# MINERALOGY AND CHEMISTRY OF THE RUGGED MOUNTAIN PLUTON: A MELANITE-BEARING ALKALINE INTRUSION (104G/13)

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*KEYWORDS:* Petrology, mineral chemistry, Rugged Mountain, syenite, pyroxenite, silica undersaturated, melanite.

## INTRODUCTION

The Rugged Mountain intrusion is a small (14 km$^2$), zoned alkaline pluton located in northwestern British Columbia, 25 kilometres southwest of Telegraph Creek (Brown *et al.*, 1992a, b). The pluton is exposed on the north side of Shakes Creek, a southeasterly flowing tributary of the Stikine River and on the south flank of Rugged Mountain from which it takes its name.

The Rugged Mountain pluton was first mapped by F.A. Kerr (1948). In his exploration of the Stikine River, Kerr mapped a series of seven alkaline bodies stretching down river from Telegraph Creek to the Iskut River. The northernmost of these bodies, referred to in his paper as the Shakes Creek mass, is known as the Rugged Mountain pluton. Souther (1972) also studied the Rugged Mountain intrusion while mapping the Telegraph Creek map sheet at 1:250 000 scale. Porphyry copper-gold exploration of the intrusion was undertaken during the 1988 and 1989 field seasons by Homestake Mineral Development Company as a joint owner with Equity Silver Mines Limited. Several samples of magnetite-rich pyroxenite with malachite staining returned copper values as high as 2.32 per cent with 1.58 grams per tonne gold.

Subsequent 1:50 000-scale mapping of the Chutine and Tahltan map sheets by the British Columbia Geological Survey Branch (Brown *et al.*, 1992b) provided an opportunity for detailed mapping of the intrusion by the senior author (Figures 1-10-1 and 1-10-2). Rocks of the Rugged Mountain pluton have similar mineralogy throughout and, in particular, have igneous melanite garnet in all phases of the intrusion. Other common minerals include aegirine-augite, potassium feldspar, magnetite, apatite and titanite. The field petrographic and chemical observations described in this paper suggest that the suite is cogenetic. Furthermore, these same field, mineralogical and chemical characteristics are found in other alkaline intrusions within the Cordillera of British Columbia, suggesting a common mechanism is dominant in the genesis of this type of alkaline pluton.

## REGIONAL GEOLOGICAL SETTING

The Rugged Mountain intrusion is one of a chain of alkaline plutons located within the western margins of the Intermontane Belt, just east of the Coast Plutonic Complex (Kerr, 1948; Woodsworth *et al.* 1991; Brown *et al.*, 1992a). It lies within Stikinia and is hosted by Upper Triassic volcanic and sedimentary rocks of the Stuhini Group. The major tectonic structures of the region include the Stikine arch, the Skeena arch, the Bowser Basin (which separates these two features) and the Atlin horst (Souther and Armstrong, 1966). The Rugged Mountain intrusion is part of the Stikine arch. The arch forms a northeasterly trending structural high of crystalline and metamorphic rocks between the Coast and the Cassiar crystalline belts and is a source of sediments for basins to the north and south.

The basal sections of the Stikine arch comprise upper Paleozoic rocks of the Stikine assemblage (Monger, 1977). This assemblage is characterized by Middle Devonian to Permian flows and pyroclastics, interbedded with thick carbonate sections, argillite and minor chert. The thick limestone sequences in the western part of the arch locally reach thicknesses of over 2800 metres (Brown *et al.*, 1992a), suggesting stable shelf conditions during the Permian (Souther, 1971). The rocks of the Stikine assemblage suffered uplift, metamorphism, intrusion and deformation during the Middle to Late Triassic Tahltanian orogeny, leaving a marked unconformity between Stikine assemblage and younger strata.

The Upper Triassic marked the end of the Tahltan orogeny and the onset of arc magmatism, leading to the formation of sequences of subaerial volcanic rocks interfingering with clastics and limestone. These rocks comprise the Stuhini Group and are the host of the Rugged Mountain intrusion. The Stuhini Group is thought to have formed from the buildup of volcanic islands, with predominantly subaerial deposition in active periods. Fringing carbonate reefs with sediment reworking mark periods of quiescence (Souther, 1971).

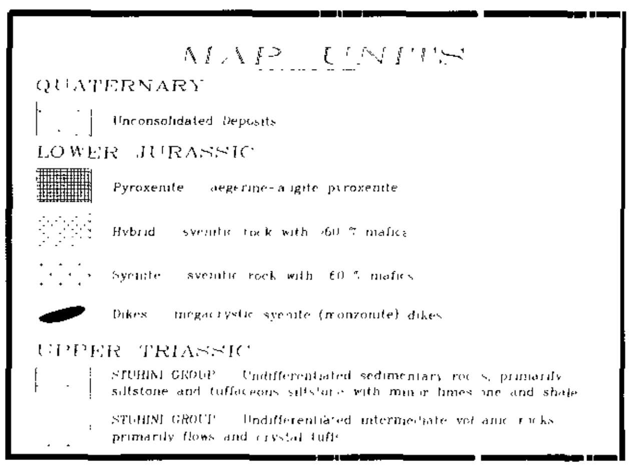


Figure 1-10-1. Map units for geological map of Rugged Mountain pluton presented as Figure 1-10-2.

