Structural Geology of the Alexander Terrane in the vicinity of Porcher Island, Northwestern British Columbia

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KEYWORDS: Alexander terrane, Coast Plutonic Complex, Cretaceous, Porcher Island, structural, shear zones, shear bands, transpression, conjugate

INTRODUCTION

This report summarizes the preliminary results of a two year study, mainly using detailed structural analysis combined with U-Pb geochronology, to elucidate the structural history of Porcher Island and the surrounding area in northwestern British Columbia (Figure 1). This work is a contribution to the North Coast subproject of the Edges Multiple Metals – NW Canadian Cordillera (British Columbia and Yukon) Project, the overall scope and results of which are elaborated upon by Nelson *et al.* (2012, this volume).

The study area is situated near the eastern margin of the southern Alexander terrane (Figure 1). The tectonic and paleogeographic history of the Alexander terrane is complex, and differs significantly from that of terranes which developed closer to the paleo-Pacific margin of North America (Gehrels and Saleeby, 1987; Colpron and Nelson, 2009). Excellent coastal exposures and a polyphase structural history make this area a strategic location to study the various tectonic events recorded by the southern Alexander terrane. New U-Pb geochronology combined with structural observations within the Ogden Channel complex (Nelson *et al*., 2010a) has led to the identification of a Late Silurian to Early Devonian tectonomagmatic event. Original interaction of the Alexander terrane with the paleo-Pacific margin of North America is interpreted as pre-Middle Jurassic (Gehrels *et al*., 1992; van der Heyden, 1992; McClelland and Mattinson, 2000; Saleeby, 2000; Gehrels, 2001). The boundary has since undergone significant contraction and extension-related deformation, with both sinistral and dextral transcurrent components. New evidence indicates that sinistral and dextral shear zones were in part coeval, forming a conjugate set.

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PREVIOUS WORK AND GEOLOGICAL SETTING

The original 1:250 000-scale mapping of the study area was conducted by Roddick (1970) and Hutchison (1982). More recent 1:50 000-scale mapping has been conducted by Nelson *et al*. (2010a, 2010b, 2012). The open file map based on these studies is the basis for Figure 2. Most of the field area is underlain by rocks assigned to the Alexander terrane, with minor constituents assigned to the Yukon-Tanana terrane and Gravina belt. Stratigraphic units of the Alexander terrane include the arc-like volcanic rocks and associated sedimentary rocks of the Ordovician Descon Formation, siliciclastic equivalents of the Devonian Karheen Formation in southeast Alaska (Eberlein and Churkin, 1970), as well as the newly identified Kumealon unit (Nelson *et al*., 2012). The local equivalent of the Karheen Formation is rusty, arkosic sedimentary rocks and marble of the Mathieson Channel Formation defined by Nelson *et al*. (2011a, b) and extended into the present area (Nelson *et al*., 2012). Gehrels *et al*. (1983) proposed that the Karheen Formation represents a clastic wedge associated with the hypothesized Silurian-Devonian Klakas orogeny, during which the primitive Alexander terrane was amalgamated with a pericratonic fragment to the southwest. Plutonic rocks of the Alexander terrane range from Ordovician to Permian with the Ogden Channel complex and Porcher Creek pluton comprising a Late Silurian to Early Devonian intermediate plutonic suite (Nelson *et al*., 2012). The Billy Bay complex is spatially and genetically associated with the Ogden Channel complex, but has a larger supracrustal component (Nelson *et al*., 2012). The Kumealon unit comprises felsic to mafic volcanic rocks, pelitic schists, and minor, interbedded marble. It also includes two infolds of thick marble containing tuffaceous partings (Nelson *et al*., 2012). Consistent Permian U-Pb ages (J.B. Mahoney, unpublished data, 2011) suggest a correlation with the Station Creek Formation of Wrangellia (Gardner *et al*., 1988). A sequence of thin bedded psammitic schists along Telegraph Passage (Figure 2) is assigned to the Middle Jurassic to Lower Cretaceous Gravina belt as defined by Berg *et al*. (1972). One locality within Kumealon inlet (Figure 2) produced a detrital zircon population characteristic of the Yukon Tanana terrane (J.B. Mahoney, unpublished data, 2010).

Deformation within and directly south of the study area has been attributed previously to mid-Cretaceous

