast-plunging linear features developed on northeast-dipping layering (Figure 13b).

Open to closed F3 folds on hundred metre scale are seen west of Graham Reach, in Griffin Passage, and affect the conglomerate-sandstone member on eastern Pooley Island. F3 fold axes trend either north or northwest. These


**Figure 14a.** Deformational features in Mathieson Channel Formation. Thin siltstone layers in marble, showing tight to isoclinal F2 minor folds refolding the transposition foliation (10JN11-05; 551556E, 5830550N).


**Figure 14b.** Deformational features in Mathieson Channel Formation. Sheath folds in siltstone-calcsilicate, east of Green Inlet (10JN07-02; 546439E, 5865759N).

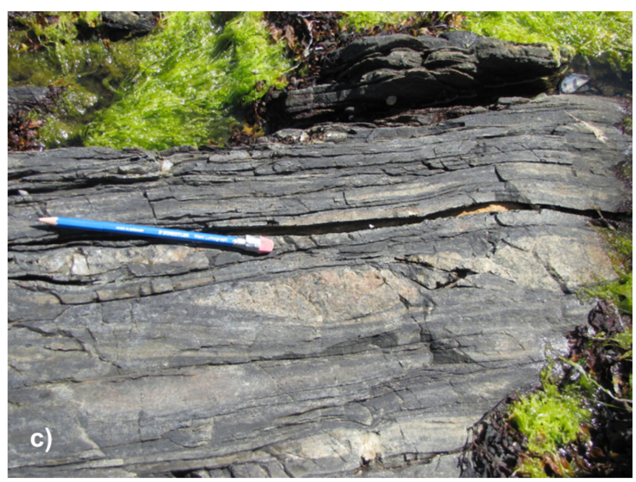


**Figure 14c.** Deformational features in Mathieson Channel Formation. Sinistrally asymmetric pressure shadows on conglomerate clasts (10JN17-03; 554736E, 5830695N).

folds appear to be local accommodation features. There is insufficient lithologic variation or sedimentary top indicators in the Mathieson Channel Formation to establish the degree of large-scale folding or internal thrust repetition that it may have experienced.

Deformation in the Mathieson Channel Formation occurred during amphibolite-facies metamorphism, as indicated by assemblages in the metabasalts that consist of trains of well-oriented subidioblastic hornblende, accompanied by polygonal aggregates of calcic plagioclase; quartz, diopside, biotite and titanite. Metasiltstones comprise laminations and thin layers of polygonal quartz, plagioclase, and in some cases orthoclase, alternating with biotite or diopside-rich layers. Strong biotite alignment parallel to compositional layering defines the transposition fabric. It is assumed that the F1 isoclines formed during the transposition event. Individual biotite platelets within the quartzofeldspathic laminations are also well aligned parallel to compositional layering. Tight to isoclinal F2 folds refold the biotite fabric, with some regrowth of biotite in axial planar cleavage.

One metatuff from Bullock Channel and a greywacke from Hiekish Narrows contain post-kinematic cordierite, probably of contact metamorphic origin. Garnet and muscovite are very rare, attesting to the alumina-poor composition of the siliciclastic protolith. Diopside is the most common calcsilicate mineral in the Mathieson Channel Formation, occurring as discrete laminations in the siltstones and marbles, and forming matrix to conglomerates and sandstones. It is accompanied by subordinate amphibole–tremolite/actinolite to hornblende, depending on rock composition, as well as clinozoisite and epidote. A few of the purer marbles contain garnet and/or phlogopite and/or forsterite. One sandstone-calcsilicate sample from eastern Pooley Island contains probable scapolite.

## EARLY CRETACEOUS PLUTONIC SUITE – METAMORPHISM AND DEFORMATION

The oldest of the three Cretaceous plutonic suites is distinguished by its degree of metamorphism and deformation. Phases in the suite are highly variable in composition, ranging from gabbros and ultramafites, through diorites to trondhjemites. Diorite is the most common phase. In the gabbro and diorite, original clinopyroxene is pseudomorphed by Mg-rich, pale-pleochroic hornblende, and original igneous hornblendes are overgrown by metamorphic aggregates, with darker hornblende along with secondary calcic plagioclase in the matrix. Ultramafites are converted to spectacular sprays of clinochlore, biotite, and amphibole. Both the trondhjemites and the Neekas granodiorite show strong metamorphic biotite fabrics.