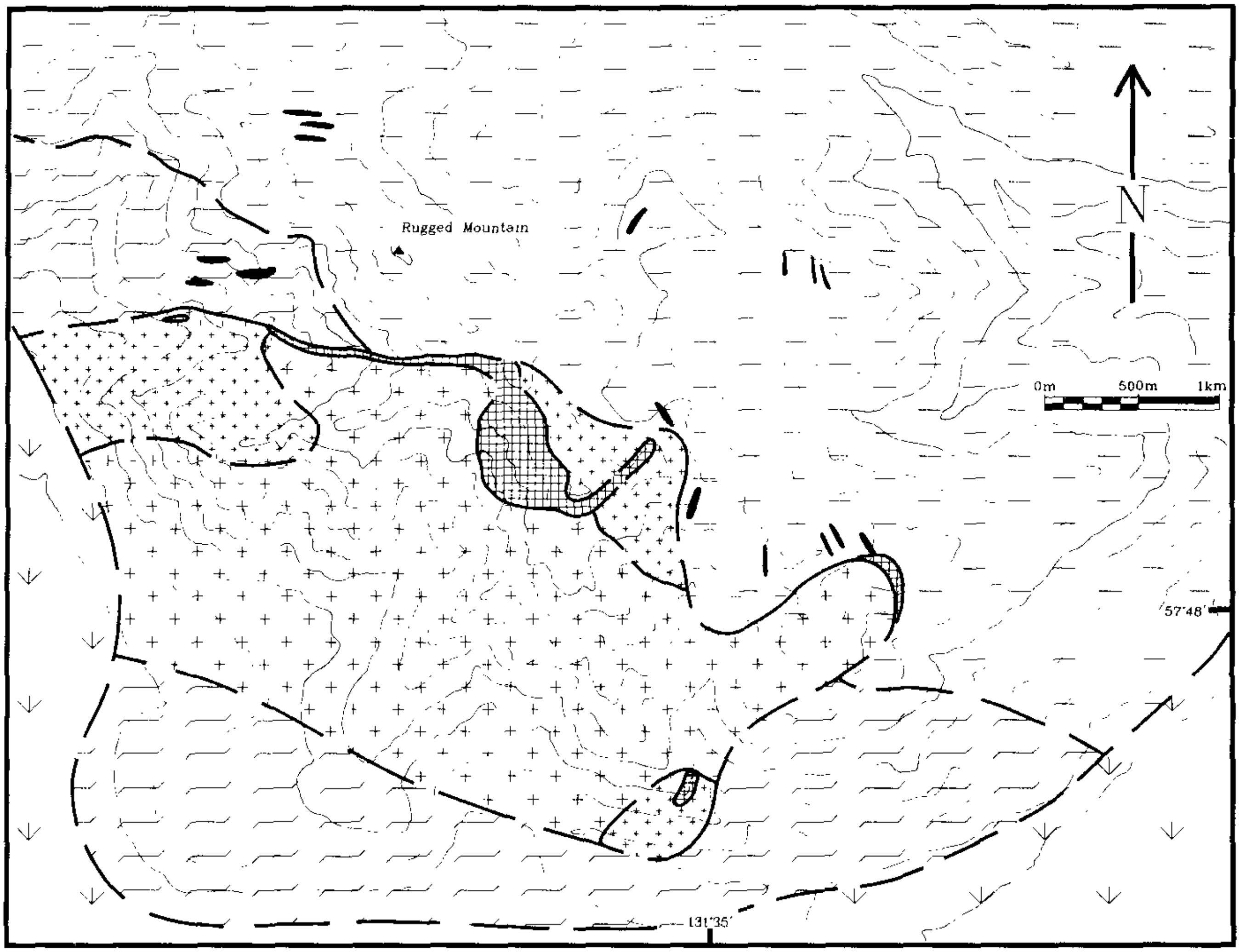


Figure 1-10-2. Geological map of Rugged Mountain intrusion.

The maximum age of the Rugged Mountain intrusion is constrained by the Upper Triassic Stuhini Group that it intrudes. Potassium-argon dating of the Ten Mile Creek syenite (Morgan, 1976), 40 kilometres to the northeast, yields an age of 209±7 Ma. Mineralogical and petrological similarities between these two plutons suggest that Rugged Mountain is coeval, implying Early Jurassic emplacement.

## THE RUGGED MOUNTAIN INTRUSION

The Rugged Mountain pluton is emplaced into Upper Triassic Stuhini Group rocks. Close to the pluton, Stuhini rocks comprise four distinct rock types, including: eastward dipping, unmetamorphosed, green and white banded crystal-ash tuff to the north of the intrusion; deformed and hornfelsed, blue-grey tuffaceous, pyritic siltstone interlayered with shale and limestone; crystal-lapilli tuff; and intermediate volcanic flows.

The pluton itself contains four main rock types with variable contact relationships including: pyroxenite, syenite, "hybrid" and a later set of dikes (Figure 1-10-1). The intrusion is concentrically zoned, with a syenite core and pyroxenite forming an incomplete border between the remainder of the intrusion and the country rocks (Figure 1-10-2). The hybrid phase is characteristically in contact with the pyroxenite and has gradational contacts with the less mafic syenitic rocks. Contacts between either syenite or hybrid and the pyroxenite are commonly sharp, such as along the thin strip of pyroxenite in the northwest part of the pluton. In other areas the syenite and hybrid clearly disrupt and brecciate the pyroxenite. Late potassium feldspar megacrystic syenite to monzonite dikes cut the intrusion as well as the country rocks.

Samples were collected from all rock types of the Rugged Mountain intrusion. Each sample was cut and stained for potassium feldspar content. Feldspathoid staining on a subset of samples using the method of Shand (1939) proved inconclusive, as the only stain which adhered to the samples appeared to be bonded to alteration assemblages. Further study of stained thin sections provided no evidence of primary feldspathoid minerals. A summary of mineral occurrence in thin section is presented in Table 1-10-1.

## Pyroxenite Phase

The pyroxenite generally occurs at the margins of the pluton, but also outcrops in a single large mass in the northern part of the intrusion (Figure 1-10-2). At the northwest limit of the pluton a continuous strip of pyroxenite, 5 to 10 metres wide, separates country rock to the north from the syenitic rocks to the south. In this locality, contact relationships between syenite and pyroxenite are sharp, unfaulted and steeply dipping to the north. Near the eastern and southeastern contacts of the intrusion, the pyroxenite also occurs as a border phase, with the mafic content of the syenitic rocks increasing with increasing proximity to the pyroxenite. The pyroxenite is brecciated by both syenite and hybrid and locally is cut by pink-weathering potassium feldspar veins.

The unit is dark green to black in colour, medium grained and weathers recessively. Pyroxene and biotite are identifiable in hand sample and the unit varies from strong to weakly magnetic. In places (*e.g.,* the northern contact) the pyroxenite has malachite staining and pyrite which correlate to the copper and gold anomalies reported by Homestake (Marud, 1990).

In thin section the primary mineralogy of the pyroxenite includes aegirine-augite, magnetite, apatite, titanite and biotite. Garnet also occurs as small anhedral crystals and in fractures. Aegirine-augite is the most common mineral and occurs as aligned, elongate euhedral crystals forming a cumulate texture. Optically the grains are strongly pleochroic and have discernible chemical zoning. Magnetite and apatite are the next most common phases: the former occurs as interstitial subhedral crystals or as irregularly shaped infillings between aegirine-augite and the latter forms small elongate prisms and stubby euhedral crystals. Biotite and titanite are less common euhedral grains. Red-brown melanite garnet occurs as small euhedral grains inferred to represent primary magmatic crystallization.

Secondary and alteration minerals include chlorite after aegirine-augite (Sample INE 91-80-2), calcite fracture fillings and space-filling brown-coloured andradite. The habit and composition of this garnet indicates that it is a secondary mineral.

## Syenite Phase

Syenite forms the core of the complex and generally lies in contact with the hybrid phase. The syenitic rocks placed within this map unit are felsic to intermediate, varying in colour index from 10 to 60. They weather light grey to pink, are medium grained and porphyritic with potassium feldspar crystals up to 2 centimetres in length.

Primary mineralogy of the syenitic rocks includes potassium feldspar, aegirine-augite, garnet, apatite, titanite, magnetite, biotite and hornblende. Plagioclase was not observed, which may be due to sericitization. Alkali feldspar occurs as phenocrysts and as large interstitial grains. Hornblende occurs both as a primary phase and as a partial replacement product of aegirine-augite. Melanite garnet has two habits; euhedral, dark red crystals suggesting a primary occurrence and light-brown space fillings commonly including feldspar, apatite and pyroxene. The latter habit is also primary. Titanite occurs as diamond-shaped, high-relief phenocrysts, identical to those seen in the pyroxenite phase. Biotite forms green and brown pleochroic subhedral to euhedral crystals and is commonly spatially associated with apatite and/or magnetite. Secondary minerals include sericite after feldspar, chlorite and hornblende after pyroxene and calcite infilling fractures.