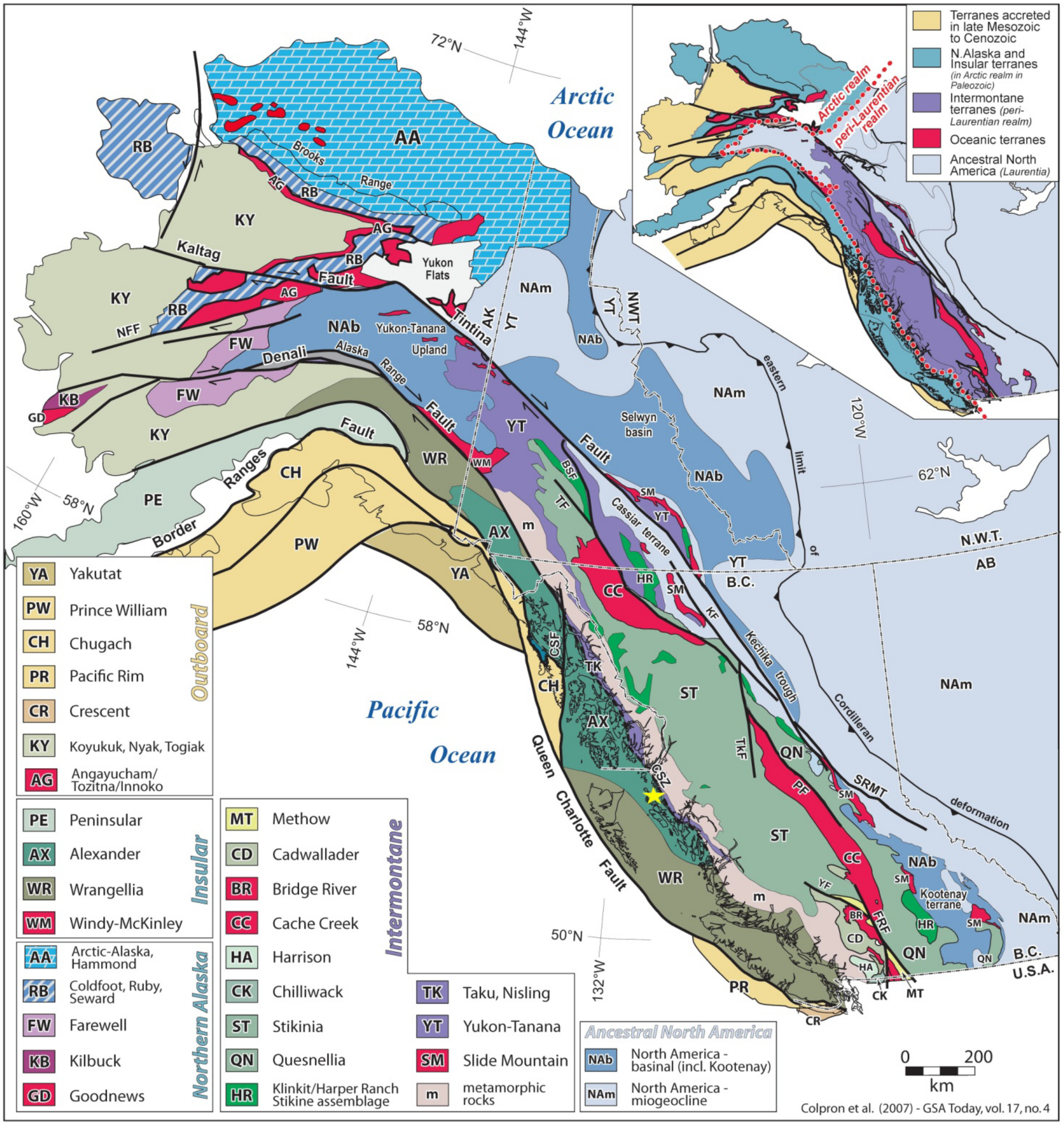

Figure 1. Location of the study area within the context of terranes of the northern Cordillera. The yellow star indicates the location of the current study (modified after Colpron *et al.*, 2007).

sinistral transpression (Chardon *et al*., 1999; Chardon, 2003). On the basis of shear sense indicators, trajectories of compiled foliation measurements, and U-Pb crystallization and Ar-Ar cooling ages, Chardon *et al*. (1999) defined three northwest striking sinistral shear zones, which were active between approximately 110 and 87 Ma. From northeast to southwest these are the Grenville Channel, Kitkatla, and Principe-Laredo shear zones. These shear zones form part of a much more extensive zone of mid-Cretaceous sinistral shearing along the western margin of the Canadian Cordillera (Hurlow, 1993; Schiarizza *et al*., 1997; Israel, 2001; Evenchick, 2001; Israel *et al*., 2006).

On the other hand, researchers working farther to the north near Prince Rupert and in southeast Alaska have emphasized the importance of orogen-normal shortening during the mid-Cretaceous in the form of west to southwest-vergent thrusting (Crawford *et al*., 1987; Rubin *et al*., 1990; Rubin and Saleeby, 1992; Haeussler, 1992; McClelland *et al*., 1992; Crawford *et al*., 2000; McClelland and Mattinson, 2000). This thrusting was

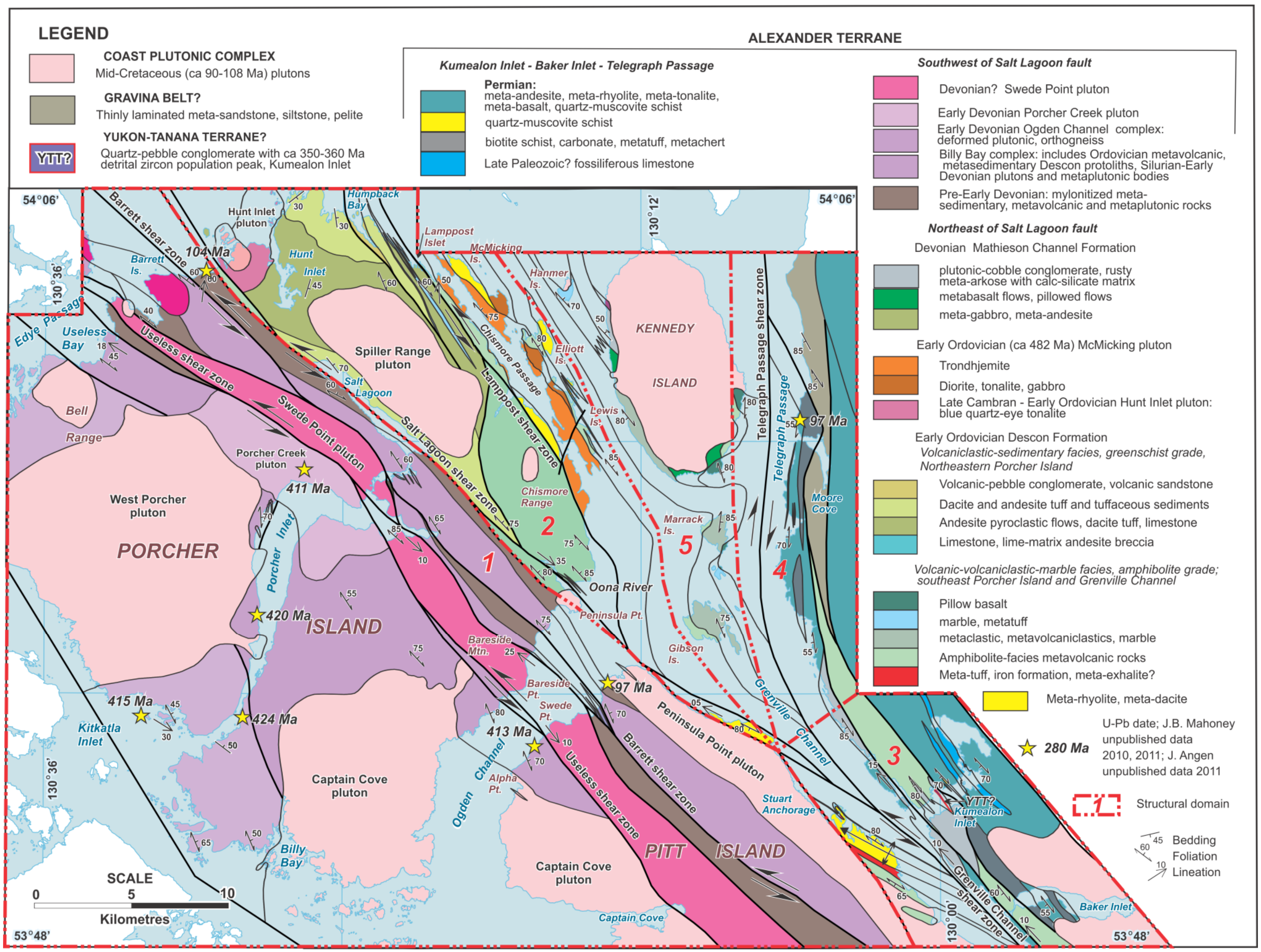

Figure 2. Geology and structural domains of Porcher Island and Grenville Channel area (modified after Nelson *et al.*, 2010b, 2012).

identified both by shear sense indicators and by inverted metamorphic gradients. Rubin and Saleeby (1992) report lineations and kinematic observations consistent with sinistral reverse motion on steeply northeast dipping shear zones in southeast Alaska. This deformation is reported as synkinematic to the *ca.* 101 Ma Moth Bay pluton (Rubin and Saleeby, 1987; no errors given). An earlier phase of thrusting associated with moderately northeast dipping foliations is constrained as post 113 Ma by the youngest affected strata. Wide angle seismic reflection data of the Portland Canal ACCRETE transect in southeast Alaska indicated that these thrusts are crustal-scale features, which can be traced to mid-crustal depths where they are truncated by the younger Coast shear zone (Morozov *et al*., 1998). McClelland *et al*. (1992) reported synkinematic ages along the Sumdum-Fanshaw fault system, which indicate that the steep southwest-vergent thrusts were active at 92.9 ±3 Ma and truncate earlier, shallower fabrics.