Widespread development of subsolidus, metamorphic and mylonitic fabrics in this suite indicates that it was emplaced synkinematically during ongoing regional sinistral deformation. Contacts between diorite and trondhjemite phases are steep, northwest-striking zones of shearing. At the *ca.* 123 Ma U-Pb sample locality north of Jackson Passage, a leucotrondhjemite dike cuts across fabric in metadiorite, but itself displays a strongly lineated mylonitic fabric parallel to its walls, which provides evidence that the cooling felsic body localized shearing (Figure 11a). Outside of discrete fault zones, shear fabrics such as asymmetric pressure shadows around plagioclase porphyroclasts are developed in the metadiorites (Figure 15). Both steeply and gently plunging streaky to mylonitic lineations are seen.

## THE GRENVILLE CHANNEL FAULT AND MID-CRETACEOUS SINISTRAL SHEARING

Regionally, the Grenville Channel fault can be traced as a prominent topographic linear feature from northern Grenville Channel, south through the channel north of Gil Island, where a small offset or deflection places it in the strong northwesterly topographic linear that transects Princess Royal Island (inset, Figure 1). It continues southeast across Laredo Inlet and into the present map area. There, it emerges on the southeastern end of Princess Royal Island in several strands under and near Cougar Bay and continues to the southeast (Figure 5). The fault cuts across plutons of the *ca.* 105-94 Ma tonalite suite. On Swindle Island and north towards Cougar Bay, a gradual transition can be traced from unfoliated tonalite to the west, to a zone in which considerable flattening has accompanied late stages of magmatic recrystallization nearer to the Grenville Channel fault. Along the fault itself, the mafic enclave-rich tonalite of the mid-Cretaceous suite has been affected by protomylonitization, with quartz ribboning, trains of neoblasts, and subsolidus biotite recrystallization. The gradual transitions from unfoliated cores into broad zones of igneous fabrics, to narrow mylonites along the fault suggest that these plutons may have been emplaced during motion on the fault.

**Figure 15.** Detail, sinistral sense of shear in *ca.* 123 Ma metagabbro, southern Mathieson Channel north of Neekas Inlet (10JN25-01; 552934E, 5814518N).

From Cougar Bay through Klemtu Pass and across Jackson and Oscar passages, dikes of plagioclase-phyric tonalite and granodiorite occupy strands of the Grenville Channel fault. These late bodies are themselves strongly protomylonitized, with pervasive porphyroclastic textures and quartz ribboning (Figure 16). Unlike the 123 Ma plutons, they were deformed in greenschist facies, as shown by stable biotite, chlorite and epidote, and igneous plagioclase overprinted by heavy saussurite. Sinistral asymmetric shear indicators such as pressure shadows and rotated porphyroclasts characterize these rocks. Plunges of mylonitic lineations are generally very shallow, indicating nearly pure translation on the Grenville Channel fault (Figure 13d). One significant exception to this is the presence of more steeply plunging lineations in the complex zone of intersecting faults at the northern end of Swindle Island. These steep faults may represent accommodation structures. On northern Swindle Island, and north along Tolmie Channel, faults with minor dextral displacement offset the main sinistral strands. The most prominent of these is a mylonite zone that strikes due north along the east side of Tolmie Channel. Its northward projection does not appear to significantly offset the sinistral fault that cuts across Sarah Island (Figure 5). Although it is possible that the dextral faults represent a separate, later transcurrent event, their intimate association with the main Grenville Channel fault array and the possibility that some of them may terminate against sinistral faults both favour the idea that they form northerly-oriented conjugate structures in a single system.

