KYANITE AT PRINCE RUPERT AND KITIMAT (103H, J)

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KEYWORDS: Industrial minerals, kyanite, staurolite, garnet, high-alumina amphibolite, refractory minerals, Prince Rupert, Dudevoir Passage, Trail Bay, Hawkesbury Island, Coast Belt.

INTRODUCTION

There are more than 45 kyanite occurrences reported in British Columbia (Figure 1). They are generally restricted to high-alumina, high-grade metasedimentary rocks in the Coast and Omineca tectonic belts. Two small occurrences near the coast were examined as part of a reconnaissance program for refractory minerals in the province.

Kyanite is the high-pressure polymorph of the aluminosilicate, Al_2SiO_5. Sister polymorphs are andalusite and sillimanite. When calcined these minerals are converted to mullite, a highly refractory material. Kyanite converts to mullite at 1370°C and the conversion is accompanied by a nonreversible volume expansion of 18% (Skillen, 1993). Because of the significant volume change, calcination is often required before manufacturing refractory shapes. Kyanite is used primarily in refractories, about half for steel making, a quarter for nonferrous metals processing and the rest in glassmaking and ceramics. In North America, kyanite is the most widely used Al_2SiO_5 polymorph, because it is abundant, found close to markets and relatively

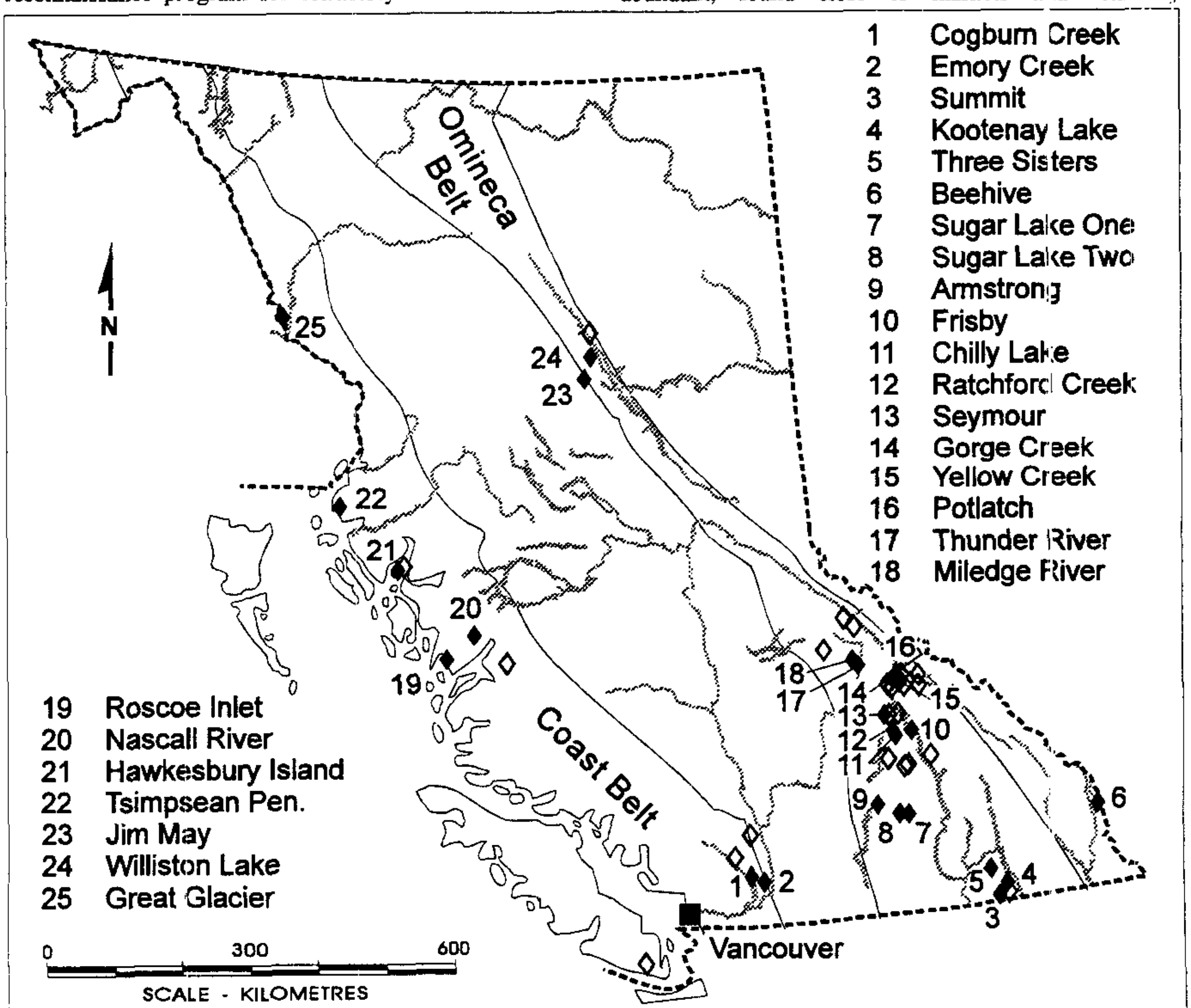

Figure 1: Location of significant kyanite occurrences in British Columbia. Major showings are named.

inexpensive energy is available. In British Columbia, a deposit with an acceptable product, located near tidewater and natural gas service, would have commercial potential. Previous work on andalusite occurrences is reported by Simandl *et al.* (1995).