## Hybrid Phase

The hybrid phase generally occurs between the pyroxenite and the syenite core. It is gradational in composition to the syenite and is arbitrarily separated from the syenitic

**TABLE 1-10-1**
**MINERAL ASSEMBLAGES OBSERVED IN THIN SECTION FOR RUGGED MOUNTAIN INTRUSIVE ROCKS.**

| | | Primary Phases | | | | | | | | | Secondary/Replacement Phases | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | Rock Type | Px | Hbl | Bi | Ksp | Pl | Gt | Ttn | Ap | Opq | Hbl | Gt | Chl | Cc | Q | Ser |
| INE 78-2 | Pyroxenite | X | | X | | | | X | X | X | | | | X | | |
| INE 80-2 | Pyroxenite | X | | | | | X | X | X | X | | X | X | X | | |
| INE 76-2 | Hybrid | X | X | X | X | X | X | X | X | X | X | | X | X | | |
| INE 115 | Hybrid | X | | | X | | X | X | X | X | | | | | | X |
| INE 119 | Hybrid | X | | X | X | X | X | X | X | X | | | | | | X |
| INE 336 | Hybrid | X | | X | X | X | | | X | X | X | | | | | X |
| INE 121 | Syenite | X | X | X | X | | X | X | X | X | X | | | | | X |
| INE 122 | Syenite | X | | | X | | | X | X | X | | | X | X | | X |
| INE 316 | Syenite | X | X | X | X | | X | | X | X | X | | | | | X |
| INE 317 | Syenite | X | | X | X | | X | X | X | | X | | X | | | X |
| INE 320 | Syenite | X | X | X | X | | X | | X | X | X | | | X | | X |
| INE 322 | Syenite | | | X | X | | X | X | X | X | | | | | | X |
| INE 324 | Syenite | X | | X | X | | X | | X | | | | | | | X |
| INE 64 | Dike | X | | | X | X | X | X | | X | | | | | | X |
| INE 73-2 | Dike | X | | | X | | | | X | X | | | X | | | X |
| INE 82 | Dike | X | X | | X | X | | X | X | X | X | | | | X | X |

Px - pyroxene, Hbl - hornblende, Bi - biotite, Ksp - potassium feldspar, Pl - plagioclase, Gt - garnet, Ttn - titanite, Ap - apatite, Opq - opaques, Chl - chlorite, Cc - calcite, Q - quartz, Ser - sericite.

rocks on the basis of percentage of mafic minerals. The hybrid phase contains greater than 60 per cent dark-coloured minerals making it mafic in composition. The geological map for the Rugged Mountain intrusion (Figure 1-10-2) marks regions where either the syenite or hybrid phase dominates. Much of the actual contact between the two phases could not be mapped because parts of the intrusion are inaccessible.

The hybid phase of the intrusion is fine grained, equigranular and weathers a dull pinkish grey. Primary mineralogy of the hybrid includes feldspar, aegirine-augite, garnet, biotite, apatite, titanite, magnetite and hornblende. The most abundant mineral in this rock type is potassium feldspar, which occurs as phenocrysts and as interstitial grains. One sample contains myrmekitic intergrowths in the groundmass. The intergrowth may be between potassium feldspar and a feldspathoid (*e.g.*, Kwak, 1964), although this has not yet been confirmed by x-ray diffraction. Aegirine-augite phenocrysts are less elongate than in the pyroxenite and occur in clusters with biotite and subordinate apatite and magnetite. Garnet varies from deep red to light brown in colour and is commonly euhedral. Apatite is a late-stage crystallization product with euhedral titanite and commonly occurs as inclusions in garnet, pyroxene or biotite. Secondary and replacement minerals in the hybrid are identical to those in the pyroxenite and syenite.

### Dike Phase

The dikes of the Rugged Mountain intrusion represent the last intrusive event. They intrude the sedimentary rocks that surround the pluton and in places cut the intrusion itself (Figure 1-10-2). The dikes are diverse in texture and in phenocryst mineralogy and probably represent a series of injections, although for this study they are grouped together. Included within this unit are trachytic to non-trachytic dikes, megacrystic to non-megacrystic dikes and dikes that are dominated by potassium feldspar or sodium feldspar phenocrysts. Also included in this group are a series of syenite pegmatites which outcrop at the margins of the pluton. Feldspar megacrysts in the dikes and pegmatitic syenite reach 7 centimetres in length.

In thin section the rocks are seen to contain feldspar, plagioclase, garnet, hornblende, apatite, titanite, magnetite and augite. Biotite was observed in several hand specimens of the dike phase but was absent in the samples for which thin sections were prepared. Pyroxene occurs infrequently in this unit as small fractured phenocrysts. Titanite is common in the dike rocks, but has a different habit than seen in the other intrusive phases. It occurs as elongate prisms with simple twinning along {100}. Garnet is present as large euhedral poikilitic grains. The garnet phenocrysts show euhedral growth banding and reach 1 centimetre in diameter. Titanite occurs as inclusions in the garnet and is aligned parallel to the crystal edges of the garnet.

Secondary and alteration mineralogy seen in the dikes consists of sericite after feldspar and chlorite, and hornblende after pyroxene. Secondary quartz was seen in one section.

## GEOCHEMISTRY

Chemical compositions, including major, minor and trace element concentrations of each phase of the Rugged Mountain intrusion were measured by inductively coupled plasma analysis with reported detection limits of 0.01 per cent. Ferrous iron was measured volumetrically for each sample and ferric iron calculated from the total iron oxide. Chemical compositions are reported with the computed normative characteristics in Table 1-10-2.

### Chemical Character of the Rugged Mountain Suite

Figure 1-10-3 is a chemical plot of alkalis against silica and indicates the definite alkaline nature of the Rugged Mountain rock suite. Silica content in the rocks ranges from 35 to 60 per cent and spans the compositional range of ultramafic to intermediate rocks (*e.g.*, Philpotts, 1990). Within the intrusion, the syenitic rocks are the most alkaline and the pyroxenites plot as mildly alkaline. The dike rocks are similar in alkali content to the syentites.

Chemically, the rock suite is strongly undersaturated with respect to silica. The calculated normative mineralogy (Table 1-10-2) shows all intrusive rocks to be nepheline to nepheline-leucite normative. Calculations in Table 1-10-2 reflect the measured ferrous and ferric iron contents of the rocks, however, the undersaturated character of the normative mineralogy is maintained regardless of the treatment of iron. These normative characteristics are somewhat at odds with the fact that neither nepheline nor leucite were observed in thin section. This may be due to alteration of intergranular feldspathoids in the original rock.

There are several notable chemical trends within this suite of igneous rock compositions. Firstly, the pyroxenites have high concentrations of $Fe_2O_3$(T), CaO and $P_2O_5$ relative to other phases of the Rugged Mountain intrusion. Within the rock suite, the concentrations of these oxides strongly decrease with increasing $SiO_2$ content. Both $TiO_2$ and MgO, although less strikingly enriched in the pyroxenite, exhibit similar patterns when examined against $SiO_2$. Constituents characteristic of alkali feldspar, $Al_2O_3$, $Na_2O$ and $K_20$, all increase in concentration with increasing $SiO_2$ (*e.g.*, from pyroxenite to dike rocks).

Trace element data are plotted on a trace element discrimination diagram to differentiate between volcanic-arc granites, syncollisional granites, within-plate granites and orogenic granites (Figure 1-10-4). All Rugged Mountain rocks, save one of the hybrids, fall within the field of volcanic-arc granites. This correlates well with the tectonic setting proposed for the area (*e.g.*, Souther, 1971; Monger, 1977).

