

# North Coast Project: Tectonics and Metallogeny of the Alexander Terrane, and Cretaceous Sinistral Shearing of the Western Coast Belt

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

## INTRODUCTION AND PROJECT HIGHLIGHTS

This article presents the results of the final field season of a three year collaborative geological investigation of north coastal British Columbia (Figures 1, 2) between the British Columbia Geological Survey, Geological Survey of Canada, and university partners University of Wisconsin at Eau Claire and University of Arizona. The North Coast bedrock mapping and mineral deposit study is part of a cooperative, Natural Resources Canada (NRCan)-led endeavor, the Edges Multiple Metals – NW Canadian Cordillera (B.C. and Yukon) Project. The first two years involved detailed mapping on and near Porcher Island in 2009 and near Klemtu in 2010, and production of open file maps (Nelson *et al.*, 2010a, 2011a). In this final field season the focus was 1) to complete regional-scale geological coverage of the intervening area from Grenville Channel to northern Princess Royal Island in order to update the provincial geological map for all of north coastal British Columbia, a very preliminary draft of which appears as Figure 3 in this paper; and 2) to address problems and questions arising from mapping and U-Pb isotopic results obtained earlier in the program.

Highlights from the 2011 field season include:

- Discovered new VMS showings on southern Kennedy Island, hosted by Ordovician rhyolite.
- Visited the Pitt showings on Pitt Island, the only previously documented VMS occurrence in the southern Alexander terrane of British Columbia,

and collected sulphide samples for lead isotopic signatures, for comparison with Neoproterozoic and Ordovician deposits in southeast Alaska.

- Collected and analysed a suite of samples of meta-igneous rocks east of northern Grenville and Telegraph channels; Permian ages throughout this belt document a previously-unknown, late Paleozoic volcanic-sedimentary unit with related dikes in intrusive contact with the Alexander terrane.
- Investigated a large tract of Late Silurian to Early Devonian (*ca.* 424-411 Ma) orthogneiss-plutonic complex on Porcher Island, intruded during a Caledonian-age deformational event that probably marked the amalgamation of pericratonic and primitive arc elements within the composite Alexander terrane.
- Traced out Grenville Channel fault for 300 kilometres along strike, collecting key plutonic phases that precisely constrain stages of sinistral motion in Early to mid-Cretaceous time.

## REGIONAL GEOLOGICAL AND TECTONIC FRAMEWORK

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 the northern coastal region of British Columbia, the Alexander terrane 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). The Banks

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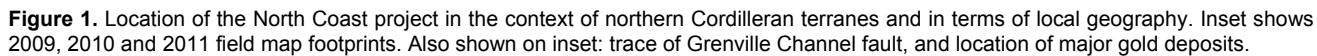
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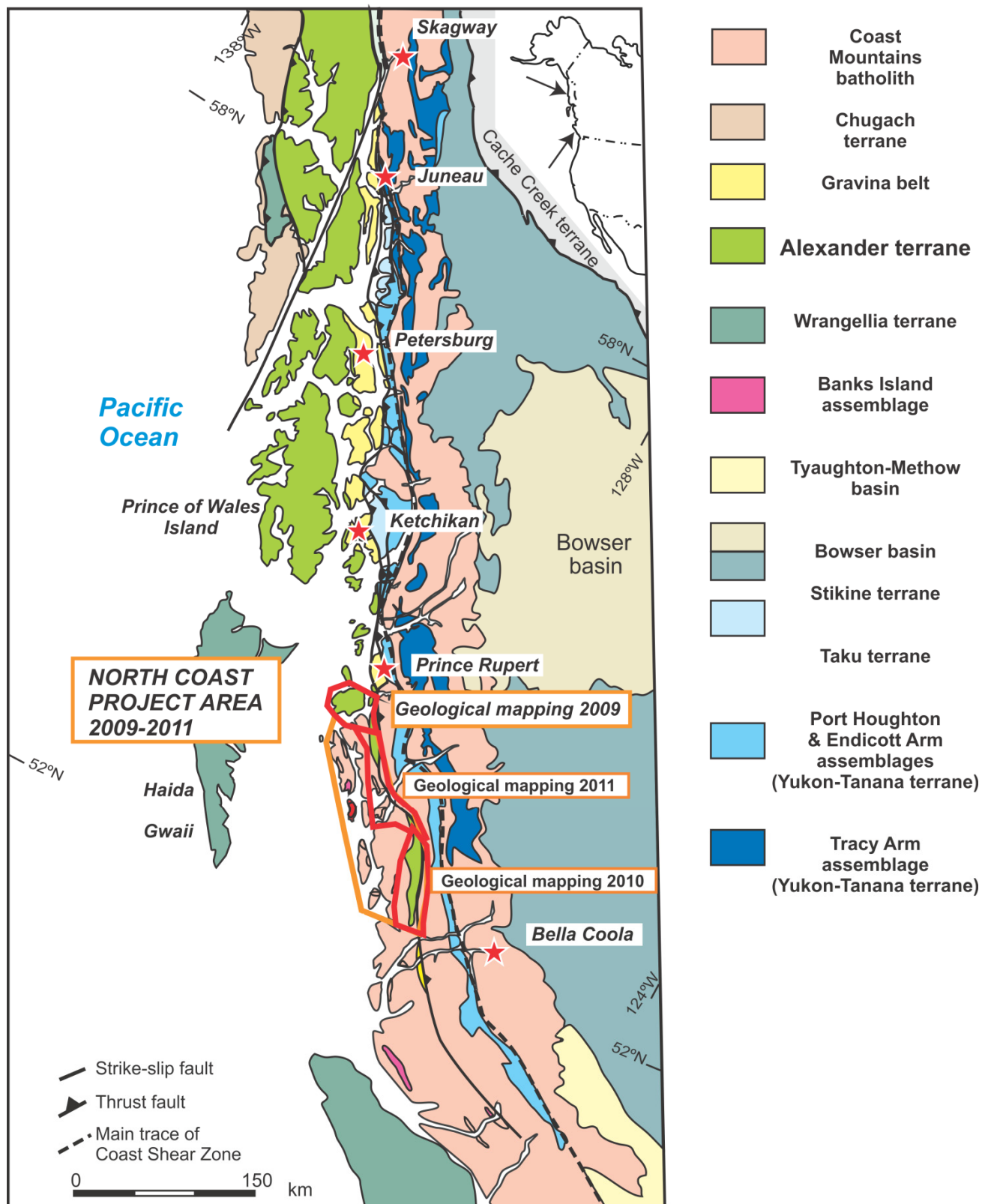
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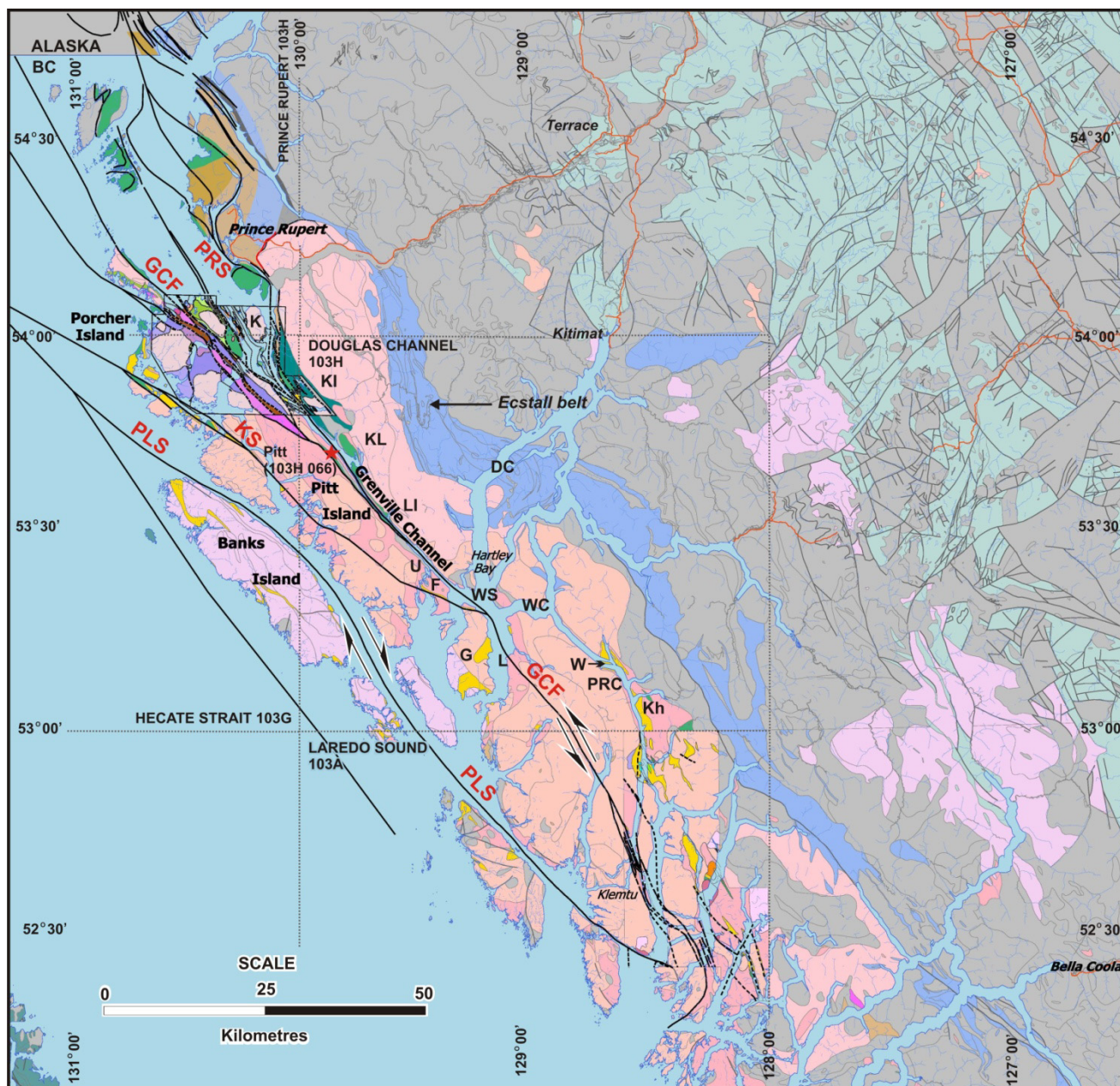
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**Figure 2.** Regional geology and terrane map of northern coastal British Columbia and southeastern Alaska; G.E. Gehrels, 2009.





