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**Tectonic, thermal and magmatic evolution
of the Central Gneiss Belt, Huntsville region
southwestern Grenville orogen**

by

Léopold Nadeau, M.Sc.

**A thesis submitted to the Faculty of
Graduate Studies and Research in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy**

Ottawa - Carleton Geoscience Centre

Carleton University

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The undersigned hereby recommend to the Faculty of Graduate Studies and Research acceptance of this thesis, submitted by Léopold Nadeau, M.Sc, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Abstract

Mid- to deep crustal, northwest-directed, breakback ductile thrust structures of a wide range of scales dominate the Grenvillian tectonic architecture of the southwestern Central Gneiss Belt (CGB). The structural and geochronological data presented here demonstrate a southeastward migration, with time, of the approximate northwestern limit of active thrusting at the scale of the belt. This trend is reflected in the Huntsville area by the breakback nature of the Seguin thrust and the breakback thrust assembly of the underlying Algonquin thrust stack.

Thrust related ductile flow in the Huntsville region does not conform to a simple picture, either in space or in time. Although regional tectonic flow conforms to northwest-directed thrusting, a zone of transpression developed near the base of the Huntsville thrust zone against a culmination in its footwall topography. Moreover, U-Pb dating demonstrates that thrusting at high structural levels triggered renewed tectonic movement at deeper levels. Finally, the thrust related flow fabric is disrupted by mesoscopic, high temperature extensional shears. These extensional shears represent mid-crustal collapse structures resulting from gravitational instability in an over-thickened cooling pile.

The thermal evolution of the southwestern CGB is marked by major crustal thickening in the ca. 1350-1170 Ma range. Minimum age limits for attainment of peak metamorphic conditions are provided by late-stage breakback thrusting ca. 1160 Ma

and ca. 1100 Ma in the Parry Sound and Huntsville areas, respectively. Post-thrusting regional cooling to 700 °C occurred ca. 1067 Ma. This is consistent with the late-orogenic, regional scale, breakback thrust stacking. It demonstrates that if the crustal thickening and high grade metamorphism in the CGB resulted from the accretion of the Central Metasedimentary Belt, docking and the deformation of the latter must predate ca. 1160 Ma.

The pre-Grenvillian history of the southwestern CGB is marked by ubiquitous plutonism with ages in the ranges 1700-1620 Ma and 1480-1420 Ma. This and the absence of significant volumes of plutonic rocks of Grenvillian age indicate that the cratonization of the CGB was completed more than 100 Ma prior to the Grenvillian Orogeny.

Abstract

Mid- to deep crustal, northwest-directed, breakback ductile thrust structures of a wide range of scales dominate the Grenvillian tectonic architecture of the southwestern Central Gneiss Belt (CGB). The structural and geochronological data presented here demonstrate a southeastward migration, with time, of the approximate northwestern limit of active thrusting at the scale of the belt. This trend is reflected in the Huntsville area by the breakback nature of the Seguin thrust and the breakback thrust assembly of the underlying Algonquin thrust stack.

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Frontispiece

Terre Sauvage; A.Y. Jackson

Chapter 1

Introduction

This thesis reports on an integrated structural, metamorphic and U-Pb zircon and monazite geochronological study of the deeply excavated Central Gneiss Belt in the Huntsville region, southwestern Grenville orogen (Fig. 1.1). It includes three independent but complementary articles which successively discuss the nature of the rocks and the meso- to regional scale structural "anatomy" of this part of the orogen (Chapter 2); its metamorphic evolution (Chapter 3); and the age constraints on its tectonic, thermal, magmatic and crustal history (Chapter 4). This is complemented by a summary of the main results and a brief discussion of the implications of the present contribution for the understanding of the Grenvillian Orogeny (Chapter 5).

The structural and metamorphic attributes of the high grade metamorphic rocks exposed in the southwestern Central Gneiss Belt resulted from a continental scale compressional event involving mid- to deep crustal thrusting towards the craton and imbrication of the entire crust (Fig. 1.1; Davidson and Morgan 1981; Davidson et al. 1982; Culshaw et al. 1983). This event was probably the result of a collision in the 1.3-1.0 Ga range between Laurentia and a continent to the south-

east, now obscured in the Appalachian orogen (Moore 1986; Rivers et al. 1989) and/or fragmented and displaced elsewhere on the Earth's surface by Phanerozoic plate tectonics (Hoffman 1990). Studies of this deeply excavated ancient orogen, believed to result from a continental collision on the scale of the presently rising Himalayas, provide direct insight of the nature of mid- to deep crustal orogenic products and of processes active in present collisional mountain chains that are inaccessible to direct observation. A seminal statement with respect to the magnitude of orogenic movements is contained in the simple observation "The summit of Mt. Everest is marine limestone" (McPhee 1981). This thesis can be summarised in the following sentence appended to the frontispiece: "The quietude emerging in Grenvillian landscape comes from rocks which, ca. 1.2 Ga ago, were part of the active substratum of rising Himalaya-like mountains".

Figure 1.1 Generalized structural map and schematic cross-section of the southwestern Central Gneiss Belt (after Davidson 1984b and Rivers et al. 1989); inset a: subdivision of the southwestern Grenville province, (after Wynne-Edwards 1972); inset b: proposed subdivision of the belt into superincumbent units (after Culshaw et al. 1983). Northwest of the Grenville Front: 1 Archean (Ar) supracrustal rocks, 2 Archean plutonic rocks, 3 Lower Proterozoic supracrustal rocks (Huronian Supergroup hsg) and Nipissing diabase sheets, 4 Sudbury irruptive, 5 Whitewater Group, 6 Killarney plutonic suite. Central Gneiss Belt (CGB): 7 gneissic rocks of varied origin, 8 anorthosite, gabbro and derived gneiss, 9 granitoid metaplutonic rocks, 10 Grenville Front and Central Metasedimentary Belt boundary thrust zone (CMBbtz), 11 southeast margin of the Grenville Front Tectonic Zone (GFTZ), 12 tectonic domains and subdomains in the southwestern Central Gneiss Belt, 13 Paleozoic (P) sedimentary cover. Line A - B is cross-section. CMB Central Metasedimentary Belt, CGT Central Granulite Terrane, M Montreal. Domains and subdomains: B Britt, P Parry Sound, N Novar, H Huntsville, S Seguin, R Rosseau and M Moon River.

Chapter 2

**Mid- to deep crustal deformation, breakback thrusting
and extension in the Central Gneiss Belt,
Huntsville region, southwestern Grenville orogen**

2.1 ABSTRACT

The Grenvillian tectonic architecture of the southwestern Central Gneiss Belt is dominated by mid- to deep crustal thrust structures. The Huntsville thrust zone comprises thin, shallowly southward-dipping sheets of strongly lineated and interleaved straight gneisses, mylonitic orthogneisses and paragneisses, all exhibiting ubiquitous evidence of intense and penetrative ductile flow under high grade metamorphic conditions. Although tectonic flow in the Huntsville thrust zone generally conforms to the northwest-directed regional pattern, a zone of northeast-southwest transpression developed in the lower part of the thrust zone as a consequence of northwestward regional thrusting against a culmination of the Novar footwall.

The Algonquin thrust stack comprises the Novar footwall, the overlying Huntsville thrust zone and the superincumbent McCraney and McClintock thrust sheets. The latter are bounded by broad ductile thrust zones which include rocks of the type recognised in the Huntsville thrust zone. The internal structural anatomy of the Algonquin thrust stack conforms to a breakback thrust sequence.

The overlying Seguin thrust sheet is a regional scale breakback structure which overrode an already deformed footwall. Its emplacement involved intense internal deformation of the thrust sheet and metamorphic remobilisation. The structural and geochronological data collected in this study demonstrate southeastward migration, with time, of the approximate northwest limit of thrusting, at the scale of the southwestern Grenville orogen. Thrusting at higher structural levels was

accompanied by renewed tectonic activity at deeper levels.

Mesoscopic high temperature extensional shears are common in the Huntsville region and widely distributed in the Central Gneiss Belt. They are probably mid-crustal, collapse structures resulting from gravitational instability in an overthickened cooling pile. These structures may have played a key role in the thinning of the orogen.

2.2 INTRODUCTION

Mid- to deep crustal thrusting plays a fundamental role in crustal thickening and mountain building (Coward et al. 1982; Coward and Butler 1985; Platt 1986; e.g., Coward and Ries 1986, Malinconico and Lillie 1989). In young orogenic belts, high level thrust systems root at depth (e.g., McClay and Price 1981, Coward and Ries 1986; Malinconico and Lillie 1989). However, few field examples of mid- to deep crustal thrust structure have been described (Le Fort 1981; Culshaw et al. 1983; Davidson 1984a; Coward and Butler 1985; Journeay 1986; Hanmer 1988) and much remains to be specified about the nature of the accompanying deformation and coupled metamorphism.

This contribution will examine the nature, geometry, stacking order and kinematics of mid- to deep crustal thrusting in the deeply excavated Central Gneiss Belt of the southwestern Grenville orogen (Fig. 1.1). Analogies have been drawn between the structure of the Central Gneiss Belt and intracontinental thrusting at the margin of the Indian subcontinent in the western Himalayas (Windley 1986). Within the Himalayas, that part of the Indian Plate which is underthrust to deep crustal levels is only accessible to indirect geophysical investigation. The nature of its tectonic response remains controversial (Molnar and Tapponnier 1975; Hirn et al. 1984a, 1984b; Molnar 1984; Mattauer 1986; Powell 1987). Furthermore, transverse extension has been documented in the higher structural levels of the Himalayan edifice (Burg and Chen 1984; Burchfiel and Royden 1985; Herren 1987),

but its expression, and even its existence, at depth remains unknown. Elsewhere, crustal-scale, shallow-dipping, inaccessible reflectors, imaged in seismic reflection surveys across the initially deep-seated parts of modern and ancient orogenic belts (COCORP, LITHOPROBE, GLIMPCE), are currently interpreted by analogy with high-level thrust systems. However, high level thrust systems are characterised by typically discrete faults whose operation leaves both the hangingwall and footwall intact. On the other hand, deep-seated thrust systems are likely to be more complex because they involve the development of broad ductile shear zones and considerable internal ductile deformation of the thrust sheets themselves.

In what follows, we shall examine the nature, geometry and kinematics of thrusting and extension at mid- to deep crustal levels in the accessible roots of an extensive Middle Proterozoic collisional orogenic belt. This study sheds useful light on the internal structure and evolution of ancient and active mountain belts, formed in similar tectonic settings.

2.3 PREVIOUS WORK AND NEW PERSPECTIVES

Over the last decade, there has been a major breakthrough in understanding the geological evolution of the Central Gneiss Belt that has stemmed from recognition of its geologically composite nature (Fig. 1.1 and 2.1; Davidson and Morgan 1981; Davidson et al. 1982; Culshaw et al. 1983; Davidson 1984a, 1984b; Nadeau 1984). This was spurred by the recognition that continuous belts of layered

high strain gneisses represent ductile shear zones. Several "domains" and "subdomains", variably contrasting in their characteristic rock assemblages, metamorphism, structural trends and geophysical signatures, bounded by broad high strain zones, or ductile shear zones, were interpreted as northwest-transported "crustal slices" and "blocks". The emerging regional picture is one of a "cell-like pattern of structural domains" (Davidson 1984b; Rivers et al. 1988). These domains and subdomains have been grouped into three "structural decks" (Culshaw et al. 1983) or "tectonostratigraphic units" (Davidson 1984b; Fig. 1.1 inset A).

The use of such terms as "domain", "subdomain", "ductile shear zone" or "high strain zone" and "cell-like pattern of structural domains" was fully justified during the reconnaissance mapping, prior to appreciation of the tectonic significance of these structural elements. However, the continued use (Rivers et al. 1988) of this terminology in reference to large thrust sheets such as the Parry Sound, Moon River and Seguin thrust sheets and to their associated thrust zones does not adequately describe the spectacular internal tectonic architecture now recognised in the Central Gneiss Belt (Hanmer and Ciesielski 1984; Windley 1986; Hanmer 1988; Rivers et al. 1989). In this paper, we consider these domains and subdomains as thrust sheets, bounded by broad ductile thrust zones, and apply the appropriate terminology (Boyer and Elliot 1982; Butler 1982).

2.4 TECTONIC SETTING

The Grenville orogen is considered to result from continental collision (in the range 1350-1000 Ma) between Laurentia and an unknown continent to the southeast, now largely obscured by the Appalachian orogen (Dewey and Burke 1973; Baer 1974, 1976; Moore 1986; Windley 1986, 1989; Rivers et al. 1988). In its exposed southwestern part, it comprises two geologically highly contrasting belts, the Central Metasedimentary Belt and the Central Gneiss Belt (Fig. 1.1 inset B; Wynne-Edwards 1972). The Central Metasedimentary Belt, dominated by the ca. 1300-1250 Ma Grenville Supergroup (Moore and Thompson 1972), comprises a volumetrically important pile of metasediments, metavolcanics and associated plutonic rocks. Conversely, the Central Gneiss Belt is essentially composed of pre-1.4 Ga crust and does not include substantial volumes of syn-Grenvillian rocks (Chapter 4) except for ca. 1.17 Ga coronitic metagabbro (Davidson and van Breemen 1988) and widespread granitic pegmatites. The Central Gneiss Belt is bounded by two crustal-scale shear zones which played an active role during its tectonic evolution (Fig. 1.1). To the northwest, a broad zone of intense ductile shearing, the Grenville Front Tectonic Zone, separates the Grenville orogen from the adjacent Superior and Southern Provinces (Wynne-Edwards 1972; Davidson 1986b; Rivers et al. 1989) and marks the northwest limit of crustal thickening (Green et al. 1989). To the southeast, the Central Metasedimentary Belt boundary thrust zone is a mid- to deep crustal shear zone, along which the post 1.3 Ga rocks

of the Central Metasedimentary Belt are thrust onto the Central Gneiss Belt (Hanmer and Ciesielski 1984; Hanmer 1988). The regional scale structures which dominate the internal tectonic architecture of the Central Gneiss Belt include the Parry Sound, Seguin and Moon River thrust sheets.

The regional importance and the relative structural position of these shear zones and thrust sheets provide the basis for the utilitarian tectonic subdivision of this part of the orogen used in this paper (Fig. 2.2). Structural level 2 extends southeastward from the Grenville Front Tectonic Zone, level 1, to form the common footwall to the Parry Sound thrust sheet, level 3, and to the Moon River and Seguin thrust sheets, parts of level 4. The latter continues to the east where it forms the footwall to the Central Metasedimentary Belt boundary thrust zone, structural level 5. In the Huntsville area (Fig. 2.3, 2.4 and 2.5), structural level 2 is represented by the Algonquin thrust stack. This new name is introduced in preference to the "Algonquin domain" of Davidson and Morgan (1981). The Algonquin thrust stack comprises the Novar footwall, the Huntsville thrust zone (Nadeau 1988) and the overlying McCraney and McClintock thrust sheets. The Seguin thrust sheet is part of the overlying structural level 4.

Throughout the Central Gneiss Belt, shear-sense criteria indicate north-west-directed thrusting along a shallowly, generally southeast plunging stretching lineation (Culshaw et al. 1983). A similar kinematic picture has also emerged along the Central Metasedimentary Belt boundary thrust zone (Hanmer and Ciesielski

1984; Hanmer 1988) and in the Grenville Front Tectonic Zone (Davidson 1986b, 1988). The initiation of Grenvillian ductile deformation in the Grenville Front Tectonic Zone has pre-dated the emplacement of the Sudbury dykes (Bethune and Davidson 1988; Davidson 1988) ca. 1240 Ma (Krogh et al. 1988). Further to the southeast, a progressive migration, southeastwards and up structural section, of the northwest limit of thrusting with time has been deduced from the U/Pb zircon ages of late-synthrusting pegmatites (Chapter 4). It ranges from ca. 1160 Ma in the Parry Sound thrust zone (van Breemen et al. 1986), via ca. 1103 and 1097 Ma in the basal thrust zones of the Moon River and Seguin thrust sheets respectively (van Breemen and Davidson 1990; Chapter 4) to 1060-1030 Ma in the Central Metasedimentary Belt boundary thrust zone (van Breemen and Hanmer 1986).

Upper amphibolite facies metamorphic conditions prevailed during the late-stages of the tectonic assembly of the southwestern Central Gneiss Belt, attesting to a mid- to deep crustal thrusting environment (Culshaw et al. 1983; Hanmer and Ciesielski 1984; Chapter 3). It is argued elsewhere (Chapter 3) that the granulite facies peak metamorphism, which affected the Parry Sound thrust sheet and the Algonquin thrust stack, occurred prior to final tectonic emplacement of the former, as well as that of Moon River and Seguin thrust sheets and the Central Metasedimentary Belt.

2.5 THE ALGONQUIN THRUST STACK

Identification of the Algonquin thrust stack (Fig. 2.5) is predicated about the ability to recognise mid- to deep crustal ductile thrust zones. In what follow, we first describe the best developed of these thrust zones prior to examine the other components of the stack.

2.5.1 The Huntsville thrust zone

The Huntsville thrust zone (Nadeau 1988) comprises a variety of flaggy, strongly lineated, fine grained, granoblastic mylonitic rocks (Fig. 2.3 and 2.4). These rocks were deformed under granulite and upper amphibolite facies conditions. This resulted in complete obliteration of the stratigraphic record, of original cross-cutting relationships and of primary and lower grade deformation features. Concordant rock units are in tectonic contact, as indicated by the preferential development of strain gradients at the margins of the least ductile layers. The mylonitic rocks are interleaved with, or enclose, lenses of their moderately strained gneissic protoliths, forming a map-scale stack of transposed, shallowly southward-dipping imbricated sheets, tens to hundreds of meters thick.

Mylonitic rock units in the Huntsville thrust zone include straight gneiss (Hanmer 1988), mylonitic orthogneiss and paragneiss.

Straight gneiss

The following observations show that straight gneisses represent annealed mylonites and that the straight layering is of tectonic origin (Davidson et al. 1982; Hanmer 1988). They are fine grained, flaggy S>L tectonites (Fig. 2.6). The continuous, 1-10 centimetre-scale layering is best expressed by the alternation of amphibolite and quartzo-feldspathic rocks, but less contrasted layering is not uncommon (Fig. 2.6; contrast b and d). In places, the layering is visibly derived by the transposition and attenuation of pre-existing gneissic banding and/or of mafic and aplitic to pegmatitic granitic dykes (Fig. 2.6 c, e and f).

Subsequently, the layering was deformed about metre-scale, tight to isoclinal intrafolial folds (Fig. 2.6 g). Detached isoclinal fold hinges, with axes coaxial to the extension lineation are widespread. Such a geometrical relationship between finite strain and fold orientation has long been recognized as characteristic of high strain zones (Bell 1978; Cobbold and Quinquis 1980). This intense deformation is generally homogeneous at both outcrop and map scales.

Straight gneisses are fine grained tectonites, in which grain size reduction was the product of dynamic recrystallisation. The microstructure is annealed, with an equigranular polygonal or sub-polygonal granoblastic texture. Quartz crystals form ubiquitous polycrystalline ribbons (aspect ratio 30:10:1). Grain-size typically ranges from 100-500 μm in the felsic layers; it tends to be larger in the mafic bands. Such fine and uniform grain size in a now granoblastic rock attests to the previous

existence of an even finer grained, dynamically recrystallized, mylonitic micro-structure.

Mylonitic orthogneiss

Several granitoid orthogneiss sheets are enclosed in the Huntsville thrust zone (Fig. 2.3; Nadeau 1985). The following observations suggest that these sheets are largely mylonitic, were the loci of important displacements and that their shapes reflect the intensity of the deformation. In low strain zones, the rocks show an augen structure typically consisting of partly recrystallized, centimetre size, stubby K-feldspar augen (Fig. 2.7 b). Polycrystalline quartz is commonly drawn out in leaves (50:10:1) (Fig. 2.7 a). A strong mineral foliation is invariably present and C/S fabrics (Berthé et al. 1979) are locally developed. With increasing strain in mesoscopic ductile shear zones, the augen structure is progressively obliterated, the K- feldspar augen are recrystallized into flat, drawn-out sugary aggregates, or even disappear altogether (Fig. 2.7 c and d). A homogeneous, fine grained, flaggy, strongly lineated ribbon mylonite is the end product (Fig. 2.7 d).

Metamorphic segregations, where observed, are recrystallized, attenuated and transposed into parallelism with the overall foliation (Fig. 2.7 e). Minor tight to isoclinal folds of the indistinct layering, with fold axes parallel to the stretching lineation, similar to those previously described in straight gneiss, are not uncommon (Fig. 2.7 f). Such structures independently suggest high ductile strain. The foliation

results from the parallel alignment of ribbon quartz, mafic minerals and feldspar augen or recrystallized aggregates. Its strong development renders these tectonites very flaggy. In low strain areas, the stretching lineation is expressed as discrete elongate clots of recrystallised K-feldspar. In high strain areas, it is expressed by streaked-out ribbon quartz and smeared-out trains of feldspar aggregates within the foliation (Fig. 2.7 a).

These mylonitic orthogneiss sheets are invariably sheared at their margins, preserving no original contact relationships, such as intrusive apophyses or chilled margins. This together with the strength of their L/S fabric suggest that the concordant sheet-like shape of these bodies is, in part if not entirely, the result of intense deformation.

Mylonitic paragneiss

Pelitic and semi-pelitic gneisses are widespread in the Huntsville thrust zone, interleaved with the mylonitic orthogneiss sheets and straight gneisses (Fig. 2.3; Nadeau 1985). The following observations suggest that these gneisses have experienced intense strain, consistent with that of the interleaved straight gneiss and mylonitic orthogneiss. Locally, in low strain zones, centimetre-scale layering, expressed by variations in the proportion of aluminosilicates, graphite and quartz, is disrupted and cut by locally derived granitic veins (Fig. 2.8 a). At higher strain these structures are attenuated and transposed parallel to the mineral

foliation, contributing to a metamorphic layering and to a strong planar fabric (Fig. 2.8 b and c). As in the straight gneisses, uniform, fine grained (100-500 μm), granoblastic microstructure suggests that the dynamic grain size was initially even finer. These paragneisses host competent calc-silicate fragments, boudinaged layers and detached fold closures (Fig. 2.8 d).

Boudinaged and transposed dykes

Isolated, widely separated, metre to decametre scale mafic masses are variably foliated and exhibit a strong marginal fabric concordant with that of their matrix (Fig. 2.9 a). Some of them are demonstrably boudinaged isoclinal fold hinges (Fig. 2.9 b). Others, showing well preserved coarse grained igneous textures, are clearly derived by the disruption of intrusive bodies (dykes ?). Notable among them are widespread coronitic metagabbro bodies which, at regional scale, tend to be concentrated in high strain zones (Davidson and Grant 1986; Davidson and van Breemen 1988). The size and the distribution of these boudinaged, originally intrusive, mafic rocks implies that the host tectonites have accommodated large ductile strains (Fig. 2.3).

Similarly, heterogeneously deformed, cross-cutting pegmatites pass progressively into sheared, mechanically disaggregated, porphyroclastic layers, concordant with the planar fabric of the wallrock (Fig. 2.9 c and d). Such sheared syntectonic pegmatites are widespread throughout the Huntsville thrust zone,

independently demonstrating the penetrative nature of the intense deformation. The absence of displaced lithologic markers or of widespread passive strain gauges precludes estimation of the displacement across the zone.

2.5.2 The Novar footwall

The fabric and internal structure of Novar footwall (Fig. 2.3) differ in intensity, style and orientation from those of the Huntsville thrust zone and of the overlying Seguin thrust sheet. Gneisses are distinctly less planar and coarser grained than in the Huntsville thrust zone. The primary texture of plutonic bodies is readily recognisable. Primary layering in metasedimentary rocks and intrusive relationships of mafic dykes are locally preserved. The large-scale structural grain is clearly discordant to that of the Huntsville thrust zone. North-northwest striking foliations prevail throughout much of the southern part of the Novar footwall but swing to the northeast along its western margin; dips vary from moderate to vertical. In the map area, the stretching lineation is parallel to the regional southeasterly plunging lineation (Fig. 2.4). The Huntsville thrust zone abruptly truncates the internal structure of the Novar footwall. However, the southeastern extension of the Novar footwall, as expressed by its aeromagnetic signature, can be recognised for several kilometres beneath the northwest margin of the Huntsville thrust zone (Fig. 2.1 and 2.10).

2.5.3 The McCraney and McClintock thrust sheets

Along their eastern flank, the Huntsville thrust zone and Novar footwall are separated from the overlying McCraney thrust sheet (Fig. 2.5) by the McCraney thrust zone. This thrust zone comprises east- to northeast-dipping straight gneisses, a few kilometres thick, of the type previously described in the Huntsville thrust zone. Its constituent straight gneisses carry a well clustered, easterly plunging extension lineation and have a strong linear magnetic anomaly and steep gradient in the total magnetic field (Fig. 2.1 and 2.10). The overlying McClintock thrust sheet is separated from the McCraney thrust sheet by the shallowly southeast dipping McClintock thrust zone, a ductile shear zone with a down-dip extension lineation. From Fig. 2.5, it is clear that the McCraney thrust zone cuts down through the Huntsville thrust zone in the east, yet is itself truncated to the south by the overlying McClintock thrust zone. Therefore, the Algonquin thrust stack must result from breakback thrusting.

2.5.4 The thrust stack

The Algonquin thrust stack is composed of several thrust sheets, separated by ductile thrust zones (Fig. 2.5). The base of the stack is marked by the first occurrence of regionally extensive footwall behavior. The top of the stack is limited by the first regionally extensive thrust sheet. The common lithological feature linking the constituent elements of the stack is principally their mixed ortho- and

paragneiss composition, which contrasts sharply with that of the overlying, orthogneiss dominated, Seguin thrust sheet (Culshaw et al. 1983; Davidson and Grant 1986).