The same chemical data are plotted on an AFM diagram, which is generally used to differentiate between calcalkaline and tholeiitic rock series. Figure 1-10-5 is used here to illustrate one of the remarkable chemical characteristics of the Rugged Mountain suite: as a whole the series is extremely iron enriched. The dike rocks and syenites plot

**TABLE 1-10-2**
**MAJOR ELEMENT OXIDES, TRACE ELEMENT COMPOSITIONS AND CALCULATED NORMATIVE MINERALOGY OF RUGGED MOUNTAIN INTRUSIVE ROCKS.**

| Sample No. | 78-2 | 80-2 | 76 | 115 | 336 | 121 | 122 | 316 | 317 | 320 | 322 | 324 | 64 | 73-2 | 82 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 38.90 | 37.59 | 46.43 | 47.73 | 48.56 | 51.86 | 52.51 | 53.72 | 50.42 | 51.17 | 54.12 | 51.52 | 60.28 | 57.09 | 58.74 |
| $TiO_2$ | 1.54 | 1.47 | 0.97 | 0.99 | 0.92 | 0.64 | 0.76 | 0.52 | 0.63 | 0.85 | 0.68 | 0.99 | 0.14 | 0.54 | 0.28 |
| $Al_2O_3$ | 3.20 | 4.47 | 15.24 | 15.23 | 15.52 | 19.29 | 19.26 | 20.78 | 18.93 | 18.71 | 20.35 | 20.09 | 21.06 | 19.21 | 19.88 |
| $Fe_2O_3$ | 9.80 | 8.05 | 4.23 | 4.10 | 3.66 | 2.53 | 3.12 | 2.25 | 2.67 | 3.30 | 1.18 | 2.43 | 0.80 | 2.03 | 1.04 |
| FeO | 10.10 | 9.45 | 4.93 | 5.21 | 5.09 | 2.81 | 2.19 | 2.03 | 2.77 | 3.6 | 3.25 | 3.21 | 0.85 | 2.33 | 1.07 |
| MnO | 0.34 | 0.32 | 0.20 | 0.17 | 0.18 | 0.15 | 0.17 | 0.13 | 0.15 | 0.18 | 0.13 | 0.12 | 0.03 | 0.10 | 0.08 |
| MgO | 9.96 | 7.91 | 3.43 | 3.33 | 3.88 | 1.41 | 1.51 | 0.99 | 1.41 | 1.78 | 0.70 | 1.32 | 0.14 | 1.06 | 0.40 |
| CaO | 21.33 | 20.24 | 10.79 | 10.33 | 9.91 | 6.33 | 5.51 | 4.91 | 6.71 | 7.74 | 4.59 | 4.98 | 2.88 | 4.86 | 2.62 |
| $Na_2O$ | 0.81 | 0.87 | 1.16 | 0.79 | 1.38 | 2.45 | 3.24 | 2.96 | 2.23 | 1.75 | 2.25 | 2.34 | 5.29 | 3.79 | 1.87 |
| $K_2O$ | 0.06 | 1.23 | 7.73 | 7.03 | 7.54 | 8.68 | 8.27 | 9.03 | 8.49 | 8.51 | 10.70 | 10.24 | 7.49 | 8.00 | 11.78 |
| $P_2O_5$ | 2.58 | 2.31 | 0.83 | 0.82 | 0.91 | 0.29 | 0.28 | 0.24 | 0.34 | 0.46 | 0.16 | 0.32 | 0.01 | 0.22 | 0.01 |
| LOI | 0.18 | 4.83 | 3.71 | 2.61 | 1.73 | 2.32 | 3.67 | 2.58 | 4.06 | 2.01 | 2.39 | 2.93 | 1.44 | 1.39 | 1.76 |
| Total | 98.80 | 98.74 | 99.65 | 98.34 | 99.28 | 98.76 | 100.49 | 100.14 | 98.81 | 100.06 | 100.50 | 100.49 | 100.41 | 100.62 | 99.53 |
| $Fe_2O_3(T)$ | 21.02 | 18.55 | 9.71 | 9.89 | 9.32 | 5.65 | 5.56 | 4.51 | 5.75 | 7.30 | 4.79 | 6.00 | 1.74 | 4.62 | 2.23 |
| **Trace Element Concentrations (ppm)** | | | | | | | | | | | | | | | |
| Sr | 1038 | 1247 | 1909 | 2932 | 2554 | 1603 | 1762 | 1505 | 2095 | 2157 | 1105 | 1498 | 1624 | 2377 | 2155 |
| Rb | <10 | 24 | 152 | 150 | 179 | 175 | 135 | 145 | 169 | 200 | 204 | 274 | 132 | 134 | 210 |
| Zr | 52 | 68 | 81 | 61 | 58 | 85 | 93 | 77 | 80 | 80 | 67 | 48 | 105 | 134 | 76 |
| Y | 26 | 23 | 22 | 21 | 19 | 20 | 22 | 26 | 20 | 22 | 17 | 18 | <10 | 18 | 11 |
| Nb | 7 | 10 | <5 | <5 | <5 | 10 | 8 | 6 | <5 | <5 | <5 | 6 | 5 | 13 | 7 |
| Sn | 29 | 23 | 19 | 28 | 15 | <15 | <15 | <15 | <15 | 18 | 16 | <15 | <15 | 15 | <15 |
| **Calculated Normative Mineralogy** | | | | | | | | | | | | | | | |
| Or | - | - | 20.09 | 37.53 | 32.67 | 53.26 | 50.59 | 54.78 | 53.03 | 49.58 | 58.60 | 48.67 | 44.78 | 47.69 | 71.30 |
| Ab | - | - | - | - | - | 2.00 | 7.99 | 6.79 | 0.55 | - | - | - | 33.30 | 19.94 | 8.71 |
| An | 4.99 | 4.96 | 14.11 | 18.03 | 14.22 | 16.61 | 14.07 | 17.20 | 17.52 | 18.44 | 13.91 | 14.58 | 11.77 | 11.91 | 11.37 |
| Lc | 0.28 | 6.07 | 21.62 | 4.62 | 10.21 | - | - | - | - | 1.40 | 4.00 | 11.08 | - | - | - |
| Ne | 3.76 | 4.24 | 5.54 | 3.78 | 6.48 | 10.56 | 11.02 | 10.23 | 10.49 | 8.18 | 10.37 | 11.11 | 6.46 | 6.70 | 4.05 |
| Dp | 62.67 | 57.17 | 26.61 | 25.12 | 25.08 | 11.83 | 9.21 | 5.45 | 11.47 | 14.81 | 7.04 | 7.78 | 2.10 | 9.24 | 2.19 |
| Wo | - | - | 1.58 | - | - | 0.03 | 0.54 | - | 0.81 | 0.11 | - | - | 0.31 | 0.22 | - |
| Ol | 2.47 | 0.93 | - | 0.67 | 1.89 | - | - | 0.78 | - | - | 0.91 | 1.99 | - | - | 0.52 |
| Cs | 2.29 | 4.70 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Mt | 14.61 | 13.40 | 6.77 | 6.66 | 5.80 | 3.97 | 4.63 | 3.37 | 4.30 | 5.01 | 3.63 | 2.28 | 1.19 | 3.04 | 1.57 |
| Il | 2.97 | 2.97 | 1.92 | 1.96 | 1.79 | 1.26 | 1.49 | 1.01 | 1.26 | 1.65 | 1.30 | 1.95 | 0.27 | 1.03 | 0.54 |
| Ap | 6.21 | 5.83 | 2.06 | 2.04 | 2.22 | 0.72 | 0.69 | 0.59 | 0.86 | 1.12 | 0.38 | 0.79 | 0.02 | 0.53 | 0.02 |

Sample numbers are without INE- prefix. Major and trace elements determined by ICP. FeO was measured by volumetric analysis.