**Figure 3.** Preliminary revision of British Columbia north and central coast map tile. Geology from BC Geology Map; Nelson *et al.* (2010a, 2011a; this paper); Gehrels, 2001, Gehrels and Boghossian (2000); pluton ages from data in Gehrels *et al.* (2009). Geographic abbreviations: DC–Douglas Channel; F–Farrant Island; G–Gil Island; K–Kennedy Island; Kh–Khutze Inlet; KI–Kumealon Inlet; KL–Klewnuggit Inlet; L–Leading Point; LI–Lowe Inlet; PRC–Princess Royal Channel; U–Union Passage; W–Work Island; WC–Whale Channel; WS–Wright Sound. Faults: GCF–Grenville Channel fault; KS–Kitkatla shear PLS–Principe-Laredo shear; PRS–Prince Rupert shear zone.

Island assemblage is a poorly understood siliciclastic unit of pericratonic affinity that has only been recognized along the outer coast of northern British Columbia (Gehrels and Boghossian, 2000).

All of the supracrustal units are extensively intruded by Late Jurassic to Late Cretaceous plutonic bodies of the Coast Plutonic Complex. In much of the western Coast belt, plutonic exposures are so extensive that older supracrustal rocks are confined to narrow pendants within them.

### 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 Late Proterozoic to early Paleozoic age, overlain in places by thin younger sequences (Figure 4a). Most of the terrane in southeastern Alaska was assigned to the Craig subterrane by Berg *et al.* (1978; definition refined by Gehrels and Berg, 1994). In southeastern Alaska, these rocks have



## LEGEND



Figure 3. continued; Legend for map.

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 metamorphism and deformation increases. In spite of these younger overprinting events, it has been possible to correlate geologic units of southeastern Alaska with those of northern coastal British Columbia. The following unit descriptions are taken from the well-preserved portion of the Alexander terrane in southern southeastern Alaska as described in Eberlein *et al.* (1983), Gehrels and Saleeby (1987) and Gehrels *et al.* (1996).

The oldest rocks recognized in the Alexander terrane in southeastern Alaska consist of Late Proterozoic to Cambrian metavolcanic and metasedimentary assemblages of the Wales Group (Figure 4; Gehrels and Saleeby, 1987). Metavolcanic components range from mafic to felsic in composition - pillowed flows and flow breccias, and pyroclastic deposits of tuffaceous breccia and tuff. Metasedimentary components consist of volcanic-derived metagreywacke, pelitic phyllite or schist, and marble. These supracrustal rocks are intruded by bodies of complexly interlayered gabbro, diorite, tonalite, and granodiorite. Our U-Pb results so far from northern coastal British Columbia have not shown any igneous protoliths older than latest Cambrian; therefore the Wales Group is not recognized here.

In southeastern Alaska, rocks of the Wales Group are overlain by a less deformed, Early Ordovician to Late Silurian suite of volcanic and sedimentary rocks referred to as the Descon Formation (Eberlein *et al.*, 1983; Gehrels and Saleeby, 1987). Dioritic to granitic plutons that are coeval (and probably cogenetic) with volcanic rocks of the Descon Formation are widespread. Mapping and U-Pb dating on and near Porcher Island has established the widespread presence of Descon-equivalent metavolcanic sequences (Nelson *et al.*, 2010a, b).

Lower Paleozoic strata of the Alexander terrane in southeastern Alaska are overlain unconformably by a variety of Devonian strata that commonly include a basal clastic sequence (conglomerates and sandstones, including red beds) of the Karheen Formation, mafic volcanic rocks of the Coronados Volcanics and St. Joseph Islands Volcanics, and limestones of the Wadleigh 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 including a preponderance of Silurian plutonic clasts (Gehrels *et al.*, 1983a; Gehrels and Saleeby, 1987). Devonian and younger volcanic units are mafic or bimodal mafic-felsic, and of limited extent. They probably are the products of local rift-related extrusive events.

Devonian clastic-carbonate sequences are abundant in the Alexander terrane in north coastal British Columbia (Figure 3). Throughout this region we have assigned them to the Mathieson Channel Formation, because of their

broad extent, physical separation from the main Karheen Formation, and somewhat different nature from it, notably the prominence of carbonate strata (Nelson *et al.*, 2011b and this paper). The variability of siliciclastic and carbonate facies and the presence of locally derived, plutonic-sourced conglomerates and bimodal volcanic sequences in these formations suggest that they were deposited in a series sub-basins formed by rifting.

Younger strata in the Alexander terrane of southeast Alaska include fine to medium grained clastic rocks, carbonate, minor basalt of Carboniferous and Permian age, and local Triassic basal conglomerates overlain by bimodal mafic-felsic volcanic rocks, carbonate, and volcanoclastic strata. The Late Jurassic to Early Cretaceous Gravina belt, described separately below, unconformably overlies the Alexander terrane (Figure 4).

## Other terranes and assemblages

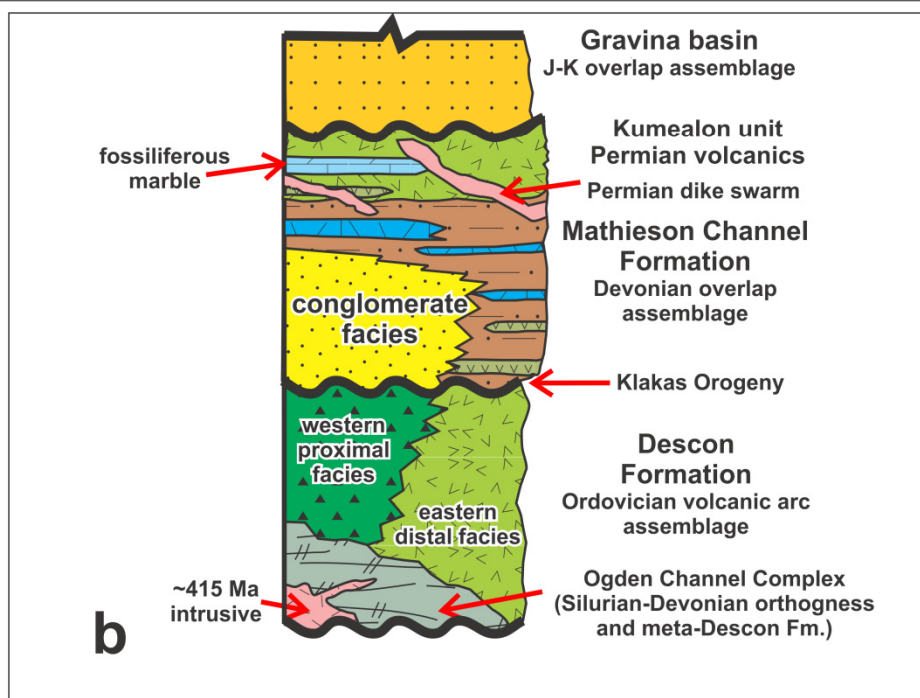
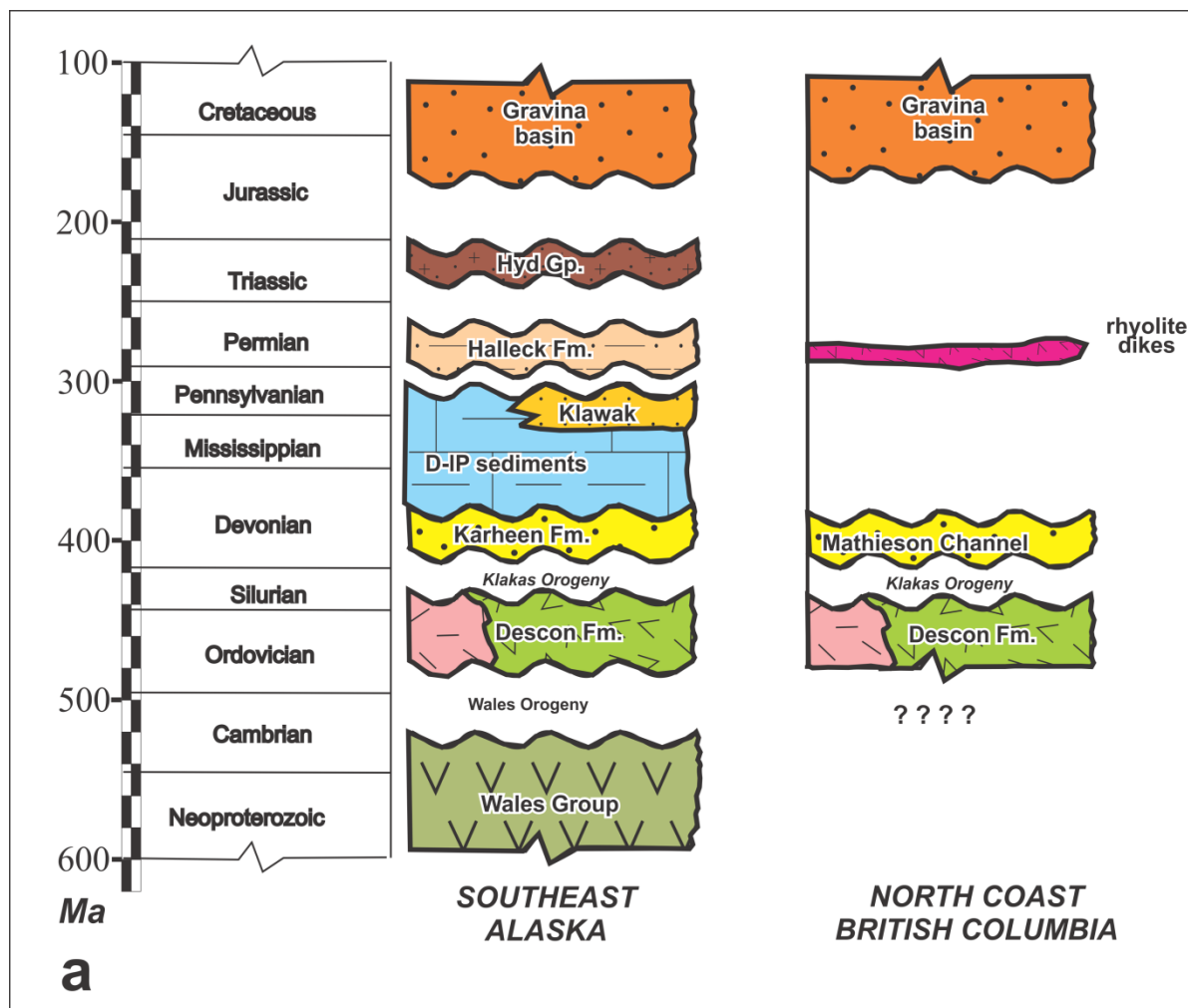
### BANKS ISLAND ASSEMBLAGE