2.6 THE SEGUIN THRUST SHEET

The Seguin thrust sheet, part of the structural level 4, defines a gently southeast plunging synformal structure, bounded by the laterally continuous, inward-dipping, Seguin ductile thrust zone (Fig. 2.2 and 2.3). The thrust sheet is primarily composed of migmatitic granodioritic gneisses, which grade locally into non-migmatitic amphibolite and granulite facies orthogneisses (Fig. 3.5 d; Nadeau 1985). Over a distance of 50 m, migmatitic gneisses near the base of the Seguin thrust sheet become progressively finer grained and transposed to flaggy straight gneisses passing into the Seguin thrust zone (Fig. 2.11 a and c). This thrust zone hosts a variety of tectonic inclusions, or boudins, including coronitic metagabbro and meta-anorthosite (Fig. 2.3, 2.11 a and d). As in the case of the Huntsville thrust zone, the dispersion of these inclusions can be taken as a qualitative indicators of intense strain in the enclosing straight gneisses. Shear-sense criteria in the Seguin thrust zone indicate northwest-directed tectonic transport (Fig. 2.12). A minimum displacement of 35 kilometres is suggested by the separation between the northwest margin of the thrust sheet and the most southeasterly outcrop of its footwall (Fig. 2.3).

The following observations demonstrate that the emplacement of the Seguin thrust sheet was accompanied by intense internal deformation of the thrust sheet and syntectonic metamorphic remobilisation. The overall internal planar fabric of the thrust sheet, expressed by the preferred orientation of metamorphic segregations, lies parallel to the straight gneisses of the Seguin thrust zone (Fig. 2.3). The extension lineation, defined by drawn-out recrystallised K-feldspar augen, plunges shallowly to the southeast (Fig. 2.4). Open to tight minor folds, with axes parallel to the lineation, are common. Metamorphic segregations deformed about sheath folds coaxial with the extension lineation (Fig. 2.11 b) are found within the thrust sheet, well away from its base, attesting to considerable penetrative, ductile strain (Cobbold and Quinquis 1980). Other, less deformed metamorphic segregations occur in the same outcrops as the sheath folds, thus demonstrating that deformation and migmatization were synchronous. The concordance of the internal planar and linear structural elements with the regional structural geometry suggests that deformation within the thrust sheet was kinematically related to regional thrusting. However, transposition of the metamorphic segregations in the Seguin thrust zone demonstrates that final emplacement of the Seguin thrust sheet outlasted metamorphic remobilization (Fig. 2.11).

From northwest to southeast, the Seguin thrust sheet successively overlies the Parry Sound thrust sheet (structural level 3), Novar footwall and the Huntsville thrust zone (structural level 2; Fig. 2.5). Accordingly, the Seguin thrust sheet

overrode an already deformed footwall comprising the Parry Sound thrust sheet and the Algonquin thrust stack. Such structural cross-cutting relationships imply breakback thrusting of the Seguin thrust sheet. Moreover, to the east, the "Kawagama zone" is a belt of dip-lineated, shallowly southeast dipping straight gneisses, outcropping between the McClintock thrust sheet and the overlying rocks of structural level 4 (Culshaw et al. 1983). Given that the Kawagama zone lies along the trace of the eastward extension of the Seguin thrust zone, we agree with Rivers et al. (1989) that the Kawagama zone is part of the Seguin thrust zone. Accordingly, we consider that structural level 4 in its entirety was also emplaced as a breakback thrust sheet.

2.7 KINEMATICS OF FLOW

Thrust dependent ductile flow

Tectonic flow in the Huntsville thrust zone does not conform to a simple picture, either in space or in time. Shear-sense indicators in the Huntsville region are consistent with regional northwest-directed thrusting along the southeast plunging extension lineation (Fig. 2.12). However, in the Huntsville thrust zone, major departures from the regional lineation trend are observed (Fig. 2.4). Whereas gently south to southeast plunging lineations predominate in the upper section of the Huntsville thrust zone, the lineation azimuth swings to a north-east-southwest trend in the lower levels of the zone.

The following observations suggest that all the lineations were developed synchronously under the same kinematic framework: i) no mesoscopic overprinting relationship of the lineation is present; ii) the change in the lineation direction is progressive, regionally extensive and focussed upon the Novar - Huntsville interface; iii) mesoscopic shear-sense indicators are consistent with northwest-directed shearing; and iv) the finite extension direction deduced from quartz crystallographic fabrics in the lower level of the thrust zone is parallel to the regional trend and normal to the anomalously northeast-southwest oriented mesoscopic stretching lineation (Fig. 2.13). The sensitivity of quartz crystallographic fabrics to changes in kinematic boundary conditions (Lister and Price 1978; Lister and Hobbs 1980; Schmid and Casey 1986; Law 1986; Gapais and Cobbold 1987) enables them to track the orientation of the latest increments of finite strain. However, the mesoscopic lineation, attached to material points, is more likely to preserve the orientation of the total principal extension.

These observations, coupled with the present geometry of the upper surface of Novar footwall, are compatible with transpressive flow resulting from northwestward thrusting over a culmination in the footwall topography which induced a localised, but important component of northeast-southwest extension.

Extensional shears

Post-thrusting, granoblastic, extensional ductile shears occur throughout the Algonquin thrust stack as well as the Seguin thrust sheet (Nadeau 1985; Fig. 2.14). They are up to several metres wide and cut across the thrust-related planar layering, described above, at moderate (30-40°) angles. The intersections of the shears with the regional layering are variably oriented with respect to the regional southeast trending extension lineation. They can rarely be traced along strike for more than a few tens of metres and have extensional offsets of less than a few metres. Where these shears transect granulite facies rocks, they are invariably developed within zones of hydration to amphibolite facies mineral assemblages, up to ten of metres wide. In large exposures, the shears occur in more than one orientation, dividing the host into large volumes. Sets which dip towards the southeast tend to predominate. We emphasise that these shears are distinct in size and distribution from the discrete, low temperature extensional shears, extending in strike length for over 100 km, recently described by van der Pluijm and Carlson (1989) and Carlson et al. (1990) from the Central Metasedimentary Belt boundary zone. The granoblastic shears examined in the present study are best interpreted as warm collapse structures resulting from gravitational instability in an overthickened, cooling pile.

Identical extensional shears are regionally developed through the Central Gneiss Belt. They have been described from the Parry Sound area (Nadeau 1984),

the Central Metasedimentary Belt boundary thrust zone (Hanmer et al. 1985; Hanmer 1988) and the eastern part of the Central Gneiss Belt (Lumbers 1982).

2.8 CONDITIONS OF THRUSTING

The relevant data and the discussion of the evolution of the metamorphic conditions in the Huntsville area are given elsewhere (Chapter 3). It suffices here to review the salient points concerning the metamorphic conditions during deformation. In the Algonquin thrust stack, the lower levels of the Huntsville thrust zone preserve granulite facies assemblages, whereas at higher structural levels upper amphibolite facies assemblages prevail within the zone. However, the overlying McCraney and McClintock thrust zones both developed under granulite facies conditions. Clearly, the tectonometamorphic development of the Algonquin thrust stack involved the superposition of hotter over cooler rocks, a classical relationship well established elsewhere (ex. Oldham 1883; St-Onge 1981; Nadeau 1984; Le Fort et al. 1986; Hubbard 1989). On the other hand, the deformation fabric in the overlying Seguin thrust sheet and thrust zone formed at uppermost amphibolite facies, after granulite facies and anatectic conditions had been attained.

2.9 DISCUSSION

Scale of thrusting and stacking order

We have shown above that breakback thrust structures, developed at widely differing scales, are the essential elements underpinning the tectonic architecture of the southwestern Central Gneiss Belt (Fig. 2.5). At the scale of the southwestern Grenville orogen, these breakback structures are bounded above and below by two crustal-scale thrust zones; the Central Metasedimentary Belt boundary thrust zone and the Grenville Front Tectonic Zone (Fig. 1.1 and 2.1). In the Grenville Front Tectonic Zone (structural level 1), the ca. 1240 Ma (Krogh et al. 1988) age of emplacement of the Sudbury dykes is the minimum age for penetrative ductile deformation in the zone (Bethune and Davidson 1988). Late ductile shearing in the Parry Sound thrust zone (structural level 3) is dated at ca. 1160 Ma (van Breemen et al. 1986). Late ductile shearing along the Moon River and Seguin thrust zones (structural level 4) occurred at ca. 1100 Ma (Chapter 4; van Breemen and Davidson 1990). Finally, major ductile deformation in the Central Metasedimentary Belt boundary thrust zone (structural level 5) was still active at ca. 1060 Ma (van Breemen and Hanmer 1986). Taken together, these data demonstrate that there is a southeastward migration, with time, of the approximate northwestern limit of active thrusting at the scale of the southwestern Grenville orogen.

Pegmatites intruded during late-thrusting movement in the Algonquin thrust stack (structural level 2) have yielded U-Pb zircon crystallization ages at ca. 1080, 1043 and, 1027 Ma (Chapter 4). When compared with the 1060-1030 Ma window of ductile thrusting along the Central Metasedimentary Belt boundary thrust zone (van Breemen and Hanmer 1986), these ages indicate that thrusting at higher structural levels was accompanied by renewed tectonic activity at deeper structural levels.

Pegmatite, syntectonic with respect to upper amphibolite granoblastic extensional shearing in the Huntsville thrust zone has yielded a zircon crystallization age of $1040 \pm 4/-2$ Ma (Chapter 4).

Thrusting on widely differing scales, involving some retrograde stacking is not unique to the southwestern Grenville orogen. Among others, analogous complex thrust assemblages have also been documented in the Moine Thrust zone (McClay and Coward 1981), in the Scandinavian Caledonides (Hossack 1983) and along the margin of the Indian subcontinent in Pakistan (Treloar et al. 1989). However, the Central Gneiss Belt contrasts with these examples in that no prograde imbricate stacks have yet been identified.

Extension tectonics

Tectonic studies in actively shortening and thickening mountain belts, such as the Himalayas and the Alps, have highlighted the existence and significance of normal faulting and extension in the process of mountain building (Himalayas: Molnar et al. 1973; York et al. 1976; Tapponnier and Molnar 1977; Ni and York 1978; Burg and Chen 1984; Burchfiel and Royden 1985; Herren 1987; Alps: Selverstone 1985, 1988; Mancel and Merle 1987; Lammerer 1987; Behrmann 1988). Burchfiel and Royden (1985) suggested that the extensional faulting in the Himalayas was the result of gravitational collapse of the Himalayan topographic front and was a secondary effect superimposed on regional north-south compression. They consider that such extension likely to be confined to the upper crustal levels and does not reflect regional extension of the entire lithosphere. Similarly, Platt's (1986) analysis of the dynamics of thick orogenic wedges undergoing prograde metamorphism predicts that such wedge will deform internally either by contraction or extension until they reach a stable configuration, in which the gravitational forces generated by the wedge geometry balance the traction exerted on its underside by the subducting slab. The extension will cause listric normal faults that may merge downwards into zones of ductile extension.

Alternatively, England (1982) has shown that extension in Tibet can be adequately accounted for by gravity spreading of overthickened crust, if the crust is modelled as a continuum with a rheological behaviour approximated by power-law

creep. Moreover, within an overthickened and deeply rooted active orogenic belt, thermal relaxation and attainment of peak metamorphic conditions after thrust related thickening (England and Thompson 1984) lead to thermal weakening of the underlying orogenic roots. Accordingly, extension can also be related to the inability of warming continental crust to sustain the superincumbent load represented by the resulting topography of the active mountain chain.

Recent field-based observations in the Himalayas report the existence of extensional shear zones in the upper parts of the mountain edifice. However, our work in the deeply excavated roots of the southwestern Grenville orogen suggests that extensional structures form in the deep, as yet inaccessible parts of such mountain chains (cf. Carlson et al. 1990). Moreover, the present study demonstrates that extensional shears are not simply related to progressive rheological weakening of overthickened, thermally relaxing crust. Indeed, the Grenville examples described in the present study clearly formed at upper amphibolite facies, at lower temperatures than those experienced during earlier crustal thickening by thrusting under granulite facies conditions (Chapter 4). Rather than forming during the phase of thermal relaxation following the onset of contractional tectonics, the Grenville examples clearly formed during a period of cooling following the attainment of peak-metamorphic temperatures in a given section of the mountain belt. How could such extensional structures form while the strength of the crustal roots of the mountain chain was presumably increasing ?

Several possible scenarios can be envisaged for this process, without attempting here to specify the extremely complex boundary variables involved. If either the rate of tectonic convergence, or the directed compressive stress due to convergence, is not uniform through time, then the lateral constraints resisting extension of the mountain belt will fluctuate. Alternatively, emplacement of a superincumbent load onto an already thickened welt would trigger extension as the body forces within the welt evolve towards equilibrium (Fleitout and Froidevaux 1982). We suggest that the geological evidence for the breakback sequence of thrusting throughout the southwestern Grenville orogen, from the scale of the Algonquin thrust stack to that of the Central Gneiss Belt in its entirety, favours the latter of these two scenarios. However, the very nature of the breakback stacking sequence begs the question of the origin of the granulite facies metamorphism in the McCraney and McClintock thrust zones. In this regard, we point out that the breakback sequence of thrusting inferred previously applies only to the timing of cessation of thrust tectonics and does not imply knowledge of the earlier orogenic history.

2.10 CONCLUSIONS

(1) Mid- to deep crustal thrusting in the southwestern Central Gneiss Belt led to the development of broad ductile thrust zones and to considerable penetrative ductile strain of the thrust sheets themselves.

(2) The identification of these ductile thrust zones relies on the recognition of the very nature of the constituent gneiss i.e. of the links between gneiss texture and structure, deformation processes and finite strain.

(3) The Algonquin thrust stack comprises the Novar footwall, whose fabric and internal structure differ in intensity, style and orientation from those of the overlying Huntsville thrust zone, and the superincumbent McCraney and McClintock thrust sheets. These are bounded by broad ductile thrust zones which include rocks of the type recognised in the Huntsville thrust zone. The internal structural architecture of the Algonquin thrust stack conforms to a breakback thrust sequence.

(4) The Huntsville thrust zone comprises thin, shallowly southward-dipping sheets of fine grained, flaggy, well lineated interleaved straight gneisses, mylonitic orthogneisses and high strain metasedimentary tectonites.

(5) The following hallmarks of these rocks confirm that they have experienced intense, penetrative, inhomogeneous, non-coaxial ductile shearing consistent with their interpretation as parts of a ductile shear zone: i) the fine, recrystallised, annealed grain size; ii) the extensive obliteration of primary textures and struc-

tures; iii) the transposition of polygenetic layering and the ubiquitous occurrence of tight to isoclinal intrafolial folds with axes parallel to the stretching lineation; iv) the disaggregation, attenuation and transposition of pegmatites and anatectic veins; v) the erratic distribution of decametre scale, amphibolite and metagabbro boudins; and vi) the localisation of intense shearing along the contacts of rock units of contrasting ductility.

(6) Thrust related ductile flow in the Huntsville thrust zone does not conform to a simple picture, either in space or in time. A zone of northeast-southwest transpressive flow developed in the basal section of the Huntsville thrust zone as a consequence of northwestward regional thrusting against a culmination of the Novar footwall.

(7) The Seguin thrust sheet is a regional-scale breakback structure which overrode an already deformed footwall. Its emplacement involved intense internal deformation of the thrust sheet and metamorphic remobilisation.

(8) Available structural and geochronological data demonstrate a south-eastward migration, with time, of the approximate northwest limit of thrusting at the scale of the southwestern Grenville orogen.

(9) Thrusting at higher structural levels was accompanied by renewed tectonic activity at deeper levels.

(10) Meso-scale, high temperature extensional shears are common in the Huntsville region and widely distributed in the southwestern Central Gneiss Belt. They are best interpreted as mid-crustal, warm collapse structures resulting from gravitational instability in an overthickened cooling pile. These structures may have played a key role in the thinning of the orogen.

(11) The very nature of the deformation and tectonics discussed in this contribution is only compatible with a mid- to deep crustal, very tectonically active environment. A neotectonic analog is best sought in the root zone of the rising Himalayas.

Figure 2.1 Magnetic anomaly map of the southwestern Grenville orogen. Grenville Front Tectonic Zone (GFTZ), Britt domain (B), Parry Sound thrust sheet (P), Moon River thrust sheet (M), Rosseau subdomain (R), Seguin thrust sheet (S), Novar footwall (N), Huntsville thrust zone (H), McCraney thrust sheet (Cr), McClintock thrust sheet (Cl), Central Metasedimentary Belt boundary thrust zone (CMBbtz). Tectonic boundaries in the Central Gneiss Belt after Wynne-Edwards (1972), Davidson and Morgan (1981), Culshaw et al. (1983) and Davidson and Grant (1986).

NANOTESLAS																			
28° 11'	105° 59'	22° 18'	-20° 15'	-18° 04'	-16° 31'	17° 41'	112° 49'	102° 49'	-14° 17'	-12° 35'	147° 25'	154° 31'	-19° 74'	-20° 31'	218° 16'	-22° 74'	-24° 31'	-26° 11'	-28° 34'
28° 11'	105° 59'	22° 18'	-20° 15'	-18° 04'	-16° 31'	17° 41'	112° 49'	102° 49'	-14° 17'	-12° 35'	147° 25'	154° 31'	-19° 74'	-20° 31'	218° 16'	-22° 74'	-24° 31'	-26° 11'	-28° 34'
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28° 11'	105° 59'	22° 18'	-20° 15'	-18° 04'	-16° 31'	17° 41'	112° 49'	102° 49'	-14° 17'	-12° 35'	147° 25'	154° 31'	-19° 74'	-20° 31'	218° 16'	-22° 74'	-24° 31'	-26° 11'	-28° 34'
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Figure 2.2 Subdivision of the southwestern Central Gneiss Belt into superincumbent structural levels. 1 Grenville Front Tectonic Zone; 2 Britt (2a) and Kiosk (2b) domains, Algonquin thrust stack (2c), Rosseau (2d) and Go Home (2e) subdomains of Muskoka domain; 3 Parry Sound thrust sheet; 4 Moon River (4a) and Seguin (4b) thrust sheets; 5 Central Metasedimentary Belt boundary thrust zone. Tectonic boundaries in the Central Gneiss Belt after Wynne-Edwards (1972), Davidson and Morgan (1981), Culshaw et al. (1983) and Davidson and Grant (1986).

Figure 2.5 Structural setting and internal structure of the Algonquin thrust stack (shaded area). Numbers refer to the subdivision of the southwestern Central Gneiss Belt into superincumbent structural levels and give the late-thrusting stacking sequence. Structural boundaries after Culshaw et al. (1983) and Davidson and Grant (1986).

Figure 2.6 Characteristics of straight gneiss. **a** and **b** Typical appearance of upper amphibolite facies straight gneiss dominated by a thin and continuous layering, a strong planar fabric and the absence of cross-cutting features. **b** Detail of the microstructure highlighting the fine recrystallized grain size, the nature of the layering and the intense and homogeneous strain of the rock. **c** Lower strain composite gneissic layering of the protolith of **a** and **b**. **d** and **e** Granulite facies straight gneiss derived from a mafic rock by the transposition of cross-cutting granitic veins. **f** Steep strain gradient illustrating the development of straight gneiss by the transposition of mafic dykes (scale = 5 cm). **g** Recumbent isoclinal fold in granulite facies straight gneiss. The axes of such folds are invariably parallel to the stretching lineation.

Figure 2.7 Mylonitic microstructure of granitoid orthogneisses. **a** Typical L/S fabric of extensively recrystallized mylonitic orthogneiss as illustrated in **c**. **b** Well preserved, partly recrystallized and **c** completely recrystallized mylonitic augen orthogneiss; **c** depicts the microstructure ubiquitous in the large orthogneiss sheets of the Huntsville thrust zone. **d** Mesoscopic strain gradient illustrating the progressive development of homogeneous, fine-grained, ribbon mylonite from mylonitic augen gneiss (scale = 5 cm). **e** Finely recrystallized, transposed and attenuated leucosome in upper amphibolite facies, hornblende porphyroblastic biotite granitic gneiss. The scale bar is 3 cm long. **f** Boudinaged and isoclinally folded mafic dykes in homogeneous, fine grained, recrystallized, granulite facies orthogneiss. Such detached isoclinal folds, together with the finely comminuted grain size and ubiquitous ribbon microstructure indicate intense and penetrative ductile strain in otherwise homogeneous appearing felsic granulite.

Figure 2.8 Hallmarks of mylonitic paragneiss. **a** and **b** Low strain metapelitic gneiss exhibiting relict primary layering disrupted by cross-cutting and layer-parallel granitic veins. **c** Characteristic appearance of high strain, garnet porphyroblastic pelitic gneiss; C/S fabric is developed near the magnifying lens. **d** Typical occurrence of isoclinally folded and boudinaged calc-silicate layer in semipelitic gneiss. The less ductile amphibolite boudins retain angular outlines.

Figure 2.9 Mafic boudins and transposed pegmatite. **a** Mafic granulite boudin in granulite facies straight gneiss, Huntsville thrust zone. **b** Boudinaged, amphibolite fold hinge in upper amphibolite facies, quartzofeldspathic straight gneiss, McClintock thrust zone. **c** and **d** Characteristic occurrence of sheared pegmatite transposed into a concordant porphyroclastic layer, Huntsville thrust zone.

Figure 2.10 Contrasting total field aeromagnetic expression of structural elements in the Huntsville region (see also Fig. 2.1; scale in gamma). Magnetic anomalies are broad and outline only map-scale features. The Huntsville thrust zone shows the lowest background and negative anomalies. Anomalies are broad and erratically distributed; this is consistent with the shallow-dipping planar fabric of this thrust zone. The southern part of Novar footwall exhibits the highest magnetic background; positive anomalies as well as a northerly-oriented pattern conform to its internal structure. Its positive signature extends a few kilometres south of the northern margin of the Huntsville thrust zone (shaded areas) independently suggesting a southern extension of the Novar footwall beneath the Huntsville thrust zone. The McCraney thrust zone is expressed by a prominent linear pattern. The magnetic background of the Seguin thrust sheet is slightly above that of the Huntsville thrust sheet, but remains markedly low relative to that of Novar footwall; it faithfully reflects the outcrop of the Seguin thrust sheet. PS = Parry Sound thrust sheet, S = Seguin thrust sheet, H = Huntsville thrust zone, N = Novar footwall, M = McCraney thrust sheet. (Data from Geological Survey of Canada, Aeromagnetic Series, Maps 31 E/6, 31 E/10 and 31 E/11).

Figure 2.11 Features of high strain gneiss from the Seguin thrust sheet.
a and c Vaguely layered, fine grained, annealed, high strain gneisses from near the base of the Seguin thrust sheet. Granitic veins are tightly folded, disaggregated and extended into the mylonitic gneiss fabric. A strong strain gradient is developed along the margin of the amphibolite boudin. Within ten meters across strike, such gneisses grade into homogeneous, flaggy straight gneisses which mark the base of the Seguin thrust sheet. **b** Sheath fold developed in Seguin migmatitic gneiss away from the base of the thrust sheet; sheath axis plunges away from viewer in the direction indicated by the pencil. **d** Isolated, decimeters size, meta-anorthosite tectonic inclusion in high strain gneiss from the Seguin thrust zone.

Figure 2.12 Distribution and orientation of shear-sense indicators in the Huntsville area.

Figure 2.14 Late-tectonic, meso-scale, extensional shears, Huntsville thrust zone.
a Steep, southeasterly dipping ductile extensional shear hosting a coarse grained granitic pegmatite. **b** Moderately northwest dipping, granoblastic, amphibolite facies extensional shear zone cutting granulite facies straight gneiss.

Chapter 3

Tectonothermal evolution of the Central Gneiss Belt, Huntsville region, southwestern Grenville orogen

3.1 ABSTRACT

The tectonic and thermal evolution of the southwestern Central Gneiss Belt is marked by a major crustal thickening event prior to final-stage thrusting of the Parry Sound thrust sheet at ca. 1160 Ma and the emplacement, in mid- to deep crust, of coronitic olivine metagabbro at ca. 1170 Ma. Intense ductile regional deformation under uppermost amphibolite and / or granulite facies conditions followed emplacement of the coronitic metagabbros and occurred prior to late-stage breakback thrust movement at ca. 1100 Ma of the Seguin and Moon River thrust sheets and structural level 4.

Thermobarometric data from post-peak metamorphic, annealed and retrograded, syntectonic pelitic mineral assemblages coupled with peak metamorphic data from pristine granulite facies mafic assemblages define a P-T trajectory which traverses the sillimanite stability field. This trajectory probably depicts the P-T-time path experienced by the rocks exposed at the present erosional surface. This path is consistent with the widespread occurrence of syntectonic sillimanite in pelitic gneiss from the area, to the exclusion of kyanite.

The post-thrusting high temperature part of the cooling history is constrained by a minimum age limit ca. 1100 Ma for peak metamorphism, the ca. 1067 Ma monazite blocking ages at ca. 700 °C and the ca. 500 °C ⁴⁰Ar/³⁹Ar hornblende cooling ages. High temperature conditions were maintained in excess of 35 Ma from peak metamorphic conditions to cooling to ca. 700 °C at ca. 1067 Ma. Clearly

the early part of the cooling path is non linear and cooling rates much greater than 10 °C/Ma can be modelled.

The thermal history of the southwestern Central Gneiss Belt is consistent with late-orogenic, southeastward migration, with time, of the approximate northwestern limit of active thrusting across the belt. It demonstrates that late-stage thrusting ca. 1060-1030 Ma in the Central Metasedimentary Belt boundary thrust zone is not the primary cause for high grade metamorphism in the Central Gneiss Belt. If the crustal thickening and high grade metamorphism in the Central Gneiss Belt resulted from the accretion of the Central Metasedimentary Belt, docking and deformation of the latter must predate ca. 1160 Ma.