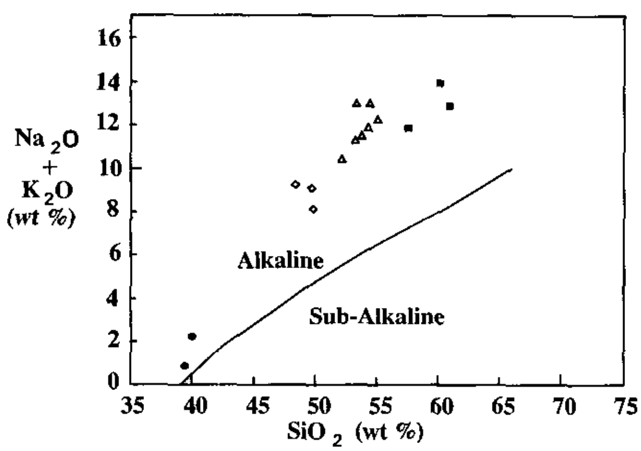


Figure 1-10-3. Compositions of Rugged Mountain intrusive rocks are plotted as per cent $Na_2O+K_2O$ *versus* $SiO_2$. Symbols correspond to pyroxenite (filled circles), hybrid rocks (diamonds), syenitic rocks (triangles) and dikes (solid squares).

toward the alkali apex but the hybrid rocks and pyroxenites define a strong iron-enrichment trend that is chemically distinct from most other rock series.

## Comparison to Other Similar Intrusions

Chemically the Rugged Mountain intrusive rocks are very similar to rocks from the Averill intrusion, a small zoned, alkaline intrusion in the Franklin mining camp comprising pyroxenite, monzogabbro, monzodiorite, monzonite and syenite (Keep, 1989, Keep and Russell, 1989; in press). Compositions of rocks from the Averill intrusion are plotted on an AFM diagram for comparison against the Rugged Mountain chemical compositions (Figure 1-10-6). The chemical patterns are very similar and share the prominent iron-enrichment trend established by the pyroxenites. This same chemical pattern is seen in the Kruger Complex (Currie, 1976) and the Duckling Creek body (Garnett, 1978; Woodsworth *et al.*, 1991), both of which have mafic to ultramafic, silica-undersaturated rock types.

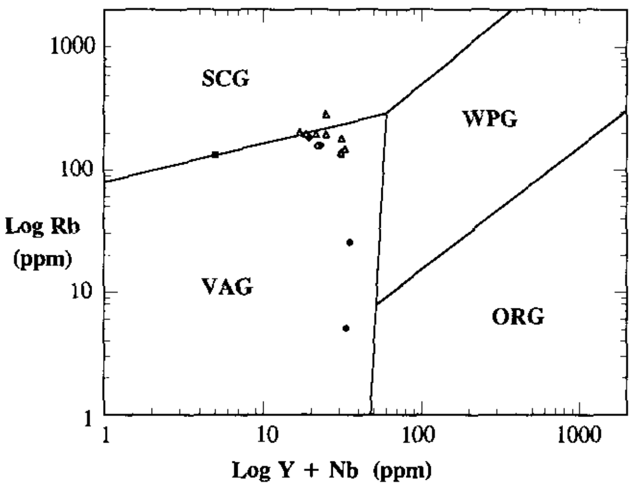


Figure 1-10-4. Trace element chemical compositions of Rugged Mountain intrusive rocks using symbols as in Figures 1-10-3.

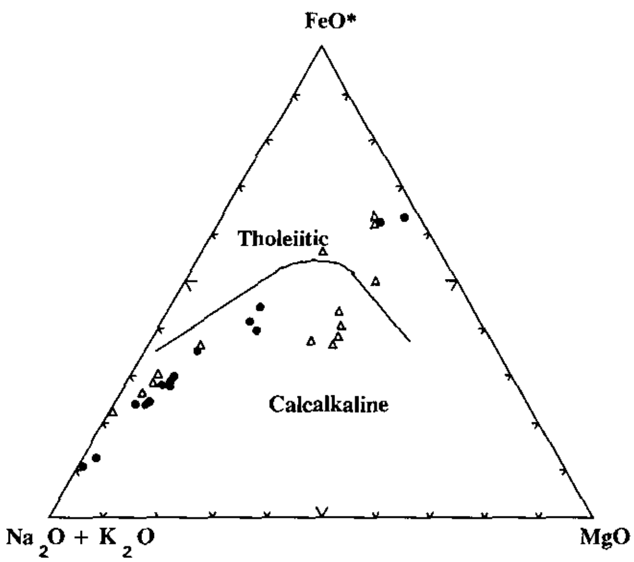


Figure 1-10-5. AFM diagram with chemical compositions of Rugged Mountain rocks plotted with same symbols as used in Figure 1-10-3.

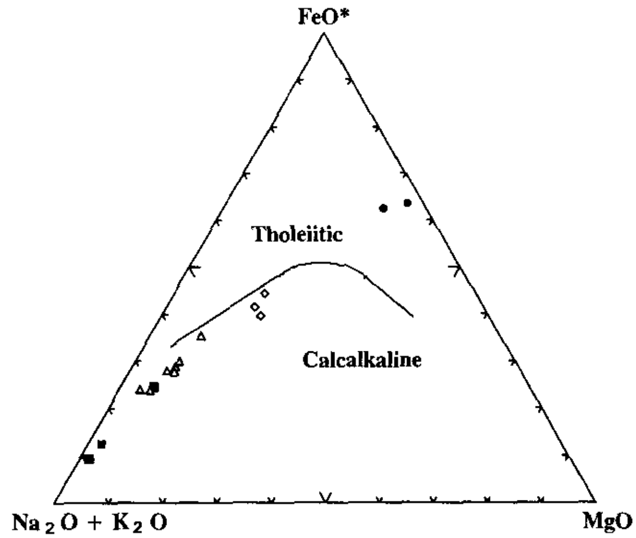


Figure 1-10-6. AFM diagram of Rugged Mountain igneous rock compositions (filled circles) and chemical compositions of Averill plutonic rocks (Keep, 1989; Keep and Russell, in press; Neill, 1991).

## MINERAL CHEMISTRY

Pyroxenes and garnets from each of the four different intrusive rock types were chemically analyzed with the Cameca SX-50 electron microprobe at the The University of British Columbia. Standard operating conditions (Keep, 1989) were used including a 15 kilovolt acceleration voltage and a 20 nanoampere beam current. Count time on standards and unknowns was 20 seconds and K-alpha peaks were used for analysis. Identical standards were used for analysis of the garnet and pyroxene unknowns. Where possible, grain cores and rims were analysed.