A presumed splay of the Grenville Channel fault corresponds with the northwest alignment of spaced high strain zones that are developed within various rock units in southern Sarah Island. At the northern exposed end of this structure on the island, the tonalite is protomylonitic, displaying porphyroclastic texture with feldspar augen. Farther south along this structure is an important locality where several probable hypabyssal intrusive phases, including potassium feldspar-rich aplite and plagioclase porphyry, are in parallel and vertical juxtaposition within a high strain zone that in turn is crosscut by comparatively weakly strained tonalite. Uranium-lead dating of each intrusive phase is part of a geochronological study by M. Pecha (2010-11). The southern extension of the fault on Sarah Island is marked by metabasite from the Mathieson Channel Formation, exposed at Pering Point. These metabasalts are at amphibolite grade and alternate with marble layers that are crosscut by tonalite dikes projecting east off the main body. Tonalite dikes also occupy another Grenville Channel fault strand striking northerly at Keen Point south of Klemtu. Here tonalite dikes form boudins paralleling a steep penetrative foliation developed in metabasalts. Sampling of these tonalite dikes for a U-Pb zircon date is intended to partly constrain timing for motion on Grenville Channel fault.

**Figure 16.** Deformation adjacent to and within Grenville Channel fault zone: mylonitized granodiorite, Klemtu shear zone. Shows sinistral rotation of plagioclase porphyroclast (10JN21-05; 534542E, 5822824N).

## STRUCTURAL HISTORY

The intense development of amphibolite-facies regional metamorphic fabrics and sinistral-oblique shear deformation in the *ca.* 123 Ma plutonic suite provides a new, important constraint on timing of this event. In northwestern British Columbia, several studies have documented that *ca.* 110-90 Ma plutons were emplaced at a late stage in the sinistral shearing (Chardon *et al.*, 1999; Chardon, 2003; Bulter *et al.*, 2006; Nelson *et al.*, 2010a), but no maximum age for this event has been established. In this area, Early Cretaceous plutons were emplaced into deeply buried Alexander terrane supracrustal rocks and shared sinistral-reverse deformation and exhumation (Figure 13a). In common with the Mathieson Channel Formation, this intrusive suite experienced amphibolite-grade dynamothermal metamorphism and distributed sinistral sense of shear associated with steeply plunging lineations. Earlier faults and shear zones may exist in the map area, but they are not required to explain the tectonic features that we observe.

By 105 Ma, the north coastal region was uplifted and exhumed to the point of quenching the amphibolite-facies assemblages. At this time a renewed pulse of intrusive activity delivered large bodies of tonalitic magma . The reverse (compressional) strain component dwindled, and the mid-Cretaceous plutonic suite was emplaced in a regime of nearly pure strike-slip motion (Figure 13a). Sinistral shear progressively focussed into a single fault zone, the Grenville Channel fault.

The tectonic cycle of burial, metamorphism, plutonism, and sinistral-orthogonal contraction described above for the western Coast Mountains predates the main Late Cretaceous contractional event in the central Coast Mountains to the east (Rusmore *et al.*, 2005) by more than 10 million years. These two events reflect changes in plate vectors and larger scale interplate relative motions. The sinistral component is unique to the Early Cretaceous event. The Late Cretaceous event was characterized by orthogonal shortening that evolved to dextral-reverse and then dextral-normal by Eocene time. Also, the Late

Cretaceous event involved much greater degrees of crustal thickening and subsequent uplift. However, both tectonic regimes involved southwest-vergent structures, and both probably probably formed in response to coupling between the overriding North American plate and subducting plates in the Pacific ocean realm. In each case the deformation was concentrated in the axial region of the arc (which migrated east between 110 and 80 Ma), and involved interplay between tectonics and emplacement of voluminous magmas over a 40 million year interval of Early and Late Cretaceous time.

## AU MINERAL POTENTIAL OF THE CENTRAL COAST

The Surf Inlet mine (MINFILE 103H 027) is located on northern Princess Royal Island 45 km north of the present map area (inset, Figure 1). A past producing gold mine with considerable remaining underground resources, its genesis represents an important aspect of the metallogeny of the central British Columbia coast. The following account is based on a brief field visit in 2010, along with detailed geological mapping available from von Einsiedel (2001), and descriptions of the property in the MINFILE database.