3.2 INTRODUCTION

It is commonly accepted that, in the lower part of tectonically thickened crust, attainment of peak metamorphic conditions postdated the deformation that caused the tectonically thickened crust (Turner 1981; England and Thompson 1984). Recent structural studies have demonstrated the importance of mid- to deep crustal thrusting in the development of the Central Gneiss Belt of the southwestern Grenville orogen (Fig. 3.1; Davidson et al. 1982; Culshaw et al. 1983; Davidson 1984a and 1984b; Davidson 1986a; Nadeau 1985; Hanmer 1988; Chapter 3). Recent geochronological studies complement the structural data base (van Breemen et al. 1986; van Breemen and Hanmer 1986; van Breemen and Davidson 1988, 1990; Chapter 4) and offer the opportunity to develop and test a comprehensive model of the coupled thermal and structural history of the exhumed root of a collisional orogen.

Recent metamorphic studies have focused either on specific petrogenetic problems (Davidson 1990; Grant 1987, 1988; Manojlovic 1987), or on regional thermobarometry (Anovitz and Essene 1990) and thermochronometry (Cosca et al. in prep.). However, the metamorphic constraints on orogenic development have not been fully evaluated. This paper integrates structural, metamorphic, thermobarometric and age constraints from the Huntsville region and takes advantage of the available regional data base in an attempt to identify the major stages of the tectonothermal history of this part of the Grenville orogen and to reconstruct the

retrograde P-T-t path.

Within the Grenville orogen, such a synthesis is timely given the recent attempts to identify important thrust zones using thermobarometric data (Indares and Martignole 1989). Moreover, at a broader scale, the importance of this synthesis is emphasised by the analogies already drawn by some workers between the Grenville orogen and the Himalayas (Dewey and Burke 1973; Baer 1974, 1976; Culshaw et al. 1983; Windley 1986); this work may shed some additional light on the tectonothermal history of tectonically thickened crust.

3.3 TECTONIC SETTING

The southwestern Central Gneiss Belt represents part of the exhumed foundations of the ca. 1.3 to 1.0 Ga. Grenville orogen (Fig. 3.1). It is composed of pre- 1400 Ma crustal materials and does not include substantial volumes of plutonic rocks of Grenvillian age (Chapter 4), except for ca. 1170 Ma coronitic metagabbro (Davidson and van Breemen 1988) and widespread granitic pegmatites. The Central Gneiss Belt is bounded by two crustal scale thrust zones (Fig. 3.1 inset a) which controlled its tectonothermal evolution: (1) the Grenville Front Tectonic Zone, a zone of northwest-directed intense ductile shearing, marks the northwest limit of the crustal thickening against the adjacent Superior and Southern shield provinces (Davidson 1986b); (2) the Central Metasedimentary Belt boundary thrust zone, a mid- to deep crustal shear zone with northwest tectonic transport, along

which the post 1300 Ma rocks of the Central Metasedimentary Belt are thrust onto the Central Gneiss Belt (Hanmer and Ciesielski 1984; Hanmer 1988). The regional scale structural geometry of the southwestern Central Gneiss Belt is dominated by the Parry Sound, Seguin and Moon River thrust sheets, transported to the northwest during the Grenvillian orogeny (Davidson et al. 1982; Culshaw et al. 1983; van Breemen et al. 1986; Chapter 4).

The relative structural position of these important shear zones and thrust sheets provide the basis for a tectonic subdivision of this part of the orogen (Fig. 3.1 inset b and 3.2). Structural level 2 extends southeastward from the Grenville Front Tectonic Zone, level 1, to form the common footwall to the Parry Sound thrust sheet, level 3, and to the Moon River and Seguin thrust sheets, parts of level 4. The latter continues to the east where it forms the footwall to the Central Metasedimentary Belt boundary thrust zone, structural level 5. In the Huntsville area (Fig. 3.2), structural level 2, represented by the Algonquin thrust stack (Chapter 2), comprises the Novar footwall, the Huntsville thrust zone (Nadeau 1988) and the overlying McCraney and McClintock thrust sheets, themselves bounded by thick ductile shear zones. The overlying Seguin thrust sheet, part of structural level 4, cuts down section, in the direction of transport, through the Algonquin thrust stack (Chapter 2).

3.4 METAMORPHIC SETTING

Metasedimentary rocks of the southwestern Central Gneiss Belt have experienced two major plutonic events at 1700-1620 Ma and 1480-1420 Ma (Chapter 4). The latter plutonic suite is time correlative with the Middle Proterozoic anorogenic magmatic belt that extends from the mid-continental region to Labrador (Bridgwater and Windley 1973; Emslie 1978; Van Schmus et al. 1987; Davidson and van Breemen 1988; Windley 1989; Chapter 4). Although controversial views have been expressed about the tectonic setting of the mid-continental magmatism, it is widely agreed that these rocks were emplaced at high levels in stable continental crust in an extensional setting (Emslie 1978; Bickford et al. 1986; Van Schmus et al. 1987; Morse et al. 1988; Windley 1989). If this interpretation is valid, it implies that the metasediments now exposed in the Huntsville thrust zone and the Novar footwall (and in structural levels 1 and 2 of the southwestern Central Gneiss Belt) were part of the upper continental crust ca. 1420 Ma. Furthermore, U/Pb data from zircons indicate that the crust now represented in the Huntsville area was subjected to a preGrenvillian metamorphism at ca. 1430 Ma (Chapter 4).

A widespread suite of coronitic olivine metagabbro boudins, yielding baddeleyite U/Pb ages of ca. 1170 Ma, occurs in the Algonquin thrust stack and elsewhere in the southeastern Central Gneiss Belt (Fig. 3.3 and 3.4 d; Davidson and van Breemen 1988; van Breemen and Davidson 1990). Petrogenetic study of the coronitic structure shows that the rocks initially crystallized under confining pres-

tures of 9-10 kbar (Grant 1987). Field evidence suggests that these rocks were originally emplaced in the form of dykes (Grant 1987; Davidson pers. comm.). These coronitic metagabbros intruded pre- 1350 Ma crust (Chapter 4) at crustal depths of 30-35 kilometres (Grant 1987). Therefore the southwestern Central Gneiss Belt must have experienced substantial crustal thickening in the interval 1350 Ma to 1170 Ma prior to the intrusion of the dykes.

Independent evidence for a major crustal thickening event in this time range is provided by the presence of sapphirine-bearing, relict eclogitic tectonic inclusions (Fig. 3.3). The inclusions occur within major ductile shear zones in structural level 2 (Culshaw et al. 1983; Davidson 1990), on which movement predated the emplacement of the Parry Sound thrust sheet at ca. 1160 Ma (Davidson et al. 1983, van Breemen et al. 1986). Phase relations indicate that the retrograded eclogite inclusions originally equilibrated under a minimum pressure of 12 kbar, equivalent to depths exceeding 45 kilometres (Grant 1990, Davidson in prep.). Locally, these inclusions are associated with meta-anorthositic rocks which contain sapphirine pseudomorphs after corundum (Davidson 1990). Similar corundum bearing, annealed meta-anorthositic mylonite occurs within the Novar footwall. As in the case of the coronitic metagabbro, these high-pressure inclusions, associated with metasediments, indicate substantial crustal thickening prior to 1160 Ma range.

Structural, metamorphic and geochronological relationships independently demonstrate that the Parry Sound, Moon River and Seguin thrust sheets were

subjected to peak metamorphic conditions prior to late-stage overthrusting at ca. 1160 Ma (Nadeau 1984; van Breemen et al. 1986), ca. 1103 Ma (van Breemen and Davidson 1990) and ca. 1097 Ma respectively (Chapter 4). The latter two dates provide minimum age constraints on the regional metamorphism.

It follows that structural levels 2, 3 and 4 had experienced peak metamorphism prior to ca. 1100 Ma and probably prior to ca. 1160 Ma.

3.5 METAMORPHISM IN THE HUNTSVILLE REGION

3.5.1 Algonquin thrust stack

Rocks in the Algonquin thrust stack record uppermost amphibolite and granulite facies metamorphic conditions. The widespread occurrence of granitic leucosome in metasediments and plutonic rocks is perhaps the most common, obvious manifestation of high grade regional metamorphism (Fig. 2.5 f, 2.6 e, 2.7 a, 3.4 a and b). Felsic leucosome is also widespread in more mafic rock types including metagabbros. Characteristic mineral assemblages in pelitic gneisses include sillimanite - garnet - biotite - K-feldspar - plagioclase - quartz - graphite - pyrite - Fe-Ti oxydes (Fig. 3.8). While cordierite and staurolite have not been found in the area, a little muscovite occurs locally in retrograded assemblages. Granulite facies rocks typically include orthopyroxene - clinopyroxene - garnet - hornblende - biotite - antiperthite +/- quartz (Fig. 3.4 c).

The western half of Novar footwall is dominated by uppermost amphibolite facies rocks which enclose kilometre-size isolated masses of granulite facies orthogneisses. In places both granulite and amphibolite facies assemblages are present in the same outcrop. In these instances, field relationships suggest that the amphibolites are derived from the granulites during post-peak metamorphic deformation. This is consistent with the widespread development of upper amphibolite facies assemblages in gneissic metagabbros. Retrogression from granulite to amphibolite facies is also observed in the wall-rocks of late-synectonic pegmatites.

The Huntsville thrust zone (Nadeau 1988; Chapter 2) comprises a 3-5 kilometre thick succession of shallowly southward dipping imbricated sheets, 10-1000 metre thick, of fine-grained, flaggy, straight gneiss, mylonitic orthogneiss and pelitic and semi-pelitic gneiss. These rocks exhibit a very strong L/S fabric and do not retain textural evidence for a pre-Grenvillian metamorphism and deformation. Deformation in the structurally lower section of the Huntsville thrust zone occurred under granulite facies conditions (Fig. 3.4 a and c), whereas both granulite and upper amphibolite facies fabrics are widespread at upper structural levels, where the latter overprint the former. Granulite to amphibolite facies transitions are observed in two structural contexts: (1) broad zones of well foliated amphibolite are developed at the margins of mafic granulite boudins; (2) granulites are converted to amphibolite facies in narrow zones cored by late-tectonic granoblastic extensional shear zones (Manojlovic 1987). Moreover, peak metamorphic anatectic and meta-

metamorphic segregations are attenuated and transposed into the foliation (Fig. 2.5 f, 2.6 e and 2.7 a, b and c). These field relationships show that (i) deformation throughout the Huntsville thrust zone occurred initially under granulite facies and/or anatectic conditions; (ii) post-granulite amphibolite facies deformation was preferentially localised in the upper section of the thrust zone; (iii) intense deformation post-dated attainment of peak conditions; and (iv) post-peak metamorphic deformation did not continue at temperatures below those of the amphibolite facies.

3.5.2 Seguin thrust sheet

The Seguin thrust sheet is composed primarily of amphibolite facies, granitic to granodioritic migmatitic gneisses (Fig. 2.11 c, 3.5 a and b). Granitic veins and stromatic leucosome commonly form 20 to 25% of the rocks, no parts of which can be assumed unchanged and equated with the protolith or paleosome. The mafic mineral subassemblage garnet - hornblende - biotite is characteristic of Seguin gneisses. These migmatitic rocks are derived from both recognisable plutonic protolith and monotonous gneiss likely of plutonic origin; no gneiss demonstrably derived from sedimentary protolith has been found in the studied area. In large exposures, the leucosome and the granitic veins commonly exhibit a variety of structural relationships to the foliation ranging from cross-cutting to transposed and disaggregated (Fig. 3.5 c). Along the basal thrust zone, the leucosome and the veins are transposed into a straight gneiss fabric (Fig. 2.11 a).

The Seguin thrust sheet also hosts several small wedge-shaped masses of orthopyroxene-bearing charnockitic orthogneisses. In favourable exposures these orthogneisses exhibit an early foliation that is sheared and crenulated (Fig. 3.5 d and 4.3 g). The shear direction and the crenulation axial surface are parallel to the Seguin planar fabric outside the body. This granulite fabric is best interpreted as a pre-thrusting and migmatization fabric.

3.6 THERMOBAROMETRY

Recent thermobarometric studies indicated that peak metamorphic conditions in the Huntsville area were of the order of 700 to 830 °C and 8 to 10.5 kbar i.e. essentially within the kyanite stability field, but straddling the kyanite / sillimanite boundary (Fig. 3.6 and 3.11; Appendix 1; Anovitz and Essene 1990; Grant 1987; Manojlovic 1987). Moreover, Anovitz and Essene (1990) also suggested that the postpeak P-T-t path for the Huntsville area also lies within the kyanite stability field (Fig. 3.7). This result is inconsistent with the observations of this study which establish that sillimanite was the stable aluminosilicate during the late-stages of the foliation development (Fig 3.8). In this study an attempt is made to construct a P-T-t path that is consistent with the available metamorphic, structural and geochronological data and with new pressure and temperature estimates made in the course of this study. This study will also provide an opportunity to determine whether a thermobarometric break can be detected between the Huntsville

thrust zone and the Novar footwall.

3.6.1 Sampling and analytical strategy

In order to obtain representative and comparable pressure and temperature determinations, ten widely separated samples of pelitic gneiss were selected from the Huntsville thrust zone, the Novar footwall and the overlying McClintock thrust sheet (Fig. 3.9). Pelitic gneisses commonly exhibit transposed and attenuated leucosomes, indicating that foliation development outlasted peak metamorphism. In all samples, sillimanite and biotite define the foliation and no retrograde mineral overgrowth is present (Fig. 3.8). Therefore, the coexisting minerals record a post-peak metamorphic equilibrium which represents the pressure and temperature conditions prevailing during or after the final stages of foliation development. The pelitic samples contain coexisting garnet - biotite - plagioclase - sillimanite - quartz - K-feldspar - Fe-Ti oxide - graphite - pyrite (Fig. 3.8). In such low variance systems, the cation partitioning between solid-solution phases is controlled by the value of the intensive variables P and T and is independent of the bulk composition of the system. The selected samples show no evidence of retrogressive alteration.

Temperature and pressure estimates were obtained through the simultaneous solution of the equilibria

and

using Berman's (1988a) method for thermobarometric calculations, the revised garnet solution model of Berman (1990) and the thermodynamic data base of Berman (1988b).

Mineral analyses were obtained by energy dispersive electron microanalysis at the Geological Survey of Canada. The same set of well analysed mineral standards were used for each calibration of the instrument. Standard operating conditions were as follows: 20 kV accelerating potential, 20 nano amps specimen current on kaersutite standard and 60 seconds counting time. The beam was focused to a fine point (approx. 2 μm) for all minerals except plagioclase where a defocussed beam was used to minimise Na loss during the analysis. The EDDI program of Pringle (1990) was used for data reduction. Complete analyses of all minerals are reported in Appendix 2.

3.6.2 Confidence limits

In all thermobarometric studies it is imperative to evaluate the confidence limits on calculated pressures and temperatures and to assess how they restrict the interpretation of the results. There are four sources of uncertainty in thermobarometry (Essene 1982; Powell 1985; Hodges and Crowley 1985; Hodges and McKenna 1987, McKenna and Hodges 1988). These are: (i) analytical uncertainty inherent to electron-microanalysis; (ii) uncertainty due to undetected or neglected disequilibrium effects; and those due to deficiencies in (iii) calibration and (iv) solution modelling.

In this study a single thermobarometric calibration pair is applied to a suite of pelitic gneisses in order: (i) to determine the "absolute" equilibration temperature and pressure of each sample; and (ii) to contrast the "relative" equilibration temperatures and pressures in a number of samples from the Huntsville thrust zone and the Novar footwall. Because the same pair of thermobarometric equilibria is applied to petrographically similar samples, the cumulative uncertainty due to deficiencies in calibration and solution modelling probably affects the data set systematically. In such a case, the confidence limits for "relative" thermobarometry depend primarily on analytical uncertainty which is qualitatively estimated to ± 60 °C and ± 0.5 kbar (McKenna and Hodges 1988; Essene 1982). In "absolute" thermobarometry, the confidence limits depend on the cumulative effects of all sources of uncertainty and the P-T results are viewed as broad

indications of the equilibrium conditions. For the equilibria used in this study, which are among the best-calibrated and the most commonly used, the cumulative uncertainty due to experimental calibration, extrapolation from experimental to geological conditions and those due to deficiencies in the solution model used to correct for nonideal solution behaviour, are probably in the order of ± 5 kbar and ± 50 °C at the 95% confidence level (Hodges and McKenna 1987). Despite these considerations, the calculated pressures and temperatures reported in Table 3.1 have not been rounded to the first significant figure because rounding would move the results in an arbitrary direction.

3.6.3 Mineral zoning

In each polished thin section, between 2 and 4 microdomains, several millimetres apart, containing sillimanite - garnet - biotite - plagioclase - K-feldspar - quartz were selected for thermobarometry. Within each microdomain, thermobarometric mineral pairs separated by neutral phases were selected in order to minimise late-reequilibration effects (Fig. 3.8 a; Tracy and Robinson 1976; Selverstone and Hollister 1980, St-Onge 1984). The effects of late reequilibration were evaluated independently by analysing mineral pairs in mutual contact. Between 50 and 80 spots were analyzed in each microdomain to detect compositional variations (Fig. 3.8). All mineral analyses are reported in Appendix 2 together with plots illustrating the compositional variability within microdomains and

between them. Small differences in composition are observed from one microdomain to another. Within a given microdomain, biotite and plagioclase away from garnet are compositionally homogeneous within analytical error. Most garnets show zoning patterns typical of slowly cooled crystals that have been heated above the compositional homogenisation temperature of ca. 650 °C (Fig. 3.10 and Appendix 2; Tracy 1982; Bohlen 1987). They preserved no evidence of prograde growth, but exhibit a broad, relatively homogeneous core in which compositional fluctuations are due to the presence of mineral inclusions. The extent of the compositional re-equilibration in the rims depends on the nature of the adjacent mineral. Near contacts with neutral phases, zones a few tens of μm thick are slightly, but systematically, enriched in Fe and depleted in Mg. Broad halos enriched in X Fe and depleted in X Mg by up to 15% occur adjacent to biotite. Conversely, biotite in contact with garnets shows complementary compositional variations. Such halos are attributed to extensive retrograde Fe-Mg exchange between biotite and garnet (Tracy 1982). Most workers agree that rim compositions, away from the retrograde halos of the type just described, record retrograde changes conditions (Bohlen 1987).

In this thermobarometric study, we have i) selected plateau compositions (near the break in slope between the core and the rim in the compositional profiles) in order to minimize the effects of late-reequilibration and ii) used the composition of mineral pairs in mutual contact to evaluate the effects of late reequilibration.

3.7 DISCUSSION

The P-T results are summarised in Table 1 and their relative structural and geographical positions are depicted in Figure 3.9. Despite the broad confidence limits attached to P-T determinations, it is remarkable that: (i) in a given sample the P-T results are reproducible from one microdomain to another; and (ii) P-T results from the Huntsville thrust zone and the Novar footwall form distinct data sets.

It is emphasised that the results of the present thermobarometric study do not represent peak metamorphic conditions but depict pressure and temperature conditions prevailing during or after the final stages of the deformation (the leucosomes are generally transposed and attenuated). In this context, it is noteworthy that the pressure and temperature estimates are consistent with constraints independently provided by the assemblage of coexisting minerals and with the approximate position of initial melting reactions in carbonate and sulfide free metapelites (Fig. 3.11).

3.7.1 Tectonic significance of the P-T results

Pressure and temperature conditions of equilibration in the Novar footwall are slightly, but systematically, higher than in the Huntsville thrust zone; the average difference is approximately 1.5 kbar and 35 °C (Fig. 3.9). The difference in pressure is larger than the confidence limit of the barometer and within the

confidence limit of the thermometer for "relative" thermobarometry. There are two possibilities: either the differences are insignificant or the estimated values reflect real differences in the conditions of equilibration.

The first possibility is supported by rigorous statistical analysis. The differences between the P and T averages of the two populations cannot be considered as significant at the third confidence level. Further support for this contention is provided by the following independent considerations which suggest that the equilibria were "blocked" after tectonic assembly during slow cooling. (i) The zoning pattern observed in the garnets is similar to that resulting from reequilibration during slow post-peak cooling. (ii) In general, the rocks from the Huntsville region are annealed. (iii) The timing (U/Pb) of blocking for lead diffusion in monazite indicates that the rocks remained at temperatures in excess of 700 °C for at least 30 Ma after development of the granulite facies fabric (Chapter 4). Such a long residence time under high temperature conditions favours diffusion-controlled textural and compositional reequilibration. According to this scenario, no tectonothermal significance could be attributed to the detected P-T differences between the Huntsville thrust zone and Novar footwall. Nonetheless, the P-T determinations provide a set of first-order constraints on the post-peak metamorphic and deformation, retrograde P-T-t path.

Let us now consider the possibility that the detected differences may be significant. It is remarkable that, in spite of the broad confidence limits and the

retrograde equilibration, P-T results are reproducible from one microdomain to another within a given sample and that systematic differences are detected between the rocks of the Huntsville thrust zone and those of the Novar footwall. Moreover, similar differences have been reported in other thermobarometric studies in which the same pair of equilibria was used, suggesting that these thermobarometers are better than statistical rigor might otherwise imply (Hodges and McKenna 1987). Accordingly, the possibility that these detected P-T differences are real cannot be ruled out. In order to pursue this line of reasoning, one must consider the question of synchronous or diachronous "blocking" of the equilibria across the area. In the synchronous case, the observed differences could be explained tectonically, either by post-equilibration regional north-side-up tilting during uplift, or by top-side-down to the southeast extensional faulting. However, according to the barometric data, the depth difference between the thrust zone and the footwall is approximately 5 kilometre. From the thermometric data, this would imply a geothermal gradient of approximately 7 °C/kilometre. Whereas the deduced depth difference is compatible with the present southeastward dipping geometry of the Huntsville thrust zone, the calculated temperature gradient is too low for either model. Furthermore, all known shear-sense indicators in the Huntsville area are related to regional north-west-directed thrusting. Regardless of these tectonic and thermal arguments, either of these models requires geochronological proof of the validity of the premise of synchronous blocking before it can be seriously entertained. In the diachronous

case, the observed differences between the thrust zone and the footwall would reflect different times of blocking as the material is uplifted and cooled. Such diachronous blocking represents the influence of a number of variables on the kinetics of the relevant reactions, such as diffusion rate.

3.7.2 Application to structural studies

Recent studies have attempted to detect the presence of important thrust zones within the high grade gneisses of the Central Gneiss Belt (Indares and Martignole 1989). In the light of the thermobarometric results of this study, it is perhaps appropriate to discuss the general applicability of such an approach in a middle to lower crustal tectonic setting. Displacement across faults, be they contractional or extensional, can be evaluated using thermobarometry, only if the pair of equilibria used as thermobarometers blocked synchronously on both sides of the fault prior to displacement and was not subsequently disturbed during the post-thrusting thermal history.

The "sine qua non" conditions stated above are in practice very difficult to satisfy. If the initial temperature difference across the fault is within the range of thermometric detection, as discussed above (ca. 50+ °C), heat transfer will occur during post-kinematic thermal relaxation. This will promote prograde metamorphism on one side of the fault and retrograde conditions on the other side. Moreover, in mid- to deep crustal faulting environment, the thermal regime of a

given fault must be considered in the context of the fault stack of which it is part. Given the slow cooling associated with mid- to deep crustal conditions, extensive reequilibration of the thermobarometers on the initially cooler side will occur and the post-thrusting metamorphic break is likely to be largely, if not totally, obliterated. For example, even in the case where a metamorphic break is visibly preserved, it is highly unlikely that the recorded magnitude of the break is the same as that resulting from thrusting alone (Crowley 1988).

3.7.3 Peak metamorphism in the Seguin thrust sheet

The structural and metamorphic relationships observed in the Seguin thrust sheet, which structurally overlies the Algonquin thrust stack, demonstrate that its emplacement was accompanied by pervasive migmatisation and intense, penetrative, ductile deformation. Moreover, the migmatitic gneisses of the thrust sheet were progressively transposed into upper amphibolite facies straight gneisses, or granoblastic mylonites (Chapter 2), within its underlying thrust zone. U/Pb zircon dating of a late-synthrusting pegmatite indicates that the granulite facies metamorphism, uppermost amphibolite facies migmatisation and thrusting occurred before ca. 1097 Ma (Chapter 4). Furthermore, the occurrence of ca. 1170 Ma (Davidson and van Breemen 1988) coronitic metagabbro masses within the migmatites of the Seguin thrust sheet, suggests that these rocks remained in the lower crust for at least 70 Ma prior to final thrust emplacement. Although the P-T-t path of the

rocks of the Seguin thrust sheet has not been documented, it is likely that these rocks evolved along a post-thrusting, retrograde P-T-t path similar to that determined for the Algonquin thrust stack discussed below.

3.7.4 Peak metamorphism in the Algonquin thrust stack

Because the Seguin thrust sheet cuts structurally down-section into the Algonquin thrust stack, its ca. 1097 Ma age of late-tectonic emplacement provides a minimum age for deformation and high grade metamorphism in the Algonquin thrust stack. Coronitic metagabbro occurs as boudined masses within the granulite and amphibolite facies straight gneisses of the Huntsville thrust zone. Therefore the rocks of the thrust zone were at great crustal depth at 1170 Ma and granulite facies deformation within the thrust zone continued for some time after this date. However, there is presently no constraint on the initiation of granulite facies metamorphism and deformation within the Huntsville thrust zone. Moreover, the occurrence of relict eclogitic rocks in the Huntsville thrust zone and Novar footwall, coupled with the absence of eclogitic assemblages in the coronitic metagabbro, suggests that they experienced a pre-1170 Ma eclogite facies metamorphism.

3.7.5 Retrograde P-T-t path

In a materially continuous, rigid block of crust, undergoing uplift and cooling, all parts experience similar P-T-t paths. Two properties of thermobarometric equilibria can be used to determine these retrograde P-T-t paths.