The K-beta peak of titanium overlaps the K-alpha peak of vanadium, thus an empirical correction factor is commonly required to eliminate the "apparent vanadium" counts induced by the presence of titanium. This factor was measured by analyzing a titanite standard containing no vanadium and calculating the correction factor from the ratio of "apparent measured vanadium" to "known titanium". This value was used to correct the vanadium measured in unknown phases containing titanium (*e.g.*, melanite garnet). The magnitude of corrections required was insignificant suggesting that, unlike many other instruments, the analysing crystals of the Cameca SX-50 are capable of discriminating between the two overlapping peaks.

### PYROXENE ANALYSES

Pyroxenes were analyzed for the elements Si, Al, Ca, Na, Fe, Mg, Ti, Mn and Cr. Representative chemical analyses are listed in Table 1-10-3 with the calculated structural formulas: chromium was below detection limits in all samples. Structural formulas were computed on the basis of four cations with adjustment of ferric-ferrous iron to obtain a best fit.

Pyroxene compositions from the pyroxenite, the syenite and the hybrid are plotted in Figure 1-10-7, which represents the ideal solid solution series augite to aegirine (solid line). The $Fe^{+2}$ - $Fe^{+3}$ distinction derives strictly from the structural formulas calculation. Most pyroxenes are augitic in composition although in some pyroxenes there is up to 20 mole per cent substitution of the aegirine molecule $NaFe^{+3}Si_2O_6$. Deviations below the ideal solid solution line represent the presence of other substitutions such as Ca-tschermaks pyroxene [$CaAl(SiAl)O_6$]. There is little chemical variation between cores and rims of analysed pyroxene grains; where chemical zoning is present, mineral grains have rims with higher sodium and lower calcium contents.

## GARNET ANALYSES

Garnets from each rock type were analyzed for the elements Si, Al, Ca, Fe, Mn, Mg, Ti, Na, Cr and V. Sodium and chromium were below detection limits in all samples. Representative chemical analyses are reported with calculated structural formulas in Table 1-10-4. Mineral formulas are based on eight cations with all iron treated as ferric.

Two compositional varieties of garnet are found in Rugged Mountain rocks. Melanite, a titanium-rich andradite, is the most common type analysed and commonly occurs as an igneous crystallization product in silica-undersaturated systems (*e.g.*, Dingwell and Brearly, 1985). The melanite garnet is also interpreted to be a primary magmatic phase on the basis of texture. In the dike rocks melanite occurs as euhedral, 1-centimetre, chemically zoned crystals with titanite inclusions in a fine-grained subvolcanic groundmass. The second and rarer type of garnet lies within the andradite-grossular solid solution which is commonly associated with hydrothermal alteration, metasomatism, contact metamorphism or other nonmagmatic origins. Commonly these compositions are encountered on the rims of melanite crystals or as fracture fillings. The titanium content of these garnets varies from 0.2 to 0.6 cations per formula unit. Representative analyses of both melanite and andradite are included in Table 1-10-4.

Within the Rugged Mountain intrusion, melanite garnet has a wide range in titanium content (Figure 1-10-8). Dingwell and Brearly (1985) state that titanium substitution occurs primarily in the tetrahedrally coordinated site replacing silica, but that titanium can also occur in the octahedrally coordinated site. The electron microprobe analyses of Rugged Mountain melanites are compared against a model solid solution line in Figure 1-10-8. The data plot significantly above the model line representing Si-Ti exchange. The figure shows that, even though there is a strong negative correlation between the two elements, the

TABLE 1-10-3
REPRESENTATIVE ELECTRON MICROPROBE PYROXENE ANALYSES FROM RUGGED MOUNTAIN INTRUSIVE ROCKS.

| Unit | Pyrox. | Pyrox. | Hybrid | Hybrid | Syenite | Syenite |
|---|---|---|---|---|---|---|
| Sample No. | 79 | 79 | 119 | 115 | 121 | 121 |
| $SiO_2$ | 47.64 | 52.34 | 48.71 | 44.70 | 42.80 | 47.00 |
| $TiO_2$ | 1.03 | 0.03 | 1.20 | 1.53 | 2.07 | 1.56 |
| $Al_2O_3$ | 4.08 | 0.20 | 3.50 | 5.89 | 7.90 | 4.03 |
| FeO | 11.19 | 9.69 | 10.69 | 13.33 | 14.56 | 13.85 |
| MnO | 0.34 | 1.14 | 0.26 | 0.43 | 0.49 | 0.43 |
| MgO | 10.46 | 11.61 | 10.80 | 9.30 | 7.23 | 8.80 |
| CaO | 22.60 | 23.63 | 22.16 | 22.28 | 22.09 | 21.82 |
| $Na_2O$ | 0.92 | 0.32 | 1.33 | 1.10 | 0.92 | 1.33 |
| Total | 98.26 | 98.96 | 98.65 | 98.56 | 98.06 | 98.82 |
| Mineral Structural Formulae Calculated on Basis of 4 Cations | | | | | | |
| Si | 1.82 | 2.00 | 1.85 | 1.72 | 1.67 | 1.81 |
| Al(IV) | 0.18 | 0.00 | 0.15 | 0.27 | 0.33 | 0.18 |
| Al(VI) | 0.01 | 0.00 | 0.01 | 0.00 | 0.03 | 0.00 |
| Ti | 0.03 | 0.00 | 0.03 | 0.04 | 0.06 | 0.05 |
| $Fe^{+3}$ | 0.18 | 0.02 | 0.17 | 0.29 | 0.24 | 0.21 |
| Mg | 0.60 | 0.66 | 0.61 | 0.53 | 0.42 | 0.50 |
| $Fe^{+2}$ | 0.18 | 0.29 | 0.17 | 0.13 | 0.23 | 0.24 |
| $Mn^{+2}$ | 0.01 | 0.04 | 0.01 | 0.01 | 0.02 | 0.01 |
| Na | 0.07 | 0.02 | 0.10 | 0.08 | 0.07 | 0.10 |
| Ca | 0.93 | 0.97 | 0.90 | 0.92 | 0.92 | 0.90 |
| Σ Oxygen | 5.91 | 5.99 | 5.91 | 5.85 | 5.88 | 5.90 |

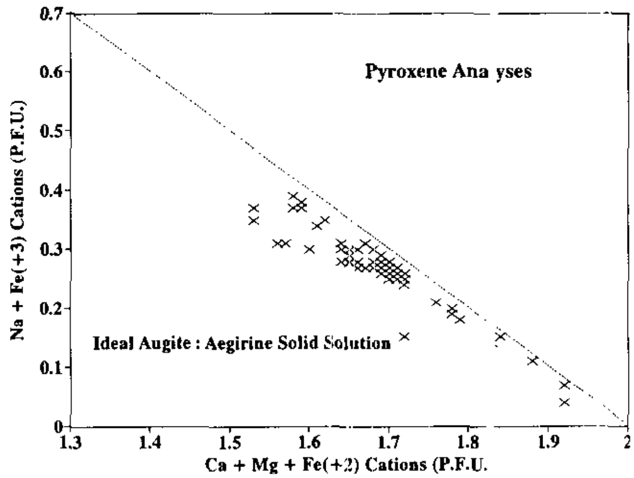


Figure 1-10-7. Electron microprobe analyses of pyroxenes from all units of the Rugged Mountain intrusion. Line represents the solid solution between ideal augite and aegirine.

melanites contain more titanium than can possibly be explained by vacancies on the tetrahedral sites. Possibilities for accomodating the titanium include replacing some of the ferric iron with ferrous, thereby creating vacancies in the octahedrally coordinated site for titanium. Vanadium was also detected in the melanite and is assumed to occur in the trivalent state and assigned to the octahedral site (Gomes, 1969; Meagher, 1982).