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; and on the presence of significant populations of Precambrian detrital zircons (Gehrels and Boghossian, 2000; G. Gehrels, unpublished data, 2011). These rocks are exposed on the outer coast of Banks Island, on northwestern Porcher Island, and on the outer islands as far south as Klemtu. The dominant lithic components are strongly deformed and regionally metamorphosed metaclastic quartzites. They commonly occur in centimetre-scale bands interlayered with marble in thicknesses of several centimetres to several tens of metres, and pelitic phyllite/schist. Everywhere, these rocks 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.

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 intrude these rocks (Gehrels *et al.*, 2009), across the regional foliation and folds. These constraints suggest that the Banks Island assemblage accumulated during mid-Paleozoic time.

Mapping in 2011 of pendants on Gil, Farrant and Pitt islands, previously assigned by Gehrels and Boghossian (2000) to the Banks Island assemblage, shows that these





**Figure 4.** a) Stratigraphic columns for Alexander terrane of southeastern Alaska and coastal northwestern British Columbia; b) Schematic stratigraphic column for coastal northwestern British Columbia.

strata strongly resemble the Mathieson Channel Formation as described in the region farther south between Return Channel and Graham Reach (Nelson *et al.*, 2011a, b). Preliminary results of detrital zircon analysis shows significant Precambrian populations from samples in this area, a feature characteristic of Banks Island detrital signatures (M. Pecha, unpublished data, 2011). The two units may have passed transitionally into each other, with a change of provenance from partly pericontinental on Banks Island to purely Ordovician-Silurian-Devonian igneous sources to the south and east captured within the Mathieson Channel formation (Mahoney *et al.*, 2011). It would thus represent a clastic overlap between a pre-Devonian primitive arc fragment (Craig subterrane of Alexander terrane) and a pericratonic one ("Banks Islandia"), which accreted to each other during the Klakas orogeny.

## YUKON-TANANA TERRANE

East of the Alexander terrane, metavolcanic and metasedimentary rocks of the Yukon-Tanana terrane underlie the western Coast Mountains, along the length of southeastern Alaska and northern coastal British Columbia (Figures 1, 2, 3). In general, these rocks form a panel that dips eastward and young 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 :

- 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.
- 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.
- 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.

Near Douglas Channel in northwestern British Columbia, the Ecstall belt (Figure 3; 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, AND ALEXANDER-YUKON-TANANA TERRANE RELATIONSHIPS

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 (Figures 1, 2). In the Chatham Strait area, Gehrels (2001) has identified a unit of mid-Jurassic basalt and rhyolite, the Moffatt volcanics, at the depositional base of the Gravina belt. It unconformably overlies Alexander terrane on Dundas Island; on Tongass Island in southeastern Alaska and on the mainland east of Port Simpson (Lax Kw'alaams). The same basalts and rhyolites overlie a sequence of metavolcanic and metasedimentary rocks that have been assigned to the Yukon-Tanana terrane. Thus in this area, the mid-Jurassic Moffatt volcanics and younger Gravina belt form an overlap on both terranes.

The initial age of accretion of Alexander to Yukon-Tanana terrane has been a long-standing topic of debate among coastal researchers. Crawford *et al.* (1987, 2001) have assigned it to the Early to early Late Cretaceous, based on analysis of the broad belt of high-grade metamorphism, plutonism and southwest-vergent thick-skinned deformation centred around the terrane boundary near Prince Rupert. However, van der Heyden (1992) described pre-Late Jurassic ductile deformation in the eastern Coast Mountains north of Bella Coola, positing that it was a response to initial Insular-Intermontane terrane accretion, largely masked to the west by subsequent tectonism and extensive emplacement of plutons. The pre-Gravina Duncan Canal shear zone in the eastern Alexander terrane of southeastern Alaska may have formed during its accretion (McClelland and Gehrels, 1990). Rubin and Saleeby (1992) and McClelland *et al.* (1992) described the Gravina belt as an overlap sequence on both Alexander and Intermontane terranes. Support for pre-Gravina accretion is also provided by detrital zircons derived from both Alexander (490-410 Ma) and Yukon-Tanana terrane (390-340 Ma) in Gravina clastic strata (Kapp and Gehrels, 1998; G. Gehrels, unpublished data, 2010).

## Plutons of the western Coast Plutonic Complex

Plutons of the Coast Plutonic Complex occur as isolated bodies in northern and western portions of northern coastal British Columbia, and increase in size and number southeastward to form huge continuous masses of plutonic rock (Gehrels *et al.*, 2009; Figure 3). Compositionally, most are tonalite and granodiorite, with subordinate diorite and minor gabbro and leucogranodiorite. A large majority of plutons have hornblende > biotite, plagioclase >> orthoclase, and are rich in titanite. 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 belt. The westernmost plutons are 160-140 Ma (Late Jurassic) tonalites and granodiorites on the outer islands (Figure 3). An extensive suite of compositionally similar Early Cretaceous (120-100 Ma) bodies lies east of the Late Jurassic belt. A nearly continuous band of 100-85 Ma plutons (*e.g.*, Ecstall pluton of Hutchison, 1982) underlies the western reaches of the Coast Mountains proper, succeeded eastward by mainly tonalitic sills of ~70-60 Ma (Latest Cretaceous-earliest Tertiary age). The central and eastern portions of the Coast Mountains are underlain by voluminous 60-50 Ma (Eocene) granodiorite bodies. The emplacement depth of plutons also increases from west to east into 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 to the east were slightly deeper, ~20 km. Even 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.

### ***The Grenville Channel fault and Early to mid-Cretaceous sinistral tectonics within the Coast Plutonic Complex***

A mid-Cretaceous sinistral transcurrent fault regime was first documented by Chardon *et al.* (1999). Work on this project in the area around Porcher Island in 2009 established the importance of Cretaceous sinistral faulting there, with many fault strands crossing the island and converging southward into the Grenville Channel fault through Grenville Channel (Figure 5; Nelson *et al.*, 2010a, b). Thesis work by Joel Angen in 2010-2011 has provided additional detail about the shear systems in Porcher Island area and also has constrained their age to mid-Cretaceous (*ca.* 105-96 Ma; Angen *et al.* this volume). In the course of regional mapping in 2010, the southern extension of the Grenville Channel fault and its splays in the Laredo Sound map-area near Klemtu were recognized similarly as a locus of mid-Cretaceous sinistral shearing. Also in this area, a somewhat older Early Cretaceous event of distributed shear occurred during amphibolite facies metamorphism (Nelson *et al.*, 2011b). Magmatic ages constrain the timing of the distributed sinistral shear event between 123 and 105 Ma, the age of the syn-kinematic versus post-kinematic plutons. These observations provide an important dimension to the mid-Cretaceous sinistral shear history of the northern Grenville Channel fault and its splays. Intense region-specific 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 (Nelson *et al.*, 2011b).

## **NORTH COAST GEOLOGICAL STUDIES IN 2011**

### ***Update on VMS occurrences and VMS potential in the southern Alexander terrane***

Ordovician basalt-andesite-dacite-rhyolite volcanic successions and probably cogenetic plutons underlie much of northeastern Porcher and Pitt islands and their vicinity (Figure 5; Nelson *et al.*, 2010a; J.B. Mahoney, unpublished U-Pb zircon data). They are equivalent to the Descon Formation and informally-named Moira unit in southeastern Alaska, which host known VMS mineralization (Gehrels *et al.*, 1983b; Slack *et al.*, 2005). Dacites and rhyolites probably originated as domes or cryptodomes at small volcanic centres. Felsic tuffs form discrete beds in the metre to decimetre range, as well as sets of laminae in dominantly andesite volcanoclastic sequences. These rocks overall are favourable hosts for Kuroko-style volcanogenic massive sulphide (VMS) occurrences.

More specific geologic indicators of Ordovician VMS environments include:

- Stratabound, stratiform magnetite along the northeastern side of Porcher Island immediately northeast of the Lamppost fault, and on the eastern side of Pitt Island near Stuart Anchorage (MINFILE 103G 016, Royal and 103J 031, Star; others shown on Nelson *et al.*, 2010a).
- Schists containing manganoan zoisite and axinite occur in association with the iron formation in Stuart Anchorage, and also within the Oona River unit on the northeastern shoulder of Pitt Island, which because of their unusual compositions and association with felsic metatuffs and iron formation are interpreted as metamorphosed exhalites.
- VMS showings on southern Kennedy Island discovered in 2011, hosted by rhyolite dated as Ordovician by U-Pb methods on zircon (J.B. Mahoney, unpublished data, 2011).

