SILICA-UNDERSATURATED, ZONED, ALKALINE INTRUSIONS WITHIN THE BRITISH COLUMBIA CORDILLERA

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INTRODUCTION

Within the framework of cordilleran alkaline intrusions, there is a unique group of plutons characterized by pyroxenite and syenite (Lueck *et al.*, 1993). Some members of this plutonic suite host porphyry copper-gold mineralization and mineralized plutons show distinct petrological differences from barren plutons.

Individual plutons show variable plutonic zonation, the most prevalent being a pyroxenite border phase with a central core of syenite. The pyroxenite encloses syenite, which typically contains an abundance of aligned alkali feldspar megacrysts. This zoning suggests that individual silica-undersaturated magma bodies fractionate aegirine-augite in their early crystallization history, thus forming the enclosing pyroxenites. Intermediate phases are mela-syenites which occur adjacent to pyroxenite and are mineralogical mixtures of pyroxenite and syenite.

THE PYROXENITE-SYENITE ASSOCIATION

DESCRIPTION

Plutons of the pyroxenite-syenite association occur in widely dispersed regions of the Canadian Cordillera (Currie, 1976; Anderson, 1993). Previous studies of the Averill pluton (Keep and Russell, 1992) and the Rugged Mountain pluton (Neil and Russell, 1993) provide the framework for a description of the chemistry and mineralogy of this suite. Distinct similarities between the Averill and Rugged Mountain plutons include: the presence of a silica-undersaturated suite of rocks spanning the compositional range from pyroxenite to syenite, strong iron enrichment for the rock suite as a whole, the presence of a distinct igneous mineral assemblage comprising alkali feldspar, aegirine-augite, biotite, melanite, titanite and apatite, and plutonic-scale petrological zonation.

Field and literature research has defined at least twelve plutons in British Columbia which share these characteristics. These plutons (Figure 1) span the length of the British Columbia Cordillera. They intrude basement and volcanic arc rocks of both the Stikine and Quesnell terranes and were emplaced during the time period from Late Triassic to Early Jurassic.

Field studies of the Zippa Mountain pluton (Lueck and Russell, in press) provide evidence of cumulate processes in the formation of this pluton. This field evidence includes the presence of: strong concentric petrological zoning in the form of a 200 to 500 metre thick pyroxenite and mela-syenite unit enclosing a core of syenite, a pervasive, mappable, inwardly dipping, non-tectonic mineral fabric formed by the planar alignment of alkali feldspar and pyroxene, and fabric-concordant mineral zonation in the form of vishnevite-cancrinite, aegirine-augite and melanite-rich layers within the syenite. A low silica activity is implied by the presence of vishnevite-cancrinite and melanite.

THE DEFINING CHARACTERISTICS OF THE SUITE

The twelve plutons shown on Figure 1 are the minimum number of plutons which can be defined as silica-undersaturated, zoned alkaline plutons. All of the plutons shown have the critical elements that indicate they are part of this suite. Most of these attributes were detailed by Neil and Russell (1993).

MINERALOGY

The mineralogy of this plutonic suite shows little variation in the characteristic mineral suite of aegirine-augite, pottassium feldspar, biotite, melanite, titanite and apatite. Various proportions of these minerals comprise the dominant rock types of pyroxenite, mela-syenite and syenite. Testing of the comagmatic hypothesis using Pearce element-ratio tests (Lueck *et. al.*, 1993), was done for the Rugged Mountain pluton (Figure 2) using zirconium as a conserved constituent of the melt. This diagram tests for the sorting of feldspar and augite to explain the chemical diversity of the plutonic suite. The test does not reject the comagmatic hypothesis.

Notable variations on the above described mineralogy include the presence of major amounts of hornblende, magnetite and vishnevite-cancrinite in some plutons (Neil and Russell, 1993; Currie, 1976; Lueck and Russell, in press). The presence of both hornblende and magnetite in these plutons is an important criteria for the differentiation of mineralized from barren intrusions (Table 1).

Figure 1. Location map of silica-undersaturated zoned intrusions within the British Columbia cordillera.