The Ecstall pluton has been interpreted to have been emplaced synkinematically with respect to thrusting (Crawford *et al*., 1987; 2000), and/or sinistral shearing (van der Heyden, 1989; Chardon *et al*., 1999). U-Pb zircon dating of the pluton has yielded ages of 90.5 ±1.0 Ma and 91.5 ±1.0 Ma (Butler *et al*., 2002). Subsequently, Chardon (2003) proposed that the Ecstall pluton intruded during sinistral transpression, with the deformation being partitioned into reverse and transcurrent shear zones. Intrusion of the Ecstall pluton had a major impact on the local strain field and was interpreted to have caused dextral shearing along a portion of the Prince Rupert thrust within an overall sinistral system. Detailed Lu-Hf dating of garnets, however, suggests that regional metamorphism occurred between 108 and 102 Ma, with a 10 Ma gap between the main phase of transpression and emplacement of the Ecstall pluton (Wolf *et al*., 2010).

STRUCTURES

The tectonometamorphic history of the area is complex and generally has transformed the rocks into metamorphic tectonites, with the grade of metamorphism varying from upper greenschist to upper amphibolite facies. The main structure is a penetrative composite transposition foliation, which is generally steeply dipping and nearly everywhere accompanied by mineral and/or stretching lineations with varying plunges. The stretching lineation is defined by elongated clasts, mineral aggregates and boudinage. Where both mineral and stretching lineations are present, they are generally parallel. The foliation locally contains at least two generations (F_1 and F_2) of intrafolial tight to isoclinal folds (Figure 3a), emphasizing its composite origin.

The deformation of the area was heterogeneous and characterised by laterally continuous zones of high strain ranging from 10 to 200 metres in width, represented by mylonite and a highly planar fabric best described as straight gneiss (Figure 3b; Hanmer and Passchier, 1991). They are separated from the surrounding lower strained rocks by marked strain gradients. The presence of asymmetric shear sense indicators, such as S-C fabrics, in the high strain tectonites indicates they represent shear zones formed by non-coaxial strain. The shear zones have various trends and their shear sense indicators suggest that in part they record different kinematic evolutions.

The map area has been divided into five domains based on their dominant structural features, metamorphism, and kinematic evolution of their structures (Figure 2). Domain 1 is a northwest-striking domain, which includes the Useless and Barrett shear zones and Paleozoic structures that are not evident in the other domains (see below). Domain 2 is also a northwest-striking domain, at a lower metamorphic grade than domain 1. It comprises two major shear zones: the Salt Lagoon and Lamppost shear zones. Domain 3 is also northwest striking and includes the Grenville Channel shear zone. Domain 4 is north striking and characterized by the Telegraph Passage shear zone and adjacent wallrocks. Domain 5 is northwest striking, similar to domains 2 and 3, but contains no significant shear zones.

Domain 1

Domain 1 comprises the southwestern portion of Porcher Island and western Pitt Island (Figure 2). It is characterized by northwest to west-northwest striking, moderately to steeply northeast dipping foliations and highly variable lineations. It includes the Useless and Barrett shear zones. Inconsistent shear sense indicators suggest these shear zones accommodated protracted deformation histories characterised by varying kinematics. Unpublished U-Pb zircon ages from the synkinematic Ogden Channel complex and Porcher Creek pluton indicate a significant Late Silurian to Early Devonian deformation event (Figures 2, 3c). Associated kinematic indicators suggest sinistral reverse sense of motion (Figure 3a; Nelson *et al*., 2012). It is not yet clear how much of the structural development of domain 1 can be attributed to this mid-Paleozoic event, and how much to superimposed Cretaceous sinistral kinematics. An increase in metamorphic grade (epidote amphibolite to amphibolite facies) is observed from southwest to northeast up to the moderately to steeply northeast dipping Salt Lagoon fault, which forms the northeastern boundary of domain 1.

USELESS SHEAR ZONE

The Useless shear zone is characterised by mylonite and is spatially associated with the tabular, elongated Swede Point pluton (Figure 2). The pluton has been overprinted, at least in part, by the shear zone, as it locally contains S-C fabrics (Figure 3d). However, inferred consanguineous dikes locally cut the mylonite (Figure 3e), suggesting the pluton was emplaced late synkinematically. Shallowly southeast plunging ridge-and-groove lineations within Swede Point pluton, as defined by Lin *et al*. (2007), suggest the sinistral shear after pluton emplacement had a minor reverse component. Dating of the Swede Point pluton using ID-TIMS yielded an age of *ca.* 382 ±14 Ma. However, the analysed zircons have complicated U-Pb systematics, making their age suspect (van der Heyden, 1989). Additional dating of the Swede Point pluton, and associated dikes, using LA-ICPMS indicated the existence of both mid-Cretaceous and older zircon growth, but failed to produce a reliable crystallization age for the pluton (J.J. Angen; J.B. Mahoney, unpublished data, 2011). The existing 382 Ma age may be a composite of an Early Devonian crystallization age as is typical of the members of the associated synkinematic Ogden Channel complex, and mid-Cretaceous metamorphic overgrowths; alternatively, the data may reflect a mid-Cretaceous crystallization age with abundant inherited xenocrystic cores. Both of these interpretations indicate that the Early Devonian shear zones were subsequently reactivated during a mid-Cretaceous tectonometamorphic or tectonomagmatic event.

The mylonite contains rare long limbed isoclinal folds (Figure 3b) and accommodated sinistral reverse motion. Shear sense indicators in the adjacent lower strain zones suggest the kinematic history was probably complex because both sinistral normal and sinistral reverse sense of shear have been observed, as well as two phases of folding (Figures 3a, f).

BARRETT SHEAR ZONE

The Barrett shear zone is located immediately north of the Useless shear zone, localised in a discontinuous belt of metasedimentary screens enclosed by the orthogneiss of the Ogden Channel complex (Figure 2). The best exposures of the Barrett shear zone are along the northwestern shore of Porcher Island (Figure 2). The orthogneiss contains straight gneiss with isoclinal F_1 folds that are refolded by asymmetrical sinistral F_2 folds (Figure 4a). F_2 fold hinge lines along the northwestern Porcher Island exposure are generally parallel to the stretching lineations, plunging moderately to the north as previously documented by Nelson *et al*., 2010a (Figure 4b). Locally sheath folds have been observed (Figure 4c), but elsewhere folds appear cylindrical without formation of sheath-like geometries (*cf.* Jiang and Williams, 1998).