### **VMS PROSPECT ON PITT ISLAND**

The best known local example of syngenetic stratiform sulphide mineralization on Pitt Island is the Pitt prospect or Pitt/Trinity claim group (MINFILE 103H 066), located 7.5 km northwest of the entrance to Klewnuggit Inlet on Grenville Channel (Figure 3). In 1980, attracted by a rusty gossan in Pyrite Creek, the discovery of massive sulphides led to exploration and property mapping to determine the geological setting of this polymetallic mineralization (Bradley, 1987). Subsequent exploration in 1992 adopted previously defined lithostratigraphic units, and conducted ground and airborne geophysical surveys that led to the discovery of additional showings (Bohme, 1993; Lo, 1992).

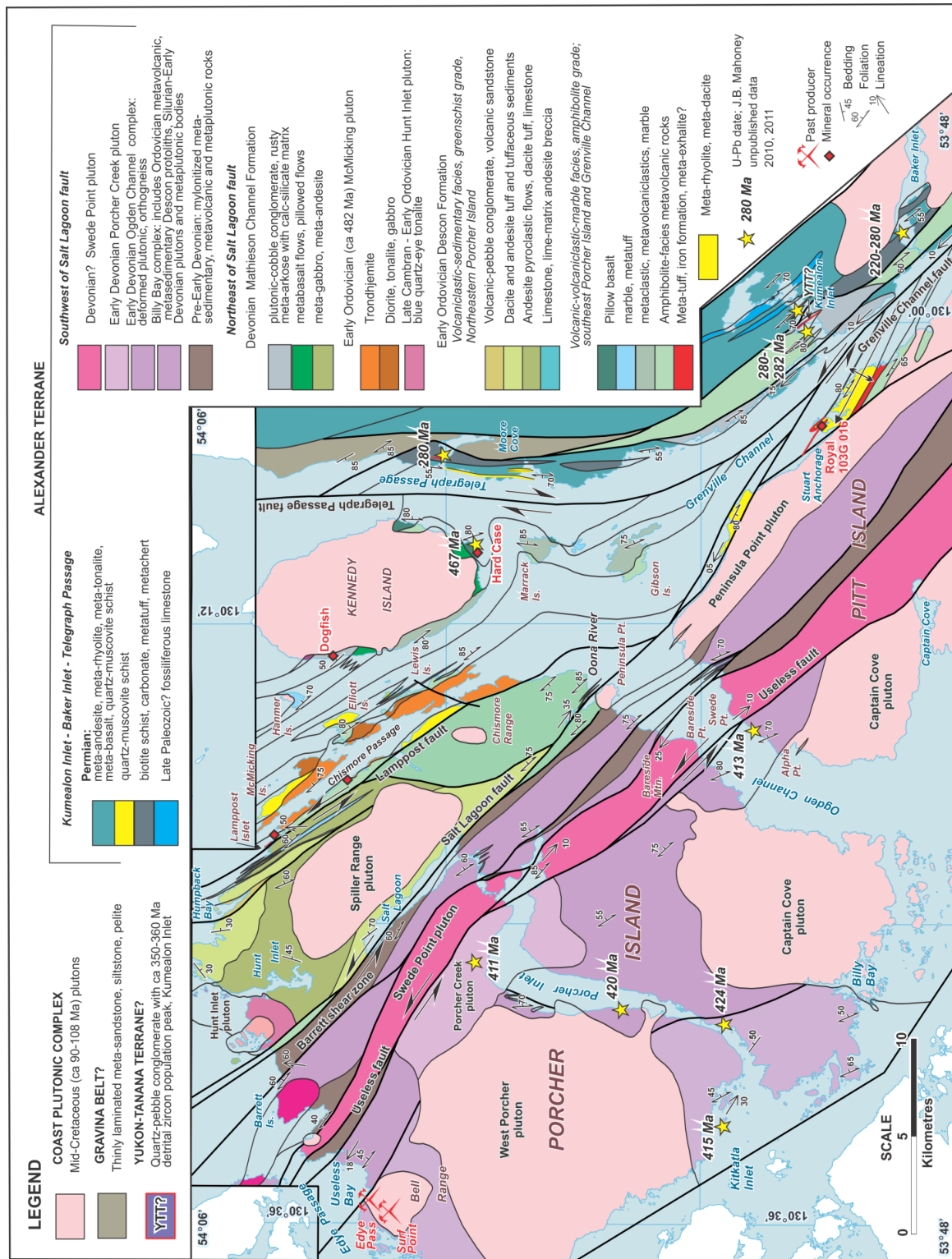


Figure 5. Geology of Porcher Island and vicinity; 2009 mapping with 2011 updates and additions.



The Pitt/Trinity claim group consists of three separate mineralized zones in two separate inliers of metasedimentary-metavolcanic rocks within foliated Cretaceous plutons that parallel the regional northwest structure (Bohme, 1993). The Pyrite Creek and Pitt zones contain most of the known mineralized showings. Located 3.5 kilometres apart along strike, they correspond with a prominent northwesterly topographic lineament, marked by incised drainages and rusty oxidized gossans, along which evidence for a major fault is reported (Bohme, 1993). In both zones, pyrite-rich, semimassive and massive sulphides occur in quartz-muscovite schist interlayered with meta-arenite (quartzite),  $\pm$ garnet-quartz-biotite schist and carbonaceous argillite (Figure 6). The true thickness of sulphides varies between 0.2 and 1.6 metres. Principal sulphide minerals consist of pyrite, chalcopyrite, sphalerite, pyrrhotite, galena, covellite and possibly bornite. Based on values of 1.0-5.5% Ba in assays, barite is suspected. Drill intersections of the Pyrite Creek zone returned between 0.94 and 2.2% Cu, 0.41 to 1.2% Pb and 1.5 to 4.9% Zn over 2 metre widths. Reported values of precious metals are low (Bohme, 1993). The B Creek zone is in a separate metasedimentary-metavolcanic inlier 2.5 kilometres northeast of Pyrite Creek.

In 2011, a brief property visit to examine and sample host rocks containing stratiform sulphide mineralization focussed on the Pyrite Creek zone. The topographically higher part of this zone, where numerous sulphide showings occur in an incised north-flowing creek (Bohme, 1993), consists of meta-arenite forming massive thick layers, alternating with thinner garnet-biotite schist. Felsic schist comprises a thin, one-half metre thick friable weathered layer exposed at creek level. It is composed mainly of muscovite and quartz with disseminated and semimassive millimetre-thick bands of pyrite-chalcopyrite $\pm$ sphalerite $\pm$ galena. Unfortunately, a sample of this felsic tuff layer failed to yield zircons for U-Pb geochronology. Another sample currently being processed for detrital zircon geochronology is a clean, well-sorted meta-arenite. Its detrital zircon population will determine affiliation of syngenetic sulphide host rocks with either Ordovician Descon Formation (or Moira unit) or Devonian Mathieson Channel Formation. Two sulphide samples will be submitted for Pb-isotopic analysis, for comparison with data from volcanogenic occurrences in southeastern Alaska (Slack *et al.*, 2005).

The strong structural control of the Pitt trend, thin width of the sulphide-rich zone and predominance of epigenetic, discontinuous vein-style mineralization suggest that it was possibly a feeder zone, controlled by a penecontemporaneous, basin-bounding fault. The Pitt trend structure has now been remobilized to form the southwestern boundary of the Grenville Channel shear zone on Pitt Island. Remobilization of original normal faults into later compressional and/or transcurrent structures is a common feature of syngenetic mineralized systems (Nelson, 1998).

## NEW SHOWINGS NEAR PORCHER ISLAND

The Hard Case showing of VMS-style mineralization was discovered during field studies in 2011, on the southeastern shore of Kennedy Island (Figure 5). It mainly comprises massive pyrite-pyrrhotite with accessory chalcopyrite and sphalerite and stockwork-like mineralization hosted by a felsic pyroclastic rock, components of which have been replaced by sulphide (Figure 7a). This unit overlies metabasalt interpreted as part of the Ordovician-Silurian Descon Formation, and below conglomerate and cross-bedded sandstone of the Mathieson Channel Formation (Nelson *et al.*, 2010b, 2011b). The host rhyolite breccia has yielded an Ordovician, *ca.* 467 Ma U-Pb age (J.B. Mahoney, unpublished data, 2011). The Dogfish showing is a second VMS-style occurrence identified in 2011 situated in the same stratigraphic setting on southwestern Kennedy Island as the Hard Case showing. Mineralization occurs in intensely quartz-sericite-altered volcanic protoliths, as disseminated pyrite and pyrrhotite, massive pyrrhotite, local pyrite, sphalerite and minor chalcopyrite, and brecciated, sulphide-bearing quartz-sericite schist veined by pyrrhotite and sphalerite (Figure 7b). Because Kennedy Island is protected as part of the Kennedy Island Conservancy Area, these two new occurrences are not potential exploration targets in themselves. However, they do highlight the fertility for additional discoveries of VMS-style deposits in this region. In sulphide textures and lithic associations they resemble an occurrence of massive marcasite-pyrite in Ordovician felsic breccia (Figures 7c, d), located on the western side of Digby Island, near the Prince Rupert airport. This site yielded a U-Pb zircon age of *ca.* 472 Ma (Gehrels and Boghossian, 2000).

### ***The Mathieson Channel Formation: a regional Devonian clastic overlap sequence in southern Alexander terrane***

The Mathieson Channel Formation is a widely distributed unit in the southern Alexander terrane in north coastal British Columbia, as of this year mapped semi-continuously over a 235 kilometre strike length from Laredo Sound map sheet (NTS 103A), northwest to Prince Rupert map sheet (NTS 103J; see Figure 3).

Originally recognized and defined in Laredo Sound map sheet (NTS 103A), it was subdivided into five provisional stratified members composed of varying proportions of sedimentary and volcanic protoliths that have undergone polyphase deformation and amphibolite facies metamorphism (Nelson *et al.*, 2011b). Based on detrital zircon populations, the Mathieson Channel Formation correlates temporally with the Early Devonian Karheen Formation in Alexander terrane of southeast Alaska. Lithological contrasts between the two formations indicate differences in environments of deposition. In particular, the Mathieson Channel Formation is dominated by interlayered siliciclastic and carbonate, as opposed to the purely clastic Karheen Formation.