Melanite appears to be an important accessory phase in a number of other alkaline intrusions in British Columbia. In addition to having similar rock types (pyroxenite/syenite) and chemical compositions to the Rugged Mountain pluton the following intrusions contain melanite; Ten Mile Creek (Morgan, 1976), Duckling Creek (Garnett, 1978; Woodsworth *et al.*, 1991), Zippa Mountain (R.G. Anderson, personal communication, 1992), Galore Creek (Allen *et al.*, 1976; Meetch, 1965) and the Averill (Keep and Russell, 1988, 1989, in press). Two other alkaline intrusions reported to have brown-coloured garnet as an accessory phase are the Kamloops syenite (Kwak, 1964) and the Bayfield River intrusion (McLean, 1973). The presence or absence of melanite has two consequences. Firstly, it is a clear indication of the degree of silica understauration in these alkaline magmas, where the feldspathoids are no longer preserved. Secondly, it may form a solid petrological basis for subdividing or classifying Cordilleran alkaline plutons more finely. It appears to us that the Coppper Mountain suite (Woodsworth *et al.*, 1991), which includes the Rugged Mountain intrusion, includes many petrologically dissimilar bodies which could be separated on the basis of accessory phases.

## CONCLUSIONS

The Rugged Mountain pluton comprises a suite of alkaline, strongly undersaturated melanite-bearing intrusive rocks. The intrusion is crudely zoned and comprises four rock types: pyroxenite, syenite, hybrid and syenite to monzonite dikes. The zonation is from pyroxenite at the

TABLE 1-10-4
REPRESENTATIVE ELECTRON MICROPROBE MELANITE GARNET ANALYSES FROM RUGGED MOUNTAIN INTRUSIVE ROCKS.

| Unit | Pyrox. | Pyrox. | Hybrid | Hybrid | Hybrid | Syenite | Syenite | Dike | Dike | Gr - And |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample No. | 78 | 78 | 119 | 115 | 115 | 322 | 322 | 64 | 64 | 115 |
| $SiO_2$ | 32.57 | 32.35 | 31.09 | 33.48 | 34.87 | 34.06 | 30.92 | 35.12 | 33.83 | 35.92 |
| $TiO_2$ | 6.62 | 3.70 | 8.07 | 4.41 | 2.63 | 2.24 | 8.94 | 2.12 | 4.34 | 0.61 |
| $Al_2O_3$ | 2.47 | 2.54 | 2.50 | 2.46 | 4.00 | 1.62 | 1.93 | 7.37 | 6.68 | 16.72 |
| $V_2O_5$ | 0.79 | 0.86 | 0.87 | 0.00 | 0.32 | 0.31 | 1.12 | 0.67 | 0.47 | 0.23 |
| $Fe_2O_3$ | 23.41 | 25.21 | 23.36 | 25.48 | 23.86 | 28.36 | 24.99 | 22.45 | 21.03 | 8.27 |
| MnO | 0.41 | 0.41 | 0.43 | 0.29 | 0.39 | 0.57 | 0.75 | 2.44 | 1.94 | 0.36 |
| MgO | 0.39 | 0.31 | 0.52 | 0.12 | 0.21 | 0.20 | 0.37 | 0.25 | 0.32 | 0.02 |
| CaO | 32.16 | 32.39 | 31.70 | 32.61 | 32.78 | 31.95 | 30.92 | 29.90 | 30.86 | 36.66 |
| Total | 98.82 | 97.77 | 98.54 | 98.85 | 99.06 | 99.31 | 99.44 | 100.32 | 99.47 | 98.79 |
| | Mineral Structural Formulae Calculated on the Basis of 8 Cations | | | | | | | | | |
| Si | 2.77 | 2.78 | 2.66 | 2.84 | 2.92 | 2.89 | 2.61 | 2.89 | 2.81 | 2.82 |
| Al(IV) | 0.23 | 0.22 | 0.25 | 0.16 | 0.08 | 0.11 | 0.20 | 0.11 | 0.19 | 0.18 |
| Ti | 0.42 | 0.24 | 0.52 | 0.28 | 0.17 | 0.14 | 0.58 | 0.13 | 0.27 | 0.04 |
| Al(VI) | 0.02 | 0.03 | 0.00 | 0.09 | 0.32 | 0.05 | 0.00 | 0.61 | 0.46 | 1.36 |
| $Fe^{+3}$ | 1.50 | 1.63 | 1.51 | 1.63 | 1.50 | 1.81 | 1.61 | 1.39 | 1.31 | 0.49 |
| V | 0.04 | 0.05 | 0.05 | 0.00 | 0.02 | 0.02 | 0.06 | 0.04 | 0.03 | 0.01 |
| Mg | 0.05 | 0.04 | 0.07 | 0.02 | 0.03 | 0.03 | 0.05 | 0.03 | 0.04 | 0.00 |
| Ca | 2.93 | 2.98 | 2.91 | 2.97 | 2.94 | 2.91 | 2.84 | 2.64 | 2.75 | 3.08 |
| $Mn^{+2}$ | 0.03 | 0.03 | 0.03 | 0.02 | 0.03 | 0.04 | 0.05 | 0.05 | 0.17 | 0.02 |
| Σ Oxygen | 12.14 | 12.03 | 12.14 | 12.06 | 12.06 | 12.05 | 12.18 | 12.13 | 12.11 | 11.89 |

margins to syenite at the core. The zonation of the pluton suggests a relatively simple genetic relationship between the syenite, pyroxenite and the transitional hybrid. Mineralogically, the rocks of the Rugged Mountain pluton share the same critical mineral assemblage of aegirine-augite, potassium feldspar, magnetite, apatite, titanite and magmatic melanite garnet. The continuity in mineral assemblage and continuum in modal proportions further suggests a cogenetic relationship between all phases of the intrusion. The chemical character of the intrusion mirrors the field and mineralogical patterns. The chemical trends are smooth and continuous and the chemical characteristics (normative mineralogy) are consistent throughout the suite.

The presence of melanite garnet and aegirine-augite throughout all phases of the intrusive further suggests the presence of a single evolving magma chamber. Electron microprobe analysis has shown a strong chemical linkage between pyroxenes from the syenite, the hybrid and the pyroxenite. The pyroxenes lie along the aegirine-augite to augite solid solution line. Similarly, electron microprobe analysis of melanite garnets in all phases of the intrusion has delineated a continuum in mineral chemistry: high titanium contents in garnets occur throughout the rock suite.

These observations suggest that the pyroxenite represents a cumulate phase of the original Rugged Mountain intrusion and that it is comagmatic the syenite. The hybrid appears to represent a transitional unit derived from later interaction between the syenite and pyroxenite. The syenite and monzonite dikes are later yet and probably represent the last stages of magmatic activity.