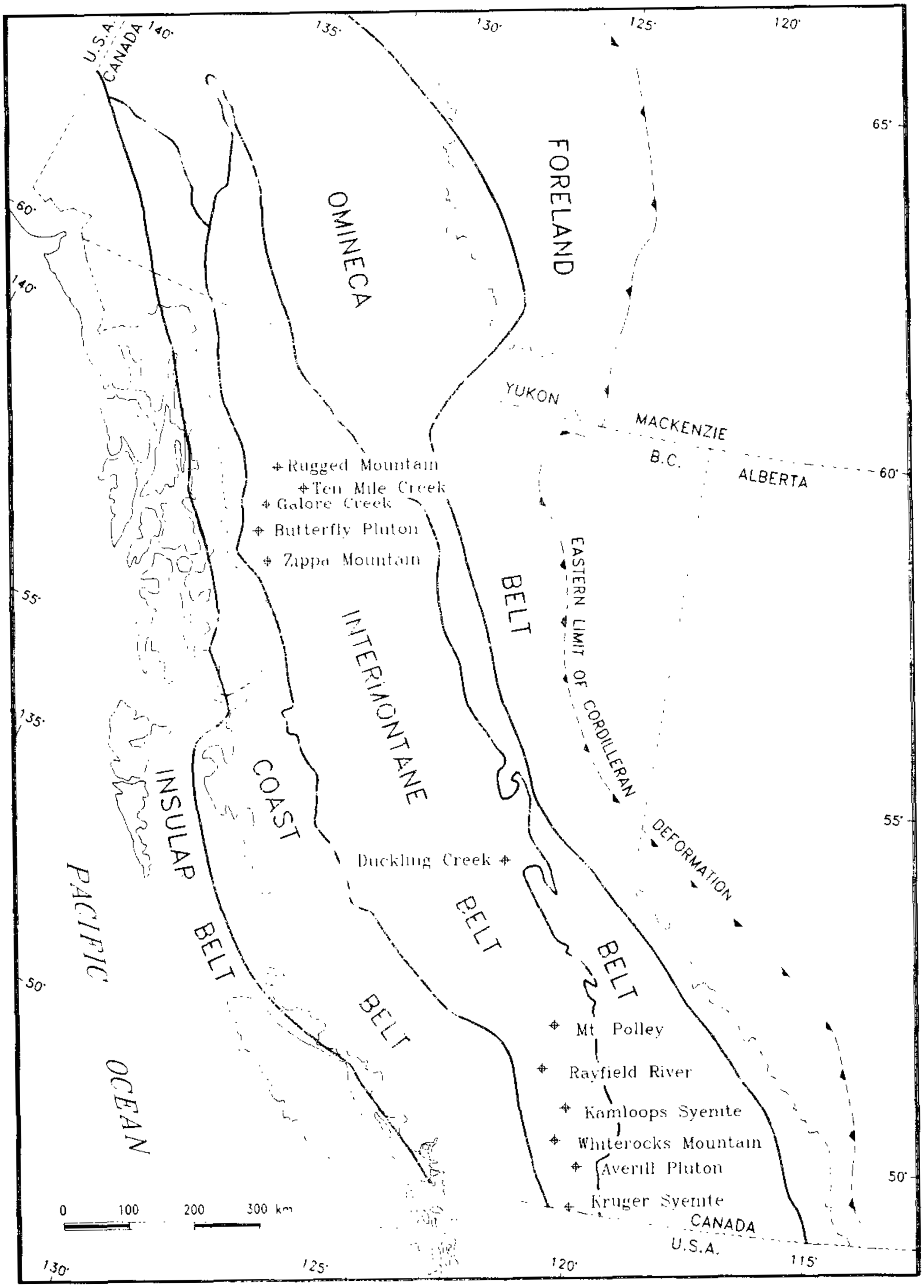

TABLE 1. Silica-undersaturated plutons and the relationship between mineralogy and Cu-Au mineralization.