(1) Within such a materially continuous block, different sets of thermobarometric equilibria will record different regions of the P-T-t paths, according to their relative blocking temperatures and to their sensitivity to down-temperature reequilibration; the temperature and pressure recorded by a given set of thermobarometric equilibria being dependent on the diffusive properties of the mineral phases involved. It follows that P-T vectors can be determined by linking the P-T estimates obtained from different thermobarometric equilibria.

(2) A given set of thermobarometric mineral pair will record different pressures and temperatures according to the variable extent of the kinetically controlled down-temperature reequilibration. Accordingly, retrograde P-T vectors can be determined by linking the pressure and temperature estimates of core and rim of zoned minerals.

This study shows that pelitic gneisses in the Algonquin thrust stack have reequilibrated to varying degree after peak metamorphism and the development of the deformation fabric. Therefore, assuming a simple cooling history and anchoring the trajectory defined by the P-T estimates from the pelitic rocks to the peak metamorphic conditions determined from mafic assemblages (Anovitz 1987; Grant 1987;

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Manojlovic 1987; Anovitz and Essene 1990), it is possible to reconstruct the high temperature region of the P-T-t path itself. The low temperature region of the retrograde P-T-t path is constrained by core-rim P-T vectors.

The deduced retrograde P-T-t path traverses the sillimanite field (Fig. 3.11 and 3.12). This agrees with the widespread occurrence of syntectonic sillimanite in the Huntsville area but contrasts with that proposed by Anovitz and Essene (1990) which lies within the kyanite field (Fig. 3.7).

The time span from attainment of peak metamorphic temperature to monazite blocking for U-Pb diffusion remains unknown. Nevertheless, first order constraints on the post-thrusting cooling history of the area (Fig. 3.13) are provided by i) the ca. 1100 Ma minimum age for peak metamorphism, ii) the monazite blocking ages ca. 1067 Ma (Chapter 4; at an estimated temperature of 725-700 °C by Parrish, in prep.), iii) the hornblende cooling ages ca. 1000 Ma (Cosca et al., in prep.; based on an estimated $^{40}\text{Ar}/^{39}\text{Ar}$ blocking temperature of 480-500 °C by Harrison 1981) and iv) the biotite and muscovite cooling ages ca. 890 Ma (Cosca et al., in prep.; based on $^{40}\text{Ar}/^{39}\text{Ar}$ blocking temperatures of 280 °C for biotite as estimated by Harrison 1985 and of 300 °C for muscovite as inferred by Cosca et al., (in prep)). These data (Fig. 3.13) indicate very slow cooling from peak metamorphic conditions to blocking of the monazite ca. 1067 Ma, followed by much more rapid cooling and uplift. According to this model, variable cooling rates up to 10 °C/Ma, i.e. three times faster than those estimated by Cosca et al. (in prep.), are

deduced. Moreover, even faster cooling rates may be obtained by fitting steeper cooling curves to the data set. In any case, the early part of the cooling history cannot be linear as suggested by Cosca et al. (in prep.).

The P-T path proposed in this study for the Huntsville region closely follows the theoretical path modelled by England and Thompson (1984) for a crustal block buried at 60 kilometre depth by a 50 kilometre thick thrust sheet and exhumed by erosion over a ca. 70 Ma period, starting 20 Ma after thrusting (Fig. 3.14). However, England and Thompson model predicts cooling from 700 to 500 °C in 20 Ma i.e. three times faster than that deduced for the Huntsville region where a time span in excess of 100 Ma separates attainment of peak metamorphic conditions prior 1100 Ma and cooling to 500 °C, ca. 1000 Ma (Cosca et al. in prep.), via cooling to 700 °C, ca. 1067 Ma (Chapter 4).

3.7.6 Regional implications

The above discussion of the tectonothermal history of the Huntsville area can be extended to the southwestern Central Gneiss Belt. Since the coronitic metagabbros occur throughout the region in a similar structural context to those in the Huntsville area, it is reasonable to propose that the region as a whole lay within the lower crust prior to ca. 1170 Ma. By similar reasoning to that already detailed for the case of the Huntsville area, the existence of relict eclogitic rocks in the Rosseau subdomain offers further support for this contention (Grant 1989; Davidson

1990). Furthermore, reworking of deformed hangingwall and footwall gneisses in the 1160 Ma ductile thrust zone at the base of the Parry Sound thrust sheet, provides an independent minimum age constraint for the high grade peak metamorphism in this area.

Therefore, the late-stage thrusting ca. 1060-1030 Ma in the Central Metasedimentary Belt boundary thrust zone (van Breemen and Hanmer 1986; Hanmer 1988) is not the primary cause of high grade metamorphism in the southwestern Central Gneiss Belt. Moreover, if the pre 1160 Ma deformation and metamorphism recorded in the southwestern Central Gneiss Belt is the direct expression of Grenvillian orogenic activity, then the "Grenvillian orogenic cycle" is not constrained to the 1160 - 970 Ma range proposed by Rivers et al. (1989).

Maximum age constraints for peak metamorphism are provided by igneous ages of ca. 1350 Ma for orthogneisses affected by peak metamorphism (van Breemen et al. 1986; Chapter 4).

3.8 CONCLUSIONS

(1) The tectonothermal evolution of the southwestern Central Gneiss Belt is marked by a major crustal thickening event subsequent to the ca. 1500-1350 Ma continental "anorogenic" plutonism and prior to the deep crustal emplacement of coronitic metagabbros ca. 1170 Ma.

(2) Granulite and uppermost amphibolite facies, and intense ductile deformation post-dated the emplacement of the coronitic metagabbros and predated final thrusting of the Parry Sound and Seguin thrust sheet ca. 1160 Ma and ca. 1100 Ma, respectively.

(3) Therefore, the late-stage thrusting ca. 1060-1030 Ma in the Central Metasedimentary Belt boundary thrust zone is not the primary cause for high grade metamorphism in the Central Gneiss Belt. If the crustal thickening and high grade metamorphism in the Central Gneiss Belt resulted from the accretion of the Central Metasedimentary Belt, docking and deformation of the latter must predate ca. 1160 Ma.

(4) Post-thrusting regional cooling to 700 °C, at the level of the present erosional surface, occurred at ca. 1067 Ma. Accordingly, cooling from peak metamorphic conditions to ca. 700 °C took place over a time interval exceeding 30 Ma. Such protracted slow cooling interval provides favourable conditions for annealing of the dynamic microstructure and retrograde mineral reequilibration.

(5) The present data set coupled with the $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende and mica cooling ages show that the early part of the cooling history is non-linear and strongly model dependent. Cooling rates exceeding $10\text{ }^{\circ}\text{C Ma}$ can be modelled.

(6) The thermobarometric data set, derived from pelitic gneisses, depicts post-thrusting retrograde P-T conditions. Assuming a simple cooling history and that the rocks studied were part of a materially continuous, rigid block of crust undergoing uplift, a retrograde P-T-t path can be re-constructed by anchoring the P-T trajectory of the data set to the peak metamorphic conditions characteristic of pristine granulite. The deduced retrograde P-T-t path traverses the sillimanite field, in agreement with the widespread occurrence of syntectonic sillimanite in the Huntsville area.

(7) The use of thermobarometry to determine fault throw in mid- to deep crustal tectonic setting is hampered by the high potential of thermobarometers to reequilibrate during the post-faulting thermal relaxation and by the difficulty associated in establishing the ages of the calculated pressures and temperatures.

Table 1: Summary of the thermobarometry. Phase composition data for coexisting biotite, garnet and plagioclase with calculated pressures (kbar) and temperatures (°C); ct. identify mineral pair in contact.

Sample Area	Biotite					Garnet				Plagioclase			P	T
	X Mg	X Fe	X Ti	X Al	X Mn	X Ca	X Mg	X Fe	X Mn	X Ca	X Na	X K	kbar	°C
1 (X171)														
A1	0.586	0.276	0.091	0.046	0.001	0.032	0.336	0.626	0.006	0.207	0.781	0.012	7.4	686
A2	0.602	0.252	0.083	0.063	0.001	0.039	0.334	0.620	0.006	0.208	0.780	0.012	7.5	650
A3	0.606	0.252	0.085	0.056	0.000	0.039	0.335	0.622	0.005	0.209	0.777	0.014	7.4	647
2 (X375)														
A1	0.367	0.460	0.095	0.077	0.000	0.056	0.172	0.749	0.023	0.312	0.674	0.015	7.9	772
A2	0.387	0.452	0.085	0.076	0.000	0.056	0.162	0.759	0.023	0.306	0.679	0.015	7.0	715
A3	0.381	0.446	0.085	0.086	0.001	0.057	0.173	0.746	0.023	0.309	0.677	0.014	7.7	750
3 (X195)														
A1 ct.	0.504	0.322	0.098	0.075	0.000	0.031	0.245	0.708	0.015	0.210	0.773	0.016	5.5	631
A1	0.504	0.322	0.098	0.075	0.000	0.034	0.256	0.695	0.015	0.210	0.773	0.016	6.4	658
A2 ct.	0.498	0.322	0.062	0.118	0.001	0.039	0.177	0.758	0.025	0.214	0.773	0.013	4.1	528
A2	0.498	0.322	0.062	0.118	0.001	0.043	0.245	0.697	0.015	0.214	0.773	0.013	7.5	670
A3	0.482	0.345	0.097	0.076	0.001	0.035	0.257	0.693	0.015	0.211	0.777	0.013	7.4	711
A4	0.501	0.323	0.094	0.081	0.001	0.037	0.261	0.687	0.015	0.214	0.770	0.016	7.1	679
4 (X182)														
A1	0.405	0.423	0.099	0.073	0.001	0.077	0.187	0.732	0.003	0.369	0.620	0.011	8.4	750
A2	0.421	0.415	0.084	0.079	0.000	0.071	0.202	0.716	0.011	0.368	0.623	0.009	8.4	769
5 (X413#1d)														
A1	0.422	0.414	0.073	0.091	0.001	0.033	0.160	0.779	0.028	0.190	0.799	0.011	5.6	622
A2	0.431	0.408	0.077	0.085	0.000	0.033	0.170	0.773	0.025	0.193	0.795	0.012	5.7	631
A3	0.438	0.404	0.077	0.080	0.000	0.033	0.174	0.768	0.025	0.193	0.797	0.010	5.8	633
6 (X317)														
A1	0.469	0.344	0.088	0.098	0.001	0.042	0.243	0.709	0.006	0.283	0.701	0.016	6.2	692
A2	0.491	0.326	0.082	0.100	0.001	0.043	0.227	0.720	0.010	0.285	0.700	0.015	5.1	625
A3	0.450	0.331	0.081	0.137	0.000	0.041	0.227	0.722	0.010	0.292	0.690	0.014	5.2	657
7 (X39)														
A1 ct.	0.515	0.287	0.095	0.102	0.000	0.037	0.250	0.708	0.005	0.249	0.732	0.019	4.7	589
A1	0.528	0.295	0.126	0.000	0.001	0.034	0.286	0.674	0.006	0.249	0.732	0.019	5.5	618
A2	0.561	0.293	0.104	0.041	0.001	0.035	0.313	0.647	0.005	0.241	0.741	0.018	6.6	681
A3 ct.	0.547	0.297	0.102	0.053	0.000	0.034	0.226	0.735	0.004	0.249	0.729	0.021	3.3	535
A3	0.543	0.306	0.102	0.049	0.000	0.037	0.298	0.659	0.006	0.249	0.729	0.021	6.6	688
8 (X38)														
A1 ct.	0.440	0.374	0.097	0.088	0.001	0.033	0.176	0.769	0.022	0.233	0.754	0.012	4.1	590
A1	0.440	0.374	0.097	0.088	0.001	0.036	0.206	0.733	0.024	0.233	0.754	0.012	5.9	669
A2	0.458	0.363	0.091	0.086	0.001	0.036	0.223	0.719	0.021	0.232	0.755	0.013	6.3	682
A3 ct.	0.493	0.332	0.084	0.091	0.001	0.038	0.195	0.744	0.023	0.251	0.737	0.013	4.0	565
A3	0.493	0.332	0.084	0.091	0.001	0.036	0.226	0.721	0.021	0.251	0.737	0.013	4.8	616
9 (X429)														
A1	0.503	0.342	0.098	0.057	0.000	0.034	0.283	0.650	0.033	0.235	0.753	0.012	7.6	754
A2 ct.	0.522	0.342	0.091	0.044	0.000	0.033	0.266	0.671	0.030	0.234	0.755	0.011	6.5	701
A2	0.522	0.342	0.091	0.044	0.000	0.034	0.285	0.649	0.032	0.234	0.755	0.011	7.5	746
A3 ct.	0.503	0.356	0.095	0.045	0.001	0.033	0.246	0.686	0.035	0.235	0.753	0.012	6.1	690
A3	0.521	0.341	0.091	0.046	0.001	0.034	0.282	0.653	0.032	0.235	0.753	0.012	7.3	738
10 (X472)														
A1	0.535	0.310	0.072	0.083	0.001	0.031	0.262	0.683	0.024	0.253	0.734	0.013	4.8	639
A2	0.526	0.315	0.073	0.085	0.001	0.031	0.281	0.669	0.018	0.252	0.734	0.014	5.6	687
A3	0.524	0.313	0.072	0.089	0.001	0.032	0.267	0.680	0.021	0.246	0.740	0.014	5.4	661
A4	0.512	0.322	0.083	0.083	0.001	0.034	0.263	0.673	0.029	0.256	0.731	0.013	5.7	677

Figure 3.1 Generalized structural map and schematic cross-section of the southwestern Central Gneiss Belt (after Davidson 1984b and Rivers et al. 1989); A subdivision of the southwestern Grenville province, (after Wynne-Edwards 1972); B proposed subdivision of the belt into superincumbent units (Chapter 2). The bold-faced rectangle refers to Figs. 3.6 and 3.9. Northwest of the Grenville Front: 1 and 2 Archean (Ar) supracrustal and plutonic rocks, 3 Lower Proterozoic supracrustal rocks (Huronian Supergroup hsg) and Nipissing diabase sheets, 4 Sudbury irruptive, 5 Whitewater Group, 6 Killarney plutonic suite. Central Gneiss Belt (CGB): 7 gneissic rocks of varied origin, 8 anorthosite, gabbro and derived gneiss, 9 granitoid metaplutonic rocks, 10 Grenville Front and Central Metasedimentary Belt boundary thrust zone (CMBbtz), 11 southeast margin of the Grenville Front Tectonic Zone (GFTZ), 12 tectonic boundaries in the southwestern Central Gneiss Belt; B Britt domain, PS Parry Sound thrust sheet, S Seguin thrust sheet, 13 Paleozoic (P) sedimentary cover. Line A - B is cross-section. CMB Central Metasedimentary Belt, CGT Central Granulite Terrane, M Montreal.

Figure 3.2 Structural setting and internal structure of the Algonquin thrust stack (shaded area). Numbers refers to the subdivision of the southwestern Central Gneiss Belt into superincumbent structural levels and give the late-thrusting stacking sequence. Structural boundaries after Culshaw et al. (1983) and Davidson and Grant (1986).

Figure 3.3 Distribution of coronitic olivine metagabbro (solid circles) and relict eclogite (open squares) in the southwestern Central Gneiss Belt (after Davidson et al. 1982; Davidson and Grant 1986 and Davidson 1990).

Figure 3.4 Metamorphic structure and texture in granulite and uppermost amphibolite facies rocks from the Huntsville thrust zone and in coronitic olivine metagabbro. **a** Hornblende-plagioclase-quartz metamorphic segregations in two pyroxene, mafic granulite. These segregations are developed in the sheared margin of the boudin illustrated in Fig. 2.8 a; the core of the boudin is homogeneous granulite. **b** Granitic leucosome in recrystallized, fine grained, foliated and crenulated, garnet-hornblende quartz-dioritic orthogneiss. **c** Characteristic annealed texture of granulite facies straight gneiss; orthopyroxene (o), clinopyroxene (c), hornblende (h) and garnet (g). **d** Coronitic olivine metagabbro exhibiting successive pyroxene, plagioclase and garnet coronas between relict (serpentinized) olivine and plagioclase. Some plagioclase crystals are clouded with spinel inclusions.

Figure 3.5 Variability of high grade metamorphic structures of Seguin thrust sheet migmatitic gneisses. **a** and **b** Typical, coarse grained, partly recrystallized, folded, stromatic, granitic leucosome in low strain, well-foliated, biotite hornblende granodioritic gneiss. The melanosome is restricted to thin, centimetre-wide, selvages along the leucosome-mesosome interface. Such migmatitic gneiss is commonly fairly homogeneous at exposure scale and can be locally traced into non-migmatitic orthogneiss. **c** Contrasting, polyphase metamorphic structures expressed via folding and boudinage of secondary layering and injection of granitic veins. The layering is partly derived from the transposition of mafic dykes and stromatic leucosome. **d** Foliated and crenulated, granulite facies, mangeritic orthogneiss showing the initial structure associated with incipient leucosome development (see also Fig. 4.3 g); this stage is marked by grain-size coarsening and destruction of the preexisting fabric.

Figure 3.6 Summary of the peak metamorphic thermobarometric data for the Huntsville area, after (A) Anovitz and Essene (1990), (G) Grant (1987) and (M) Manojlovic (1987). **A** Temperature distribution in degrees centigrade. **B** Pressure distribution in kilobars. See Appendix 1 for details of the thermobarometry.

Figure 3.7 P-T path proposed by Anovitz and Essene (1990) for the Huntsville region. This path is derived from one garnet using garnet - pyroxene - plagioclase core-rim thermobarometry. The kyanite - sillimanite boundary is as calculated by Anovitz and Essene (1990).

Figure 3.8 Metamorphic textures in pelitic gneiss. **a** Typical microdomain selected for thermobarometry (Sample 10, area A). Solid circles and appended numbers identify individual analyses. **b** Characteristic sillimanite contribution to the foliation.

Figure 3.9 Retrograde pressures (kbar) and temperatures (°C) obtained in the present study from pelitic gneisses of the Huntsville area.

Figure 3.10 Examples of garnet compositional zoning profile in terms of X_{Fe} , X_{Mg} , X_{Ca} and X_{Mn} as calculated for thermobarometric determinations (see also Appendix 2).

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Figure 3.11 P-T diagram summarizing pressures and temperatures of retrograded metapelitic rocks from the Huntsville area. Solid circles refer to the best determinations from isolated grains (see text) whereas open circles refer to determinations from mineral pairs in contact; the appended numbers identify the sample and the microdomain, respectively. The squares outline the ranges in peak metamorphic conditions as determined by (A) Anovitz and Essene (1990), (G) Grant (1987) and (M) Manojlovic (1987) for the Huntsville area.

Reactions (1) and (2) outline the stability field of kyanite and sillimanite (Holdaway 1971). Reactions (3) ($\text{mus} + \text{alb} + \text{bio} + \text{ksp} + \text{qtz} + \text{vapor} = \text{melt}$), (4) ($\text{mus} + \text{alb} + \text{qtz} = \text{bio} + \text{ksp} + \text{Al}_2\text{SiO}_5 + \text{melt}$), and (5) ($\text{Al}_2\text{SiO}_5 + \text{bio} + \text{ksp} + \text{alb} + \text{qtz} = \text{melt}$) depict the approximate position of initial melting in the carbonate and sulfide free complex pelitic system $\text{CaO-K}_2\text{O-Na}_2\text{O-FeO-MgO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$ (Thompson and Tracy 1979; Thompson 1982). Initial melting will occur at the P-T conditions of reactions (3) and (5) if aqueous fluid is present (wet melting) whereas reaction (4) mark the beginning of dehydration melting (dry melting). Reaction (6) ($\text{amp} + \text{plg} + \text{cpx} + \text{qtz} + \text{vapor} = \text{liquid}$) marks the beginning of melting in hydrous amphibolites (Yoder and Tilley 1962).

Figure 3.12 P-T-depth diagram illustrating the possible retrograde P-T-t trajectory of the Huntsville region. The high pressure part of the curve is anchored to a lower age limit of ca. 1100 Ma. The age of cooling below ca. 700 °C and ca. 500 °C are constrained by U-Pb monazite and ⁴⁰Ar/³⁹Ar hornblende blocking ages respectively (see text for details). Reactions are labelled as in Fig. 3.10. Labelled P-T fields: eclogite facies (E), granulite facies (G), kyanite-sillimanite (K/S) and andalusite-sillimanite (A/S) facies series. Crustal depth derived assuming an average rock density of 2.8 gcm⁻³.

Figure 3.13 T-time diagram and possible cooling path for the Huntsville region. The cooling path is constructed by anchoring the monazite blocking ages (B) to the ca. 1100 Ma lower age limit for peak metamorphic temperature (A) and to the $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende (C) and combined muscovite and biotite (D) cooling ages. Solid circles on the proposed cooling path identify points with cooling rates of 2.5 and 10 $^{\circ}\text{C}/\text{Ma}$. Both much shallower and steeper paths can also be fitted to the data set (i.e. the cooling path and cooling rates are strongly model dependent). The $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages are from Cosca et al., (in prep).

Figure 3.14 Retrograde P-T path for the Huntsville area (heavy line) and comparable modelled P-T-time paths (thin lines) of England and Thompson (1984) for rock involved in a continental thickening episode resulting from the emplacement of a 50 kilometre thick thrust sheet. The P-T-t paths for rocks initially buried at 30, 40, 50, 60 and 70 kilometre below the surface are shown by thin lines with solid circles at 10 Ma intervals. The thermal model assumes (1) a 20 Ma interval between the emplacement of the thrust sheet and the onset of erosion, (2) erosion of 50 kilometre at a constant rate over the subsequent 50 Ma, (3) a thermal conductivity of $2.25 \text{ Wm}^{-1}\text{k}^{-1}$ and (4) an average surface heat flux of 60 mWm^{-2} . Reaction curves (3) and (5) and the P-T fields of the andalusite-sillimanite and kyanite-sillimanite facies series are labelled as in Fig. 3.12.

Chapter 4

**U-Pb ages of Middle Proterozoic deformation,
metamorphism and plutonism,
Huntsville region, southwestern Grenville orogen**

4.1 ABSTRACT

The southwestern Central Gneiss Belt consists of distinct rock assemblages ranging in age from Archean to Middle Proterozoic and comprises a number of northwest transported, mid- to deep crustal thrust sheets which constitute one of the hallmarks of Grenvillian reactivation. This study reports on ten sets of U-Pb analyses of zircon and monazite from orthogneisses and late synthrusting pegmatites from the region structurally and/or spatially intermediate between the Parry Sound thrust sheet and the Central Metasedimentary Belt boundary thrust zone. These data, combined with published results from adjacent parts of the orogen, allow detailed study of Grenvillian kinematic, thrust sequence and thermal evolution and precise definition of pre-Grenvillian plutonic events.

The intrusion ca. 1097 $\pm$ 3 Ma of a late synthrusting pegmatite near the base of the Seguin thrust sheet is intermediate in age between late-thrusting in the underlying Parry Sound shear zone ca. 1160 Ma and in the overlying Central Metasedimentary Belt boundary thrust zone between 1060-1030 Ma. This, together with a similar age from the basal section of the Moon River thrust sheet, demonstrates a regional and up-structural-section southeastward migration of the limit of northwest-directed thrusting with time. The emplacement of late syntectonic pegmatites ca. 1080 $\pm$ 1 Ma, 1046 $\pm$ 2 Ma and 1027 $\pm$ 2 Ma in the footwall of the Seguin thrust sheet indicates that northwest-directed thrust stacking at higher structural levels may have caused renewed deformation at depth, tens of millions of

years after the main thrust assembly. The development ca. 1039 $\pm$ 4-2 Ma of extensional shear zones demonstrates that the initiation of uplift and associated extension was coeval with the latest stages of the regional northwest-directed shortening.

A lower limit of ca. 1097 $\pm$ 3 Ma for the development of the metamorphic fabric of the Seguin thrust sheet and of its footwall is provided by the age of a late synthrusting pegmatite from near the base of the thrust sheet. This coupled with monazite blocking ages ca. 1065 Ma, indicates that temperatures above ca. 700 C persist for more than 35 Ma after the Grenvillian tectonothermal event.

The pre-Grenvillian history of the southwestern Central Gneiss Belt is marked by ubiquitous, felsic and intermediate plutonism in the 1700-1620 Ma and 1480-1420 Ma ranges. The ca. 1714 $\pm$ 123-71 Ma age of a quartz-monzonite from the Huntsville thrust zone significantly extends the distribution of the rocks of the older suite previously known only from the Grenville Front Tectonic Zone - Lake Nipissing area. The ca. 1444 $\pm$ 12-8 Ma, 1442 $\pm$ 9-8 Ma, 1453 $\pm$ 6 Ma and 1427 $\pm$ 16-13 Ma ages of the other orthogneisses demonstrate the predominance of 1480-1420 Ma plutonism. This and the absence of volumetrically significant Grenvillian orogenic plutonic rocks indicate that the cratonization of the belt was completed more than 100 Ma prior to the Grenvillian Orogeny. The distribution and the consensus of maximum plutonic ages and of Sm-Nd T_{DM} model ages across the southwestern Central Gneiss Belt permit a tentative subdivision of the belt into four crustal age provinces which reflect its pre-Grenvillian growth history.

4.2 INTRODUCTION

The Central Gneiss Belt, southwestern Grenville orogen, consists of poly-deformed gneisses of supracrustal and plutonic origin and comprises a number of geologically distinct, northwest transported, mid- to deep crustal thrust sheets (Culshaw et al. 1983; Davidson 1984, 1986; Culshaw et al. 1988; Chapter 2). In the absence of stratigraphy, precise U-Pb dating of zircon and other accessory minerals provides some of the essential keys to penetrate the Early and Middle Proterozoic igneous, metamorphic and deformational history. This paper seeks to address three principal questions concerning the migration of the limit of thrusting with time, the age of metamorphism and the age of dominant plutonism or cratonization.