A swarm of mylonitized pegmatite dikes are observed both crosscutting the F_2 folds parallel to the axial planes and incorporated in folding (Figure 4d). Lineations within the mylonitized dikes vary from shallowly northwest to steeply north plunging, and δ-porphyroclasts associated with these lineations indicate sinistral oblique normal motion. One of these dikes yielded a U-Pb zircon LA-ICPMS age of 104.5 ±0.9 Ma (J.B. Mahoney, unpublished data), indicating that at least some of the shearing was mid-Cretaceous.

Domain 2

Domain 2 includes the northeastern part of Porcher Island, as well as McMicking, Elliot, and Lewis islands (Figure 2). It includes the Salt Lagoon and Lamppost shear zones, the former bounding its southwestern margin. This domain is characterized by moderately to steeply northeast dipping foliations and variable lineations, similar to domain 1. It is distinguished on the basis of lithological and metamorphic contrasts, being comprised mainly of greenschist grade metavolcanic and metasedimentary rocks of the Ordovician Descon Formation. Structurally, it lacks evidence for the Early Devonian deformation event observed in domain 1.

SALT LAGOON SHEAR ZONE

The Salt Lagoon shear zone is topographically defined by a steep valley bisecting Porcher Island (Figure 2). This shear zone is interpreted as a major structure because it separates the Ogden Channel orthogneiss to the southwest from the Descon Formation to the northeast. It is characterised by a mylonite zone, which has a width of 100 metres or less and dips moderately to steeply to the northeast. Shear sense indicators comprise folded and/or boudinaged veins and dikes, porphyroclasts, and drag folds. They indicate dominantly sinistral shear with minor superimposed dextral shear. Stretching lineations plunge moderately to the southeast and to the northwest, suggesting a complicated movement history.

Granodioritic dikes in the wallrocks of the Salt Lagoon shear zone show evidence for stretching and folding consistent with a small amount of sinistral shear (Figure 5). They are therefore interpreted to have intruded late synkinematically with respect to sinistral shearing. The dikes yielded a U-Pb zircon age of 96.8 ±4.8 Ma (ID-TIMS unpublished data).

LAMPPOST SHEAR ZONE

The Lamppost shear zone is a 50-100 metre wide, heterogeneous deformation zone, comprising numerous smaller scale, anastomosing greenschist grade shear zones. This structure occurs along the northeastern shore of Porcher Island (Figure 2). It is localised in rocks of the Descon Formation and separates the *ca.* 482 ±15 Ma McMicking trondhjemite (Gehrels and Boghossian, 2000) from metavolcanic rocks and interlayered marble to the south. Shear sense indicators such as S-C fabrics and boudinaged veins record sinistral-normal shear, consistent with a component of the motion observed in the Salt Lagoon shear zone.

Domain 3

Domain 3 comprises highly strained rocks on both margins of Grenville Channel (Figure 2). It is cored by the Grenville Channel fault itself, which lies under the strong topographic linear of the shipping channel. The notable structures in this domain are the nearly upright, shallowly northwest plunging, open to isoclinal F_2 folds and an accompanying S_2 axial planar foliation. Strain increases and the folds become tighter upon approaching the Grenville Channel shear zone from the northeast, through Kumealon Inlet (Figure 2). A cobble

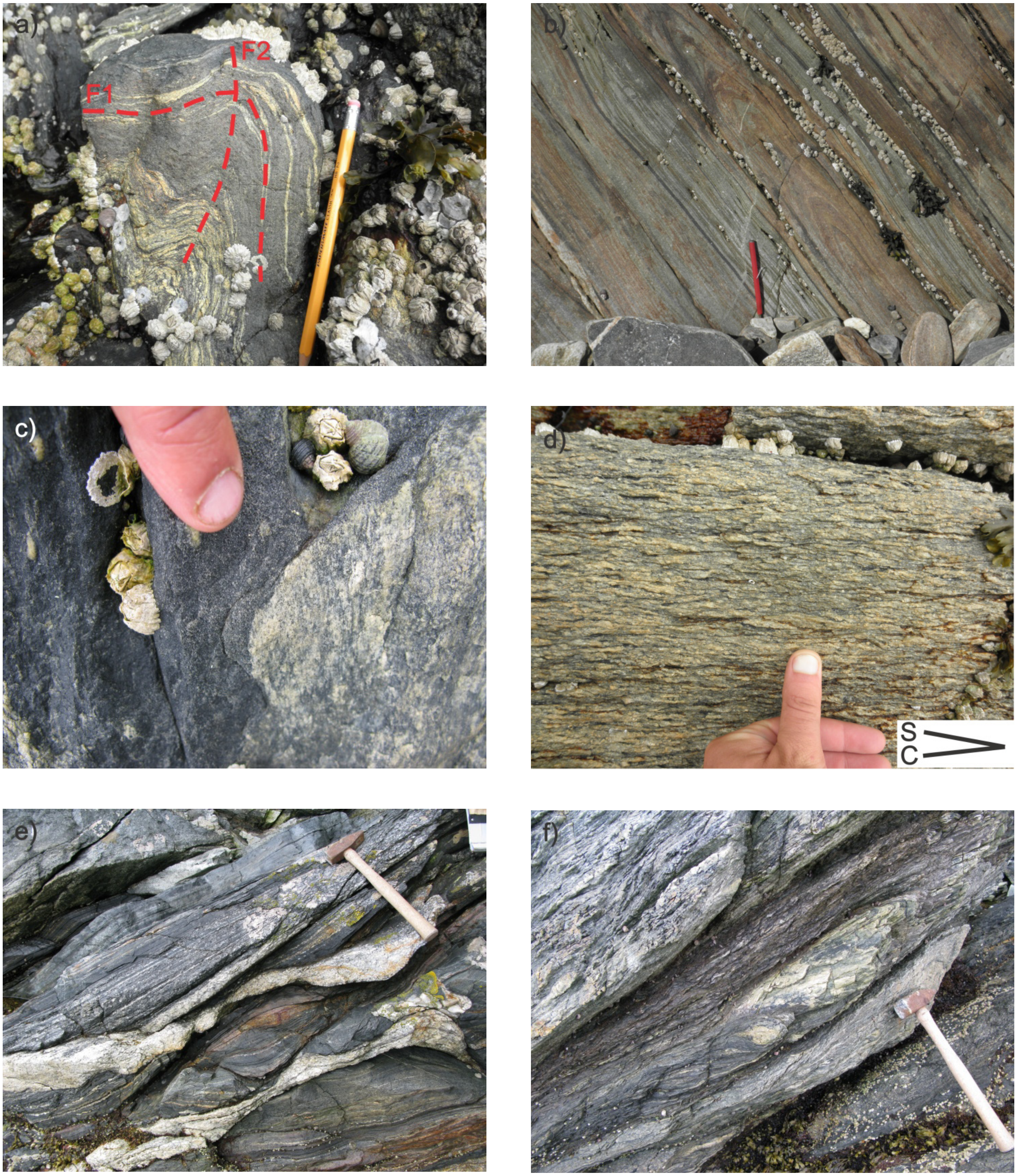

Figure 3. Structural observations within Domain 1. a) Ogden Channel orthogneiss with F_1 isoclinal folds refolded around F_2 folds. Dotted lines represent axial traces, photograph was taken looking down toward the northwest. Both phases of folding are consistent with sinistral reverse sense of shear, Useless shear zone south of Bareside Point on southeastern Porcher Island; b) Straight gneiss of the Ogden Channel complex including a long limbed isoclinal fold, Useless shear zone north of Bareside Point on southeastern Porcher Island; c) foliated dike which crosscuts stronger foliation in adjacent dike, both *ca.* 412-413 Ma, Ogden Channel complex, northwestern Pitt Island; d) S-C fabric within the Swede Point pluton indicating sinistral shear, Bareside point on southeastern Porcher Island; e) Weakly deformed leucotonalite dikes crosscutting amphibolite grade straight gneiss of the Ogden Channel complex, Useless Bay on northwestern Porcher Island; f) Evidence for sinistral normal motion including a sigma porphyroclast and shear bands, Useless Bay on northwestern Porcher Island.