Pluton	Dominant Mafic Phase	Abundant Magnetite	Terrane Affinity
Mineralized (Cu-Au)			
Galore Creek	Hornblende	Yes	Stikinia
Averill	Hornblende	Yes	Quesnellia
Duckling Creek	Hornblende	Yes	Quesnellia
Mt. Polley	Hornblende	Yes	Quesnellia
Rayfield River	Hornblende	Yes	Quesnellia
No known reserves			
Zippa Mountain	Augite	No	Stikinia
Rugged Mountain	Augite	No	Stikinia
Ten Mile Creek	Augite	No	Stikinia
Whiterocks Mountain	Augite	No	Stikinia
Kruger Mountain	Augite	No	Quesnellia
Kamloops Syenite	Augite	No	Quesnellia

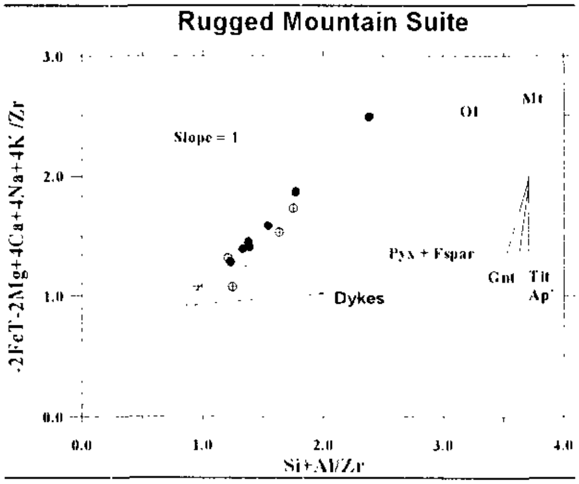

Figure 2. Pearce element-ratio diagram for rocks from the Rugged Mountain pluton. This diagram tests for the sorting of feldspars and augite to explain the chemical diversity of the suite. This test does not reject the comagmatic hypothesis

Table 1 clearly shows the positive relationship between porphyry copper-gold mineralization and the presence of hornblende and magnetite. Plutons classified as unmineralized often contain sparse or discontinuous copper deposits. These areas of copper mineralization are generally associated with the mafic plutonic phases and are invariably associated with the local presence of hornblende and/or magnetite (*e.g.* Whiterocks Mountain pluton; Wilkins, 1981).

CHEMICAL COMPOSITION

Based on alkali and silica content, these plutons are chemically alkaline (Neil and Russell, 1993). They are strongly undersaturated with respect to silica and this is universally expressed both chemically and mineralogically as normative feldspathoid and modal melanite. Other notable occurrences of silica-undersaturated phases include: nepheline in the Kruger syenite (Currie, 1976); pseudo-leucite at Mount Polley and Galore Creek (Currie, 1976); and vishnevite-cancrinite at Zippa Mountain (Lueck and Russell, in press).

Figure 3 is a ternary AFM diagram which shows the representative compositions of rocks from both the Averill (Keep and Russell, 1992) and Rugged Mountain plutons (Neil and Russell, 1993). Both suites show a strong iron enrichment trend which is typical of this plutonic association. Iron enrichment is expressed mineralogically by iron-rich aegirine-augite, melanite garnet, iron-rich biotite and magnetite.

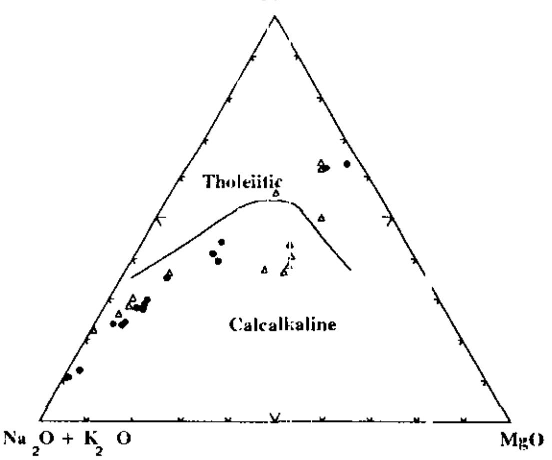

Figure 3. AFM diagram for rocks from the Averill and Rugged Mountain plutons.

IGNEOUS MELANITE GARNET

The presence of igneous melanite garnet, a titanium-bearing andradite, is a primary distinguishing feature of these plutons (Lueck *et. al.* 1993). Melanite garnet occurs in varying amounts within these bodies and becomes a major phase locally. Melanite is a common phase in the Zippa Mountain pluton and occurs as rare cumulate bands (Lueck and Russell, in press). The presence of melanite and aegirine-augite suggests a high oxygen fugacity in these melts as these minerals require significant Fe^{3+} in their crystal structure.