At the time of writing (November, 1995), United States kyanite prices are US$116-146 for raw kyanite and US$210-240 for calcined product, both with 54 to 60% Al_2O_3 in 18-ton lots, ex-plant (Industrial Minerals, Number 337, October, 1995). The sizes of typical US kyanite products are 35, 48, 100, 200 and 325 mesh. Concentrates are about 91% kyanite, less than 1% iron oxides and the rest quartz (Sweet, 1994). The composition of this product is listed in Table 1.

TABLE 1: COMPOSITION OF TYPICAL US KYANITE PRODUCT (SWEET, 1994)

Al_2O_3	54 to 60.06%
SiO_2	37.64 to 43.70%
Fe_2O_3	0.40 to 1.16%
TiO_2	0.67%

LOCATION

During 1995, kyanite occurrences were examined at Dudevoir Passage and Trail Bay, 36 and 31 kilometres respectively, north of Prince Rupert on Tsimpsean Peninsula, and at the central height of land on Hawkesbury Island, 40 kilometres south of Kitimat. Access to the showings is by boat and helicopter, respectively.

An important note is that occurrences on Hawkesbury Island are at the southern limit of the Foch-Miskatla-Kitsaway protected area, which is currently under review. Part of the described showings are within a no-staking reserve but the kyanite zones extend downslope, to the east and away from the protected area. The authors' objective was to characterize and describe high-grade metamorphic kyanite occurrences in the Coast Belt.

DUDEVOIR PASSAGE AND TRAIL BAY

GEOLOGICAL SETTING

The Dudevoir Passage and Trail Bay kyanite

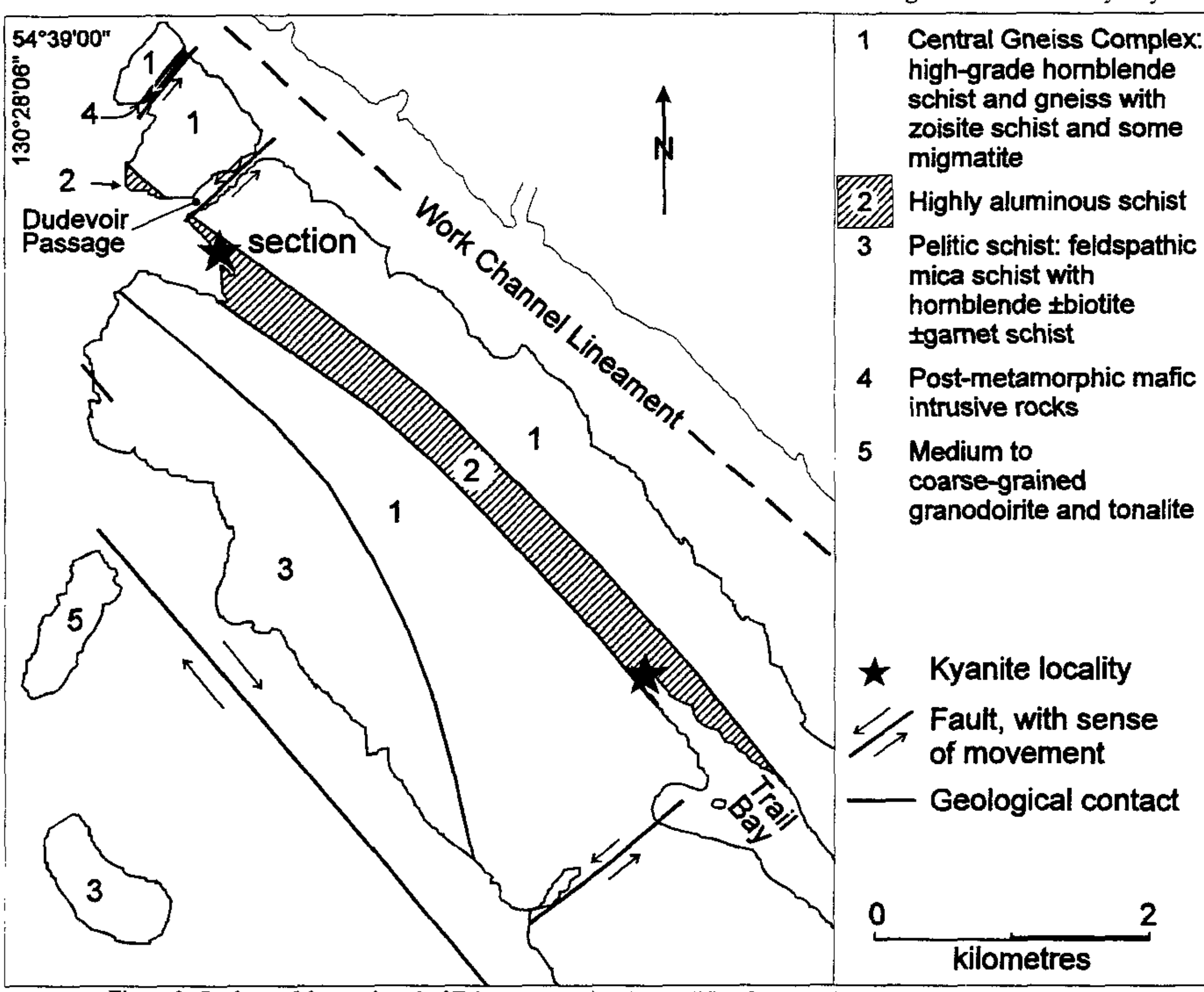

Figure 2: Geology of the north end of Tsimpsean Peninsula (modified from Snyder, 1980 and Hutchison, 1982)

occurrences are on the Tsimpsean Peninsula within the Coast Belt. The geology of the area is summarized from Hutchison (1982) and Snyder (1980). Two regional-scale units and two intrusive rock types are mapped in the area: high-grade hornblende schist and gneiss, pelitic schist, weakly metamorphosed mafic intrusions and granodiorite (Figure 2).