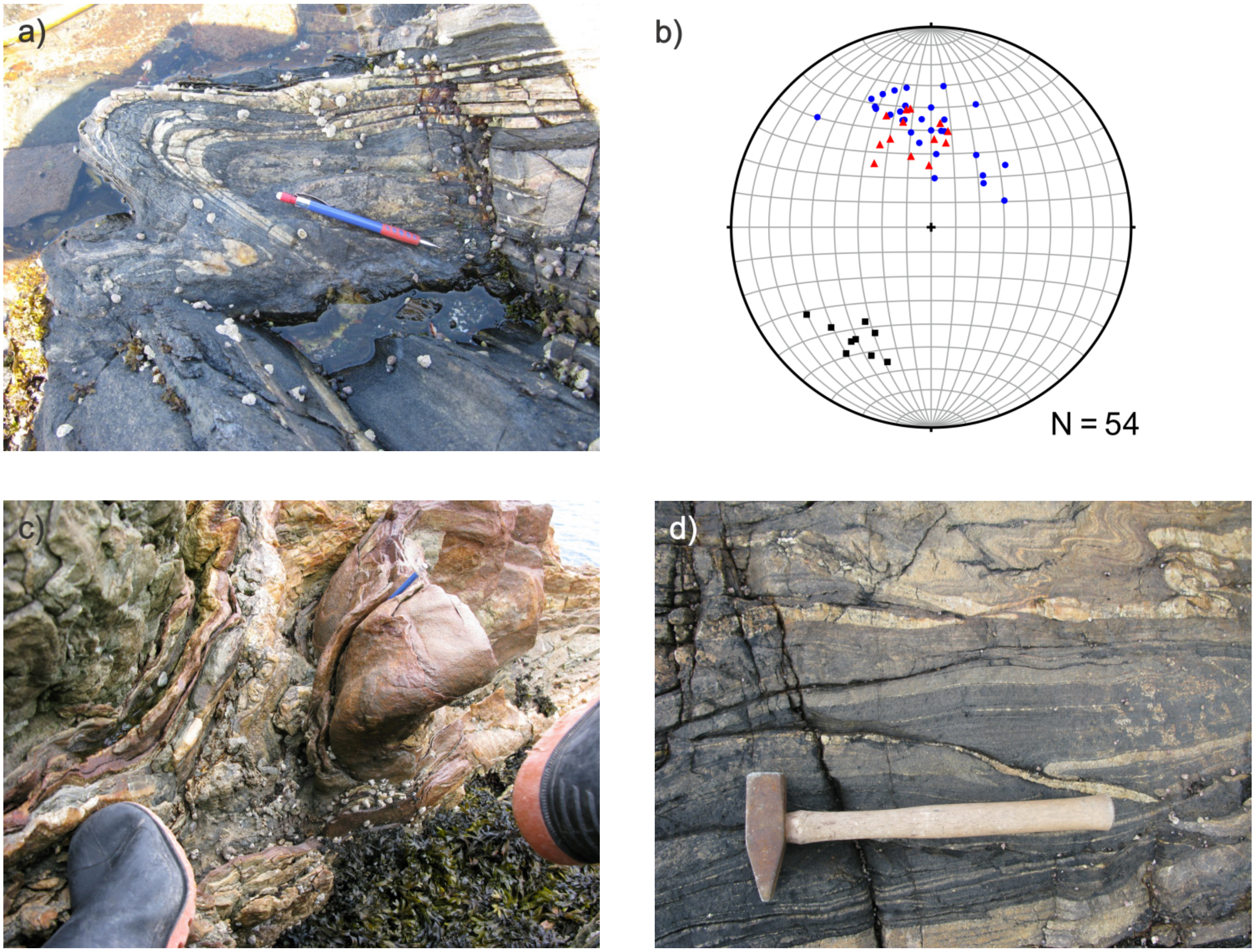

Figure 4. Structures associated with the Barrett shear zone, from both northwestern and southeastern Porcher Island. a) F_1 isoclinal folds refolded around F_2 folds, northwestern Porcher Island; b) Lower hemisphere, equal area stereonet plot of lineations and foliations from the Barrett shear zone along northwestern Porcher Island. Fold hinge lines and crenulation lineations are plotted as blue circles, and stretching lineations are plotted as red triangles. Poles to transposition foliation are plotted as black squares; c) Highly curvilinear hinge of a sheath fold along the Barrett shear zone, southeastern Porcher Island; d) Mylonitized pegmatite dikes both cutting F_2 folds parallel to their axial planes, and being incorporated in folding, northwestern Porcher Island.

conglomerate approximately 500 metres from the mouth of Kumealon Inlet records aspect ratios of 6:1 whereas pillow basalt at the mouth of the inlet records aspect ratios of 20:1 (Figures 6a, b). This strain gradient culminates with formation of a composite $S_{1\text{-}2}$ transposition foliation and is accompanied by an increase in sinistral shear sense indicators (Figure 6c). Boudinage and intense rodding (L>S tectonites) record a dominant horizontal stretching in the shear zone (Figure 6d).

Domain 3 includes the apparent structural boundary between rocks assigned to the Alexander terrane and those assigned to the Yukon Tanana terrane. The proposed boundary zone between the two terranes is exposed in the northeastern portion of Kumealon Inlet. The inferred structural contact is outlined by a thin, isoclinally F_2 folded layer (~20 cm thick) of virtually monomineralic, coarse-grained garnet parallel to S_1. It occurs along the contacts of a quartz pebble conglomerate which produced a Mississippian detrital zircon spectra characteristic of the Yukon Tanana terrane (J.B. Mahoney, unpublished data; Nelson *et al*., 2012). This 'garnetite' layer is interpreted as the metamorphic product of a hydrothermally altered fault zone. The F_2 folds here generally have a northeast vergence with a shallowly southwest dipping enveloping surface. A strong crenulation lineation is parallel to the F_2 fold axes and stretching lineations. Rare kyanite blades locally occur along this lineation as well. Wolf *et al*. (2010) published a 102.6 ±3.7 Ma Lu-Hf age of garnet porphyroblasts within Kumealon Inlet, suggesting that peak metamorphism and associated deformation took place during the mid-Cretaceous.