The presence of titanium in the structure of andradite is problematic (Dingwell and Brearly, 1985; Howie and Wooley, 1968; Huckenholz, 1969; Huggins *et. al.*, 1977; Issacs, 1968; Moore and White, 1971; Schwartz, 1979; Tarte, 1979). The presence of aluminum in the andradite structure within natural melanites complicates the substitution behavior. A definitive solution to the problem has yet to be determined.

A plot of cationic titanium *versus* silica in melanite garnet (Figure 4) from the Rugged Mountain pluton (Neil and Russell, 1993) shows that there is more titanium in the garnet structure than can be accommodated by the silica vacancies. There is, however, a strong linear relationship between the two elements of 1.5 titanium atoms for every 1 silica absence. This suggests a coupled substitution of titanium in both the tetrahedrally coordinated silica site and also in the octahedrally coordinated Fe^{3+} site. The latter substitution would require the reduction of Fe^{3+} to Fe^{2+}.

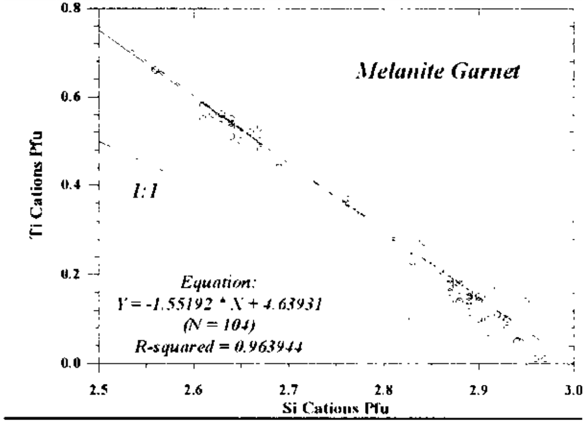

Figure 4. Plot of cationic silica vs. titanium in melanite garnet from Rugged Mountain pluton (Neil and Russell, 1993). Upper dashed line is ideal 1.5:1 substitution; solid line is fitted curve.

PLUTONIC ZONATION

Plutonic zonation is another distinguishing feature of these undersaturated plutons. The suite is characterized by a zonation from pyroxenite to syenite. Pyroxenite encloses a core of trachytic syenite in many of these plutons (*eg.* Rugged Mountain, Ten Mile Creek [Morgan, 1976], Zippa Mountain, Whiterocks Mountain). Intermediate mela-syenites are found adjacent to pyroxenites (*eg.* Rugged Mountain, Zippa Mountain) and are mineralogical mixtures of syenite and pyroxenite. This zoning suggests that the lithological diversity within these plutons is a result of magmatic differentiation processes. Magmatic fractionation of aegirine-augite early in the crystallization history of the pluton is a possible explanation for both the plutonic geometry and the lithological inhomogeneity of this pyroxenite-syenite association.

PLUTONIC FABRIC

The presence of a prominant mineral fabric in the form of planar crystal alignment is another diagnostic feature of this plutonic association. Trachytic syenite is a dominant rock type in all of these plutons and this may reflect on the origins of the syenite phase. At Zippa Mountain (Lueck and Russell, in press) trachytic alignments of potassium feldspar crystals outline a well-developed and mappable fabric within the syenite phase of the pluton. This fabric is non-tectonic in origin, as evidenced by the lack of strain within the interlocking crystals that outline the fabric. The foliation outlines a map pattern which is inwardly dipping, concordant with the pluton margins and steepest at the pyroxenite border. This geometry is consistent with a crystal cumulate model for the formation of these plutons.

CONCLUSIONS

Silica undersaturated, zoned alkalic intrusions occur in both the Stikine and Quesnell Terranes within British Columbia. These plutons intrude Paleozoic to Triassic assemblages, are latest Triassic to Early Jurassic in age and are formed from arc-related magmas. Pyroxenite and syenite are compositional end members within this plutonic suite that are believed to be comagmatic and related by the sorting of mineral phases within the cooling magma chambers.

Porphyry copper-gold deposits are found within several of these plutons and the presence of significant mineralization is restricted to plutons which contain an abundance of hornblende and magnetite.

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