The high-grade hornblende schist and gneiss, with zoisite schist and some migmatite, are part of Hutchison's Central Gneiss Complex.

The amphibolite-grade pelitic schist is predominantly calcareous with some feldspathic mica schist, dark greenish grey hornblende±biotite±garnet schist, and some interlayers of metabasite. A strongly aluminous pelitic schist (unit 2, Figure 2) is part of this package and hosts the Dudevoir Passage and Trail Bay kyanite-garnet occurrences. In outcrop, kyanite-bearing rocks are indistinguishable from the surrounding host. However, on close inspection of the weathered surface, kyanite appears as small rectagular knobs and bumps. In the "high-grade" zones the kyanite forms crystal "mats" and is very distinctive. Weathering and wave action have also created kyanite and garnet placer concentrations in the shoreline debris of rock and gravel. This has proven to be a useful prospecting tool where beaches have developed at the toe of the rock bluffs.

Other units present in the area examined include postmetamorphic mafic intrusive rocks and later, medium to coarse-grained granodiorite and tonalite intrusions (Snyder, 1980).

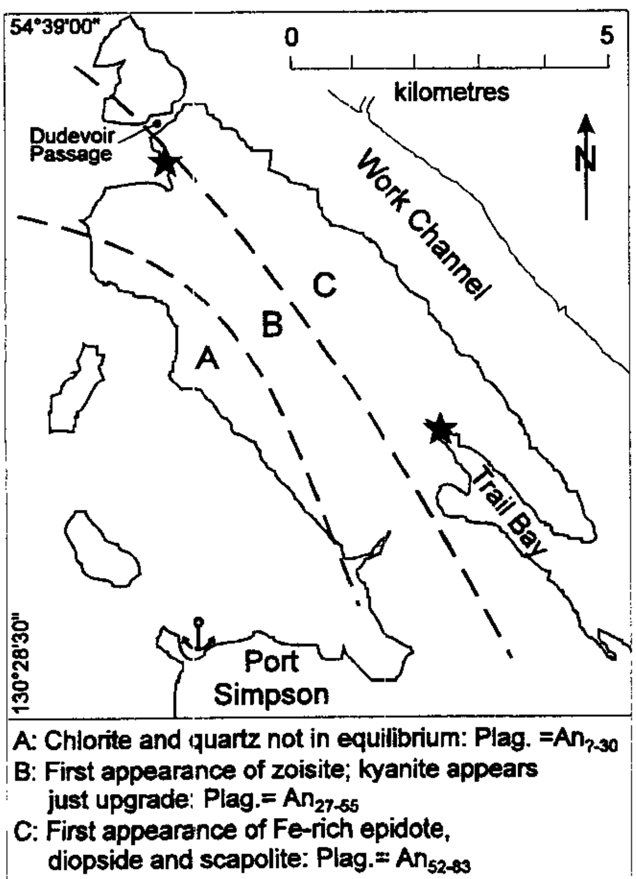

Figure 3: Metamorphic zones at the north end of Tsimpsean Peninsula (from Snyder, 1980)

Rocks on the Tsimpsean Peninsula have a well developed planar structural fabric that strikes northwest and dips moderately to gently to the southwest. At the northern end of the peninsula, along the Work Channel lineament, the fabric is subvertical. Small-scale folds appear to have a generally random orientation.

Metamorphic grade increases from west to east, from greenschist to amphibolite facies. The metamorphic mineral assemblages have been examined by Snyder (*ibid.*) and are shown in Figure 3. The lower boundary of zone A is defined by the final disappearance of chlorite in the presence of quartz. Zone B is defined by the first appeareance of anhedral zoisite prophyroblasts that crosscut foliation. Kyanite appears just above this boundary. Zone C is defined by the first appearance of iron-rich epidote, diopside and scapolite Most of the alumina-rich zone that hosts the kyanite occurrences is in zone C.

KYANITE OCCURRENCES

DUDEVOIR PASSAGE

Dudevoir Passage is at the northern end of the peninsula. The kyanite outcrops are small bluffs at the waters edge, approximately 450 metres south of the western mouth of the passage. Thick coastal rainforest covers the bedrock and makes travel on foot from the coastline very difficult.

A section was measured across the Dudevoir Passage showing from west to east (Figure 4). The layers are oriented 130°/80° SW. The section begins in dark grey to purplish brown and medium to coarse-grained kyanite schist. The schist comprises mainly quartz and plagioclase with 10 to 15% each of biotite and muscovite flakes less than 3 millimetres across. Pyrite and magnetite are minor constituents (< 1% each).The dark grey rocks contain up to 0.5% graphite. Kyanite content is variable, about 10 to 25% in the schist and 20 to 25% in the graphitic layers, with crystal lengths from a few millimetres to about 2 centimetres. Kyanite crystals contain some microscopic quartz inclusions.