Domain 4

Domain 4 is a narrow zone along the shores of Telegraph Passage (Figure 2). It comprises the

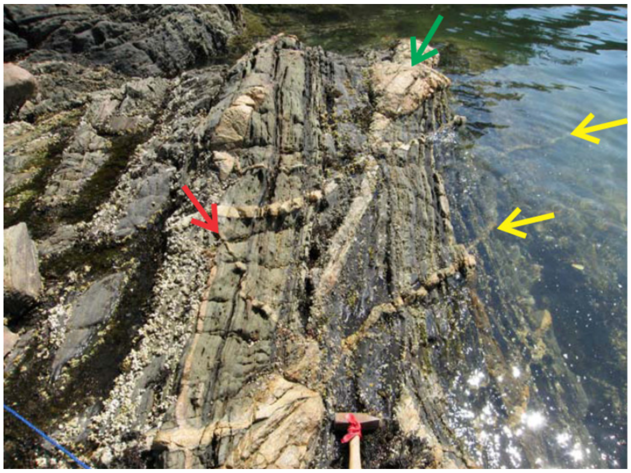

Figure 5. Granodioritic dikes late synkinematic to sinistral shear near the Salt Lagoon shear zone, northwestern Pitt Island. The red arrow indicates a dike in the shortening quadrant, exhibiting folds; the green arrow indicates a dike in the extensional quadrant, exhibiting pinch and swell structures; and the two yellow arrows indicate a single dike which has rotated from the shortening quadrant into the extensional quadrant and thus contains folds as well as pinch and swell structures.

anomalously north striking Telegraph Passage shear zone and its wallrocks. The wallrocks preserve a strain gradient and display steepening and a slight clockwise deflection of the S_1 foliation on approaching the shear zone. The Telegraph Passage shear zone itself is poorly exposed, because it is largely under water. Lineations along the eastern shore of Telegraph passage plunge moderately to the south. Asymmetric folds, obliquely boudinaged veins and the sense of deflection and/or refraction of the foliations indicate dextral motion with a west side up component (Figures 7a, b). The large degree of separation of boudins in pulled-apart veins and pegmatite dikes suggest the main stretching was subhorizontal. All structures are consistent with a predominantly dextral horizontal component of shear. The Telegraph Passage shear zone lies on strike with the Prince Rupert shear zone to the north, which in part also records dextral sense of shear (Chardon, 2003).

A quartz diorite dike was collected which crosscuts well developed foliation, contains a weakly developed foliation, and records stretching consistent with dextral

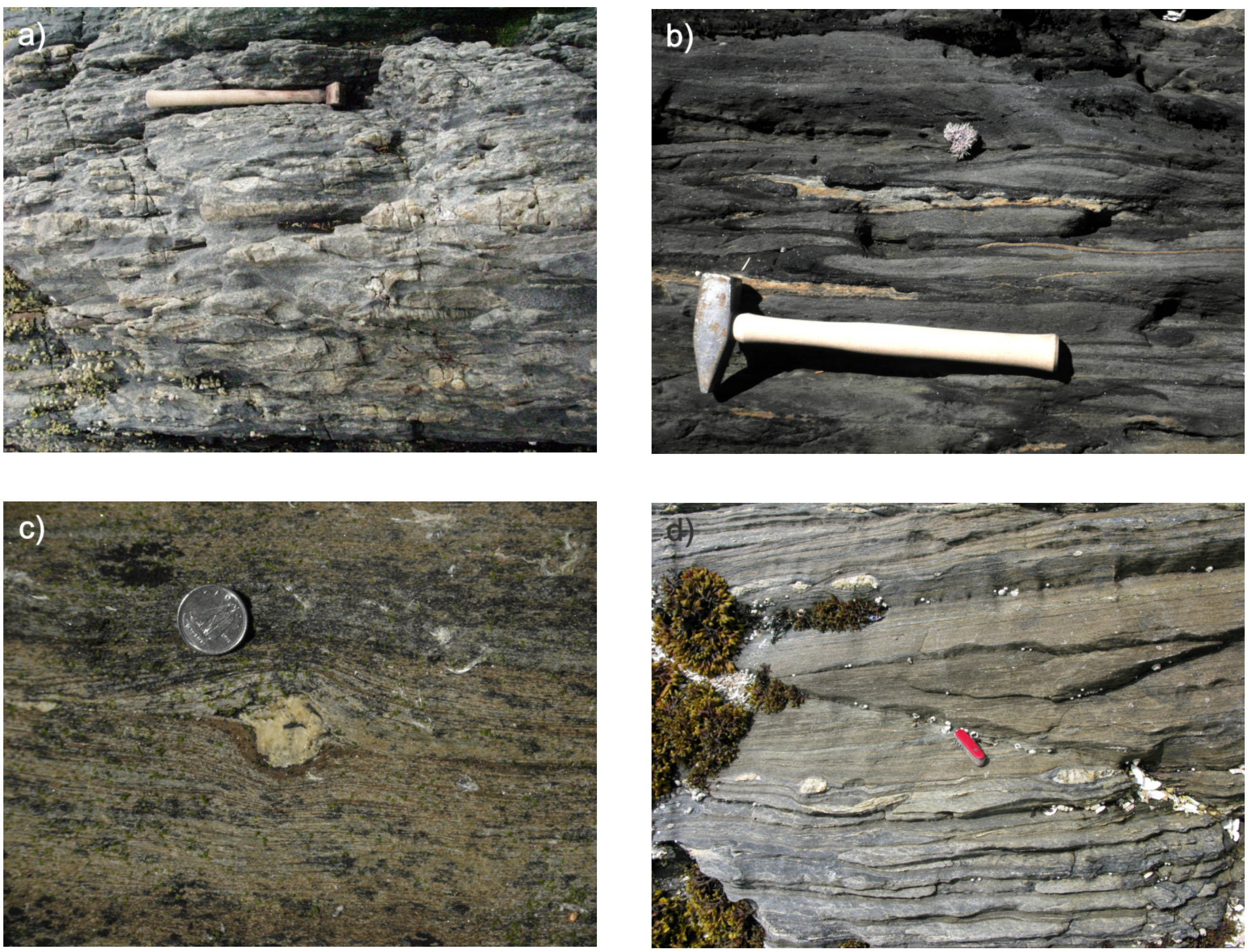

Figure 6. Structural features of domain 3. a) Cobble conglomerate of the Mathieson Channel Formation with 6:1 aspect ratios; b) Pillow basalt of the Descon Formation with 20:1 aspect ratios; c) Sigma porphyroclast indicating sinistral shear; d) Boudinage of a vein indicating significant horizontal stretching associated with sinistral shear.