**Figure 6.** View of rusty quartz-sericite schist along the Pitt zone linear.

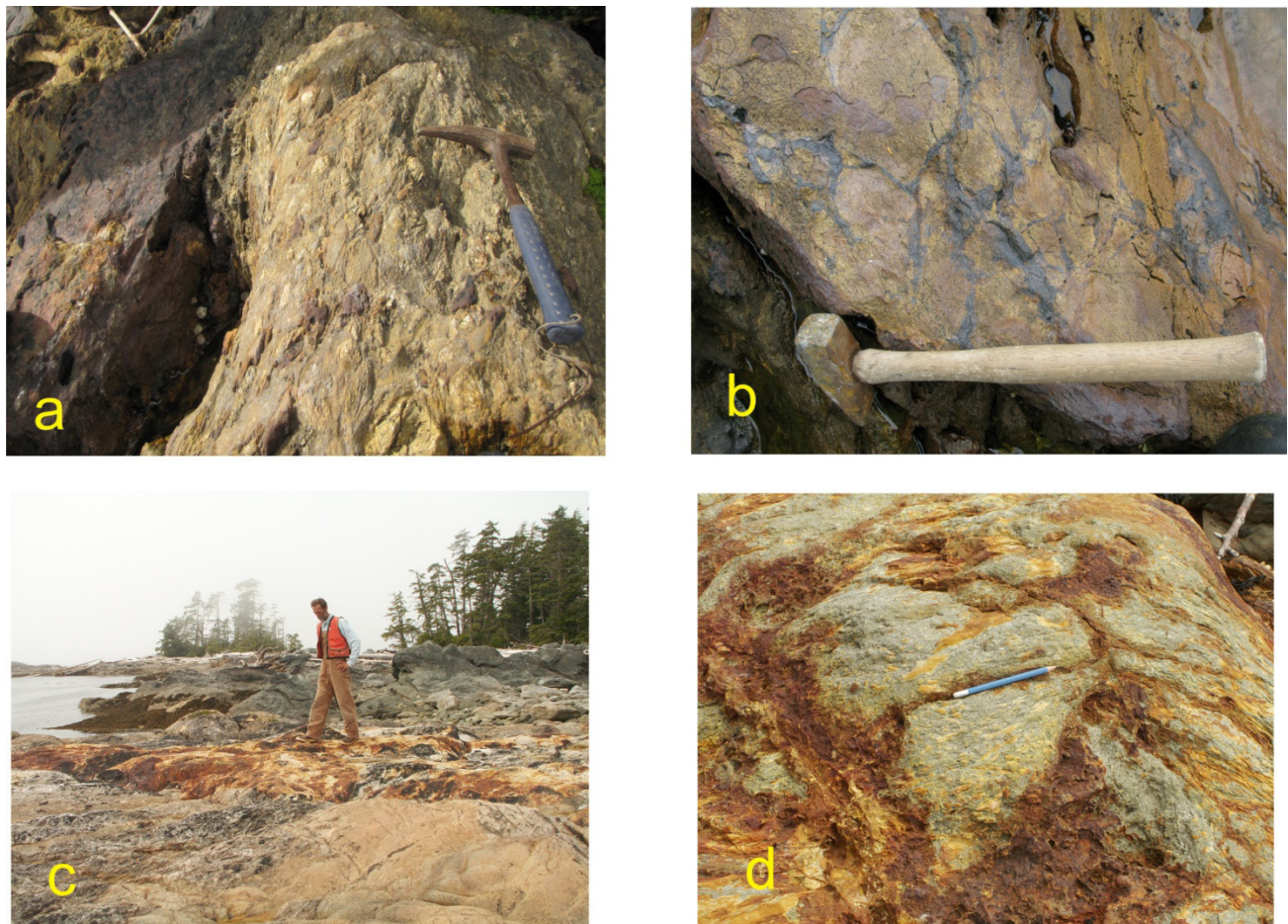
Mapping in 2011 has shown continuity of character between outcrops in the type area in Laredo Sound, northward to exposures of sandstone on Kennedy Island that Nelson *et al.* (2010a, b) originally assigned to the Karheen Formation. Because of their local consistency and geographic isolation from type exposures of the Karheen Formation in southeast Alaska, we recommend that all related rocks in northwestern British Columbia be assigned to the Mathieson Channel Formation (Figure 4b).

Rock units of the Mathieson Channel Formation in northern Laredo Sound area extend northwest into Douglas Channel map sheet (NTS 103H), traced throughout the Princess Royal Channel-Whale Channel-Grenville Channel corridor in 2011 (Figure 3). In this area, the formation occupies comparatively narrow bands within broader Cretaceous plutonic bodies, paralleling much of Grenville and Princess Royal channels. These bands reflect strong transposition of original bedded units, parallel to regionally persistent northwest trending strike-slip faults and a pervasive subvertical foliation. In contrast, broader panels of Mathieson Channel strata are found southwest of the Grenville Channel fault on eastern and southern Gil Island and farther northwest in Union

Passage. These panels, oriented obliquely to the regional northwest structural fabric, exhibit characteristic tightly appressed folds that perhaps account for stratigraphic repetition and greater structural thicknesses. Preliminary detrital zircon results from these packages show significant Precambrian populations (M. Pecha, unpublished data, 2011), which are absent in Mathieson Channel samples northeast of the Grenville Channel fault. Nevertheless, the rock units are not readily distinguishable: they both consist of interlayered arenite and carbonate, with possibly more detrital quartz in pendants southwest of the Grenville Channel fault. The siliciclastic-carbonate rocks on Gil Island and along Union Passage were considered part of the Banks Island assemblage by Gehrels and Boghossian (2000). We note that this corresponds to a provenance difference (partly pericratonic versus solely mid-Paleozoic) within a single mappable unit. The present Grenville Channel fault appears to mark the boundary between the two sources.

The lower contact of the Mathieson Channel Formation is exposed on Kennedy Island (Figure 5), where it overlies well preserved pillow basalts that are believed to be continuous with metavolcanic rocks of the underlying Descon Formation. Other metabasalt units that





**Figure 7.** a) Hard Case showing, with massive sulphides replacing matrix of felsic breccia; b) Dogfish showing, displaying brecciated sulphide-bearing quartz-sericite schist surrounded by pyrrhotite and sphalerite; c) Massive marcasite-pyrite in Ordovician metarhyolite, Digby Island; George Gehrels examining the site of ca. 472 Ma U-Pb zircon sample reported in Gehrels and Boghossian (2000); d) Detail of Digby Island metarhyolite breccia with irregular replacement and fracture-filling sulphides.

underlie the clastic part of the formation in Laredo Sound map area (Nelson *et al.*, 2011a,b) and also in Kumealon Inlet (Figure 5) may belong either to the Ordovician Descon Formation, or be part of the Mathieson Channel Formation itself. No U-Pb ages are available to resolve this issue. Although not in direct contact, possibly overlying rocks are found locally along Princess Royal Channel south of Khutze Inlet. They consist of garnet-biotite grade metasandstone, which is tentatively assigned to the Upper Jurassic to mid-Cretaceous Gravina belt.

Most stratigraphic members recognized as part of the Mathieson Channel Formation in Laredo Sound area (Nelson *et al.*, 2011b) extend into the current study area. However, maintaining existing subdivisions is difficult, due to the gradational nature of contacts separating metasedimentary rocks that overall appear less extensive and thinner towards the northwest in Douglas Channel area. Consequently, in this area the Mathieson Channel Formation is considered an unsubdivided map unit, composed of variable proportions of meta-arenite and metagreywacke, with lesser marble and calcsilicate and pelitic schist and locally abundant conglomerate, that in places alternate with intervals of metavolcanic rocks of intermediate to mafic compositions. A multitude of mafic

and pegmatitic felsic dikes and attenuated apophyses of larger, simple and composite plutons intrude, and locally comprise a significant volume within the interlayered metasedimentary assemblage. Felsic rocks occur in rare, isolated narrow bands in the Mathieson Channel Formation (Nelson *et al.*, 2011a, b). Another possible occurrence, west of Grenville Channel on Pitt Island, consists of sulphide-rich quartz-sericite schist, derived presumably from a felsic volcanic protolith. This felsic unit was the focus of past mining exploration for volcanogenic massive sulphide mineralization at the Pitt showing. Metaconglomerate, locally present in Laredo Sound area, is notably absent from the Mathieson Channel Formation in Douglas Channel area; it however recurs farther north at Kennedy Island and Kumealon Inlet (Figures 3, 5; Nelson, *et al.*, 2010a, b).

#### **METASILICICLASTIC-MARBLE-VOLCANIC UNIT**

This unit typifies the varied lithological character of the Mathieson Channel formation in the Douglas Channel area, comprising an aggregate of the “clastic-carbonate, marble, and volcanic member” subdivisions established for the formation in Laredo Sound area (Nelson *et al.*, 2011a, b).



The metasiliciclastic lithologies form parallel, thin to medium-thick, subvertical pale grey to dark grey-green layers, weathering to rusty brownish orange hues (Figure 8). This weathered coloration reflects ubiquitous iron-bearing phases, probably metamorphic pyrite and/or pyrrhotite derived from authigenic hematite (see Nelson *et al.*, 2011b). The siliciclastic components, composed of fine to medium grained, well-sorted quartz and plagioclase, with or without orthoclase, form resistant layers exhibiting internal parallel laminations. The laminations are defined by slight variations in texture and color and aligned minerals, particularly biotite. Psammitic schist interlayers attest to a greater argillaceous content in the matrix of some quartzofeldspathic rocks, distinguished by their relatively recessive, biotite-rich, and crumbly weathering. Pelite, composed of biotite-garnet schist, occupies centimetre-thick layers separating marble-siliciclastic layers throughout the unit exposed along the eastern shore of Grenville Channel between Klewnuggit and Lowe inlets.