Porphyroblastic coarse-grained amphibole-garnet gneiss (metabasite) is garnet rich near its contacts and rich in feldspar and mafic minerals towards the centre of the unit. The garnets are porphyroblastic and masses can be up to 5 centimetres across. The mafic-rich centre consists of amphibole and possibly pyroxene and makes up 30 to 60% of the rock mass; crystals are from 1 to 5 centimetres long, some partially chloritized. Iron oxides and pyrite make up less than 1% of the rock.

The kyanite-garnet schist contains kyanite (10-25%), thin layers of very dark red garnets (5-7%), muscovite (>10%), graphite (2%) and quartz (50%). The garnets contain abundant quartz inclusions. The graphite occurs as very fine interstitial flakes and intergrowths with biotite. Magnetite and pyrite form less than 0.5% of the rock.

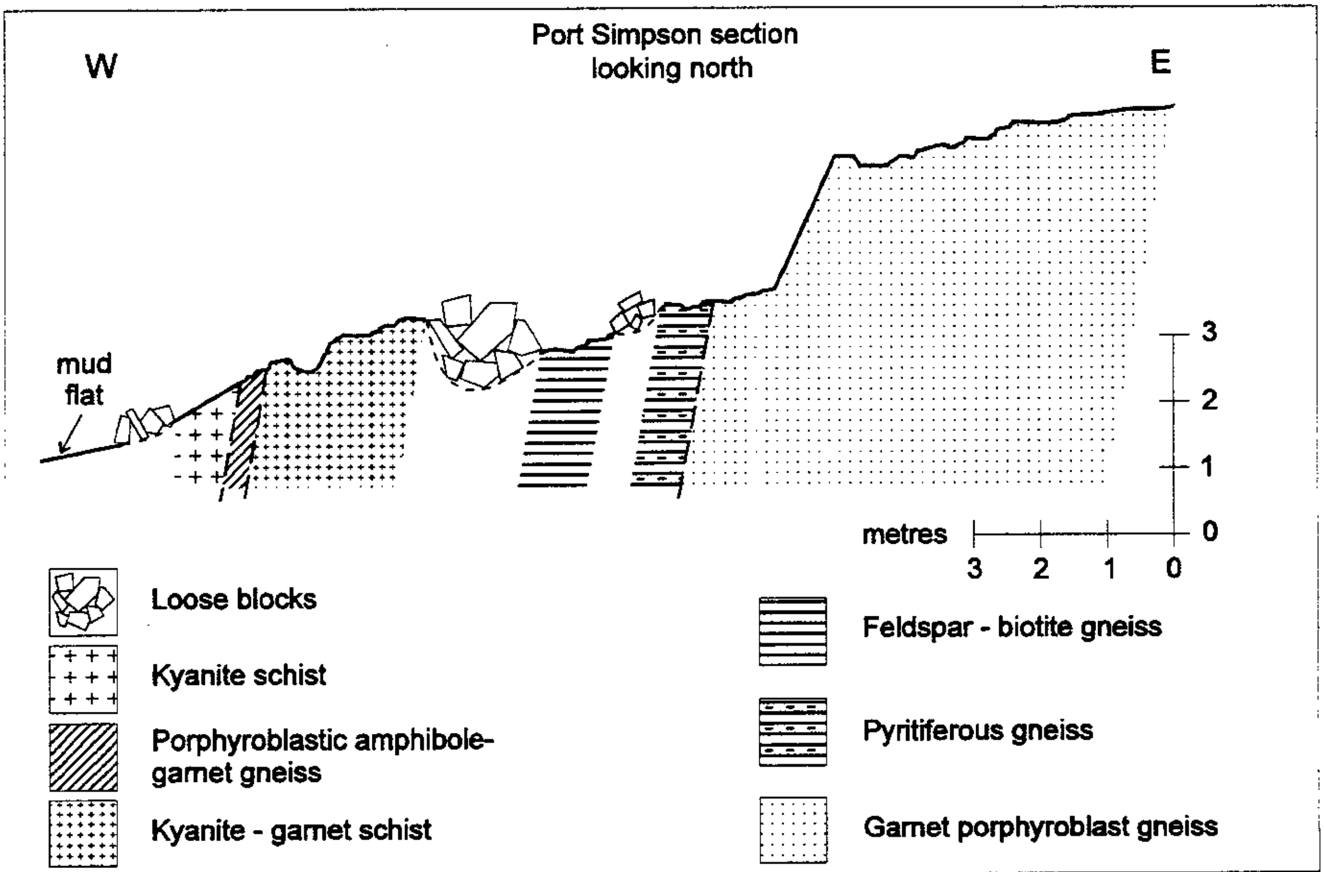

Figure 4: Section across the Dudevoir Passage kyanite showing.

Feldspar-biotite gneiss is rusty brown, medium to coarse grained and contains less than 1% fine-grained, disseminated pyrite. The fresh surface is greenish grey. The gneiss comprises mostly feldspar and quartz with about 10% biotite and less than 1% pyrite. There is less than 1% disseminated garnet, with grains less than 1 millimetre in diameter.