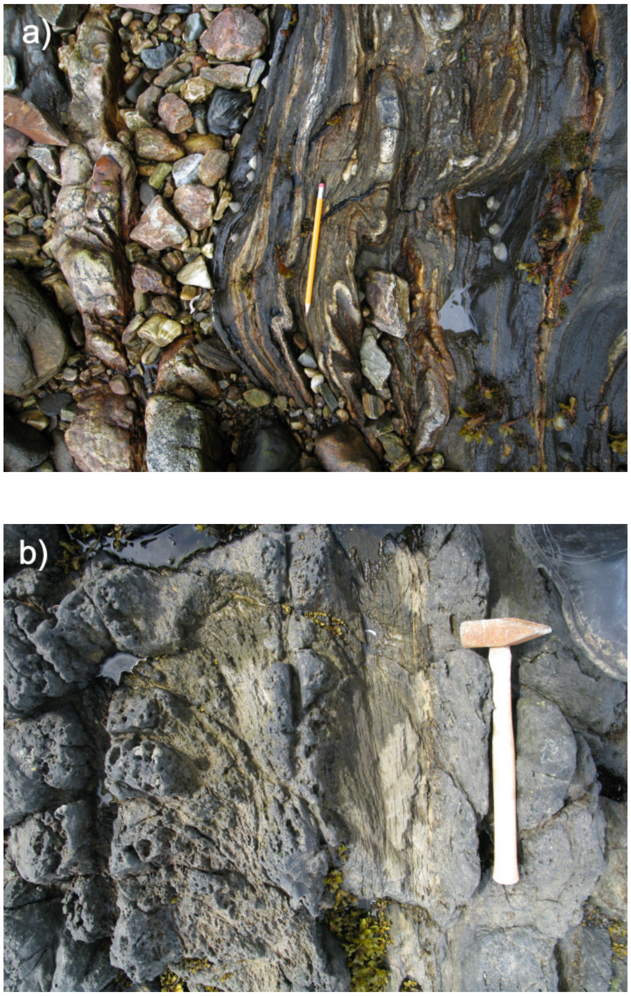

Figure 7. Kinematic indicators associated with Telegraph Passage shear zone along the eastern shore of Telegraph Passage. a) Strongly asymmetric folds indicating dextral shear; b) Dextral deflection of foliation into a local high strain zone.

shear. This dike yielded a U-Pb zircon age of 97.2 ±2.1 Ma (ID-TIMS unpublished data), suggesting that the dextral Telegraph Passage shear zone was roughly coeval with shear in the sinistral Grenville Channel and Salt Lagoon shear zones. Nevertheless, the north-striking foliation associated with the Telegraph Passage shear zone was deflected sinistrally by the northwest striking Grenville Channel shear zone to the south, indicating that sinistral shearing outlasted dextral shearing, at least locally.

Another north striking dextral shear zone has been documented south of Grenville Channel, approximately 100 km to the southeast (Chardon *et al*., 1999). Nelson *et al*. (2012) estimate that mid-Cretaceous offset along the Grenville Channel shear zone was approximately 5 kilometres; therefore, this is unlikely to represent the continuation of the Telegraph Passage shear zone. It may, however, represent another conjugate to the northwest striking Grenville Channel shear zone.

Domain 5

This is a complex zone occupying the apex situated between the northwest striking Lamppost shear zone of domain 2 and the north striking Telegraph Passage shear zone of domain 4. The dominant foliation dips moderately to steeply to the northeast. As in domain 3, open to isoclinal upright folds are common; however, here the plunges of the hinge lines display much more variation, between northwest and southeast. A significant feature of this domain is the presence of a conjugate set of small scale sinistral and dextral shear bands, which are parallel to the large scale shear zones (Figures 8a-c). The conjugate angle of the shear bands is 117^{o}, well within the range of observed and predicted values for ductile conjugate faults (Zheng *et al*., 2004, 2011).

DISCUSSION

Age and nature of the various phases of deformation

The structural observations summarized herein contribute to the understanding of the complex tectonic history of the Alexander terrane. They have been divided into one Paleozoic and two Mesozoic events on the basis of existing timing constraints.

D_{1P}

The Alexander terrane preserves strong evidence, within domain 1, for formation of a northeast dipping transposition foliation, isoclinal folding and sinistral oblique reverse shearing coeval with Late Silurian to Early Devonian intrusion of the Ogden Channel plutonic complex (Nelson *et al*., 2012). These Paleozoic structures are referred to herein as D_{1p} (Paleozoic). The very weakly deformed *ca.* 411 Ma Porcher Creek pluton suggests that $D1_p$ ended in the Early Devonian. So far, no evidence of Paleozoic transposition fabrics has been found north of the Salt Lagoon shear zone. On northeastern Porcher Island (domain 2), volcanic rocks of the Descon Formation typically display well preserved primary textures, and transposition fabrics are restricted to the vicinity of discrete shear zones.

D_{1M}

Observed D_1 structures in domains 2 to 5 are solely represented by S_1, which is continuous across the inferred Alexander-Yukon-Tanana terrane boundary in domain 3. This implies S_1 in these domains formed during or after the initial latest Triassic-Middle Jurassic docking of these two terranes (Gehrels *et al*., 1992; van der Heyden, 1992; McClelland and Mattinson, 2000; Saleeby, 2000; Gehrels, 2001). The responsible deformation is therefore referred to herein as D_{1m} (Mesozoic), to highlight its difference from D_{1p} in domain 1.

The age of D_{1m} is poorly constrained between the late Triassic and the mid-Cretaceous age of D_2 (see below) and attainment of peak metamorphism. S_1 is parallel to