Surf Inlet is a classic mesothermal (orogenic) gold-quartz vein system that formed in a series of third order structures, along a second-order splay of the Grenville Channel fault. There are two separate orebodies, the Surf and Pugley mines, both located within 2 km of the main fault, which underlies Bear Lake (Figure 17). The second order fault that controls the orebodies diverges northward from the main fault, curving to the northeast. The two mines are located within the north striking, middle section of the fault trajectory. Here, the fault zone consists of several shear zones with average dips of 45° to the west. The hostrock, a deformed and protomylonitic diorite-tonalite body, has yielded a U-Pb zircon age of 106 Ma (J. Mortensen and R. Friedman in Gehrels *et al.*, 2009). Quartz veins occupy late-stage, brittle structures and typically have alteration selvages composed of sheared chlorite, sericite, carbonate and epidote. In the veins, coarse quartz contains very coarse clots of pyrite and chalcopyrite, with lesser chalcocite, bornite, covellite and molybdenite (Figure 18).

Production from the mine was carried out intermittently by several companies between 1917 and 1946. In total, nearly 1 million tonnes was produced from the two mines averaging 13.0 grams per tonne gold, 6.8 grams per tonne silver and 0.31 per cent copper (BC MINFILE). The property is currently held by Rupert Resources Ltd. Economic potential is recognized for downdip extensions of the mined ore zones.

The host pluton to the Surf Inlet mine bears strong similarities to mid-Cretaceous plutons elsewhere. It is unmetamorphosed, so emplacement post-dated the amphibolite-facies event that affected the older Cretaceous plutons. Igneous foliation manifested by

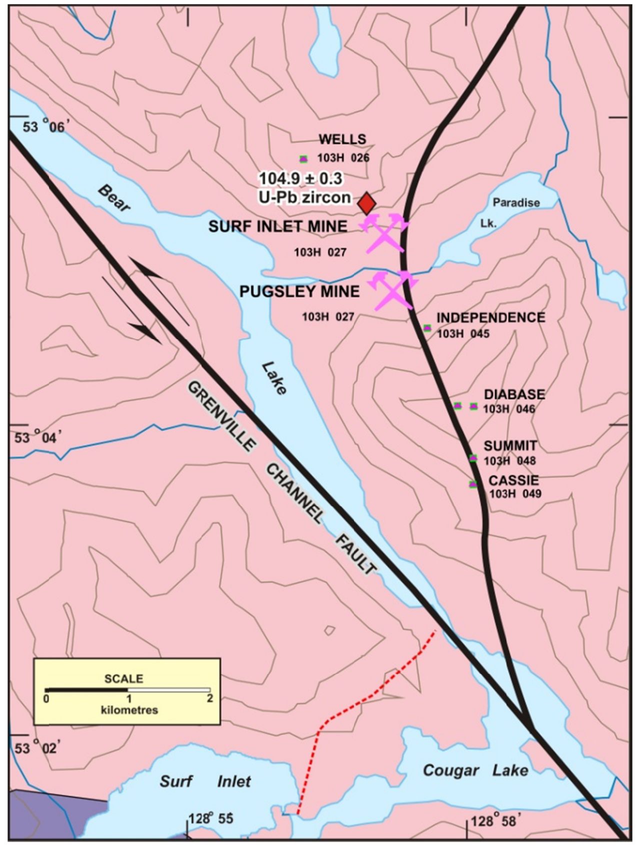


**Figure 17.** Detailed map of Surf Inlet mine and its surroundings. Pink = Cretaceous granitoids; purple = metamorphic rocks.