Marble in siliciclastic sections is clean, off-white and medium crystalline. It weathers yellowish tan in recessive, relatively sparse, spaced layers typically less than several tens of centimetres thick (Figure 8 ). An unusually thick interval dominated by marble with subordinate siliciclastic layers crops out semi-continuously for about 2 kilometres in western Union Passage, north of Hinton Island. Marble layers have



**Figure 8.** Interlayered siliciclastic and marble, southern Gil Island.

preferential tendency to deform plastically relative to adjacent siliciclastic layers. This strain partitioning yields contorted marble layers that display varying scales of tight folds. Any thinner siliclastic and orthoamphibolite layers that commonly interlayer thicker marbles also record strain in the form of folds, boudins or become segmented with the broken fragments aligned in trains. Calcsilicate layers, identified by their pale green weathering and metamorphic mineralogy, including diopside, garnet and epidote, indicate original siliclastic intervals containing a high proportion of carbonate cement.

Metavolcanic rocks comprise a significant component of the Mathieson Channel Formation in parts of Laredo Sound map area, where they are commonly interlayered with marble (Nelson *et al.*, 2011b). However, similar rocks in Douglas Channel map area are far less voluminous, found mainly at several mappable sections along the eastern shoreline of Princess Royal Channel, directly east of Work Island, and in Grenville Channel, several kilometres south of the entrance to Klewnuggit Inlet. At these localities, intervals of massive flows of basaltic composition, up to tens of metres wide, alternate across abrupt contacts with layered siliciclastic rocks containing sparse, thin layers of marble. The flows are dark green, massive varieties of aphyric metabasite and rare sparsely plagioclase-phyric metabasalts. Alteration of basalt by epidote is widespread, as diffuse rounded clots and crosscutting veins.

## AGE OF THE MATHIESON CHANNEL FORMATION

An attempt to obtain a U-Pb zircon date on rare felsic volcanic rocks from the Mathieson Channel Formation was unsuccessful because the sample was devoid of zircon. The sampled rocks were from a laminated rhyolite flow in Return Channel, Laredo Sound area (see Nelson *et al.*, 2011b).

Detrital zircon geochronology on metamorphosed siliciclastic assemblages in north coastal British Columbia is utilized to unravel the depositional history of southern Alexander terrane and correlate with its less metamorphosed counterparts in southeast Alaska (Gehrels and Boghossian, 2000; Mahoney *et al.*, 2011). Recent detrital zircon data for the Mathieson Channel Formation, determined by J.B. Mahoney, have been obtained from meta-arenaceous and conglomeratic samples collected from opposite ends of the mapped extent of these rocks, including samples from Laredo Sound map sheet in the south, and Prince Rupert and Douglas Channel map areas in the north (Mahoney *et al.*, 2011). Meta-arenite/meta-arkose samples collected in 2011 from the intervening Douglas Channel map sheet are currently in analysis, with pending results intended for future publication.

Detrital zircon samples (N=13) for the Mathieson Channel Formation show a consistent zircon population range between 400 Ma and 460 Ma, with a peak at 426 Ma (Mahoney *et al.*, 2011). These data also confirm the

initial detrital zircon age for the Mathieson Channel Formation from conglomeratic rocks on Pooley Island in Laredo Sound map area, which shows a unimodal signature centred at about 420 Ma (Gehrels and Boghossian, 2000). Collectively, the detrital zircon data suggest that deposition of the Mathieson Channel Formation initiated in Early Devonian time. The quartz-feldspar-rich arenaceous rocks that characterise the formation suggest a source region probably composed of chemically evolved granitoid rocks of Middle Ordovician to Early Devonian age.

***The Ogden Channel complex: a Late Silurian-Early Devonian syntectonic intrusive complex within the Alexander terrane***

**LITHOLOGIES AND FIELD CHARACTERISTICS**

The Ogden Channel complex is located on southwestern Porcher Island, bounded to the northeast by the Salt Lagoon fault (Figure 5). It is a felsic to mafic plutonic suite, with intermediate rocks such as tonalite and quartz diorite being most common. The bodies of this suite intruded syn-tectonically during regional deformation and amphibolite facies metamorphism that produced a foliation of varying intensity on outcrop and map scale. Where deformation is intense, the plutonic rocks have been transformed into orthogneisses and amphibolite (Figure 9a). Mutual crosscutting relationships between the various plutonic members and the foliation, and relationships such as deformed xenoliths of one igneous member in another, less deformed host (Figure 9b) attest to their syntectonic nature. The Ogden Channel complex strongly resembles the middle to lower crustal segments of other syntectonic magmatic arc complexes, such as the Notre Dame arc in western Newfoundland (van Staal *et al.*, 2007) and the Westcoast Crystalline and Wark-Colquitz gneiss complexes of Vancouver Island, deformed Early Jurassic intrusive-metamorphic complexes thought to be a deep level of the Bonanza arc (DeBari *et al.*, 1999).

Included now as subunits of the Ogden Channel complex are the Billy Bay complex and Porcher Creek pluton, in contrast to earlier interpretations of these units (see Nelson *et al.*, 2010b). The Billy Bay complex contains more identifiable volcanic protoliths compared to the Ogden Channel complex, intermixed with strongly deformed plutonic phases. U-Pb results so far include an Ordovician detrital zircon population in a meta-arkose, an Early Devonian igneous age from a felsic lapilli tuff, and a latest Silurian igneous age from granitoid similar to one dated in the Ogden Channel complex nearby (Figure 5; J.B. Mahoney, unpublished data, 2010, 2011). Originally, this complex was interpreted as the deep roots of the Descon arc (Nelson *et al.*, 2010b). However, it contains an abundance of deformed plutons of similar mid-Paleozoic age and character to those in the main Ogden Channel complex. This suggests that it is a variant of the

complex that includes more supracrustal material, both older Descon strata and penecontemporaneous mid-Paleozoic volcanic units (Figure 4b). The epidote amphibolite facies metamorphism within it is a further point of similarity.

The Porcher Creek pluton is a weakly to undeformed mainly tonalite-diorite body that was originally considered Early Cretaceous based on its resemblance to plutons of that suite (Nelson *et al.*, 2010a, b). However, it returned a U-Pb zircon age of *ca.* 411 Ma (J.B. Mahoney, unpublished data, 2010). It crosscuts deformed metaplutonic rocks of the Ogden Channel complex, and is itself late to post tectonic (Figure 9c).

**STRUCTURE**

Deformation of the Ogden Channel complex is typically heterogeneous, characterised by steeply northeast dipping, anastomosing mylonitic shear zones of varying width and associated folding (Figure 10a). Lineations vary in plunge and range between downdip and horizontal. Combined with abundant shear-sense indicators (*e.g.* S-C shear bands, porphyroclasts) they suggest sinistral oblique reverse motion (Figure 10b) directed to the southwest, which is consistent with the vergence of the folds. Involvement of melt phases in shear zones, and crosscutting dikes, show that many of these structures were synmagmatic (Figure 10a).

**AGE AND TECTONIC AFFINITY**

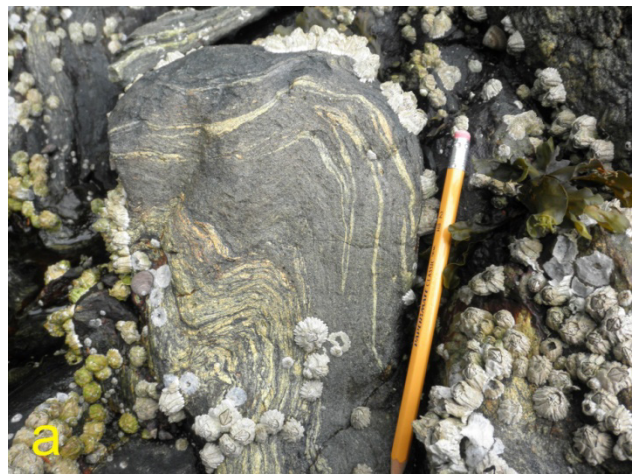
The Ogden Channel complex was originally interpreted as an intrusive equivalent to the arc volcanic rocks of the Ediacaran to Early Cambrian Wales Group (Gehrels and Saleeby, 1987), based on their arc-like composition, variable degree of deformation and amphibolite facies metamorphism (Nelson *et al.*, 2010b). New U-Pb zircon geochronology suggests that this suite intruded in a relatively short period during the late Silurian to Early Devonian, based on ages of 424–413 and 411 Ma for highly deformed metadiorite and metagranodiorite within the Ogden Channel complex; and much more weakly deformed diorite and tonalite of the Porcher Creek pluton, respectively (J.B. Mahoney, J. Angen; unpublished data; 2010, 2011). The Ogden Channel complex is thus unrelated to the Wales arc. It post-dates igneous activity associated with the Descon arc, based upon both U-Pb data from extrusive units in the immediate area (no younger than 469 Ma), and on regional stratigraphic relationships. Descon volcanics in southeastern Alaska are overlain by late Early to Late Silurian carbonates of the Heceta Limestone (Eberlein and Churkin, 1970; Ovenshine and Webster, 1970) and Early to Late Silurian clastics of the Bay of Pillars Formation (Brew *et al.*, 1984). The event that the Ogden Channel complex does correspond to is the Klakas orogeny of Gehrels *et al.* (1983a, 1996). The sinistral-transpressive, southwest-vergent structures in it are consistent with the southwesterly tectonic transport direction documented by Gehrels *et al.* (1996) in the





**Figure 9.** a) Amphibolitic orthogneiss in Ogden Channel complex; b) Foliated dike cutting orthogneissic dike; the older dike has yielded a *ca.* 412 Ma U-Pb age (J.B. Mahoney, unpublished data, 2011); c) Porcher Creek pluton: unfoliated tonalite with foliated inclusions (*ca.* 411 Ma, unpublished U-Pb data, J.B. Mahoney, 2010).

southwestern Alaskan panhandle. The main age of plutonism in the Ogden Channel complex is coeval with the cumulative early Paleozoic detrital zircon peak (*ca.*



**Figure 10.** a) Synplutonic mylonitic shear zone in Ogden Channel complex; b) Sinistral shear bands, Ogden Channel complex.