The pyritiferous gneiss has a notable reddish patina on the seawashed surface: it is medium grained and contains 8% pyrite. Disseminated pyrite grains are less than 3 millimetres long but have been stretched along the fabric of the gneiss forming "smears". Iron oxides form less than 1% of the rock. Calcite is a minor accessory mineral.

Garnet gneiss is distinctive by virtue of its large garnet porphyroblasts. These are up to several centimetres across and form up to 15% of the rock. The porphyroblasts are partly altered to chlorite and contain abundant clear white to colorless, acicular quartz inclusions. Biotite forms "smears", suggesting it may be a retrograde product of pyroxene or amphibole.

TRAIL BAY

The best kyanite outcrops in Trail Bay are at the head of the bay. Kyanite also occurs along the western shore in discontinuous outcrops over approximately 600 metres (Figure 2). The outcrops are best exposed at low tide but caution is necessary as the mud beach is very flat and the tide changes are ±8 metres. The outcrops are small bluffs along the shore, similar to those at Dudevoir Passage to the north.

The kyanite-bearing gneiss comprises roughly 35 to 40% kyanite, 40% quartz, 10% biotite (<6 mm), 5% feldspar, less than 5% staurolite (1-2 mm), 2% garnet (<2 mm) and trace pyrite. Kyanite contains a few inclusions of iron oxides and some graphitic material. The graphitic material is almost amorphous. A single kyanite zone is well exposed in many outcrops at the head of the bay but, towards the southern limit of the exposures, the strike is quite variable and more than one zone may be present. The kyanite-bearing gneiss is interlayered with medium-grained biotite gneiss.

The kyanite-bearing gneiss is about 3 metres wide and is exposed for nearly 50 metres along strike. It is bronze-grey on weathered surfaces and steel grey when broken. Kyanite crystals often appear to be steel grey rather than the more typical blueish hue. Very coarse kyanite crystals, up to 5 centimetres long, form between 20 and 40% of the gneiss. In a few places, kyanite makes up 80% of the rock. Other minerals include quartz (±40%), biotite (±10%), feldspar (±5%), staurolite(?) (<1%) and trace graphite.

A section across the zone was not mapped in detail due to a rising tide. A quick overview indicates it comprises, from west to east: the kyanite gneiss, 3 metres wide with the western margin not exposed; a band of interlayered biotite gneiss and porphyroblastic amphibolite or pyroxenite less than 50 centimetres wide; a massive, black, coarse-grained porphyroblastic amphibolite or pyroxenite 4 to 5 metres wide; 7 metres of biotite gneiss followed by about 7 metres of biotite gneiss with foliation-parallel, massive white feldspar pegmatite layers/veins(?), from 0.1 to 2 metres wide that end in a cover of saltwater grasses. The pyroxenite was not seen elsewhere in the bay and the feldspar pegmatite is confined to the eastern shore.

Individual kyanite-bearing outcrops along the west side of the bay typically contain 5% kyanite, 2 to 5 centimetres long; about 1% garnet, 2 to 5 millimetres in diameter and, sporadically, up to 5% fine-grained graphite. The trend of the gneissosity is between 140°/75° and 340°/80°.

In a general sense, all these showings, and other locations reported by Hutchison (*ibid.*) on the shore below Basil Lump and opposite the mouth of Quottoon Inlet, are on strike with each other and probably part of a single alumina-rich zone, parallel to Work Channel.

HAWKESBURY ISLAND

GEOLOGICAL SETTING

The geological setting of Hawkesbury Island is summarized from Roddick (1970).

Eight major units are mapped on the island (Figure 5). They are, from north to south: hornblende biotite granodiorite (1), granitiod gneiss (2), a complex agmatite (3), hornblende-plagioclase-amphibolite schist (4), hornblende-biotite quartz diorite (5), biotite quartz diorite (6), gneissic diorite migmatite complex (7) and hornblende diorite (8). Hornblende-plagioclase amphibolite schist underlies the centre of the island with granitiod gneiss and agmatite exposed at the northern end and the other lithologies to the south.

The hornblende-plagioclase-amphibolite schist contains alumina-rich metapelite that carries kyanite. The schist is part of a regional suite of metasedimentary rocks, largely hornblende-plagioclase schist with lesser quartzite, crystalline limestone, migmatite and some granitiod rocks. It appears to grade into the adjacent units but contact relationships are not clear. It has poorly developed layering and weakly developed foliation, especially where there is little biotite. The unit is also shot through with irregular masses of quartz-feldspar gneiss, *lit-par-lit* gneiss, agmatite and quartz diorite or granodiorite.

Metamorphism on the island has reached amphibolite facies and the staurolite-quartz and kyanite-muscovite-quartz grades. Sillimanite has been found in stream sediments in a few small areas at the north end of the island, suggesting some slightly higher metamorphic grades may occur locally.