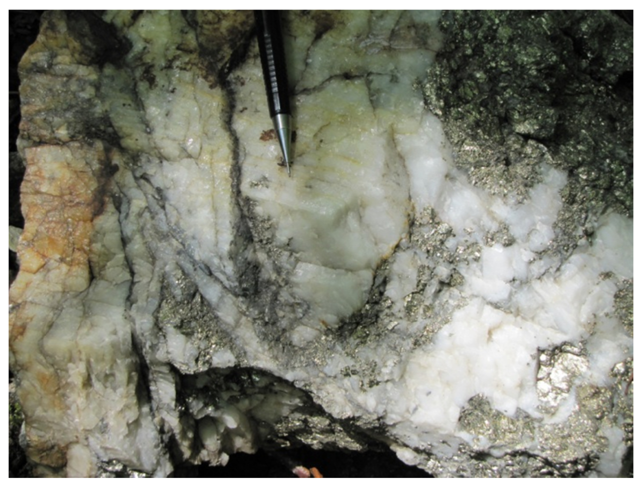

**Figure 18.** Surf Inlet ore, from creekbed in tallings dump (507636E, 5881725N).

alignment of coarse biotites with subordinate, late, cross-cutting plates is identical to textures in the ca 105 Ma pluton west of Klemtu. The protomylonitic overprint occurred at low temperatures, with high $H_2O$ and $CO_2$ contents. This deposit is similar in type and structural setting to the Surf Point (Edye Pass) gold-quartz system on northwestern Porcher Island (inset, Figure 1; Nelson *et al.*, 2010a). Surf Point is also located on second and third order shears related to the Grenville Channel fault. The repeated association of significant mesothermal gold-quartz veins with structures related to the later, brittle phases of sinistral motion on the Grenville Channel and related faults demonstrates an important mid-Cretaceous metallotect in coastal British Columbia.

## DISCUSSION

### *The southern Alexander Terrane in coastal British Columbia*

In 2009 and 2010, detailed mapping was completed for the Alexander terrane near both ends of its extent south of Alaska. The two areas are underlain by stratigraphically different units. At the northern end of the Alexander terrane, Ordovician volcanogenic and related plutonic rocks are widespread on Porcher Island and northern Pitt Island. By contrast, the southern end of the Alexander terrane consists of a siliclastic, carbonate and bimodal volcanic unit named herein the Mathieson Channel Formation and speculated to be of Devonian age. Broadly similar clastic rocks are limited to a few locales in the north. Regionally, the oldest exposed Alexander terrane rocks progress in age from Precambrian-Cambrian Wales Group on southern Prince of Wales Island, through Ordovician rocks along the northern Inside Passage, to possible Devonian clastic rocks in the far south, in the Laredo Sound map area.

Volcanogenic base metal mineral potential in the Alexander terrane is primarily associated with Ordovician arc sequences, notably the Moira Sound unit of Karl *et al.* (2009), which hosts the Niblack deposit on southern Prince of Wales Island. Thus the Mathieson Channel Formation in the current map area is considered unprospective for syngenetic volcanogenic deposits. The bimodal volcanic rocks in it erupted into a shallow basin, probably under oxidizing conditions as indicated by the possible presence of redbeds.

The Mathieson Channel Formation and the quartzite-siltstone-volcanic conglomerate at Jorkins Point are significant indicators of the tectonic history of the Alexander terrane. They reflect patterns of tectonics and sedimentation in the aftermath of the earliest Devonian Klakas orogeny. The Mathieson Channel Formation, with its dominant fine-grained siliciclastics and carbonates, its narrow intervals of bimodal and potentially alkalic volcanics, and its sporadic local influxes of very coarse clastic debris, is inferred to represent a rift basin fill.

In the Alexander terrane of southeastern Alaska, the slightly older Silurian Heceta conglomerates have been speculated to be equivalent to late Caledonian rift basin sequences (Soja and Krutikov, 2008). A similar correlation will be possible for the Mathieson Channel Formation, if suspected Devonian ages are confirmed by detrital U-Pb geochronology of possible rift-related clastic rocks.

The Jorkins Point conglomerate may have been deposited in or near the Mathieson Channel basin. The presence of Mathieson-like siltstone clasts supports this idea; although its depositional age is not yet known. The prominence of quartzite clasts in Jorkins Point conglomerate certainly demonstrates recycling of continentally derived debris, possibly due to arc-continent sliver amalgamation events such as the Early Devonian Klakas orogeny.