Five geologically contrasting structural levels are recognised between the Grenville Front and the Central Metasedimentary Belt boundary thrust zone (Fig. 4.1 inset B; Wynne-Edwards 1972; Culshaw et al. 1983). In the Huntsville area, structural level 2 ("Algonquin Domain" of Davidson and Morgan 1981) is an imbricated stack of northwest-directed thrusts and thrust sheets (Chapter 2) herein termed the Algonquin thrust stack (Fig. 4.2). The stack includes the following structural elements: the Huntsville thrust zone, a major southeast dipping ductile shear zone (Nadeau 1988), a footwall (Novar "subdomain" of Culshaw et al. 1983) and an hangingwall made up of two thrust sheets bounded by ductile shear zones (McCraney and McClintock "subdomains" of Culshaw et al. 1983). The Algonquin thrust stack is immediately overlain by the Seguin thrust sheet (Culshaw et al. 1983;

part of structural level 4), which cuts structurally down section in the direction of transport. The intervening structural level 3 (Parry Sound "domain" of Davidson and Morgan 1981), not represented in the Huntsville area, is underlain by a ductile thrust zone which was active ca. 1160 Ma (van Breemen et al. 1986). The overlying structural level 5, the Central Metasedimentary Belt boundary thrust zone, was active ca. 1060 Ma (van Breemen and Hanmer 1986). The presently available but limited geochronological data suggest a southeastward migration of the limit of northwest-directed thrusting with time, a trend reflected within the Huntsville area by the out-of-sequence nature of the Seguin thrust sheet. Precise dating of the emplacement of the Seguin thrust sheet and of displacements within the Huntsville thrust zone will allow this hypothesis to be tested, both at the scale of the southwestern Central Gneiss Belt and within the Huntsville area, and will refine our understanding of the variation in the thrust displacement pattern with time.

Understanding of the tectonothermal evolution of the southwestern Central Gneiss Belt requires reliable estimates of the timing of metamorphism. Until now, U-Pb dating has yielded precise ages of pre- and syntectonic intrusions temporally delimiting igneous rock-forming events and deformation (Krogh et al. 1968; Krogh and Davis 1968, 1973; Krogh and Wardle 1984; van Breemen et al. 1986; van Breemen and Hanmer 1986; Davidson and van Breemen 1988; van Breemen and Davidson 1988). In this study, three types of U-Pb data have been obtained which yield information on the timing of regional metamorphism, namely,

the age of late syntectonic pegmatites which cross-cut the high grade fabric of their wallrock, lower concordia intercepts of mixed zircon populations from metaplutonic rocks consisting of inner igneous cores and outer metamorphic rims and monazite cooling ages. This is complemented by the U-Pb ages of two types of metamorphic zircons from coronitic metagabbro bodies of the same region, one of which forms coronas on igneous baddeleyite (Davidson and van Breemen 1988; van Breemen and Davidson 1990). This data base provides lower age limits for the development of the high grade metamorphic fabric and constraints on the early cooling history of the area. It serves to discuss the significance of lower concordia intercept ages of metaplutonic rocks and of the ages yielded by metamorphic zircon populations from coronitic metagabbros.

Determination of ages of igneous precursors in the southwestern Central Gneiss Belt (Fig. 4.1) has, hitherto, suggested an absence of Grenvillian age intermediate and felsic plutonism, a bimodal distribution of Middle Proterozoic plutonic ages similar to that of the "granite-rhyolite terranes" of subsurface mid-continental North America (Bickford et al. 1986) and demonstrated the predominance of 1670-1620 Ma plutonism in the Grenville Front-Lake Nipissing area. Furthermore, the distribution of the age data across the southwestern Central Gneiss Belt suggests that the age of predominant initial plutonism (or cratonization) decreases structurally up-section, step-wise towards the southeast (Fig. 4.1 inset C).

The validity of these observations can be tested by extending the isotopic age mapping to the area structurally and geographically intermediate between the Parry Sound thrust sheet and the Central Metasedimentary Belt boundary thrust zone (Fig. 4.1). The U-Pb isotopic data from plutonic rocks reported in the present study provides such a test. By selecting a meta-quartz diorite, the compositional range of dated plutonic bodies is also extended to more mafic compositions. Furthermore, these new ages provide strong support to the hypothesis that the southwestern Central Gneiss Belt may be a tectonically telescoped extension of the "eastern granite-rhyolite terrane" of the mid-continental region (van Breemen and Davidson 1988).

4.3 SAMPLING AND ANALYTICAL PROCEDURE

Fresh samples weighting between 50 and 100 kg were collected. Meta-plutonic rock samples were obtained from exposures of very homogeneous rocks away from potential sources of contamination such as inclusions, pegmatite dykes and mafic boudins. Pegmatite samples were obtained from the interior of bodies at least several tens of centimetres thick. Heavy mineral separates were prepared by standard crushing and fine sand-size rock grinding, Rogers™ table and heavy liquid flotation. The mineral concentrates were washed in warm 10% reagent grade HNO₃ for 10 minutes in an ultrasonic bath and rinsed in water. The least magnetic concentrate (employing a Frantz™ LB-1 separator, front tilt 15 degrees, side tilt 2

degrees and 1.8 amperes current) were sieved to +149, -149+105, -105+74 and -74 micron (μm) size fractions.

Polished grain mounts of randomly picked zircons were made for each sample. Mounted zircons were etched in concentrated HF vapour to enhance internal structure and examined with a scanning electron microscope. Crystals selected for analysis were hand-picked in ethyl alcohol under the microscope. Verification of the quality of the zircons and final fraction selection were done by optical microscopy (100X magnification). All zircon fractions were strongly abraded (Krogh 1982) commonly until the crystals assumed an elliptical, well rounded shape (Fig. 4.4 a) to minimize the effects of peripheral lead loss.

The chemical extraction procedure used for U-Pb isotopes in zircon and monazite is summarized by Parrish et al. (1987). Mass spectrometry, data reduction and method of propagation of analytical uncertainties of the relevant components in the calculation of isotopic ratios and ages, followed the numerical procedure of Roddick et al. (1987). A modified form of York's (1969) method for linear regression analysis was used (see Parrish et al. 1987). The isotopic data are presented in Table 4.1 and displayed in Figures 5, 7-9 and 11-15 where the notation for the plotted data points is similar to that in Table 4.1. All age uncertainties are given at the second confidence level (95%).

4.4 AGE OF SYNTECTONIC PEGMATITES

Syntectonic granitic pegmatites are common throughout the southwestern Central Gneiss Belt. They commonly form small bodies typically less than a metre thick, traceable at most for a few tens of metres which cannot be linked to larger plutons. Pre- and early-syntectonic bodies are invariably rotated towards the extension direction, sheared, boudinaged and disaggregated. Late syntectonic pegmatites include those developed during late-stage northwest-directed thrusting (Fig. 4.3 a and c), as well as post-thrusting bodies (Fig. 4.3d) emplaced in extensional or contractional shear zones associated with extension, uplift and gravitational collapse of the thickened crust (Nadeau 1985, 1990; Chapter 2). Although commonly internally foliated and partly rotated, late synthrusting pegmatites remain discordant with respect to the fabric of their host gneisses. Post-thrusting pegmatites are commonly internally unstrained and occur in conjugate sets. Where they cut granulite facies rocks, they provoke hydration reactions and are bordered by zones of amphibolite facies wall-rock, several metres wide (Nadeau 1985; Manojlovic 1987).

Five late syntectonic pegmatites (Fig. 4.2) have been studied in order to constrain the age of late-stage northwest-directed thrusting (samples 1 to 4) and of initiation of uplift and accompanying extension (sample 5): sample 1 is from the base of the Seguin thrust sheet; samples 2 and 3 are from the Huntsville thrust zone; sample 4 is from within the McClintock thrust sheet and sample 5 repre-

sents a post-thrusting pegmatite from the Huntsville thrust zone.

(1) Late synthrusting pegmatite, Seguin thrust sheet (X543)

This late syntectonic intrusion, from the northwestern basal section of the Seguin thrust sheet, cuts southeasterly dipping, planar, Seguin migmatitic gneisses (Fig. 4.2 and 4.3 a). These medium grey, garnet-biotite-hornblende granodioritic, highly migmatitic gneisses display a transposed and attenuated leucosome that parallels the mineral foliation and give the rocks a very planar tectonic fabric. These planar gneisses enclose dispersed mafic boudins and sheared and boudined pegmatites at various stages of transposition and disaggregation, attesting to the high shear strains associated with the tectonic emplacement of the Seguin thrust sheet. The sampled pegmatite cuts the southeasterly dipping tectonic fabric of the transposed migmatitic gneisses at a high angle (Fig. 4.3 a). Following crystallization, a weak southeasterly dipping internal foliation developed, demonstrating the late thrusting emplacement of the pegmatite. Its age constrains the lower age limit of northwest-directed thrusting along the northern margin of the Seguin thrust sheet.

Zircon crystals (Fig. 4.4 c) are euhedral, exhibit well developed regular faces limited by sharp edges and terminations. Common crystal shapes include disks, flat and stubby prisms and needles which allow selection of zircon for analysis on the basis of crystal shapes. All the zircons are clear, colourless and are devoid of internal zoning consistent with their low uranium content (≈ 250 ppm U;

Table 4.1). Most crystals lack inclusions. Weakly contrasting cores were detected in a few crystals (Fig. 4.4 d). All analyzed zircons were vigorously abraded such that fractures, if present, were propagated and the broken faces abraded.

The zircon data points lie on two lines (Fig. 4.5) which provide direct evidence for a component of inheritance in the zircon. Three of the zircon fractions are nearly concordant and agreed within analytical error. These data points define a line (MSWD = 2.55) with a lower intercept at 100 Ma and an upper intercept age of 1097 ± 3 Ma, interpreted as the igneous crystallization and emplacement age of the pegmatite as fractions D and F were picked to contain needle-shaped prisms (Fig. 4.4 c), a morphology known generally to lack inheritance. Three other data points plot close to a line (MSWD 2.5) between 1382 ± 50 Ma and a lower intercept of $1088 \pm 9-12$ Ma which corresponds, within analytical error, to the crystallization age of the pegmatite. In view of the late-tectonic nature of the pegmatite, the presence of contrasting cores in some of the zircons and the crystallization ages of metaplutonic rocks from the Seguin thrust sheet (sample 9 and 10; see below), the chord is best interpreted as a mixing line between the crystallization age of the pegmatite and of its wallrock, tentatively assigned at ca. 1400 Ma.

(2) Late synthrusting pegmatite, Huntsville thrust zone (X25)

This foliated and sheared zircon-monazite-garnet-pyrite bearing biotite granitic pegmatite is emplaced in a metre-wide shear zone, cutting across a mafic granulite boudin, a few tens of metres wide, that lies between semi-pelitic and quartzofeldspathic straight gneiss interpreted as granoblastic mylonite (Fig. 4.6 a; Chapter 2). The overall internal foliation of the boudin is parallel to that of the enclosing tectonites. Both this fabric and the boudinage developed under granulite facies. Continued shearing during pegmatite emplacement resulted in local rotation of the wall-rock foliation and retrogression to amphibolite facies. This, together with the fact that the pegmatite is deflected and cut off along the boudin margin with the overlying tectonites attest to post-emplacement ductile deformation. These field relationships demonstrate late synthrusting emplacement of the pegmatite after peak metamorphism, boudinage and development of the overall fabric. Dating this pegmatite provides a constraint on the timing of late Grenvillian deformation within Huntsville subdomain and a lower limit for granulite peak metamorphism. The monazite age provides information on the cooling history.

Abundant zircons were recovered from the non-magnetic separate. Short stubby prisms with smooth, slightly irregular faces and well-defined edges and terminations predominate (Fig. 4.4 f). Such undulating crystal faces contrast with the flat and regular faces typical of zircons from the other pegmatites (Fig. 4.4 b, c). This is attributed to post crystallization deformation and metamorphic effects,

an hypothesis consistent with the relatively old crystallization age (see below) and internal strain state of the pegmatite. Crystals are clear and glassy, slightly pleochroic and exhibit weakly contrasting, regular, euhedral, internal zoning consistent with the low uranium content (≈ 365 ppm; Table 4.1) of the analyzed fractions. Most crystals were inclusion-free and no cores were detected. The weak internal zoning attests to limited fluctuation in the uranium concentration during crystallization. Fracture-free crystals from the coarsest size fraction ($+149 \mu\text{m}$) were selected for analysis and abraded to smooth off faces, edges and terminations.

The zircon data points are slightly discordant, yield similar $^{207}\text{Pb}/^{206}\text{Pb}$ ages and have overlapping error envelopes (Fig. 4.7; Table 4.1). A zircon crystallization age at 1080 ± 1 Ma is obtained assuming minor lead loss at 150 Ma (MSWD = .03). Alternatively, assuming that lead loss occurred at 500 Ma rather than at 0 Ma increases the calculated age by only 3 Ma.

Three additional monazite fractions from this sample show a slight normal discordancy (Fig. 4.7) with $^{207}\text{Pb}/^{206}\text{Pb}$ ages ranging from 1058 to 1065 Ma (Table 4.1). This together with the older zircon age suggest a two stage post crystallization history involving i) an initial slow cooling and lead loss under high temperature conditions which would have caused the monazite composition-time path to approach concordia asymptotically at the time of closing of the system to lead diffusion (Parrish, in prep.) and ii) recent isotopic disturbance which drove the isotopic ratios below concordia. The 7 Ma spread in the $^{207}\text{Pb}/^{206}\text{Pb}$ ages (Table 4.1)

likely reflects the combined effects of initial differences in the isotopic composition and of differential lead loss during slow, high-temperature cooling and uplift. The average and two standard errors of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the two monazite fractions with oldest model ages, that is 1063 ± 3 Ma, is interpreted as the minimum age for the closing of monazite to high temperature lead diffusion.

(3) Late synthrusting pegmatite, Huntsville thrust zone (X322)

The second syntectonic pegmatite sample occurs in a very similar context as sample 2. It is emplaced in the lower half of the Huntsville thrust zone and lies between mylonitic granite orthogneiss and a small amphibolite body. The internal fabric of this one-metre-thick, well-foliated, sheared pegmatite is concordant with that of the underlying mylonitic granite and that marginal to the amphibolite lens. An intrusive apophysis of pegmatite does however cross-cut the foliated margin of the amphibolite lens (Fig. 4.6 b), demonstrating a late syntectonic intrusive relationship. Amphibolite facies metamorphic conditions prevailed during pegmatite deformation. As in the previous sample, the zircon and monazite age of this body provide a lower limit for deformation and metamorphism in the Huntsville thrust zone and information on the cooling history respectively.

This pyrite-bearing biotite granitic pegmatite contains abundant, colourless and glassy, gem quality zircons of various forms (Fig. 4.4 b). Although stubby to needle-shape prisms (aspect ratio in the range 1:1:2 to 1:1:10) dominate, multi-

faceted disc, and spindles and equant crystals exhibiting high index faces, sharp edges and well formed pyramids are common. Fluid inclusions are rare and no zoning or cores were detected in polished and severely etched crystals, attesting to constant uranium concentration during crystallization. All selected zircons are elongated prisms from the $+149\ \mu\text{m}$ size fraction. They are free of detectable fractures and inclusions.

The four zircon data points are clustered slightly below concordia (Fig. 4.7) in accordance with the measured low uranium contents of the zircons (Table 4.1). This, together with the narrow range of $^{207}\text{Pb}/^{206}\text{Pb}$ ages between 1045 and 1049 Ma, indicates a simple post igneous crystallization history for these zircons involving limited recent lead loss. Fractions 3A and 3C, which are slightly displaced from concordia toward older $^{207}\text{Pb}/^{206}\text{Pb}$ ages relative to fractions 3B and 3D, probably host a minor component of inheritance. Accordingly, the best estimate of crystallization age of this pegmatite is considered to be the average and two standard errors of the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the zircon fractions B and D, that is 1046 ± 2 Ma. This age would be increased to 1048 Ma if lead loss at 500 Ma is assumed in the age calculation. Monazite analyses with overlapping error envelopes plot above concordia with $^{207}\text{Pb}/^{235}\text{U}$ ages of 1047.7 and 1049.9 Ma (Fig. 4.7). Within error these ages duplicate the $^{207}\text{Pb}/^{206}\text{Pb}$ zircon ages. The reverse discordancy indicates that the monazite system has not been thermally reset since igneous crystallization. It resulted from syn-crystallization incorporation of ^{230}Th in the monazite structure

(Parrish, in prep.; Schärer 1984). The combined zircon and monazite results indicate that the crystallization of the pegmatite ca. 1046 Ma occurred under temperature conditions below the closure temperature of monazite.

(4) Late synthrusting pegmatite, McClintock thrust sheet (X531)

At this locality within McClintock thrust sheet, medium grained garnet-biotite-hornblende granodioritic gneisses are planar. They host a preferentially oriented leucosome and dip gently to the southeast. The sampled pegmatite intrudes these gneisses at very high angle and has been somewhat folded and rotated towards the northwest (Fig. 4.3 c). The pegmatite is not internally foliated, attesting to late-tectonic emplacement. The cusped margin suggests that movement took place along the host foliation. Accordingly, this sample dates the latest stages of the ductile deformation within the McClintock thrust sheet.

The pegmatite contains abundant clear and colourless, non-magnetic zircons with crystal forms and internal structure closely resembling those of sample 1 and 2 (Fig. 4.4 b and c). Short, doubly-terminated prisms dominate over disc and multi-faceted, ornamented, spindle-shaped crystals. Acicular prisms are rare. Crystal faces are flat, edges are sharp and pyramids are well developed. Although irregular fluid inclusions are common, many crystals are inclusion-free. Microscopic study of lower quality, magnetic zircons demonstrates the presence of a few crystals enclosing contrasting football-shaped, metamict, inherited, cores as previously il-

illustrated (Fig. 4.4 d). Such crystals were not found in the non-magnetic fraction. Examination of the internal structure of the non-magnetic zircons reveals regular concentric igneous zoning and a single stage growth history. Zircons selected for analysis host rare colourless fluid inclusions and no optically detectable fractures or cores. They average 180 ppm uranium (Table 4.1).

Figure 4.8 shows that the U/Pb isotopic ratios of zircon fractions C and D define concordant points within analytical uncertainty. Zircon fractions A and B plot slightly below concordia between the two concordant fractions. In view of the narrow range of $^{207}\text{Pb}/^{206}\text{Pb}$ ages of fractions A and D and of their small error envelopes, the best estimate of crystallization age for this late-tectonic pegmatite is obtained by regressing a line through these fractions and 100 Ma. This line yields an upper intercept age at 1027 ± 2 Ma (MSWD = 1.72). The discordancy pattern defined by fractions B, C and E resulted from the contribution of an inherited zircon component. A linear regression of all five data points yields an upper intercept age of 1465 ± 65 Ma (MSWD = 1.13) which is taken to provide some indication of the age of the metaplutonic wallrock, the probable source of the inherited zircon component.

(5) Post-thrusting pegmatite, Huntsville thrust zone (X532)

This internally undeformed body is typical of the post-thrusting pegmatites, emplaced in an uplift related extensional shear (Fig. 4.3 d). The sample site is

at the same structural level and located between samples 2 and 3. The pegmatite cuts across shallowly southeasterly dipping straight gneisses of the Huntsville thrust zone at high angle and is associated with amphibolite facies recrystallization in the wallrocks, indicative of mid- to deep crustal emplacement. This late-tectonic, locally post-thrusting pegmatite dates uplift and provides a lower limit for Grenvillian related deformation within Huntsville thrust zone.

The sampled granitic pegmatite contains large, amber to brown, cloudy, metamict zircons. Prisms (aspect ratio 1:2:4-5) and large, disc-shaped, euhedral crystals showing regular flat faces, well defined edges and terminations and high index facets are common. The non-magnetic crystals are clear, amber and contain rare inclusions. Most polished and etched zircon sections display no cores or metamorphic overgrowths and are dominated by a fine and regular euhedral igneous-type zoning. However, a few crystals show uranium-enriched irregular and resorbed cores and/or thin metamorphic overgrowths (Fig. 4.4 e). The uranium-rich cores may be inherited xenocrysts or, alternatively, they may represent crystals formed in the early stages of the pegmatite crystallization that have been subsequently resorbed. Resorption may be caused by fluctuations in temperature, or in fluid composition, due to influx of fluid during the pegmatite emplacement. The presence of a thin, metamorphic-like, outer rim on zircons suggests that the pegmatite was emplaced into hot crust. Special attention was taken during hand-picking to avoid crystals with optically detectable cores, inclusions and fractures.

Data points from the four zircon fractions analyzed form a linear array (Fig. 4.9). The best-fit Davis regression defines an upper intercept at 1039 ± 4.2 Ma and a lower intercept at 230 Ma. The deviation from colinearity and the high lower intercept probably do not reflect an undetected inherited xenocrystic component in the zircon but, for the most part, they are probably due to variations in the amount of lead loss consequent to radiation damage in the zircon analyzed. This is in accordance with the high uranium content of the zircon which average 2220 ppm (Table 4.1). The upper intercept age is best interpreted as the igneous crystallization age. This age is close to the ca. 1046 Ma crystallization age of the neighbouring late-thrusting pegmatite (sample 3).

4.5 EARLY MIDDLE PROTEROZOIC PLUTONISM

Granitic to dioritic meta-plutonic masses are common throughout the Huntsville region (Fig. 4.2; Nadeau 1985). These rocks are inhomogeneously deformed. Strain intensity varies widely across strike, both from one outcrop to the next and from one body to another. Five bodies have been selected for this study: samples 6, 7 and 8 are from structural levels 2 while samples 9 and 10 are from structural level 4 (Fig. 4.2). Sample 6 is a meta-quartz-diorite from the footwall of the Huntsville thrust zone. It represents the first plutonic rock of intermediate composition to be dated from structural level 2. Samples 7 and 8 are from two amphibolite facies, quartz monzonite sheets of the Huntsville thrust zone. The bodies

sampled contrast widely in their structural overprint (Fig. 4.3 b and f). Sample 7 represents rocks from a remarkably well preserved, folded, augen granite body, whereas sample 8 is from a thoroughly mylonitized concordant sheet. Samples 9 and 10 represent amphibolite and granulite facies, granitic meta-plutonic rocks from the Seguin thrust sheet (Fig. 4.3 e and g).

(6) Meta quartz-diorite, Novar footwall (X14)

After granitoid rocks, meta-diorite and quartz-diorite, locally hosting small gabbroic phases are the most extensive plutonic rocks in the southwestern Central Gneiss Belt. They occur as sheets in the Huntsville thrust zone and form the largest plutonic mass so far mapped in Novar footwall (Fig. 4.2). They exhibit amphibolite facies stable mineral assemblages and they are composed of 25 to 40 percent hornblende and garnet, with or without subordinate biotite and relict pyroxene. Accessory minerals include zircon, titanite and apatite. These rocks are extensively recrystallized and relict igneous texture is locally preserved only in their most mafic parts. Sample 6 is from the large folded mass outcropping in southwestern part of Novar footwall (Fig. 4.2). It is typical of the entire mass and of rocks of the diorite to quartz-diorite suite. The dating of this quartz-diorite complements previous age determinations of granitic and granodioritic rocks of the Central Gneiss Belt. It extends the dated range of rock compositions which characterise the parent plutonic event and provides additional constraints for the reconstitution of

the tectonic context.

Abundant colourless and glassy non-magnetic zircons exhibiting forms similar to those illustrated in Figure 4.10 g were recovered. Euhedral, equant disks and elongate to stubby prisms are the dominant crystal forms. Crystal faces are smoothly undulating, edges and terminations are rounded, and high index facets are rare. Fluid inclusions are not abundant and were absent from most of the crystals selected for analysis. The internal structure of zircons with visible cores (Fig. 4.10 b) confirms a growth history involving an inherited component, the igneous overgrowth of a high uranium mantle featuring a regular euhedral zoning and metamorphic resorption and further growth of a wide weakly zoned low-uranium rim. Zircons larger than 105 μm , with no optically detectable core, and with contrasting shapes were selected for analysis. They average 160 ppm uranium (Table 4.1).

The four zircon analyses yield colinear data points (MSWD = 0.14) fitting a chord with a lower intercept age of 900 $\pm$ 120 Ma and an upper intercept age of 1444 $\pm$ 12.8 Ma (Fig. 4.11). The lower intercept age cannot be linked to any geological event other than uplift and is considered to represent a mixed age involving Grenville high grade metamorphism as well as post peak metamorphic lead loss. As a result of the rotation of the chord the upper intercept age is probably somewhat low and is considered to represent a lower limit for the age of igneous crystallization.

(7) Granitic orthogneiss, Huntsville thrust zone (X135)

Granitic sheets enclosed in the Huntsville thrust zone are inhomogeneously deformed along and across strike and from one sheet to another. The quartz monzonite sheet selected in this study is well preserved exhibiting a widespread K-feldspar augen structure and no evidence for refoliation (Fig. 4.3 b). Simple foliation, locally mylonitic, is axial planar to a broad fold defined by the granitic sheet itself (Fig. 4.2), suggesting that the body was affected by only one phase of deformation. Sample 7 is representative of this body. Biotite with subordinate hornblende and garnet account for less than 10% of the sample which includes accessory apatite and zircon.

Abundant zircons were recovered in the non-magnetic concentrate. Crystals are colourless and glassy, euhedral and exhibit a wide variety of forms ranging from flat discs and equant spindles to needle-like prisms (Fig. 4.10 c); crystal faces are fairly regular, edges are sharp and high index facets common. Most zircons host a few colourless fluid inclusions and rare brown mineral inclusions. Scanning electron microscope imaging of polished and etched zircons show uranium-rich, rounded igneous cores, characterized by internal fine and regular euhedral zoning that is intersected at the margin and overgrown by wide, low-uranium, unzoned, metamorphic rims (Fig. 4.10 d). Zircons of contrasting crystal forms (Fig. 4.10 c), with no optically detectable core and the lowest inclusion content, were selected for analysis from the -149+105 μm size fraction. They

average 118 ppm uranium.