Other alkaline intrusions of British Columbia show some of the same characteristics, including: petrological zoning, a similar pyroxenite-syenite association, strong silica undersaturation, strong iron-enrichment trends, aegirine-augite and potassium feldspar dominated mineralogies and the presence of accessory melanite garnet. Several show enough of these attributes to suggest a separate sub-class of alkaline intrusion (perhaps within the Copper Mountain suite of Woodsworth *et al.*, 1991). At the very least, the repetition of these chemical, petrographic and field relationships in other Cordilleran intrusions in British Columbia suggests a common mechanism operating throughout time and space.

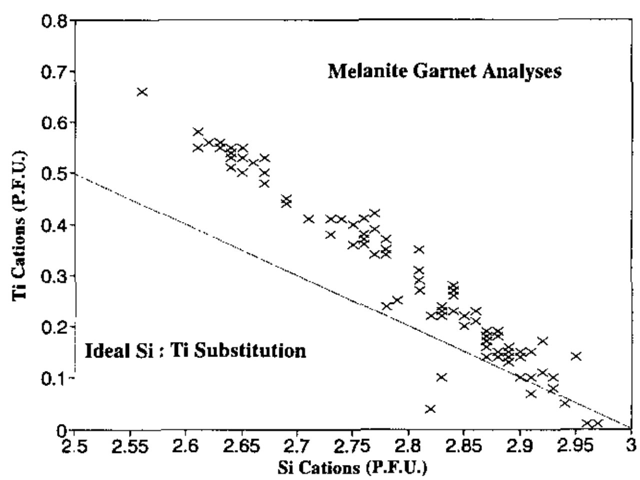


Figure 1-10-8. Electron microprobe analyses of garnets from all units of the Rugged Mountain intrusion. Line represents the effects of cationic exchange between tetrahedrally coordinated Si and Ti (*see* text).

## ACKNOWLEDGMENTS

Field mapping by the senior author was completed in the summer of 1991 with the support of the British Columbia Ministry of Energy, Mines and Petroleum Resources and the supervision and support of Derek Brown. Additional research funding derived from the Natural Sciences and Engineering Research Council through Operating Grant A0820 and Infrastructure Grant (Electron Microprobe Laboratory) INF000992. The EMP analytical work of I.N. was facilitated immensely by Dr. Mati Raudsepp.

## REFERENCES

Allen, D.G., Panteleyev, A. and Armstrong, A.T. (1976): Galore Creek, *in* Porphyry Deposits of the Canadian Cordillera, Sutherland Brown, A., Editor, *Canadian Institute of Mining and Metallurgy*, Special Volume 15, pages 402-414.

Brown, D.A., Harvey-Kelly, F.E.L., Neill, I. and Timmerman, J. (1992a): Geology of the Chutine River - Tahltan Lake Area, Northwestern British Columbia (104G/12W and 13); *in* Geological Fieldwork 1991, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-1, pages 179-195.

Brown, D.A., Neill, I., Timmerman, J. and Harvey-Kelly, F. (1992b): Geology and Geochemistry of the Chutine River and Tahltan Lake Areas, Northwestern B.C. (104G/12W, 13); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1992-2.

Currie, K.L. (1976): The Alkaline Rocks of Canada; *Geological Survey of Canada*, Bulletin 239, 278 pages.

Dingwell D.B. and Brearly, M. (1985): Mineral Chemistry of Igneous Melanite Garnets from Analcite-bearing Volcanic Rocks, Alberta, Canada; *Contributions to Mineralogy and Petrology*, Volume 90, pages 29-35.

Garnett, J.A. (1978): Geology and Mineral Occurrences of the Southern Hogem Batholith; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Bulletin 70, 75 pages.

Gómes, Celso de Barros (1969): Electron Microprobe Analysis of Zoned Melanites; *American Mineralogist*, Volume 54, pages 1654-1661.

Keep, M. (1989): The Averill Plutonic Complex, near Grand Forks, British Columbia; unpublished M.Sc. thesis, *The University of British Columbia*, 167 pages.

Keep, M. and Russell, J.K. (1988): Geology of the Averill Plutonic Complex, Franklin Mining Camp; *in* Geological Fieldwork 1987, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1988-1, pages 49-53.

Keep, M. and Russell, J.K. (1989): The Geology of the Averill Plutonic Complex, Grand Forks, British Columbia; *in* Geological Fieldwork 1988, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1989-1, pages 27-31.

Keep, M. and Russell, J.K. (in press) Mesozoic Alkaline Rocks of the Averill Plutonic Complex; *Canadian Journal of Earth Sciences*.

Kerr, F.A. (1948): Lower Stikine and Western Iskut River Areas, B.C.; *Geological Survey of Canada*, Memoir 246, 94 pages.

Kwak, T.A.P. (1964): A Garnet-bearing Syenite near Kamloops, B.C.; unpublished M.Sc. thesis, *The University of British Columbia*, 53 pages.

Marud, D. (1990): Report of Activities on the Rugged Mountain Property; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Assessment Report 20154.

McLean, D.C. (1973): A Zoned Syenite Intrusion, Hayfield River, South-central B.C.; unpublished B.Sc. thesis, *The University of British Columbia*, 50 pages.

Meagher, E.P. (1982): Silicate Garnets; *in* Orthosilicates, Ribbe, P.H., Editor, *Reviews in Mineralogy*, Volume 5, pages 25-66.

Meetch, L. (1965): A Garnet-bearing Syenite Porphyry, Galore Creek, British Columbia; unpublished B.Sc. thesis, *The University of British Columbia*, 32 pages.

Monger, J.W.H. (1977): Upper Paleozoic Rocks of the Western Canadian Cordillera and their Bearing on Cordilleran Evolution; *Canadian Journal of Earth Sciences*, Volume 14, pages 1832-1859.

Morgan, J.T. (1976): Geology of the Ten Mile Creek Syenite-Pyroxenite Pluton, Telegraph Creek, B.C.; unpublished B.Sc. thesis, *The University of British Columbia*, 41 pages.

Neill, I. (1991): Geology, Petrography and Chemistry of the Rugged Mountain Alkaline Pluton, Northwestern British Columbia (104G/13); unpublished B.Sc. thesis, *The University of British Columbia*, 75 pages.

Philpotts, A.R. (1990): Principles of Igneous and Metamorphic Petrology; *Prentice Hall*, New Jersey, 498 pages.

Shand, S.J. (1939): On the Staining of Feldspathoids; *American Mineralogist*, Volume 24, pages 508-513.

Souther, J.G. (1971): Geology and Mineral Deposits of Tulsequah Map-area, British Columbia; *Geological Survey of Canada*, Memoir 362, 84 pages

Souther, J.G. (1972): Telegraph Creek Map Area, B.C.; *Geological Survey of Canada*, Paper 71-44, 34 pages.

Souther, J.G. and Armstrong, J.E. (1966): North Central Belt of the Cordillera of British Columbia; *in* Tectonic History and Mineral Deposits of the Western Cordillera, *Canadian Institute of Mining and Metallurgy*, Special Volume 8, pages 171-189.

Woodsworth, G.J., Anderson, R.G. and Armstrong, R.L. (1991): Plutonic Regimes, Chapter 15; *in* Geology of the Cordilleran Orogen in Canada, Gabrielse, H. and Yorath, C.J., Editors, *Geological Survey of Canada*, Geology of Canada, Number 4, pages 491-531.

# NOTES