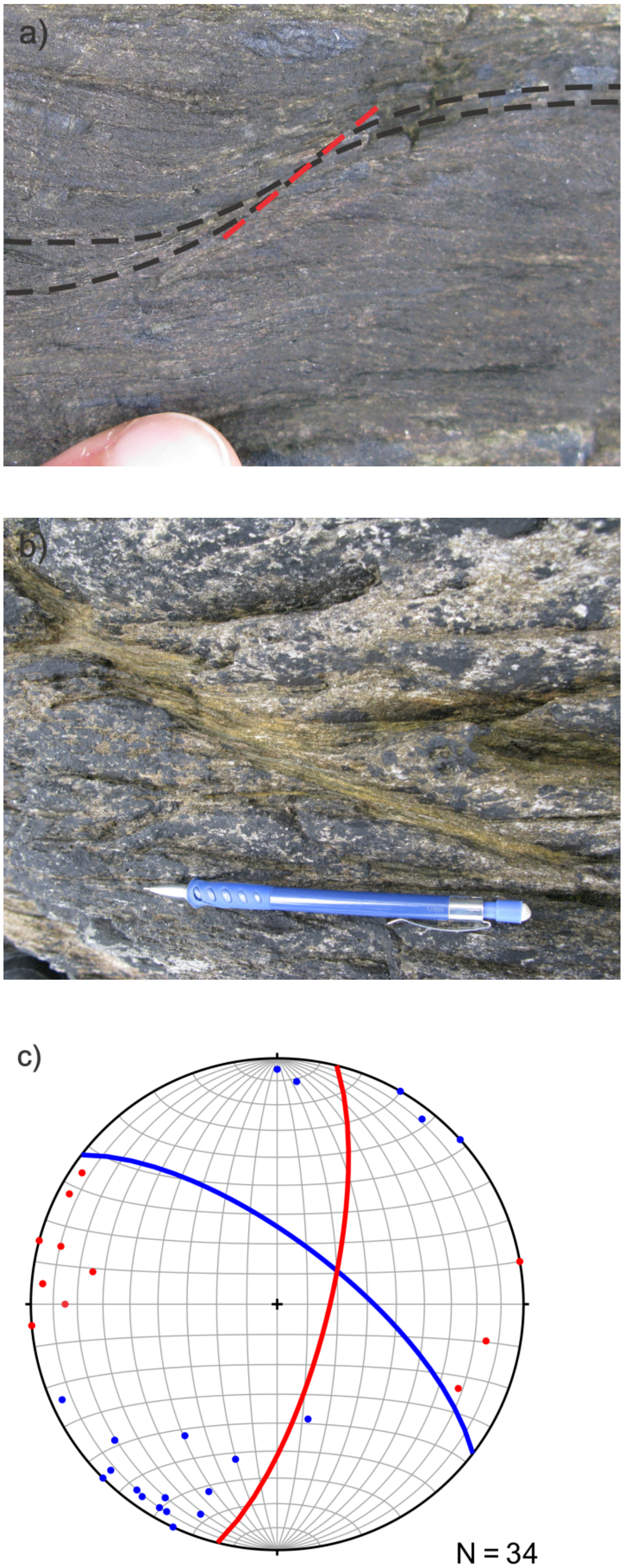

Figure 8. Shear bands in domain 5. a) Sinistral shear band, foliation traces (black dashed lines) curve into shear band (red dashed line) indicating sinistral shear; b) Dextral shear band; c) Lower hemisphere, equal area stereonet plot showing poles to sinistral shear bands in blue and poles to dextral shear bands in red, average values are plotted as the corresponding planes.

the contacts between the major lithological units, including the 'garnetite' layer interpreted as the cryptic terrane-bounding fault. This fault formed prior to peak metamorphism, and was subsequently annealed to its current representation.

D_2

D_2 encompasses F_2 upright folding of the pre-existing transposition foliation, formation of the S_2 axial planar foliation, and formation of a conjugate set of shears, both on outcrop scale (shear band) and map scale (shear zone). Although there are minor differences in the nature of the D_2 structures from one domain to another, there is a strong consistency in their overall structural style and kinematics, suggesting they formed during the same deformation event. Existing geochronological constraints indicate that D_2-related sinistral and dextral shearing was mid-Cretaceous (104-97 Ma), which is coeval with peak metamorphism (Wolf *et al*., 2010).

Significance and tectonic setting of D_{1p}

D_{1p} structures have been recognised solely in domain 1. Here F_2 folds refold earlier F_1 isoclines, which in turn fold an older foliation in amphibolite facies tectonite. These F_1 isoclines and the older foliation have only been observed in domain 1 and formed synkinematic with respect to the emplacement of intrusions in the Late Silurian to Early Devonian Ogden Channel complex. Domain 1 thus appears to contain an earlier phase of structures compared to those recorded elsewhere. In addition, plutonic correlatives of the Ogden Channel complex are absent in the other domains. We tentatively attribute this difference in deformation and plutonic history to domain 1 having been situated in a different tectonic setting within the Alexander terrane than the other domains during the Early Devonian. The Ogden Channel complex of domain 1 represents the previously undocumented lower crustal roots of a Late Silurian to Early Devonian magmatic arc, Nelson *et al*. (2012) suggested that it formed during amalgamation of primitive arc and pericratonic fragments within the Alexander terrane, assigning it to the Klakas orogeny of Gehrels *et al*. (1983). The orientation and sense of shear of D_{1p} structures indicates sinistral transpression and southwest vergence, similar to southwest vergent thrusts ascribed to the Klakas orogeny by Gehrels *et al*. (1996).

Significance and tectonic setting of D_{1m}

The distribution of the Alexander and proposed Yukon Tanana terrane rocks in Kumealon Inlet (see above) suggests that the cryptic D_{1m} fault was folded, together with S_1, into upright, shallowly northwest plunging F_2 folds in domain 3. At present, the quartz-pebble conglomerate and its surrounding pelite and garnetite occupy the core of a tight F_2 fold, surrounded by Alexander terrane units. The F_2 folds are slightly asymmetric and verge to the northeast. The F_2 enveloping surface has a shallow dip to the west. Since an enveloping surface connects the crests or troughs of a given layer, S_1 probably had a shallow dip prior to F_2 in this domain. The upright nature of F_2 folds throughout the area described herein, suggest that S_1 in general was a shallowly-dipping structure prior to F_2, although its paleodip is unknown at present. Given the probable shallow dip of S_1 prior to F_2, its parallelism to lithological contacts, and development prior to peak metamorphism, we suggest that D_{1m} formed during thrusting and concomitant thickening. If correct, D_{1m} may be related to the initial latest Triassic – Middle Jurassic interaction of these terranes (Gehrels *et al*., 1992; van der Heyden, 1992; McClelland and Mattinson, 2000; Saleeby, 2000; Gehrels, 2001). Alternatively, D_{1m} and D_2 could represent a continuous deformation event whereby D_{1m} thrusting progressed to folding and formation of steeply dipping shear zones.

Significance and tectonic setting of D_2

The outstanding structures in the area are northwest striking, steeply northeast dipping shear zones on outcrop and map scales, which overall have accommodated an important component of sinistral transcurrent shear. Some of these shear zones also accommodated a significant dip slip component; both reverse and normal sense of movements have been observed. However, the relative timing of these dip slip components is poorly known at present, although both the normal and reverse motions accompanied the sinistral shear. The area also contains a subordinate, north striking, steeply west dipping shear zone, the Telegraph Passage shear zone, which mainly has accommodated dextral transcurrent movements with a minor reverse component (west-side-up). Based on relationships observed in outcrop, we have interpreted that both sets of transcurrent shear zones originally formed as a conjugate pair. Evidence from domain 4 suggests that sinistral shear in the Grenville Channel shear zone outlasted dextral shear in the Telegraph Passage shear zone. Dominance of one shear zone over the other in such a way is a common feature of conjugate shear zones (Ramsay and Huber, 1987). This interpretation implies that the bulk shortening direction during initial shear zone development was oriented northeast-southwest, which is perpendicular to the axial planes of the more upright F_2 folds in domains 3 and 5. This observation supports our interpretation that shearing and F_2 folding form part of the same progressive deformation event (D_2). Following earlier workers (Monger *et al*., 1994; Chardon *et al*; 1999; Israel *et al*., 2006; Gehrels *et al*., 2009) we relate D_2 to an overall sinistral transpressive deformation regime associated with southward motion of the Alexander terrane relative to the paleo-Pacific margin of Laurentia during the mid-Cretaceous.

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