410-420 Ma) in the Banks Island clastic rocks, and slightly younger than the *ca.* 426 Ma cumulative detrital zircon peak from the Mathieson Channel Formation (Mahoney *et al.*, 2011).

Gehrels *et al.* (1996) interpreted the Karheen Formation as a clastic overlap related to collision of the primitive arc of the Alexander terrane of southeastern Alaska (Craig subterrane) with an unknown pericratonic fragment to the west. They hypothesized an event named the Klakas orogeny, based on the sudden appearance of coarse conglomerate and presence of Precambrian detrital grains in the Karheen Formation. The pericratonic Banks Island belt is located west (outboard) of the Ogden Channel complex, although there is a belt of intervening exposures of Ordovician volcanoclastics along Kitkatla Channel. We hypothesize that the Ogden Channel complex was part of a short-lived magmatic arc that developed near a collisional subterrane boundary sutured during the Klakas orogeny, between the Craig subterrane of Alexander, and a pericratonic fragment that underlay and sourced the Banks Island assemblage. The Mathieson Channel Formation, like the Karheen Formation farther north, represents the associated clastic overlap sequence.



### **Kumealon unit: A new late Paleozoic intrusive/supracrustal suite east of northern Grenville Channel and Telegraph Passage**

In 2009, mapping and U-Pb geochronology on the mainland shores near Kumealon and Baker inlets identified several units that do not occur elsewhere within the Alexander terrane. These were assigned to the Yukon-Tanana terrane (Nelson *et al.*, 2010a). Re-examination and detailed re-sampling of these exposures became an important component of the 2011 field program.

The Alexander terrane in western Kumealon Inlet consists of two isoclinally interfolded and locally strongly sheared units: dark green amphibolite-facies metabasalt and minor marble of the Descon Formation, which is overlain by plutonic-cobble conglomerate and rusty meta-arkose of the Mathieson Channel Formation (Figure 11a). At one locality, a pyrite-bearing felsic fragmental pyroclastic rock marks the contact, similar to what is observed on Kennedy Island to the west. A typical Mathieson Channel detrital age spectra has been obtained from one of the conglomerates (G. Gehrels, unpublished data, 2007). Both of these units are extensively intruded by voluminous, thick, pale green, pre-kinematic felsic dikes that contain anhedral metamorphic garnets, particularly near their margins. Relict chilled margins were observed in 2011 (Figure 11b), establishing that these are indeed transposed dikes, and not metasedimentary layers as was originally thought (Nelson *et al.*, 2011a, b). One of the dikes yielded a Permian U-Pb age of *ca.* 280 Ma (J.B. Mahoney, unpublished data, 2011), in accord with an earlier analysis (J.B. Mahoney, unpublished data, 2010).

Near the eastern limit of the combined Mathieson Channel–metabasalt section, a narrow lens of quartz-pebble conglomerate lies within the amphibolite (Figure 11c). It shows a typical, Early Mississippian Yukon Tanana detrital zircon signature (Figure 5; J.B. Mahoney, unpublished data, 2010). The contact between the quartz-pebble conglomerate and the metabasalt on both sides of it is a layer of nearly pure garnet approximately 20 cm thick (Figure 11d), which has been interpreted tentatively as a metamorphosed and altered clay-rich fault gouge. If correct, the Alexander terrane structurally underlies a tightly synformal klippe of Yukon-Tanana terrane, which was thrust above it before a phase of regional folding characterized by nearly upright folds.

Seventy-five metres east of the quartz-pebble conglomerate, across a sharp contact, the dominant unit becomes mainly meta-andesite with lesser metabasalt, metadacite, muscovitic orthogneiss and quartz-muscovite-cordierite-sillimanite schist. These rocks were assigned to the Yukon-Tanana terrane by Nelson *et al.* (2010a, b); however, the transposed section contains felsic dikes identical to those within the Alexander unit to the west. Permian U-Pb ages have been obtained from two bodies of kyanite-bearing muscovitic orthogneiss at this locality, and the metavolcanic unit continues south into Baker

Inlet, where a polymictic felsic breccia (Figure 11e) has also yielded a Permian age (J.B. Mahoney, unpublished data, 2011). The metavolcanic unit is in gradational contact with two units of marble containing tuffaceous partings and impure marble, probably the same body repeated by isoclinal folding (Figure 5). Sparse macrofauna including brachiopods and solitary corals were observed (Figure 11f), but not sufficient for constraining the age of the marble beyond probably middle to late Paleozoic. Small bodies of quartz-sericite schist, pyritic quartz-sericite schist and metamorphosed silicified rhyolite near Moore Cove east of Telegraph Passage were originally assigned to the Alexander terrane, and considered to be Ordovician metarhyolites (Nelson *et al.*, 2010a, b). A metarhyolite sample collected in 2011 has returned a Permian age (J.B. Mahoney, unpublished data, 2011). On the basis of this and the set of U-Pb dates from Kumealon and Baker inlets, a new late Paleozoic, mainly Early Permian intrusive/supracrustal unit, the Kumealon unit, has been identified along the length of the mainland coast between northern Grenville Channel and Telegraph Passage. It includes a varied suite of probably arc-related volcanic rocks, basalt, andesite, and rhyolite. Permian muscovitic granites intrude the westernmost volcanics north of Kumealon Inlet, along strike with a zone of pre- metamorphic quartz-muscovite alteration south of the inlet (now as coarse grained quartz-muscovite-garnet-kyanite-sillimanite+cordierite schist). Coeval, Permian fine grained felsic dikes intrude both the volcanic pile and the underlying strata of the Alexander terrane. They establish that the mid-Paleozoic and older Alexander terrane was the basement to the late Paleozoic volcanogenic Kumealon unit (Figure 4b).

The Kumealon unit has no correlatives in the Alexander terrane of southeastern Alaska, where the only late Paleozoic volcanic units are minor basalts interlayered with platform carbonates. Its closest parallel is the Icefield Ranges plutonic suite (Figure 1) and cogenetic Station Creek Formation in the St. Elias Mountains of southwestern Yukon and adjacent eastern Alaska. Plutons of the Icefield Ranges suite have been dated by K-Ar and U-Pb methods as *ca.* 270–310 Ma (Dodds and Campbell, 1988; Gardner *et al.*, 1988; L. Beranek, unpublished data, 2011). The Pennsylvanian (*ca.* 309 Ma, U-Pb zircon) Barnard Glacier pluton cuts both coeval volcanic rocks of the Station Creek Formation and the lower Paleozoic Kaskawulsh Group of the Alexander terrane (Gardner *et al.*, 1988). This relationship is highly significant in Cordilleran tectonics, because the Pennsylvanian-Lower Permian Station Creek Formation in turn is in stratigraphic continuity with the Triassic Nikolai basalts, hallmark of the terrane Wrangellia. The intervening Early Permian Hasen Creek Formation contains fossiliferous limestones (Israel and Cobbett, 2008), a possible equivalent of the marble in Kumealon Inlet.

Correlation of the Permian Kumealon unit with the Station Creek Formation and Icefield Ranges plutonic



**Figure 11.** Units in Kumealon and Baker inlets. a) Mathieson Channel plutonic-clast conglomerate; b) Metamorphosed felsic dikes, ca. 280 Ma; c) Quartz-pebble conglomerate with ca. 350-360 Ma detrital peak signature; d) Garnetite in pelite near contact of quartz-pebble conglomerate and amphibolite; e) Felsic heterolithic breccia, ca. 280 Ma, Baker Inlet; f) Solitary corals in limestone, Kumealon Inlet.

suite would lead to two important tectonic implications. The correlation would provide a second instance of late Paleozoic “Wrangellian” arc terrane being built on a pre-existing Alexander basement; additional confirmation that Wrangellia probably developed as in intra-oceanic arc attached at one end to the Alexander crustal fragment, in a similar setting to the relationship between the modern Aleutian arc and the Kamchatka Peninsula. Further, the

absence of comparable Pennsylvanian-Permian igneous suites elsewhere in the Alexander terrane could suggest that the Kumealon unit and its underlying rocks might restore to a location west of the St. Elias Mountains, perhaps near the southern cut-off of the Icefield suite near Windy Craggy (Figure 1). This would require approximately 800 km of post-Paleozoic sinistral strike-slip motion.



## **New Investigations of the Grenville Channel fault between northern Grenville Channel and Princess Royal Island**

Mapping in 2009 and 2010 covered the northern and southern extents of the Grenville Channel fault and demonstrated significant, albeit not quantified, sinistral motion along it in Early to mid-Cretaceous time. In the course of field work in 2011, these two sections were linked, via tracing of the fault along Grenville Channel, past the northern tip of Gil Island, to its shoreline exposure on western Princess Royal Island (Figure 3).

Work of this project in 2009 showed that the structural framework of Porcher Island and its vicinity is dominated by a series of northwesterly sinistral fault strands (Figure 2; Nelson *et al.*, 2010a, b; Angen *et al.*, this volume). These strands converge southward into the Grenville Channel fault. Field work in 2011 traced the Grenville Channel fault along Grenville Channel southwards into Wright Sound, where it deflects around northeastern Gil Island, thence following a more southerly trajectory, entering Princess Royal Island at Leading Point (Figure 3). Although undocumented by current regional mapping, the fault crosses Princess Royal Island, its trace corresponding with a topographic linear of aligned drainages, lakes and inlets (Figure 3; Nelson *et al.*, 2011b, Figure 17). The Grenville Channel fault exits Princess Royal Island in the southeast via a broad zone of splay faults near Cougar Bay on Tolmie Channel, mapped in 2010 (Nelson *et al.*, 2011a), and continues southeast across the islands between Finlayson and Mathieson channels as spaced high-strain zones with sinistral kinematic indicators (Nelson, *et al.*, 2011b). The southerly extent and nature of the Grenville Channel fault beyond Mathieson Channel is unknown and a potential topic for future study.