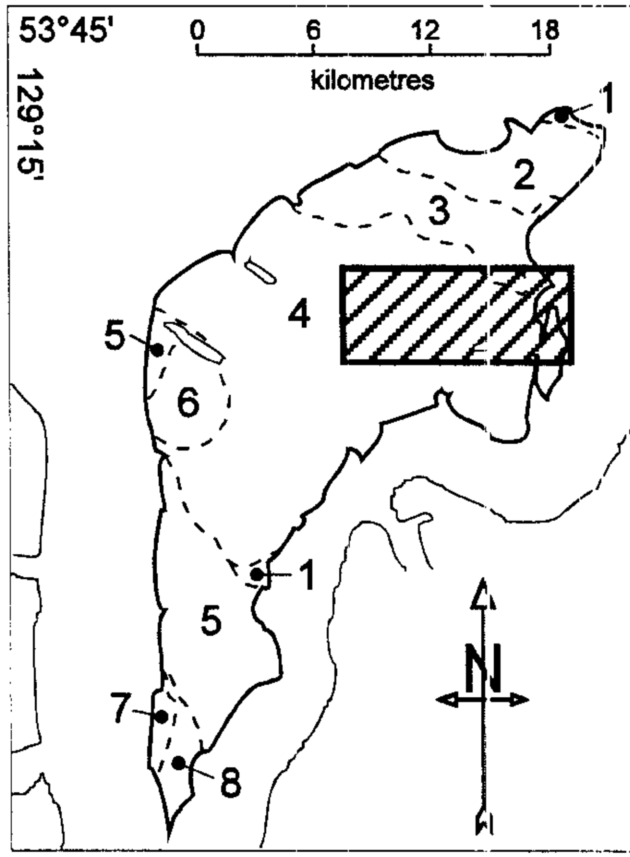

Figure 5: Geology of Hawkesbury Island (modified from Hutchison, 1982; see text for unit names; inset is location of Figure 6).

KYANITE OCCURRENCES

Kyanite was first noted on Hawkesbury Island by Money (1959) while mapping the geology of the island for Texas Gulf Sulphur Company as part of a regional exploration program for volcanogenic massive sulphides in the Ecstall River pendant. Kyanite occurs in a number of discrete zones of high-grade metapelitic gneiss that are part of Roddick's feldspar-hornblende schist unit. Only two of the zones were examined and a detailed section was mapped across one of them (zone 1, Figure 6).

ZONE 1

The first kyanite-bearing zone, in a quartz-feldspar-biotite gneiss, was traced for 900 metres along strike and varies from 3 to 25 metres across. It has an easterly trend and a subvertical northerly dip (280°/70°). Individual gneissic layers pinch and swell by an order of magnitude, from 0.1 to 1 metre, and are complexly folded. Quartz-feldspar pegmatite layers/veins/sweats exhibit ptygmatic folding. Significant minerals include kyanite, garnet and staurolite.

Individual subunits are difficult to trace for more than several tens of metres. In general, larger subunits, like the kyanite zone, can be traced out, but it too has

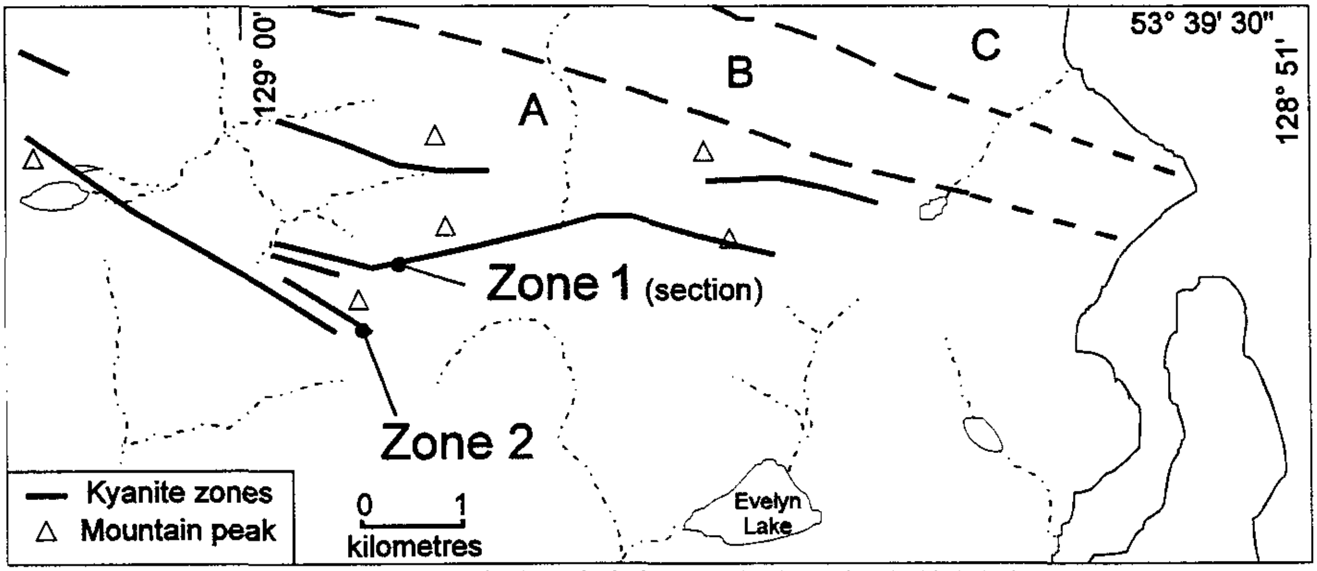

Figure 6: Kyanite occurrences on Hawkesbury Island. A: plagioclase amphibolite; B: interbedded plagioclase amphibolite and quartz-potassium-feldspar-plagioclase gneiss; C: quartz-potassium-feldspar-plagioclase gneiss (from Money, 1959).

significant thickness variations. The mapped section is on one of the widest zones, exposed across 25 metres. The many kyanite zones exposed in the area appear to be distinct stratigraphic units, but may well be part of a structurally repeated sequence. Rock units exposed in the section are described below, from north to south.