The four zircon data points plot within analytical error on a line (Fig. 4.12; MSWD = .11) with upper and lower concordia intercept ages at $1442 \pm 9-8$ Ma and 1018 ± 45 Ma respectively. The colinearity of the data points coupled with the internal structure of the zircons testify to a two stage history involving igneous crystallization and high grade metamorphic zircon growth (assuming negligible recent lead loss). Accordingly, the upper intercept is interpreted as the lower age limit for igneous crystallization. Since one fraction is concordant within analytical error and two other fractions plot near the upper intercept end of discordia, rotation of the chord due to lead loss is expected to have a limited effect on the calculated upper intercept age. Accordingly the upper intercept age, that is $1442 \pm 9-8$ Ma, is considered to reflect closely the age of igneous crystallization.

(8) Mylonitic granitic orthogneiss, Huntsville thrust zone (X299)

At map scale, this quartz monzonite orthogneiss forms a thin, gently, southeast dipping sheet that typifies the mode of occurrence of plutonic units within the Huntsville subdomain. The internal foliation parallels foliation and layering in the host straight gneisses. Contacts are concordant and tectonically reworked. These rocks have been intensely deformed and recrystallized under upper amphibolite facies conditions (Fig. 4.3 f). In thin sections the groundmass is fine grained and granoblastic and the rock no longer retains an igneous texture. Both biotite and

very continuous quartz blades contribute to a very strong foliation. A lineation defined by quartz blades parallels the stretching of the recrystallized K-feldspar augen. The finely comminuted grain-size of K-feldspar, the strength of the L-S fabric and mesoscopic strain gradients are all indicative of the mylonitic nature of the rocks (Fig. 4.3 f). The study of the zircon and monazite isotopic signature of this granite aims to constrain its plutonic, metamorphic and cooling history.

Light grey with centimetre-size extensively recrystallized K-feldspar augen and streaks, this originally megacrystic quartz-monzonite contains less than 10% garnet and biotite. Neither pyroxene nor metamorphic segregations are present. In places, however, the rocks exhibit a dark, waxy, olive-green hue, typical of granulite facies rocks. Accessory minerals include apatite, monazite, zircon and pyrite. Zircons are colourless, glassy and typically show smooth undulating faces with rounded edges and terminations typical of resorbed crystals (Fig. 4.10 e). Elongate prisms dominate, but a few disc-shaped crystals are also present. The crystals host irregularly distributed, colourless fluid inclusions and rare inclusions of brown material.

Scanning electron microscope examination of polished and severely etched zircons from the lower quality magnetic separate (Fig. 4.10 f) reveals three apparent growth stages, namely a low U core with regular igneous zoning, an inner high U igneous mantle featuring discordant zoning, and an outer low U mantle which does not show zoning but which imparts a rounded external perimeter to the grains (Fig. 4.10 e), a surface which while featuring multiple facets appears partly corroded.

Whereas synnuesis twinning indicating an igneous origin characterises the second stage growth, the outer multifaceted rim could have grown during metamorphic conditions. Irregular and discordant zoning as seen in the igneous part of the crystal has been attributed to impeded igneous zircon growth in a partially crystallized magma during tectonic movements (van Breemen and Hanmer, 1986). It is apparent that the rounded shape of the cores has resulted from repeated contact resorption during the growth of the inner mantle (Fig. 4.10 f). The textural evidence is thus consistent with alternative hypotheses according to which either the cores represent inherited zircons or are crystals which have grown in the magma before final emplacement in a tectonically active environment. The presence in some crystals of zonal discordance within the inner cores favours the latter hypothesis. Examination of zircons from the non-magnetic fraction confirmed the predominance of the igneous second stage growth and the limited extent of the late metamorphic rim, but did not reveal the presence of first stage contrasting core. Zircons from the $-149 + 105$ μm non-magnetic size fraction were selected for analysis. All selected crystals were devoid of detectable fractures and contrasting cores. Each fraction comprised crystals of similar morphology and aspect ratio (Fig. 4.10 e).

Monazite occurs as equidimensional multifaceted crystals and as metamorphic rims overgrowing apatite (Fig. 4.10 a). In some such coronas, garnet, quartz and feldspars are present along the interface of the two phosphates indicating that at least some of the monazite is of metamorphic rather than igneous origin.

On a concordia diagram (Fig. 4.13) six of the seven zircon fractions define a linear array (MSWD = 3.52) with an upper intercept age at 1714 ± 123 -71 Ma and a lower intercept at 1432 ± 54 -98 Ma. The data are most simply interpreted in terms of a two fold history with igneous crystallization represented by the upper intercept and metamorphism by the lower intercept. The lower intercept is controlled by data point E for which the corresponding zircon fraction has a low U content of 27 ppm. This low U content is interpreted as a zircon fraction in which the outer low U rims were abundant and enhanced during abrasion because of a lack of lattice damage. Because of the near concordance of data point E, the lower intercept is interpreted in terms of the age of metamorphism. Although a hypothesis of Grenvillian metamorphic growth cannot be ruled out, a line through 1100 Ma and point E has an upper intercept with corresponding age of 1540 Ma, younger than the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the remaining data points. The array of data points is consistent with an upper intercept corresponding to a single igneous event in which case the scatter of points is the result of Grenvillian effects and recent lead loss. The alternative hypothesis, that the upper scatter is the result of a mixed igneous event and memory represented by inner cores is considered less likely, but cannot be ruled out.

The five analyzed monazite fractions are slightly discordant and four of them define a chord (MSWD = 0.01) with concordia intercepts of ca. 1068 ± 50 -12 Ma and 942 ± 72 -108 Ma (Fig. 4.15 a). Although abraded, fractions K and L are

the most discordant. As in the case of sample 2, the upper intercept age is interpreted as the time of blocking of the monazite system during regional cooling. This is also a minimum age limit for the metamorphic growth of the monazite corona.

(9) Granodioritic orthogneiss, Seguin thrust sheet (X535)

Several small bodies of amphibolite facies, augen granitic orthogneiss are enclosed and locally grade into migmatitic gneisses of the Seguin thrust sheet (Fig. 4.2). This sample is representative of such occurrences. It is a grey, strongly lineated, extensively recrystallized, K-feldspar megacrystic granodioritic orthogneiss (Fig. 4.3 e) which contains accessory pyrite, titanite, apatite and zircon and nearly 15 percent mafic minerals, mainly hornblende with subordinate biotite and garnet.

At the sampling site, the rocks are non-migmatitic and show no evidence of granulite facies metamorphism. In adjacent exposures, they grade into compositionally equivalent, highly migmatitic, somewhat layered gneisses. Accordingly, dating this body provides constraints on the age of the plutonic protolith to the derived migmatites. Similar migmatitic gneisses compose a large proportion of Seguin thrust sheet and of the northeast extension of structural level 4, which forms the footwall to the Central Metasedimentary Belt boundary thrust zone (Fig. 4.1 b).

Zircons, from the non-magnetic concentrate, exhibit crystal forms which resemble those of sample 10 (Fig. 4.10 g). Although euhedral, crystal faces are undulating, edges are rounded and pyramid facets are poorly expressed (as in Fig. 4.10

e). Stubby to elongate (aspect ratio 1 / 1-2 / 2-5) prisms predominate over other forms. Colourless irregular fluid inclusions and inverse crystals are abundant. No contrasting cores were revealed by optical microscopy. Scanning electron microscope images of polished and etched zircon sections feature thin, rounded, metamorphic overgrowths on regular, euhedral, concentrically zoned igneous cores, as well as crystals where the internal zoning is intersected at the smooth and undulating outer surface. These observations attest to metamorphic corrosion and limited overgrowth. The best developed prisms, enclosing a minimum of inclusions, were selected for analysis. Many fluid inclusions were breached during severe abrasion. Most crystals were free of optically detectable fractures. Analyzed zircons averaged 180 ppm uranium.

The four zircon data points fit a chord (MSWD=0.90) with an upper intercept age of 1453 ± 6 Ma (95% confidence) and a lower intercept at 968 ± 45 Ma (Fig. 4.11). The lower intercept age cannot be directly linked to a Grenvillian age, high grade metamorphic event. It is younger than the $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages ca. 1.0 Ga (Cosca et al., in prep). This anomalously low lower intercept is probably related to late disturbance of the isotopic system during uplift. Because of the rotation of the discordia line toward an anomalously low lower intercept, the upper intercept is interpreted as a minimum age for igneous crystallization.

(10) Mangeritic orthogneiss, Seguin thrust sheet (X542)

In addition to amphibolite facies orthogneisses, the Seguin migmatites also host small granite and granodiorite bodies metamorphosed to granulite facies. Rocks from the sampled body are dark waxy brown, very homogeneous in outcrop and exhibit an equigranular texture. Although containing less than 15 percent mafics, hypersthene, augite and hornblende are ubiquitous in thin section and accompanied by accessory apatite and allanite. Perthite dominates over plagioclase.

These granulites show a strong foliation, locally at high angles to and overprinted by the main Seguin fabric (Fig. 4.3 g). Where present, leucosomes are preferentially parallel to the latter demonstrating that the rocks have experienced a granulite facies deformation prior to remobilization and overthrusting of the Seguin migmatites. These granulite orthogneisses were dated in order to determine the age of crystallization of the Seguin thrust sheet meta-plutonic assemblage.

Abundant clear, colourless, euhedral zircons of several distinct forms were recovered in the non magnetic separate (Fig. 4.10 g). They feature small high index facets and smooth edges. Rare zircons with weakly contrasting cores are optically recognizable and zoning is uncommon. Numerous crystals are inclusion free; others host a few irregular fluid inclusions. Scanning electron microscope examination of several polished and severely etched (exposed to HF fumes for more than 2 hours !) sections of crystals with optically recognizable cores suggest a three stage growth history (Fig. 4.10 h). A severely damaged uranium-rich core with a fine regular

concentric igneous zoning is corroded and mantled by a relatively thick, in some cases weakly zoned, smooth second stage rim. The latter is overgrown by a slightly uranium enriched, unzoned outer rim. Zircons greater than 149 microns were selected for analyses on the basis of their crystal shape.

The zircon isotopic analyses define a chord (MSWD 1.57) with concordia upper intercept age at 1427 ± 16 -13 Ma, interpreted as the time of igneous crystallization, and a lower intercept at 1043 ± 42 Ma (Fig. 4.14). The lower intercept coincides with the estimated age for the initiation of uplift and late-thrusting movement in the footwall of the Seguin thrust sheet (sample 5).

4.6 DISCUSSION

The U-Pb zircon and monazite age results are summarised in Tables 4.1 and 4.2. Igneous ages, both in terms of precursors to major units and structurally dated pegmatites are plotted in a cumulative frequency diagram (Fig. 4.16). This diagram also includes previously published plutonic ages for the southwestern Central Gneiss Belt and the Central Metasedimentary Belt boundary thrust zone.

4.6.1 Age of major plutonic events

One of the most significant facts revealed by the accumulation of isotopic data is the absence of Grenvillian age felsic and intermediate plutonic rocks (other than pegmatites) from the southwestern Central Gneiss Belt (Fig. 4.1 and 4.16).

Apart from the ca. 1170 Ma coronitic metagabbro (Davidson and van Breemen 1988), two major plutonic events ca. 1700-1620 Ma and ca. 1480-1420 Ma mark the pre-Grenvillian Proterozoic development of the southwestern Central Gneiss Belt.

Early Proterozoic plutonism

The ca. 1714 ± 123-71 Ma zircon igneous crystallization age of sample 8, a mylonitic quartz monzonite from the Huntsville thrust zone, extends significantly the spatial distribution of the rocks of the older plutonic suite to the southeast limit of structural level 2; the previously known occurrences of plutonic rocks of this suite were limited to the Grenville Front Tectonic Zone - Lake Nipissing area (Fig. 4.1). This confirms that a large proportion of the rocks represented in structural levels 1 and 2 were assembled in Early Proterozoic.

The plutonic rocks of this suite are significantly younger than the 1890-1830 Ma Penokean orogen (Bickford et al. 1986). They are coeval with the 1710-1620 Ma Labrador and 1800-1630 Ma Central Plains orogens of the extreme east and southwest of Laurentia, respectively (Thomas et al. 1985, 1986; Wardle et al. 1986; Schärer et al. 1986; Sims and Peterman 1986). Such correlation indicates that the Early Proterozoic history of the rocks comprised in the structural levels 1 and 2 of the southwestern Central Gneiss Belt is in harmony with orogenic manifestations elsewhere along the margin of Laurentia.

Middle Proterozoic plutonism

The ca. 1444 $\pm$ 12-8 Ma, ca. 1442 $\pm$ 9-8 Ma, ca. 1453 $\pm$ 6 Ma and ca. 1427 $\pm$ 16-13 Ma igneous crystallization ages of the plutonic samples 6, 7, 9 and 10, respectively, demonstrate the predominance of ca. 1480-1420 Ma plutonic rocks in the southeast half of the southwestern Central Gneiss Belt (Fig. 4.1 and 4.2). The ca. 1444 $\pm$ 12-8 Ma of sample 6 indicates that plutonic rocks of this suite are not limited to granitic and granodioritic compositions but also include diorites and quartz-diorites. The importance of intermediate plutonism to the ca. 1480-1420 Ma plutonic suite is unknown. However, the fact that plutonic bodies of intermediate compositions are ubiquitous in the southwestern Central Gneiss Belt suggests that this contribution might be significant.

The ca. 1453 $\pm$ 6 Ma and ca. 1427 $\pm$ 16-13 Ma zircon igneous crystallization ages of samples 9 and 10 represent the first dating of metaplutonic rocks from the Seguin thrust sheet and structural level 4. These dates and the field relationships of the bodies provide age constraints for igneous precursors of the associated migmatitic gneisses. No zircon inheritance is recorded in the U-Pb isotope systematics of these samples. The ages are even more significant when compared to the Sm-Nd T_{DM} model ages of Dickin and McNutt (1990) and to the ca. 1350 $\pm$ 50 Ma and the ca. 1425 $\pm$ 75 Ma zircon igneous crystallization ages of the Whitestone gabbroic-anorthosite and the McKellar orthogneiss (van Breemen et al. 1986), parts of the Parry Sound thrust sheet (structural level 3). T_{DM} model ages

(Dickin and McNutt 1990) suggest a maximum crustal residence time of 1550 Ma for the crustal material represented in structural levels 3 and 4. The close agreement of T_{DM} model ages and of zircon igneous crystallization ages suggests that mantle extraction of the crustal material represented in these structural levels was immediately followed by cratonization. Confirmation of the presence of early Middle Proterozoic juvenile crust in these structural levels awaits further U-Pb and Sm-Nd isotopic studies. It implies that the crust represented in the upper structural levels (3 and 4) is markedly younger than that in the subjacent structural levels, in agreement with the fact that the rock assemblages of the upper structural levels contrast strongly with those in their common footwall (structural level 2).

The plutonic rocks of the ca. 1480-1420 Ma plutonic suite are time correlative with the ca. 1510 - 1430 Ma "eastern granite-rhyolite terrane" of the subsurface of central North America (Bickford et al. 1986; Hoffman in prep.). Only two plutonic bodies, including the Britt marginal granite and the Whitestone anorthosite, yield younger plutonic ages ca. 1350 Ma (Fig. 4.1 and 4.16; van Breemen et al. 1986). Similarly in the St. Francois Mountains (southeastern Missouri), a small granite-porphyry yielded an age ca. 100 Ma younger than the main plutonic event (Bickford et al. 1986). Although sharing many similarities with the rocks of the mid-continent region, the 1480-1420 Ma time correlative rocks from the southwestern Central Gneiss Belt exhibit contrasting rock associations and textural attributes and differ in their Sm-Nd T_{DM} model ages. Plutonic rocks of the "eastern

granite-rhyolite terrane" are typically pink, fine grained, characterised by micro-graphic or granophyric textures and form subvolcanic plutons associated with caldera complexes (Bickford et al. 1986 and references therein). They yield Sm-Nd T_{DM} model ages of 2.0 to 1.7 Ga (Nelson and DePaolo 1985; Bennett and DePaolo 1987). The time correlative rocks of the southwestern Central Gneiss Belt are associated with sediments and/or with more compositionally varied plutonic rocks. They are generally coarse grained and megacrystic. Moreover, the Sm-Nd T_{DM} model ages of their enclosing crustal gneisses are bimodal: model ages of 1.9-1.7 Ga dominate in structural level 2 and contrast with the 1.6-1.4 model ages which characterise structural levels 3 and 4 (Dickin and McNutt 1990).

The previous observations suggest that the tectonic setting of the 1480-1420 Ma plutonism in the southwestern Central Gneiss Belt differs from that of the "eastern granite-rhyolite terrane" of the mid-continental region. The plutonism represented in structural levels 3 and 4 possibly reflects a near continental margin arc-type setting.

4.6.2 Structural levels and crustal ages

The present accumulation of isotopic data for the southwestern Central Gneiss Belt allows a tentative subdivision of the belt into four distinct crustal age provinces (Fig. 4.17). The contribution of Archean crust to the Grenville Belt in this area immediately south of the Grenville Front is proven by the presence of

Archean U/Pb and Rb/Sr ages and the field continuity of Superior Province rock units (Fig. 4.1). North of the 2.0 Ga Sm-Nd T_{DM} model age limit, the model ages of Dickin and McNutt (1989) are best interpreted in terms of crustal-residence ages (O'Nions et al. 1983). They delimit a crustal segment with a 2.8-2.0 Ga isotopic signature. That part of structural level 2 south of the 2.0 Ga Sm-Nd T_{DM} model age limit includes rocks with 1.8 to 1.4 Ga U-Pb and Rb-Sr isotopic ages characterised by 1.9-1.6 Ga T_{DM} model ages (Dickin and McNutt 1990). The crust represented in structural levels 3 and 4 is tentatively assigned an early Middle Proterozoic age according to the previous section of this discussion.

These crustal age provinces reflect the crustal growth history of the southwestern Central Gneiss Belt. They indicate the importance of plutonic and associated tectonothermal events in the 1.8-1.6 Ga and 1.5-1.4 Ga intervals and show that the bulk of the rocks comprised in the belt were formed more than 100 Ma prior to the Grenvillian Orogeny. By contrast, the four-fold structural division of the southwestern Central Gneiss Belt is a Grenvillian architecture. Accordingly, a direct correlation between structural levels and crustal age provinces should not be expected, since these divisional schemes reflect the operation of different and temporally unrelated orogenic processes. However, a certain correspondence may be expected because of the likelihood that the Grenvillian structural imprint was influenced by the nature of the pre-existing crustal assemblage.

4.6.3 Grenvillian deformation and thrust stacking order

Mid- to deep crustal thrusting on widely differing scales is the prime manifestation of the Grenvillian Orogeny in the Central Gneiss Belt (Davidson 1986; Hanmer 1988; Rivers et al. 1989; Chapter 2). The regional northwest-directed tectonic transport and the systematic cross-cutting of footwall structures of the larger thrust sheets indicate the retrogressive migration of the northwest limit of late-thrusting with time. This relationship is also seen, at smaller scale, in the Algonquin thrust stack (Chapter 2) and the Central Metasedimentary Belt boundary thrust zone (Hanmer 1988). The ca. 1097 $\pm$ 3 Ma late synthrusting pegmatite from the basal part of the Seguin thrust sheet (sample 1, structural level 4) is considerably younger than the ca. 1160 Ma late synthrusting pegmatite from the Parry Sound shear zone (structural level 3; van Breemen et al. 1986), but ca. 37 Ma older than the ca. 1060 Ma age of late synthrusting intrusions in the Central Metasedimentary Belt boundary thrust zone (structural level 5; van Breemen and Hanmer 1986). These data confirm a regional scale retrogressive migration with time of the northwest limit of thrusting in the southwestern Central Gneiss Belt. Moreover, within structural level 4 near Gravenhurst, the Seguin thrust sheet apparently overlies and cuts the Moon River thrust sheet (Fig. 4.1). The fact that sample 1 is probably slightly younger than the ca. 1103 $\pm$ 6/-4 Ma late synthrusting pegmatite from the base of the Moon River thrust sheet (van Breemen and Davidson 1990), is consistent with the apparent stacking sequence within this structural level.

Since the Seguin thrust sheet cuts structurally down section in the Algonquin thrust stack (structural level 2), the tectonic assembly of the latter must predate the 1097 Ma emplacement of the level 4. However, late synthrusting pegmatites from the Huntsville thrust zone and the McClintock thrust sheet give ages of 1080 ± 1 Ma, 1046 ± 2 Ma (samples 2 and 3) and 1027 ± 2 Ma (sample 4). Given the similar ages of thrusting in the Central Metasedimentary Belt boundary thrust zone (van Breemen and Hanmer 1986), northwest-directed shortening and thrust stacking at higher structural levels may have caused renewed deformation at lower structural levels, tens of millions of years after the main thrust assembly of the Central Gneiss Belt.

We have shown that a granoblastic extensional shear zone, cutting granulite facies straight gneisses of the Huntsville thrust zone, formed at 1039 ± 4 Ma (sample 5). This suggests that uplift and/or associated extension and gravitational collapse was initiated during the latest stages of regional northwest-directed thrusting. The geochronological data from syntectonic intrusions, combined with detailed structural study in the Huntsville area (Chapter 4), indicate that deep crustal thrusting and associated penetrative ductile deformation do not conform to a simple pattern, either in space or in time, at either the local or the regional scales.

4.6.4 Interpretation of metamorphic ages

In this study, three types of U-Pb data have been obtained which yield information on the timing of regional metamorphism, namely, the age of late syntectonic pegmatites which cross-cut the high grade fabric of their wallrock, lower concordia intercepts from mixed zircon populations consisting of inner igneous cores and outer metamorphic rims and monazite cooling ages. This is complemented by the U-Pb ages of two types of metamorphic zircons, one of which form coronas on igneous baddeleyite, from coronitic metagabbro bodies of the same region (Davidson and van Breemen 1988; van Breemen and Davidson 1990). This data base provides a lower age limit for the development of the high grade metamorphic fabric and constraints on the early cooling history of the area. It serves to discuss the significance of lower concordia intercept ages of metaplutonic rocks and of the ages yielded by metamorphic zircons populations from coronitic metagabbros.

Isotopic evidence for a pre-Grenvillian ca. 1430 $\pm$ 54-98 Ma regional metamorphism affecting the rocks of structural level 2 is provided by the lower intercept age of sample 8, a mylonitic orthogneiss now part of the Huntsville thrust zone. Metamorphic growth of zircon at that time is consistent with the regime of high heat flow set by the emplacement of the numerous plutonic masses of the 1480-1420 Ma suite discussed above. This is also consistent with isotopic evidence for regional metamorphism in the same time interval reported by Krogh (1989) and Corrigan et al. (1989) from the Lake Nipissing - Georgian Bay area. If this isotopic

evidence is independently corroborated by field studies, such regional metamorphism would support an orogenic setting for the 1480-1420 Ma plutonism and associated cratonization.

The lower age limits for the development of the high grade Grenvillian metamorphic fabric in gneisses of the Seguin thrust sheet (structural level 4) is provided by the ca. 1097 $\pm$ 3 Ma zircon igneous crystallization age of sample 1, a weakly foliated late synthrusting pegmatite which cross-cut at high angle the uppermost amphibolite facies fabric of the gneisses of its basal section. This age is independently confirmed by the ca. 1103 $\pm$ 6-4 Ma zircon igneous crystallization age of a similarly occurring late synthrusting cross-cutting and boudinaged pegmatite from near the base of the Moon River thrust sheet, also part of structural level 4 (van Breemen and Davidson 1990). Because the Seguin thrust zone cuts structurally down section into the Algonquin thrust stack (Fig. 4.2), the ca. 1097 $\pm$ 3 Ma age of sample 1 also provides a lower age limit for the Grenvillian deformation fabric in structural level 2 in the Huntsville area. This is consistent with the ca. 1080 $\pm$ 1 Ma zircon igneous crystallization age of sample 3, a post granulite facies late synthrusting pegmatite from the Huntsville thrust zone.

Data on the early regional cooling history are provided by precise U/Pb determinations of monazite crystallization and blocking ages for samples 2, 3 and 8 from the Huntsville Thrust Zone (Fig. 4.15 a). Four monazite crystals from a mylonitic granite (sample 8) define a discordia chord (MSWD = 0.01) with an upper in-

tercept age ca. 1068 Ma and a lower intercept ca. 950 Ma. The upper intercept age is best interpreted as the time of initial blocking of the monazite isotopic system for lead diffusion. This is confirmed by the ca. 1062 $\pm$ 1 Ma and ca. 1065 $\pm$ 1 Ma $^{207}\text{Pb}/^{235}\text{U}$ age of slightly discordant and nearly overlapping monazite crystals from a late synthrusting pegmatite (sample 2) which yields ca. 1080 $\pm$ 1 Ma nearly concordant igneous zircons (Fig. 4.15 a). These monazite blocking ages are consistent with the ca. 1049 $\pm$ 2 Ma $^{207}\text{Pb}/^{235}\text{U}$ of reversely discordant igneous monazite from another late syntectonic pegmatite (sample 3; Fig. 4.15). The reverse discordancy of the monazite crystals implies that they have not experienced significant isotopic disturbance since igneous crystallization. This is in agreement with their low uranium content (813-1039 ppm; Table 4.1). Conversely, the significantly higher uranium contents of monazites from samples 8 and 2 (2131-3453 and 3369-4520 ppm U respectively; Table 4.1) account for the greater sensitivity of these crystals to isotopic resetting during late stages uplift. Given the previously discussed minimum age of ca. 1100 Ma for the development of the high grade metamorphic fabric, the consensus of monazite blocking ages and an estimated monazite blocking temperature of 725-700 °C for lead diffusion (Parrish in prep.), the rocks must have remained at temperatures in excess of 700 °C for more than 35 Ma after the climax of regional Grenvillian deformation and metamorphism. Subsequent cooling to the ca. 500 °C crustal isotherm occurred ca. 1000 Ma (Cosca et al., in prep), given the estimated $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende blocking temperature of 480-500 °C by Harrison

(1981). Such residence time at mid- to deep crustal levels provides ample time for annealing of the dynamic fabric and for mineral reequilibration.