The segment of the Grenville Channel fault along Grenville Channel is a narrow zone of extremely high strain affecting juxtaposed orthogneiss, several similar protomylonitic tonalite intrusions, and subvertically layered Mathieson Channel Formation. Rocks forming the eastern shore of the channel consist in part of the Mathieson Channel Formation, in which schistose fabric is prevalent in mainly thin pelitic layers containing biotite and garnet porphyroblasts. Skarn bands consisting of garnet-diopside-epidote form contorted and boudinaged bands in contact with, and as enclaves in, tonalite. The tonalite here is sheared, evident from augen-shaped porphyroclasts with trails of finer grained feldspar in asymmetric pressure shadows, which impart a streaky protomylonitic foliation.

Two tonalite bodies, located along opposite side of Grenville channel near Lowe Inlet, have identical mineralogy and protomylonitic fabrics. However, uranium-lead-zircon geochronology on these two tonalitic intrusions indicates that, despite their similarities, they are

separate plutons; the older west of the channel,  $108.2 \pm 1.4$  Ma, and the younger sampled at James Point at the entrance to Lowe Inlet,  $95.2 \pm 1.5$  Ma (M. Pecha, unpublished data, 2011). The younger date gives a maximum constraint for late ductile deformation on the Grenville Channel segment of the fault. The older tonalite, which is associated with banded dioritic orthogneiss, continues down the west side of the channel to Farrant Island. Both tonalite and banded orthogneiss include highly strained bands and enclaves of metasedimentary rocks of the Mathieson Channel Formation. Throughout Grenville Channel all rocks display a persistent northwest trending, subvertical penetrative foliation and mineral lineation that plunges consistently between 30 and 40 degrees towards the southeast, and kinematic indicators suggest sinistral reverse motion.

The Grenville Channel fault under Grenville Channel is part of broader zone of very strong foliation developed for several kilometres on both sides of the channel. It is expressed as a pattern of northwesterly topographic linears, and development of extreme foliation and lineation in plutonic phases as young as 95 Ma. The western side of Ecstall pluton is well-foliated and shows weakly developed sinistral indicators at the mouth of Lowe Inlet; however, the interior of the pluton at this latitude is not deformed.

On northern Gil Island, pre mid-Cretaceous banded orthogneiss is cut off by an weakly foliated garnet-bearing tonalite pluton dated as *ca.* 100 Ma (age data from Gehrels *et al.*, 2009). The expression of the Grenville Channel fault here is similar to that in Grenville Channel, partly obliterated by this later intrusive phase (Figures 12a, b). Where the fault passes onto Princess Royal Island, a narrow zone of protomylonite lies between identical mid-Cretaceous (*ca.* 104-106 Ma), enclave-bearing, weakly magmatically foliated but otherwise undeformed tonalites, which are probably parts of same body. Displacement of the margin of this large tonalite pluton across the Grenville Channel fault suggests sinistral offset in the order of 5 kilometres (Figure 3). As is the case in the area around Klemtu, the younger (*ca.* 95-106 Ma) large tonalite bodies are cut by discrete strands of the Grenville Channel fault, but are not penetratively foliated in their interiors.

Diorite of presumed pre-mid-Cretaceous age continues southwest of the Grenville Channel fault along the shores of Farrant Island. From orthogneiss in the shear zone on the northern shore, fabric development declines markedly. More than a few hundred metres from the fault, it is not foliated. On southern Gil Island, a Late Jurassic *ca.* 148 Ma tonalitic pluton (G. Gehrels, unpublished data, 2010) is also undeformed (Figure 13). Relationships here are similar to those observed on Banks Island, where Late Jurassic plutons crosscut structures in transposed metasedimentary rocks.





**Figure 12.** a) Banded orthogneiss of probable Early Cretaceous age, northern Farrant Island; b) Undeformed tonalite, northernmost Gil Island, with inclusions of banded orthogneiss, ca. 100 Ma.



**Figure 13.** Undeformed tonalite, southern Gil Island; dated at ca. 148 Ma (G. Gehrels, unpublished data, 2010).

### **SIGNIFICANCE AND ROLE OF THE GRENVILLE CHANNEL FAULT IN CRETACEOUS TECTONICS OF THE COAST BELT**

The Grenville Channel fault is of regional extent, over 300 kilometres in strike length. Throughout its

length it manifests as a continuous, strong but fairly narrow zone of intense ductile shearing. At its widest near Grenville Channel, the zone is several kilometres in width. On northern Princess Royal Island, the fault zone comprises less than a hundred metres of mylonite between exposures of unfoliated tonalite. To the north, on Porcher Island, it consists of a set of splays, each a discrete but fairly narrow ductile shear zone. A similar pattern is seen in Laredo Sound map area near Klemtu. The latest movement on the Grenville Channel fault is ca. 105-96 Ma, based on offsets of and fabric development within dated plutonic bodies (Nelson *et al.*, 2010b, 2011b; Angen *et al.*, 2012, this volume). Earlier motion is probable, corresponding to regional-scale fabric development in the ca. 123-116 Ma Early Cretaceous plutonic suite northeast of the fault in Laredo Sound area, which is crosscut by ca. 106-95 Ma plutons (Nelson *et al.*, 2011b). This zone of deformation extends eastward until it is caught up in younger high strain zones such as the Coast shear zone (ca. 50-70 Ma).

There is a strong contrast between the degree of Early Cretaceous regional deformation across the Grenville Channel fault. To the northeast, penetrative fabrics showing sinistral asymmetry are widely developed. To the southwest, however, Early Cretaceous and older units were apparently not affected by this event. Farrant Island is underlain by undeformed pre-100 Ma diorite. Late Jurassic plutons on Gil as well as on Banks Island are similarly post-kinematic. Furthermore, most of the deformation in Ogden Channel complex now appears to have been Early Devonian, except along discrete splays of the Grenville Channel fault such as the Useless fault (Angen *et al.*, 2012, this volume). All of these observations suggest an absence of Cretaceous regional penetrative ductile deformation in most of the block that lies between the Grenville Channel fault and Kitkatla shear. The Grenville Channel fault seems to mark a strain boundary between a broad zone of Early Cretaceous sinistral ductile deformation to the northeast, and an outboard rigid block. The fault itself localized the last, mid-Cretaceous, focused sinistral motion. Displacement of the tonalite on northern Princess Royal Island suggests a fairly modest magnitude, about 5 kilometres for this final phase of motion (Figure 3). The Grenville Channel as a strong, persistent topographic linear marks the northeastern edge of the rigid block.

Regional considerations point to hundreds of kilometres of sinistral motion across the Coast belt in Early to mid Cretaceous time. Primary evidence is the closure of the Bridge River–Tyaughton basin, which Monger *et al.* (1994) consider to be the result of southward displacement of the western Coast belt by approximately 400 km. Also, the northern edge of west-northwest trending belt of mid to Late Jurassic arc-related volcanism and plutonism lies at about 54 degrees, near Kitimat, east of Coast Mountains. To the west, the mid to Late Jurassic magmatic province is best developed on northern Vancouver Island and the adjacent mainland. If

its northern limit is assumed to lie at about the latitude of northern Vancouver Island, 51 degrees, then the apparent sinistral offset across the Coast belt is about 400 km, equivalent to displacement necessary to close the Tyaughton basin. However, the northern limit of the mid to Late Jurassic plutonic belt in the west is still not well understood. There is a paucity of available ages for the entire Coast Plutonic Complex between Bella Bella and Bute Inlet. Gehrels *et al.* (2009) presented an extensive U-Pb database for the Coast Mountains north of Bella Bella, and the southern Coast Mountains have been extensively studied (*cf.* Monger and McNicoll 1993; Monger and Journeay, 1994). The region in between represents a large gap in current knowledge.

The Late Jurassic intrusive body on Gil Island is part of a more extensive suite that outcrops extensively on Banks Island, probably dextrally offset approximately 80 kilometres to the northwest on the Cenozoic Principe-Laredo fault (Figure 3). The body on southern Gil Island may be an isolated outlier. However, if it represents the true northern extent of the mid to Late Jurassic plutonic belt, then it only lies 100 kilometres south of the northern limit of age-equivalent magmatism east of the Coast Mountains near Kitimat; as a pinning point this would reduce the required Early to mid-Cretaceous sinistral offset to less than a hundred kilometres. Resolution of this puzzle will require systematic dating of plutons in the region in between.

In any event, assuming that there was Cretaceous sinistral motion across the Coast Mountains of 100 to 400, or even 800 (Monger and Struik, 2006), kilometres in total, our results show that only a small fraction of that motion occurred along the Grenville Channel fault after about 108 Ma. Instead, it probably occurred as distributed shear, mainly in Early Cretaceous time, in the broad region between the Grenville Channel fault and the Pootlass shear near Bella Coola (Mahoney *et al.*, 2009).

## FUTURE WORK ON THE NORTH COAST PROJECT

The 2011 season concluded the collection of field data and samples related to this project. So far we have produced, but not published, about 20 U-Pb dates; with 15 more samples in processing. A suite of over 50 metavolcanic samples have been analysed for major and trace elements in order to characterize the mainly Ordovician magmatism. Once these important data sets are edited and complete, a series of papers are planned to cover the various themes that have emerged during the project: the history and tectonic significance of Ordovician magmatism in the Alexander terrane, along with its implications for VMS potential; the ultimate crustal origins of the Alexander terrane and the Devonian accretionary events within it. The thesis work of Joel Angen continues, with its focus on the history of sinistral Cretaceous faulting and deformation within the Coast belt of northern British Columbia. This detailed work will

complement more regional results. An open file map will be released in 2012-13 that will incorporate new mapping and analytical results of this project. An ultimate aim of the project is an extensive update of the existing digital coverage of the northern Coast belt on the provincial government's online BC Geology Map, based on the new mapping and U-Pb dating results.

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