Quartz-feldspar-biotite gneiss is light grey and fine grained with well developed centimetre-scale layering. Massive quartz lenses with order of magnitude variations in thickness and length are scattered across this unit.

Large lenses or sweats of quartz-feldspar pegmatite are common throughout the section. They are usually subparallel to layering, massive to coarse grained and often contorted. Staurolite, muscovite and garnet are often concentrated at their edges and form masses of very coarse crystals, especially muscovite.

Crenulated feldspar-quartz-biotite-garnet gneiss bounds the alumina-rich zone. It is medium grey in colour and well layered with massive quartz lenses and layers scattered through it. It is strongly crenulated in parts, but not across the whole unit. Disseminated garnet occurs as small grains (<1 mm) comprising about 1% of the rock; disseminated staurolite forms up to 5% of the rock, especially on the south side of the subunit.

Staurolite-garnet-muscovite gneiss, the first unit in the alumina-rich zone, is mottled brown on weathered surfaces and is strongly crenulated. In places, staurolite makes up to 70% of the rock. Small disseminated garnets are fairly uniformly distributed across the unit. Large lenses and sweats of quartz-feldspar pegmatite are subparallel to layering. Staurolite forms dense masses along pegmatite contacts and large muscovite books form prominent pockets in the pegmatites.

Kyanite±staurolite gneiss layers vary from 0.1 to 7 metres wide. Kyanite content is variable, reaching 60%, with crystals from 0.2 to 4 centimetres long. The crystals contain inclusions of quartz and are almost free of iron oxides. Layers with high kyanite concentrations (>10%) have a distinctive grey-blue colour. In the wider layers, kyanite-rich rock is interlayered with discontinuous quartz-feldspar-muscovite lenses, about 5 centimetres thick and a few metres long. Staurolite is commonly disseminated in concentrations of up to 5%, but up to 40% in some layers. Up to 5% garnet, several millimetres in diameter, is disseminated throughout these layers. In a few places garnet forms small, massive lenses. The gneiss is also muscovite rich and biotite content is only a few percent, with quartz and feldspar making up the balance of the rock.

Staurolite-kyanite-muscovite gneiss contains up to 65% staurolite and kyanite but averages about 7% overall. Staurolite and kyanite crystals are coarse, from 2 to 10 millimetres in diameter and 5 to 20 millimetres long. Garnet grains are up to 1 centimetre in diameter but comprise less than 5% of the rock. Muscovite books are scattered and are less than 5 millimetres across. The groundmass is feldspar and quartz.

Staurolite-garnet gneiss is about 5% staurolite, 3% garnet and less than 10% biotite with the balance feldspar and quartz. Feldspar-quartz pegmatite layers are common. Staurolite and garnet grains are typically less than 3 millimetres in diameter. Garnets are partly retrograded to chlorite.

Fine-grained staurolite-garnet-kyanite gneiss is shot through with feldspar-quartz pegmatite layers. It contains 10% staurolite, 5% garnet and 5% kyanite with the remainder feldspar and quartz.

Coarse-grained staurolite-garnet-kyanite gneiss is distinct from the previous unit in that the high-grade metamorphic minerals are much coarser and more abundant. Staurolite forms about 40% of the rock with crystals 4 to 20 millimetres in diameter. There is about 10% garnet, from 5 to 30 millimetres in diameter and less than 10% kyanite. Quartz-rich layers, 5 to 50 millimetres wide, make up about 30% of this unit.

Kyanite-muscovite gneiss is distinctive because of the 15% muscovite content. Coarse kyanite crystals