In spite of strong abrasion (Fig. 4.4 a) and of their low uranium content (Table 4.1), the analyzed zircons from the early Middle Proterozoic metaplutonic samples 6, 7, 9 and 10 define chords with lower concordia intercepts spread between 1050 and 900 Ma significantly younger than the previously discussed lower age limit for peak metamorphism. The ca. 968 $\pm$ 45 Ma and ca. 1043 $\pm$ 42 Ma lower concordia intercepts of samples 9 and 10 from the Seguin thrust sheet are much younger than the post peak metamorphic, amphibolite facies fabric of the Seguin thrust zone which developed prior ca. 1097 $\pm$ 3 Ma (sample 1). Independently, the ca. 900 $\pm$ 120 Ma and ca. 1018 $\pm$ 45 Ma lower intercepts of samples 6 and 7 may be significantly younger than the ca. 1046 $\pm$ 2 Ma monazite and zircon igneous crystallization age of a late synthrusting pegmatite (sample 3) and the ca. 1039 $\pm$ 4-2 Ma pegmatite emplaced in a post metamorphic, extensional shear zone (sample 5). Furthermore, the lower intercepts of samples 6 and 9 are even younger than the ca. 1000 Ma $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages from the area (Cosca et al. in prep.).

Zircons from these high grade metaplutonic rocks consist of subhedral, multifaceted, internally weakly zoned or unzoned, metamorphic overgrowths on contrasting subhedral to anhedral igneous cores exhibiting fine-drawn internal regular zoning (Fig. 4.10 b, d, f and h; van Breemen et al. 1986). Such composite

metaplutonic zircons typically yield discordant linear arrays on concordia diagrams for which the upper and lower intercepts approximate the ages of igneous crystallization and regional metamorphism, respectively. As demonstrated above, such simple interpretations cannot be invoked in the present cases because the metamorphic ages determined in this manner somewhat underestimate the real age of high grade metamorphism.

Recent lead loss has contributed to some degree to the rotation of all the discordia chords. The fact that despite severe abrasion, zircons of near gem quality and low uranium content from the late tectonic pegmatites (samples 1, 2, 3 and 4) remain slightly discordant, demonstrates the sensitivity of zircons from this area to recent lead loss. Comparable recent lead loss coupled with the large uncertainties due to the long extrapolations to the lower intercepts can cause rotations of discordia by tens of million of years towards lower (younger) intercept ages. However, in view of the quality of the analyzed zircons and of their extensive abrasion, it is unlikely that the above effects alone could account for the anomalously young lower intercepts. This is illustrated in sample 10 which yields a lower intercept ca. 1043 ± 42 Ma in spite of the extreme abrasion of the zircons, of their gem quality and very low uranium content (35 ppm U) and of the wide spreading of the analyses on the discordia chord. Moreover, the main weakness of this metamorphic dating approach is that the growth of metamorphic zircon can neither be demonstrated to be coeval with the development of the metamorphic mineral

assemblage nor with the deformation fabric.

This shortcoming appeared to have been overcome in the petrogenetic and geochronological study of coronitic metagabbro (Davidson and van Breemen 1988) where it was proposed on petrological grounds, that aggregates of fine-grained metamorphic zircon which form coronas on igneous baddeleyite crystallized synchronously with the development of other metamorphic coronas between major silicate phases, all the corona structures being related to high grade Grenvillian metamorphism. Although slightly discordant, ten analyses of corona-forming zircon aggregates from five regionally distributed coronitic metagabbro bodies yield strongly clustered analyses giving $^{207}\text{Pb}/^{206}\text{Pb}$ ages ca. 1060 Ma (Fig. 4.15 c; Davidson and van Breemen 1988; van Breemen and Davidson 1990). Davidson and van Breemen (1988) also suggested that fine zircon aggregates could recrystallize into larger grains during continued tectonothermal activity. Complementary isotopic data appeared to confirm that such a process could yield a spread of somewhat younger zircon recrystallization ages (Fig. 4.15 b; van Breemen and Davidson 1990).

These results are even more significant when compared to the ca. 1065 Ma monazite blocking ages (Fig. 4.15 a) which clearly do not record the age of the uppermost amphibolite or granulite facies peak metamorphic conditions as the estimated closing temperature of monazite is ca. 700-725 °C (Parrish 1990). It is clear from Figure 4.15 that the young zircon ages do not mark the climax of regional metamorphism in spite of the fact that the observations and petrogenetic argument

of Davidson and van Breemen (1988) for the development of the zircon coronas on baddeleyites during regional metamorphism appear indisputable. Moreover, in view of the low uranium content of these metamorphic zircons (80-160 ppm U; Davidson and van Breemen 1988), it is very unlikely that their young U-Pb ages resulted from recent lead loss solely.

At least three hypotheses to account for the type of discrepancies pointed out here, between the age of peak regional metamorphism and that yielded by metamorphic zircons, warrant consideration. 1) The metamorphic zircon growth post-dated peak metamorphism. It occurred during the extended tectonothermal episode which lasted until ca. 1040 Ma. This hypothesis may be invoked in the case of the amphibolite facies metaplutonic samples 6, 7 and 9. However, it is inconsistent with the strong evidence, in the coronitic metagabbros, for the coeval growth of the metamorphic zircon coronas and of the other major silicate mineral coronas which most likely occurred during the climax of regional metamorphism (Davidson and van Breemen 1988). 2) Incomplete resetting of the U-Pb zircon system due to the annealing recrystallization of the fine zircon aggregates into larger grains during the extended tectonothermal episode which followed peak metamorphism could account for the young age of the large metamorphic zircons from coronitic metagabbros (Fig. 4.15 b). However, such a mechanism does not account for the young ages of corona-forming zircon aggregates on baddeleyites nor for the young lower intercept age of the other metaplutonic samples. Moreover, in the latter cases, no

textural evidence for the recrystallization of the zircon overgrowths has been found.

3) Incomplete resetting of the U-Pb isotopic system consequent to high temperature diffusion may also be invoked. The preservation of an old igneous zircon component in the isotope systematics of the metaplutonic samples demonstrates that zircon U-Pb systems survives uppermost amphibolite and granulite facies metamorphism. This, however, does not preclude the possibility that, under favourable conditions, high temperature isotopic diffusion could cause some resetting of the U-Pb zircon system. A long residence time under high temperature conditions such as we have demonstrated for this area could provide such favourable conditions. This is consistent with the observation that the highly strained gneisses of the Huntsville area are typically granoblastic and annealed, preserving little trace of their dynamic microstructure and with the fact that thermobarometric determinations from pelitic rocks indicate extensive post peak metamorphic and post-kinematic reequilibration (Chapters 2 and 3).

Clearly, the apparent contradiction discussed above in both the cases of the metaplutonic orthogneisses and of the coronitic metagabbros between the petrological evidence for the crystallization of metamorphic zircons during regional high grade metamorphism and their post peak regional metamorphic age requires the consideration of mechanisms capable of some resetting of the U-Pb system of metamorphic zircons other than recent lead loss. The catalysts for partial resetting of the U-Pb zircon system are likely to have been the elevated temperature and

accompanying deformation, given the present evidence for post peak-metamorphic slow cooling and that some deformation occurred until ca. 1027 $\pm$ 2 Ma (sample 4).

The type of discrepancy discussed here between the age of regional metamorphism and that yielded by metamorphic zircons is not unique. Although several mechanisms may be responsible for the anomalous young ages of metamorphic-like zircon overgrowths, this study suggests that the potential of zircon U-Pb systems for high temperature isotopic diffusion should not be disregarded. However, further evidence is clearly required to substantiate such an hypothesis.

4.6.5 Tectonic implications

Although a full assessment of the tectonic significance of the presently available isotopic data is beyond the scope of this paper and awaits geochemical studies of the plutonic rock suites and additional integrated structural, metamorphic and geochronological regional studies, some of the potential tectonic implications are tentatively explored. These considerations are offered primarily to catalyze current thinking concerning the Proterozoic evolution of the Central Gneiss Belt.

The crust represented in the 2.5-2.0 Ga and 1.8-1.6 Ga crustal age provinces does not include Penokean age igneous rocks but appears to be dominated by ca. 1700-1620 Ma felsic and intermediate plutonic rocks. These rocks occur on both sides of the Sm-Nd $T_{DM} = 2.0$ Ga model age limit recognized and origi-

nally interpreted by Dickin and McNutt (1989) as a Penokean collisional suture between an Archean foreland and an island arc. It is emphasized that there is no field evidence to support their interpretation.

An alternative model for the Sm-Nd $T_{DM} = 2.0$ Ga model age limit involves the development and the oceanward migration of an ensialic arc (Fig. 4.18). The growth of an Andean-type arc along the pre-existing margin of Laurentia may have caused the early development of a topographic culmination and of a sedimentary barrier. Sediments accumulating on the northwest side of the arc came from Archean and Early Proterozoic sources and from the arc itself, while those deposited on its southeast side may have been derived exclusively from the arc. Concurrently, thickening in the forearc region led to oceanward migration of the active arc, away from the preexisting continental margin and from older sources of magmatic contamination. The occurrence of the 1.7-1.6 Ga intrusive rocks, both north and south of the Sm-Nd $T_{DM} = 2.0$ Ga model age limit, supports such an ensialic arc model, providing that this plutonic activity is the direct expression of a crust-forming event.

The 1480-1420 Ma plutonism in the southwestern Central Gneiss Belt is time correlative with widespread anorogenic magmatism in Labrador, southern mid-continent and southwest United States (Bridgwater and Windley 1973; Emslie 1978; Anderson 1983; Van Schmus et al. 1987). It is emphasized that the plutonic rocks of the southwestern Central Gneiss Belt differ in their lithological association, petro-

graphic attributes and Sm-Nd T_{DM} model age signature from those of the granite-rhyolite terrane. The agreement of U-Pb zircon ages and of the Sm-Nd T_{DM} model ages for the rocks which compose structural levels 3 and 4 suggests that they represent juvenile crust. According to the structural evidence, these rocks lay furthest to the southeast before the Grenvillian Orogeny. They may represent dismembered parts of a marginal arc. Contemporaneous plutonism in the adjacent crustal age provinces may have resulted from low-angle continentward subduction or back-arc extension. Such an hypothesis clearly requires further and independent substantiation. However, it is in agreement with the documentation of 1450-1350 Ma closely coeval Sm-Nd ages and U-Pb zircon crystallization ages in the Adirondacks (Daly and McLelland 1989, 1990) and with the occurrences of 1600-1400 Ma ages in the Grenvillian age basement of Mexico (Patchett and Ruiz 1987).

The lack of significant post 1350 Ma plutonism in the Central Gneiss Belt indicates that the convergence with the Central Metasedimentary Belt is likely associated with southeastward dipping subduction, an hypothesis consistent with the occurrence of arc-related igneous activity in the latter belt.

The demonstration of regional and up-structural section retrogressive migration of the northwest limit of thrusting with time across the Central Gneiss Belt has major tectonic implications when considered in the broader orogenic context of the southwestern Grenville orogen. This requires that the colliding of large geological edifices along the pre-existing southeast margin of the Central

Gneiss Belt must have been initiated somewhat prior to ca. 1160 Ma, if the thrusting is consequent to a collisional event. The ca. 1103 $\pm$ 6-4 to ca. 1097 $\pm$ 3 Ma age for late-thrusting movement in the Seguin and Moon River thrust zone (structural level 4) is coeval with deformation and regional metamorphism in the Elzevir terrane of the Central Metasedimentary Belt in the range ca. 1102 $\pm$ 4-3 Ma to 1088 $\pm$ 3-2 Ma (Davis and Bartlett 1988).

Perhaps even more significant is the fact that the number and the spread of U-Pb zircon crystallization ages for late syntectonic pegmatites across the southwestern Central Gneiss Belt suggest more or less continuous deformation for a time interval in excess of 130 Ma from somewhat prior ca. 1160 Ma to ca. 1030 Ma (Fig. 4.16). This continuous tectonic activity is in part coeval with the ca. 1160-1130 Ma extensive anorthosite-mangerite-charnockite-granite plutonism in the Adirondacks and in the central Grenville orogen (Emslie and Hunt 1990) and with the ca. 1120-1050 Ma Keweenawan rifting (Davis and Sutcliffe 1985).

4.7 CONCLUSIONS

1) The Early and Middle Proterozoic development of the southwestern Central Gneiss Belt is marked by ubiquitous, felsic and intermediate plutonism in the 1700-1620 Ma and 1480-1420 Ma ranges. The predominance of 1480-1420 Ma felsic and intermediate plutonic rocks and the lack of significant Grenvillian age plutonism indicate that the cratonization of the belt was completed more than 100 Ma prior to the Grenvillian Orogeny.

2) While plutonism in the 1700-1620 Ma range is time correlative with the Mazatzal and Labrador orogens of the extreme southwest and east of Laurentia, plutonism in the 1480-1420 Ma range is coeval with the development of the eastern granite-rhyolite terrane of the mid-continental region. Such correlations confirm that the pre-Grenvillian history of the southwestern Central Gneiss Belt was in harmony with coeval plutonic and coupled orogenic activity elsewhere along the margin of Laurentia. However, variations on the tectonic setting of time correlative plutonic and associated orogenic belts should be expected.

3) The distribution and cluster of maximum plutonic ages and of Sm-Nd ages is compatible with a tentative subdivision of the southwestern Central Gneiss Belt into four crustal age provinces which reflect the pre-Grenvillian growth history of the belt.

4) The lack of field evidence for an accretionary suture and the fact that felsic and intermediate plutonic rocks predominate largely over mafic rocks in the 2.5-2.0 Ga and 1.8-1.6 Ga crustal age provinces suggest the development of an Andean type ensialic arc along part of the Early Proterozoic Laurentian margin.

5) Confirmation of the presence of 1.5-1.4 Ga juvenile crust in the Parry Sound (structural level 3) and Moon River-Seguin-Muskoka thrust sheets (structural level 4) would argue for the occurrence of a volcanic arc and accretionary setting along a segment of the early Middle Proterozoic Laurentian margin. Contemporaneous plutonism in the adjacent crustal age provinces may have resulted from low-angle continentward subduction or back-arc extension.

6) The Grenvillian tectonic architecture of the southwestern Central Gneiss Belt comprises five structural levels. A close correlation between structural levels and crustal age provinces should not be expected, since these divisional schemes reflect the operation of different and temporally unrelated orogenic processes. However, a certain degree of correspondence is present because of the likelihood that the Grenvillian orogenic overprint was influenced by the nature and structure of the pre-existing lithotectonic assemblage.

7) Late synthrusting movement of age ca. 1097 Ma at the base of the Seguin thrust sheet (structural level 4) is intermediate between late-thrusting in the underlying Parry Sound shear zone (ca. 1160 Ma, structural level 3) and in the overlying Central Metasedimentary Belt boundary thrust zone (1060-1030 Ma, structural

level 5). These data confirm a regional and up structural section retrogressive migration of the northwest limit of thrusting with time.

8) Late northwest-directed shearing within the Huntsville thrust zone and the McClintock thrust sheet (structural level 2) in the 1080-1027 Ma range postdated emplacement of the Seguin thrust sheet (structural level 4). This shearing likely resulted from deep-level renewed deformation consequent to breakback thrusting in the Central Metasedimentary Belt boundary thrust zone (structural level 5).

9) The development of granoblastic extensional shear zones ca. 1039 $\pm$ 4-2 Ma indicates that uplift and associated gravitational collapse of the crust was initiated during the latest stages of regional northwest-directed thrusting.

10) The present isotopic data combined with detailed structural study show that deep crustal thrusting and associated penetrative ductile deformation in the southwestern Central Gneiss Belt do not conform to a simple pattern, either in space or in time at either the local or the regional scale.

11) The lower age limits for major thrusting in the southwestern Central Gneiss Belt require that the colliding of large geological edifices along the pre-existing southeast margin of the Central Gneiss Belt must have been initiated somewhat prior ca. 1160 Ma, if the thrusting is consequent to a collisional event. Moreover, the number and the spread of ages of late syntectonic pegmatites across the belt suggest more or less continuous deformation for a time interval in excess of 130 Ma, ending at ca. 1027 Ma.

12) Tectonic activity in the ca. 1160-1050 Ma range is partly coeval with deformation and regional metamorphism in the Elzevir terrane of the Central Metasedimentary Belt, with the extensive anorthosite-mangerite-charnockite-granite plutonism in the Adirondacks and in the central Grenville orogen and with the Keweenawan rifting.

13) Lower age limits for the development of the high grade Grenvillian metamorphic fabric are provided by the ages of late tectonic, cross-cutting pegmatites. A minimum age ca. 1097 $\pm$ 3 Ma for the development of the metamorphic fabric of the Seguin thrust sheet and of its footwall is consistent with the ca. 1080 $\pm$ 1 Ma age of a post peak metamorphic shearing in the Huntsville thrust zone.

14) This minimum age for peak metamorphism coupled with the consensus of monazite blocking ages at ca. 1065 Ma (at an estimated blocking temperature of 725-700 °C) indicate that the rocks have remained at high temperature for more than 35 Ma after the climax of regional Grenvillian deformation and metamorphism. Subsequent cooling to the ca. 500 °C crustal isotherm occurred ca. 1000 Ma.

Table 4.1 U-Pb zircon and monazite isotope data

Fraction, Size	Weight (mg)	U (ppm)	Pb ² (ppm)	$\frac{206\text{Pb}}{204\text{Pb}}$	Pb _C (ppb)	$2\sigma\text{-}^3\text{Pb}^2$ (%)	$\frac{206\text{Pb}}{235\text{U}} \pm \text{SEM}^5$	$\frac{207\text{Pb}}{235\text{U}} \pm \text{SEM}^5$	$\frac{207\text{Pb}}{206\text{Pb}} \pm 1\text{-SEM}^5$	R	$\frac{207\text{Pb}}{206\text{Pb}} \text{ age } (+/-)$ (Ma)
1. Late synthrusting pegmatite, Seguin thrust sheet (K543); 608250E 5032250N.											
A +105 Zr	0.025	261.4	45.45	2484	30.56	1.889	0.18457 (.08)	1.9361 (.11)	0.07608 (.05)	.89	1097.2 (2.0)
B +100 Zr	0.019	309.0	58.5	5901	12.14	4.526	0.19488 (.10)	2.1141 (.11)	0.07868 (.03)	.95	1164.0 (1.3)
C +120 Zr	0.053	228.4	41.0	12100	11.9	2.849	0.18838 (.08)	2.0001 (.09)	0.07700 (.03)	.95	1121.3 (1.2)
D +120 Zr	0.021	316.3	55.6	6176	12.7	3.128	0.18404 (.08)	1.9303 (.10)	0.07607 (.04)	.94	1097.0 (1.2)
E +105 Zr	0.026	92.6	17.66	6326	4.63	5.685	0.19388 (.09)	2.0993 (.10)	0.07853 (.03)	.94	1160.3 (1.4)
F +105 Zr	0.019	304.7	56.24	2359	28.92	3.753	0.18448 (.08)	1.9328 (.11)	0.07599 (.05)	.91	1094.7 (1.9)
2. Late synthrusting pegmatite, Munteville thrust zone (K25); 643250E 5022350N.											
A +149 Zr	0.068	332.0	56.73	5958	43.16	1.867	0.18140 (.18)	1.8862 (.19)	0.07541 (.03)	.98	1079.6 (1.4)
B +149 Zr	0.189	380.7	64.83	48950	16.89	1.350	0.18177 (.10)	1.8904 (.11)	0.07543 (.03)	.97	1079.9 (1.1)
C +149 Zr	0.091	312.6	53.53	33000	9.87	2.133	0.18131 (.09)	1.8854 (.10)	0.07542 (.03)	.96	1079.7 (1.1)
D +149 Zr	0.079	436.9	73.69	25680	15.27	1.007	0.18053 (.10)	1.8937 (.11)	0.07608 (.03)	.97	1097.1 (1.1)
E +105 Mn	0.011	4506.2	2975	27280	21.12	74.965	0.17774 (.09)	1.8283 (.10)	0.07461 (.03)	.96	1057.9 (1.1)
F +105 Mn	0.011	4519.5	2177	34840	27.52	65.500	0.17882 (.09)	1.8458 (.10)	0.07486 (.03)	.96	1064.8 (1.1)
G +105 Mn	0.012	3368.9	2242	12150	38.1	75.047	0.17833 (.10)	1.8382 (.11)	0.07476 (.03)	.97	1062.0 (1.2)
3. Late synthrusting pegmatite, Munteville thrust zone (K322); 649950E 5023800N.											
A +149 Zr	0.045	190.6	35.02	1545	61.85	11.582	0.17581 (.10)	1.8002 (.12)	0.07426 (.05)	.92	1048.6 (1.9)
B +149 Zr	0.040	205.1	37.64	1655	55.16	11.646	0.17549 (.10)	1.7949 (.12)	0.07418 (.05)	.90	1046.4 (2.1)
C +149 Zr	0.053	136.7	25.23	4042	20.0	11.960	0.17576 (.09)	1.7992 (.11)	0.07424 (.04)	.93	1048.1 (1.6)
D +149 Zr	0.045	96.9	17.80	3272	14.96	11.742	0.17541 (.09)	1.7928 (.10)	0.07413 (.04)	.93	1044.9 (1.6)
E +105 Mn	0.009	1038.9	2899	5212	20.06	94.102	0.17672 (.09)	1.8060 (.10)	0.07412 (.04)	.91	1044.6 (1.7)
F +105 Mn	0.008	812.5	2659	3882	19.74	94.955	0.17720 (.09)	1.8122 (.10)	0.07417 (.04)	.92	1046.1 (1.7)
4. Late synthrusting pegmatite, McClintock thrust sheet (K531); 662150E 5016600N.											
A +149 Zr	0.050	206.9	36.48	3155	35.72	9.853	0.17216 (.08)	1.7447 (.10)	0.07350 (.04)	.91	1027.7 (1.8)
B +149 Zr	0.054	90.6	15.94	2455	21.97	9.411	0.17258 (.09)	1.7514 (.11)	0.07361 (.04)	.91	1030.7 (1.8)
C +149 Zr	0.042	158.7	27.95	721	104.2	9.169	0.17323 (.10)	1.7586 (.22)	0.07363 (.16)	.71	1031.3 (6.6)
D +105 Zr	0.038	214.1	37.69	3228	27.53	9.663	0.17219 (.11)	1.7433 (.13)	0.07343 (.06)	.88	1025.8 (2.4)
E +105 Zr	0.019	226.3	41.76	1633	30.08	9.131	0.18116 (.13)	1.9054 (.14)	0.07628 (.06)	.91	1102.5 (2.2)
5. Post thrusting pegmatite, Munteville thrust zone (K532); 644400E 5022650N.											
A +149 Zr	0.021	1899.5	322.7	23000	18.81	4.890	0.17357 (.09)	1.7674 (.10)	0.07385 (.03)	.96	1037.5 (1.1)
B +105 Zr	0.033	2120	359.1	55080	14.03	5.679	0.17303 (.10)	1.7628 (.11)	0.07389 (.03)	.97	1038.5 (1.1)
C +105 Zr	0.025	2523.4	406.8	15610	42.39	4.890	0.16612 (.09)	1.6829 (.11)	0.07347 (.03)	.97	1027.0 (1.2)
D +105 Zr	0.018	2343.2	375.5	4499	94.98	5.178	0.16463 (.14)	1.6713 (.15)	0.07363 (.04)	.96	1031.4 (1.7)