### *Early to mid-Cretaceous sinistral tectonics, the Grenville Channel fault, and mesothermal gold mineralization*

In 2010 mapping, we have recognized the southern Grenville Channel fault near Klemtu as a locus of mid-Cretaceous sinistral shearing, and also documented a somewhat older Early Cretaceous event of distributed shear during amphibolite facies metamorphism. Magmatic ages constrain the timing of the distributed sinistral shear event between 123 and 105 Ma, the age of the synkinematic versus postkinematic plutons. These observations provide an important dimension to the mid-Cretaceous sinistral shear history of the northern Grenville Channel fault and its splays. Intense fabric development in the *ca.* 123 Ma plutonic suite indicates that this deformation is entirely Early Cretaceous, rather than a continuation of the mid-Jurassic accretion kinematics of Alexander and Yukon-Tanana terranes.

The Early to mid-Cretaceous sinistral-oblique shear system, as recorded in exposed rocks, evolved from deep-crustal, sinistral-reverse motion, to upper crustal, nearly pure transcurrent motion on the Grenville Channel fault, in which the latest synkinematic phases record greenschist facies metamorphism at high fluid pressures as shown by the presence of abundant chlorite, sericite and carbonate. Tectonically, regimes of partitioned transcurrent motion during exhumation from amphibolite to greenschist facies are recognized worldwide as highly favourable to the emplacement of mesothermal (orogenic) gold-quartz vein systems. Therefore it is no surprise that two significant ex-producing gold mines of this type lie proximal to the Grenville Channel fault, controlled by second and third order fault arrays. Another promising gold-quartz vein system, Yellow Giant (MINFILE 103G 021, 24, 25, 26, 30), is located on Banks Island. It is currently held by Imperial Metals, who hope to begin an exploration program there in 2011 (Jim Miller-Tait, personal communication, November 2010).

## FUTURE RESEARCH DIRECTIONS AND MAPPING PLANS

The third and final field season of the North Coast Project is planned for 2011. It will have the following key goals:

1) Revisit and resample for geochronology parts of the areas previously mapped, in which present structural, lithologic and geochronometric data indicate unsolved problems. Examples of this include a) the Devonian pluton in Porcher Inlet, which cuts an older orthogneiss complex that so far has only yielded an apparent Jurassic U-Pb

Laserchron age displaying complex systematics (J.B. Mahoney, unpublished data, 2010); b) the Swede Point pluton on Porcher Island, which may be Mississippian or, alternatively, Mesozoic with inherited cores and c) Kumealon Inlet, where a structural contact between Alexander terrane and Yukon-Tanana terrane has been inferred (Nelson *et al.*, 2010b), but detrital zircon data are conflicting, and where U-Pb dating of the metavolcanic rocks has yet to be done.

2) Collaborate with Joel Angen, who is studying the fault systems on Porcher Island and along northern Grenville Channel as an M.Sc. thesis at the University of Waterloo. His work is sponsored by the Geological Survey of Canada as a contribution to the Edges project.

3) Visit key mineral occurrences in the area, particularly the Yellow Giant mesothermal Au deposit and the Pitt volcanogenic prospect, in order to place them in regional context.

4) Complete field investigation of the Alexander terrane between Grenville Channel and northern Princess Royal Island, targeting a full update of this part of the BC Geological Map in 2012.

## SUMMARY AND CONCLUSIONS

In this second year of operation, the North Coast project can list the following accomplishments:

Completion of geological map coverage of an area of 30 by 50 km, covering the channels and islands between Return Channel and northern Princess Royal Island, in eastern Laredo Sound map area (103A). This map will be released as a British Columbia Geological Survey open file in early 2011 (Nelson *et al.*, 2011).

Rock units of the Alexander terrane of southeastern Alaska can be traced into northwestern British Columbia (Porcher and Pitt islands), including those that are known to host Ordovician volcanogenic massive sulphide mineralization. Farther south, in the current map area, the Alexander terrane is represented by younger, probably Devonian, clastic-carbonate strata.

The Grenville Channel fault is a mid-Cretaceous sinistral fault of regional extent (>150 km). It and its splays form the tectonic framework for mesothermal gold-quartz vein systems including Surf Point on Porcher Island, Surf Inlet on Princess Royal Island, and probably Yellow Giant on Banks Island. This is an important new metallotect on the coast of British Columbia.

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