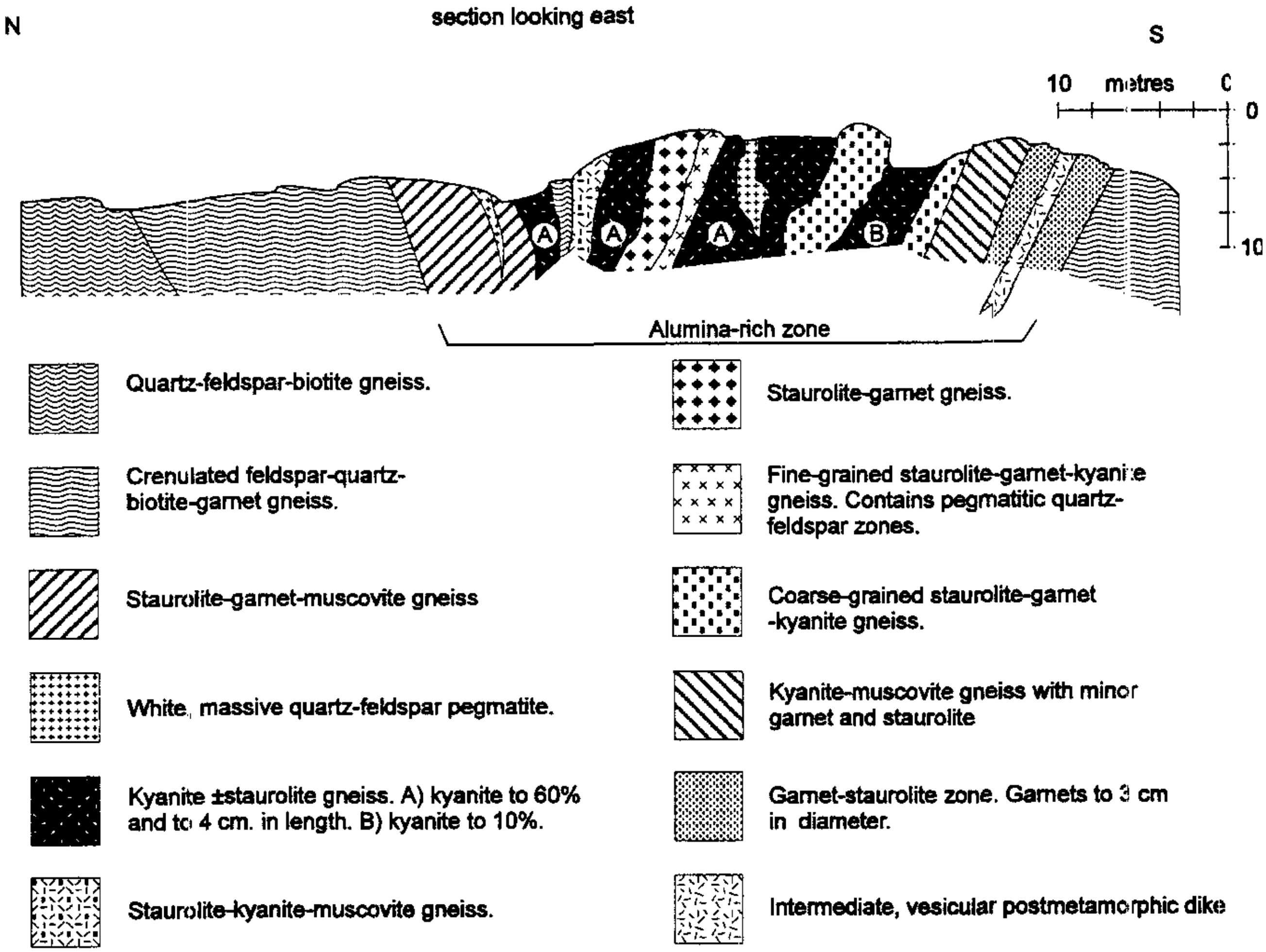

Figure 7: Section across the zone 1 kyanite showing on Hawkesbury Island (see Figure 6 for location).

comprise 20% of the rock with garnet at 1 to 5% and staurolite scattered and variable from 0 to 20%.

The garnet-staurolite gneiss is spectacular as the garnets are large, up to 3 centimetres in diameter, and form about 30% of the rock. Staurolite is present as an accessory mineral.

A slightly altered, postmetamorphic intermediate dike crosscuts the section. It is fine grained and vesicular with about 30% amphibole, more than 60% feldspar and 10% quartz, in the vesicles.

ZONE 2

The second zone, located 450 metres south of zone 1, at the crest of a ridge, was traced for 225 metres along strike and is about 10 metres wide (Figure 6). It is similar in character to the first zone. It too is complexly folded on outcrop scale and along strike. Individual concentrations of kyanite, garnet, staurolite and muscovite vary greatly from one layer to the next. Typically kyanite occurs in concentrations of 10% in layers less than 25 centimetres thick with grains 1 to 2 centimetres long. Staurolite averages less than 5%; grains are up to 2 centimetres long, nearly black and often forms dense masses adjacent to coarse-grained quartz-feldspar lenses. Garnets are almost ubiquitous as disseminated grains 0.5 to 2 centimetres in diameter with concentrations in the 1 to 10% range. In or immediately adjacent to quartz-feldspar lenses, garnets form masses about a metre long, with euhedral crystals up to 7 centimetres in diameter. Garnets in pegmatites and felsic layers are much less resorbed than those in the surrounding schist or gneiss. Layers rich in kyanite, garnet or staurolite tend to have a few percent muscovite and low concentrations of biotite. Magnetite crystals, less than 10 millimetres in diameter, are scattered through some of the pegmatites.

ECONOMIC CONSIDERATIONS

TSIMPSEAN PENINSULA

At Dudevoir Passage and Trail Bay, the kyanite occurrences are probably part of the same alumina-rich zone. It is possible that kyanite reported on the shore 13 and 29 kilometres southeast of Trail Bay (Hutchison, *ibid.*) may be part of this same zone. Where measured, the zone is about 3 metres wide but may be thicker in fold hinges. The kyanite crystals are coarse, up to 2 centimetres long, with relatively few, coarse inclusions of quartz. Graphitic material present in the kyanite layers could probably be removed by calcination.

HAWKESBURY ISLAND

There are at least seven major kyanite zones on Hawkesbury Island. They vary in size from a few metres to several tens of metres wide and some have been traced for up to 5 kilometres. Individual zones contain 10 to 70% kyanite, 0.2 to 4 centimetres long. It is unlikely that kyanite alone could be economically recovered, but mining for kyanite, garnet, staurolite and possibly muscovite may be feasible.

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