6. Meta quartz-diorite, Mover footwall (X14); 637850E 5031200N.											
A +149 Zr	0.020	153.1	39.1	2379	20.16	10.815	0.24294 (.13)	3.0078 (.14)	0.08980 (.05)	.95	1421.2 (1.7)
B +149 Zr	0.054	194.6	47.8	10280	15.53	7.667	0.24203 (.09)	2.9915 (.10)	0.08964 (.03)	.96	1417.9 (1.1)
C +149 Zr	0.038	108.2	27.3	4166	15.03	10.942	0.23911 (.11)	2.9426 (.12)	0.08926 (.04)	.95	1409.6 (1.4)
D +105 Zr	0.029	185.9	46.86	4423	17.14	9.248	0.24401 (.10)	3.0257 (.11)	0.08994 (.03)	.96	1424.1 (1.2)
7. Granitic orthogneiss, Muntaville thrust zone (X135); 629150E 5022050N.											
A +105 Zr	0.014	96.9	26.53	633	32.91	16.435	0.24382 (.14)	3.0147 (.21)	0.08968 (.14)	.75	1418.6 (5.2)
B +105 Zr	0.016	106.5	29.22	1347	19.78	16.408	0.24458 (.12)	3.0296 (.13)	0.08984 (.05)	.93	1422.1 (1.8)
C +105 Zr	0.025	142.4	36.29	2204	23.61	14.859	0.23184 (.10)	2.8032 (.12)	0.08769 (.04)	.93	1375.8 (1.7)
D +105 Zr	0.026	128.3	35.96	355	15.41	16.876	0.24823 (.16)	3.0905 (.42)	0.09030 (.33)	.68	1431.8 (12.6)
8. Mylonitic granitic orthogneiss, Muntaville thrust zone (X209); 651350E 5024350N.											
A +105 Zr	0.028	281.8	76.17	6282	21.75	5.113	0.27183 (.14)	3.6387 (.15)	0.09708 (.03)	.98	1568.8 (1.2)
B +105 Zr	0.027	364.9	98.74	8524	19.67	5.392	0.27130 (.10)	3.6409 (.11)	0.09733 (.03)	.96	1573.6 (1.2)
C +105 Zr	0.013	292.8	82.80	558	121.9	7.339	0.27740 (.12)	3.7562 (.26)	0.09821 (.19)	.69	1590.3 (7.2)
D +105 Zr	0.017	257.1	71.67	4478	16.59	7.470	0.27324 (.09)	3.6780 (.10)	0.09762 (.04)	.93	1579.2 (1.4)
E +105 Zr	0.033	27.35	7.30	439	35.32	8.289	0.26017 (.15)	3.3759 (.25)	0.09411 (.19)	.69	1510.3 (7.0)
F +105 Zr	0.019	257.2	70.81	8931	9.53	6.483	0.27278 (.08)	3.6630 (.10)	0.09739 (.03)	.96	1574.7 (1.1)
G +105 Zr	0.020	379.3	102.2	17050	7.69	5.648	0.26963 (.08)	3.5836 (.10)	0.09639 (.03)	.96	1555.4 (1.1)
H +149 Mn	0.024	3453	3606	18910	48.02	84.198	0.17729 (.09)	1.8205 (.10)	0.07447 (.03)	.96	1054.3 (1.2)
I +105 Mn	0.016	2131	2007	7051	55.29	82.567	0.17649 (.10)	1.8087 (.11)	0.07432 (.03)	.96	1050.3 (1.3)
J +105 Mn	0.011	2889	2831	2648	133.3	83.382	0.17504 (.09)	1.7875 (.11)	0.07406 (.05)	.91	1043.2 (2.0)
K +105 Mn	0.009	2334	2413	3332	69.74	84.301	0.17448 (.09)	1.7794 (.11)	0.07397 (.04)	.94	1040.6 (1.6)
L +105 Mn	0.036	2837	2551	33520	33.55	81.740	0.17646 (.09)	1.8101 (.10)	0.07440 (.03)	.96	1052.2 (1.2)
9. Granodioritic orthogneiss, Seguin thrust sheet (X535); 624750E 5015900N.											
A +149 Zr	0.098	151.9	38.02	8494	26.15	11.354	0.23686 (.08)	2.9045 (.10)	0.08894 (.03)	.95	1402.8 (1.1)
B +149 Zr	0.113	136.6	35.14	11190	21.31	10.410	0.24575 (.09)	3.0595 (.10)	0.09029 (.03)	.96	1431.7 (1.1)
C +105 Zr	0.029	179.8	45.01	4277	18.38	10.263	0.23974 (.10)	2.9526 (.11)	0.08932 (.03)	.95	1411.1 (1.3)
D +105 Zr	0.049	206.5	53.36	6289	24.96	11.668	0.24340 (.09)	3.0185 (.10)	0.08994 (.03)	.95	1424.3 (1.2)
10. Margeritic orthogneiss, Seguin thrust sheet (X542); 626450E 5016650N.											
A +149 Zr	0.069	29.82	7.22	1089	28.33	9.068	0.23519 (.13)	2.8484 (.17)	0.08784 (.12)	.74	1378.9 (4.5)
B +149 Zr	0.048	48.63	10.32	1979	16.01	7.166	0.21153 (.14)	2.4292 (.17)	0.08330 (.11)	.75	1276.0 (4.5)
C +149 Zr	0.038	33.49	7.67	399	47.83	8.137	0.22577 (.44)	2.6626 (.73)	0.08553 (.53)	.69	1327.7 (20.4)
D +149 Zr	0.042	15.60	3.42	430	22.03	7.426	0.21760 (.32)	2.5321 (.39)	0.08440 (.24)	.78	1301.7 (9.6)
E +149 Zr	0.164	41.40	9.47	4449	21.81	8.054	0.22521 (.08)	2.6769 (.10)	0.08621 (.03)	.94	1342.8 (1.3)
F +149 Zr	0.148	38.51	9.16	4081	20.48	8.950	0.23144 (.08)	2.7862 (.10)	0.08731 (.03)	.95	1367.3 (1.2)

Notes: ¹ sizes (+105) refer to length aspect of zircons in microns (i.e. stop by the 105 μ m sieve); ² radiogenic Pb; ³ measured ratio, corrected for spike and fractionation; ⁴ total common Pb in analysis corrected for fractionation and spike; ⁵ corrected for blank Pb and U, common Pb, errors quoted are one sigma in percent; ⁶ corrected for blank and common Pb, errors are two sigmas in Ma; decay constants used are those of Steiger and Jager (1977); for analytical details see Parrish et al. (1987).

Table 4.2 New age results from the Central Gneiss Belt

Sample 1:	Late synthrusting pegmatite, Seguin thrust sheet
1097 +/-3	Ma zircon igneous crystallization age
1382 +/-50	Ma inherited zircon component from Seguin gneisses
Sample 2:	Late synthrusting pegmatite, Huntsville thrust zone
1080 +/-1	Ma zircon igneous crystallization age
1063 +/-3	Ma $^{207}\text{Pb}/^{206}\text{Pb}$ monazite blocking age
Sample 3:	Late synthrusting pegmatite, Huntsville thrust zone
1046 +/-2	Ma zircon igneous crystallization age
1049 +/-2	Ma $^{207}\text{Pb}/^{206}\text{Pb}$ reversely discordant igneous monazite
Sample 4:	Late synthrusting pegmatite, McClintock thrust sheet
1027 +/-2	Ma zircon igneous crystallization age
1465 +/-65	Ma inherited zircon component from McClintock gneisses
Sample 5:	Post-thrusting pegmatite, Huntsville thrust zone
1039 +/-4	Ma zircon igneous crystallization age
Sample 6:	Meta quartz-diorite, Novar footwall
1444 +/-12	Ma zircon igneous crystallization age
900 +/-120	Ma lower intercept age
Sample 7:	Granitic orthogneiss, Huntsville thrust zone
1442 +/-9	Ma zircon igneous crystallization age
1018 +/-45	Ma lower intercept age
Sample 8:	Mylonitic orthogneiss, Huntsville thrust zone
1714 +/-123	Ma zircon igneous crystallization age
1432 +/-54	Ma zircon lower intercept metamorphic age
1068 +/-51	Ma monazite blocking age
Sample 9:	Granodioritic orthogneiss, Seguin thrust sheet
1453 +/-6	Ma zircon igneous crystallization age
968 +/-45	Ma lower intercept age
Sample 10:	Mangeritic orthogneiss, Seguin thrust sheet
1427 +/-16	Ma zircon igneous crystallization age
1043 +/-42	Ma lower intercept

Figure 4.1 Structural setting and previous isotopic data from the southwestern Central Gneiss Belt; **B** structural and **C** chronologic subdivisions of the belt; **D** distribution of previous plutonic ages. **Age symbols:** ages are Ga, closed circle = U-Pb plutonic ages, open circle = Rb-Sr plutonic ages, closed square = U-Pb age of gneiss, open square = Rb-Sr age of gneiss, close losanges = U-Pb age of coronitic metagabbro, hour-glass = U-Pb age of late syntectonic pegmatite. **Grenvillian structures:** **CGB** = Central Gneiss Belt, **CMB** = Central Metasedimentary Belt, **GFTZ** = Grenville Front Tectonic Zone, **CMBbtz** = Central Metasedimentary Belt boundary thrust zone, **PS** = Parry Sound thrust sheet, **MR** = Moon River thrust sheet, **S** = Seguin thrust sheet. **Locations:** **M** = Montreal, **S** = Sudbury, **N** = North Bay, **P** = Parry Sound, **G** = Gravenhurst, **Hu** = Huntsville, **Ha** = Haliburton. **References:** **L)** Lumbers 1975; **M)** Bell and Blenkinsop 1980; **N)** Stockwell 1982; **O)** van Breemen et al. 1986; **P)** van Breemen and Hanmer 1986; **Q)** van Breemen and Davidson 1988; **R)** Davidson and van Breemen 1988; **S)** Krogh 1989; **T)** Corrigan et al. 1989; **U)** van Breemen and Davidson 1990; and the following as compiled by Easton 1986: **A)** Grant 1964; **B)** Davis et al. 1966; **C)** Krogh and Hurley 1968; **D)** Krogh et al. 1968; **E)** Krogh and Davis 1969a, 1969b; **F)** Steiger and Wasserburg 1969; **G)** Krogh and Davis 1970a, 1970b; **H)** Krogh and Davis 1971a, 1971b; **I)** Krogh et al. 1971; **J)** Krogh and Davis 1972, 1973; **K)** Wanless and Loveridge 1972 and Wanless et al. 1968, 1974).

Figure 4.2 Sampling localities and geological setting Huntsville area.

Figure 4.3 Field occurrences of late synthrusting, granitic pegmatites and orthogneisses. Late, cross-cutting, synthrusting pegmatites **a** from the basal section of the Seguin thrust sheet and, **c** from within the McClintock thrust sheet (samples 1 and 4, respectively). **d** Granoblastic, amphibolite facies, extensional shear zone hosting a pegmatite in its dilatancy zone; sample 5 is from a similar occurrence. **b** Well preserved, partly recrystallized (scale = 4 cm) and, **f** totally recrystallized, mylonitic K-feldspar augen orthogneisses from the Huntsville thrust zone (samples 7 and 8, respectively). **e** Strongly lineated, recrystallized, non migmatitic, granodiorite (scale = 3 cm) and **g** crenulated mangerite from the Seguin thrust sheet (samples 9 and 10, respectively); **g** shows incipient leucosome development along a shear zone; sample 10 is from homogeneous mangerite away from metamorphic segregations.

Figure 4.4 a Typical example of abraded zircon fraction. Originally euhedral crystals, as in b, c and e are reduced to smooth ellipsoids. b-e Scanning electron microscope images of zircons and polished and etched grain mounts from late syntectonic pegmatites: b, c and f multiple faceted zircon morphologies common in samples 3, 1 and 2 respectively. Note the smooth surface irregularities of zircon in sample 2; d-e uncommon growth structure of zircons in sample 1 and 5, respectively. The letters identify the zircon forms typical of the fractions analyzed. Scale bar = 100 μm . See text for detail descriptions.

3

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

Figure 4.5 Concordia diagram with isotopic ratios of zircon fractions from sample 1, a late synthrusting pegmatite from the Seguin thrust sheet.

Figure 4.7 Concordia diagram with isotopic ratios of zircon (open ellipses) and monazite (closed ellipses) fractions from samples 2 and 3, two late synthrusting pegmatites from the Huntsville thrust zone, respectively.

Figure 4.6 Field relationships of sample 2 (A) and 3 (B). Cross-hashed pattern - amphibolite; cross pattern - quartzofeldspathic gneiss (A) and mylonitic granitoid orthogneiss (B); closed circle - pegmatite sampling site. The foliation is nearly perpendicular to the sections.

Figure 4.8 Concordia diagram with isotopic ratios of zircon fractions from sample 4, a late synthrusting pegmatite from the McClintock thrust sheet.

Figure 4.9 Concordia diagram with isotopic ratios of zircon fractions from sample 5, a late tectonic pegmatite emplaced in an extensional shear zone from the Huntsville thrust zone.

Figure 4.10 a Metamorphic monazite corona on apatite from sample 8. b-h Scanning electron microscope images of zircons and polished and etched grain mounts: b growth structure of metaigneous zircons from sample 6; the pairs c - d, e - f and g - h illustrate typical crystal forms, surface features and the composite growth structures of meta-igneous zircons from samples 7, 8 and 10, respectively. The letters identify the zircon morphologies typical of the fractions analyzed. See text for detail descriptions.

Figure 4.11 Concordia diagrams with isotopic ratios of zircon fractions from samples 6 and 9, a meta quartz-dioritic orthogneiss from Novar thrust sheet and, a granodioritic orthogneiss from the Seguin thrust sheet, respectively.

Figure 4.12 Concordia diagram with isotopic ratios of zircon fractions from sample 7, a granitic orthogneiss from the Huntsville thrust sheet.

Figure 4.13 Concordia diagram with isotopic ratios of zircon fractions from sample 8, a mylonitic, granitic orthogneiss from the Huntsville thrust sheet.

Figure 4.14 Concordia diagram with isotopic ratios of zircon fractions from sample 10, a mangeritic orthogneiss from the Seguin thrust sheet.

Figure 4.15 Concordia diagrams with isotopic ratios of **a** monazite fractions from sample 2, 3 and 8; **b** coarse recrystallized zircons and **c** polycrystalline zircon aggregates on igneous baddeleyite from coronitic metagabbros (data for **b** and **c** are from Davidson and van Breemen (1988) and van Breemen and Davidson (1990)).

Figure 4.16 Cumulative frequency diagram of plutonic rocks and late syn-thrusting pegmatites from the southwestern Central Gneiss Belt and age spans of Proterozoic events in adjacent regions. Close symbol = U-Pb age, open symbol = Rb-Sr age, arrows identify age quoted without error limits, square = plutonic rock, lozenge = coronitic metagabbro, dot = late synthrusting pegmatite, triangle = pegmatite in extensional shear zone. The attached number gives the present structural level of the dated body. Pe = Penokean, Mk = Makkovik, Ya = Yavapai, L-Mz = Labrador-Mazatzal, EGR = eastern granite-rhyolite terrane, WGR = western granite-rhyolite terrane, AMCG = anorthosite-mangerite-charnockite-granite suite, Ke = Keweenawan. This diagram integrates the age results of the present study and previous age data (Fig. 4.1).

Figure 4.17 Chronologic subdivision of the Southwestern Central Gneiss Belt.

Figure 4.18 An ensialic arc model for the development of the Sm-Nd $T_{DM} = 2.0$ Ga model age limit.

Chapter 5

SUMMARY AND CONCLUSIONS

In this thesis, I have attempted to address a number of questions concerning the geological history of the southwestern Central Gneiss Belt of the Grenville orogen in Ontario. The foregoing chapters contain my detailed observations, results, deductions and conclusions relating to these questions. In what follows, I now seek to summarise and to place into perspective the main body of this work.

5.1 THE NATURE OF MID- TO DEEP-SEATED CRUSTAL THICKENING

Having recognised the tectonic significance of extensive tracts of variously straight, porphyroclastic, fine-grained and flaggy gneisses of both plutonic and metasedimentary origin, it has been possible to reconstruct the geometry of stacks of northwest-directed thrusts, assembled at different scales, under uppermost amphibolite to granulite facies conditions at mid- to deep crustal depths. The relative timing of thrusting within these stacks can be directly read from the large scale map constructed during field mapping (Fig. 2.3).

The Algonquin thrust stack (Fig. 2.10) is composed of the McCraney and McClintock thrust sheets, the Huntsville thrust zone and the Novar footwall. The McCraney and McClintock thrusts cut structurally down-section in the direction of transport through the underlying Huntsville thrust zone and Novar footwall; the Huntsville thrust zone itself truncates the structure in the Novar footwall. At a broader scale, the superincumbent Seguin thrust sheet cuts structurally downsection across the Algonquin thrust stack. Therefore the assembly of the Algonquin thrust stack and the emplacement of the Seguin thrust sheet involve break-back thrusting.

In contrast to the discrete nature of thrusts in linked systems formed at shallow crustal levels, the Huntsville thrust zone is a 5-6 kilometre thick, shallow-dipping ductile shear zone. Flow within this very prominent shear zone is a function of the large scale interaction between the regional northwest-directed ductile thrusting and a culmination in the topography of the upper surface of the footwall. Whereas the transport direction remains northwest-southeast oriented throughout the shear zone, the finite extension direction progressively swings to a northeast-southwest orientation in the lower levels of the ductile thrust. The culmination in the Novar footwall surface has acted as a buttress. Northwest-directed thrusting over the buttress resulted in transpressive flow and the development of a regionally anomalous lineation pattern.

The thrust-related tectonites are cut by granoblastic extensional shears, up to several metres in thickness. U/Pb dating of the extensional shears, combined with their upper amphibolite facies mineral assemblages, shows that they developed at depth during the late-stages of the northwest-directed thrusting. Such extension is apparently related to gravitational collapse of crust, overthickened by thrusting and compressional tectonics. Whereas other workers have suggested that such gravitational collapse is related to thermal weakening by relaxation of the isotherms in the thickened crust, the extension documented in this study accompanies cooling and increase in material strength, as evidenced by the retrogression from granulite to amphibolite facies.

5.2 THERMAL EVOLUTION

In contrast to both observations of natural examples and thermal modelling of regions of tectonically thickened crust, this study establishes that peak metamorphic conditions were attained in part prior to thrusting. If one takes account of the tectonic and metamorphic evolution of the Parry Sound thrust sheet then peak metamorphic conditions may have preceded the latest major thrusting in the study area by at least 60 Ma. Moreover, cooling from peak metamorphic temperatures was slow. Monazite data demonstrate that cooling to 700 °C took at least 90 Ma, corresponding to 35 Ma after emplacement of the Seguin thrust sheet. Combining thermobarometric and geochronological data obtained during this study

with those of other workers, a retrograde P-T-t path was constructed. This path is more consistent than previously proposed paths with both field observations and thermal models and predicts cooling rates comparable with those observed for modern orogens.

5.3 TIMING OF PLUTONISM, DEFORMATION AND METAMORPHISM

From U/Pb geochronology of zircons in plutonic protoliths and syntectonic pegmatites, undertaken in this study, it is now possible to draw some inferences concerning crustal growth in the Central Gneiss Belt and to document the timing of the deformation and metamorphism of that crust. Compilation of the plutonic age data with previous work establishes the regional importance of felsic and intermediate plutonism in the ca. 1700-1620 Ma and ca. 1480-1420 Ma range. The occurrence of ca. 1420 Ma and 1350 Ma plutonic rocks in the Parry Sound thrust sheet and of ca. 1453 Ma and ca. 1427 Ma plutonic rocks in the Seguin thrust sheet, coupled with the Middle Proterozoic Sm-Nd T_{DM} model ages of Dickin and McNutt (1990), indicates that structural levels 3 and 4 of the Central Gneiss Belt may include a juvenile crustal component. This study also confirms the absence of volumetrically significant Grenvillian orogenic plutonism. Taken altogether, it is clear that the Central Gneiss Belt was cratonized at least 100 Ma prior to the Grenvillian crustal thickening.

Compilation of the syntectonic pegmatite age data with previous work independently confirms the regional break-back thrusting, already deduced from field mapping. The Seguin thrust sheet was emplaced at ca. 1100 Ma. The underlying Parry Sound thrust sheet was emplaced at ca. 1160 Ma (van Breemen et al. 1986), whereas major thrusting in the overlying Central Metasedimentary Belt boundary thrust zone was active at ca. 1060 Ma (van Breemen and Hanmer 1986). Data from this study also demonstrate that thrusting in the overlying structural levels was accompanied by renewed tectonic movement within the Algonquin thrust stack. Furthermore, these data also indicate that extension by gravitational collapse was initiated prior to the cessation of regional northwestward thrusting.

In the Central Gneiss Belt, crustal thickening occurred before the emplacement of coronitic metagabbro ca. 1170 Ma. Maximum preserved pressures imply burial to depths of 35-40 kilometre. If the overlying crust is indeed represented by the Central Metasedimentary Belt, then docking and significant overthrusting by the latter must have occurred pre-1170 Ma.

Several time brackets have been proposed for the Grenvillian Orogeny. The term "Grenvillian orogenic cycle" was used by Rivers et al. (1988) to refer to the deformation, metamorphism and plutonism in the range 1160-970 Ma. Conversely, Windley (1988) proposed a "Grenvillian Wilson cycle" extending from 1500 Ma to 1000 Ma. Davidson (1988) relates pre- 1240 Ma ductile deformation along the Grenville Front to early Grenvillian events. This interpretation is consistent with

the younger age limit at ca. 1170 Ma proposed in this study for initial Grenvillian crustal thickening in the southwestern Central Gneiss Belt. It is difficult to justify Windley's (1988) Wilson cycle model for the southwest Grenville, according to which the 1500-1350 Ma plutonism represents rifting tectonics which occurred 200 Ma before the Grenvillian orogenic climax. In the Central Gneiss Belt, ca. 1480-1420 Ma plutonism may represent new juvenile crust and be related to an arc-type setting.

Turning now to the Rivers et al. (1989) definition of the Grenvillian Orogeny, it is proposed in this study that, at least in the southwestern Central Gneiss Belt, it should be extended to include pre-1170 Ma events directly related to high grade metamorphism and crustal thickening. The older limit may be extended to include early events in the Grenville Front Tectonic Zone prior to ca. 1240 Ma. Combining the above with the $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende cooling ages of Cosca et al. (1989), the Grenvillian Orogeny should range from somewhere between ca. 1350 Ma through to ca. 1000 Ma.

5.4 STRUCTURAL SUBDIVISION OF THE BELT

A five-fold structural subdivision of the southwestern Central Gneiss Belt was used in this thesis (Fig. 2.2). The five structural levels reflect structural relationships within the Grenvillian orogen. On the other hand, it was also possible to propose a subdivision of the Central Gneiss Belt based upon the crustal growth

history (Fig. 4.17). The substantial degree of correspondence between these two schemes suggests that crust in structural levels 1 and 2 was formed and modified by Archean and Early Proterozoic events, whereas that in structural levels 3 and 4 only record a Middle Proterozoic history. This probably reflects the influence of the pre-Grenvillian crustal structure on the Grenvillian structural imprint.

It is appropriate here to critically assess some aspects of the three-fold subdivision of the Grenville orogen proposed by Rivers et al. (1989). It comprises, from northwest to southeast, (1) a parautochthonous belt, (2) a central allochthonous polycyclic belt showing evidence of pre- Grenvillian orogenic activity and (3) a southeastern allochthonous monocyclic belt, composed of rocks that only record Grenvillian events. The Parautochthonous Belt is separated from the Allochthonous Belt by the Allochthon Boundary Thrust. According to Rivers et al. (1988), the Allochthon Boundary Thrust runs from the base of structural level 3 up section to the base of structural level 4. According to the present study, this implies that the Allochthonous Boundary Thrust is in fact a composite structure, which involved thrusting at two different structural levels over a time interval of the order of 60 Ma.

5.5 GRENVILLIAN TECTONICS

The present work leads to further inferences into the tectonic evolution of the southwestern Central Gneiss Belt. The establishment of the breakback nature

of thrusting and of the time relationship to peak metamorphism demand a tectonically sound justification.

It has been established that regional scale crustal thickening occurred prior to breakback thrusting intimating that the latter was preceded by the construction of an orogenic culmination or wedge. Critical wedge theories (Davis et al. 1983; Chapple 1978) cannot be directly applied to the tectonic development of the southwestern Central Gneiss Belt because the initial internal structure and boundary conditions of the previously cratonized Central Gneiss Belt differ significantly from those of any simple theoretical wedges. However, some elements of these theories can be invoked to explain the breakback thrusting in the Central Gneiss Belt.

Among other predictions, these theories show that conditions for breakback thrusting within an orogenic wedge are met when changes in the boundary conditions cause destruction of the geometry of the wedge taper. Subsequent internal shortening and thickening of the wedge tend to restore its critical geometry. Variations in a number of boundary conditions control the wedge propagation and shape. Among other instances, the internal geometry and dynamics of an orogenic wedge are severely modified when the wedge abuts a crustal scale buttress (Morley 1988; Jamieson and Beaumont 1988). With respect to Grenvillian crustal thickening, the pre-existing Superior and Southern shield province margins likely represent such a crustal scale buttress. The direct and indirect tectonic effects of this

buttress are unlikely to be limited to the Grenville Front Tectonic Zone but may have led to significant backward thickening within the belt.

5.6 PRE-GRENVILLIAN CRUSTAL GROWTH

Indications concerning the pre-Grenvillian crustal growth history of the belt can be deduced from the nature and distribution, in space and time, of the constituent plutonic rocks.

Questions about the nature and significance of North-American mid-Proterozoic "anorogenic" magmatism have been the focus of many studies (Bridgwater and Windley 1973; Emslie 1978; Van Schmus 1987; Emslie and Hunt 1990). Establishment of the regional importance of ca. 1480-1420 Ma plutonism in the Central Gneiss Belt prompts questions about the significance, the tectonic-setting and the possible correlation of these rocks with those of the time correlative "anorogenic" suite.

Significant differences in texture, rock associations and Sm-Nd T_{DM} model ages between the early Middle Proterozoic plutonic rocks of the Central Gneiss Belt and those of the eastern granite-rhyolite terrane argue for distinct tectonic settings. The continental and extensional nature of the eastern granite-rhyolite terrane is firmly established (Van Schmus and Bickford 1981; Bickford et al. 1986; Van Schmus et al. 1987; Bickford 1988). Conversely, confirmation of the presence of juvenile crustal material in the Central Gneiss Belt would argue for the existence of

volcanic arc-related setting along the pre-Grenvillian southeastern Laurentian margin. Accordingly, Grenvillian manifestations in the Central Gneiss Belt may involve the accretion of juvenile crust.

Independent of the previous considerations, the establishment of the regional importance of plutonism in the ca. 1480-1420 Ma range coupled with the confirmation of the absence of Grenvillian age orogenic plutonism confirm that cratonization of the rocks represented in the southwestern Central Gneiss Belt resulted from pre-Grenvillian events and was completed more than 100 Ma prior to the final Grenvillian assembly.

Early Proterozoic history

It is noteworthy that only one Early Proterozoic plutonic event ca. 1700-1620 Ma is recognised in the southwestern Central Gneiss Belt. Furthermore, no direct evidence for an orogenic event, time correlative with this plutonic activity, is present in the immediately adjacent Superior and Southern shield provinces of Ontario (van Breemen and Davidson 1988; Davidson 1988). Rocks from the ca. 1740 Ma Killarney complex (van Breemen and Davidson 1988), immediately north of the Grenville Front in the Georgian Bay area, are significantly younger than the 1890-1820 Ma Penokean orogeny and somewhat older than the ca. 1700-1620 Ma event discussed here. It is emphasised, however, that the quoted 1700-1620 Ma age limits are constrained by imprecise Rb-Sr and early U-Pb ages and that additional

precise age determinations may either confirm a time gap or extend the older age limit to overlap the age bracket of the Killarney complex.

Stockwell (1982) invokes a "Killarney event" to account for the regional singularity of the Killarney complex. If further dating demonstrates a ca. 1740 Ma older age limit for the early Proterozoic plutonism, the regional importance of the proposed "Killarney event" in the early history of the Central Gneiss Belt will have been demonstrated. This event is time correlative with the ca. 1790-1690 Ma age bracket of the Yavapai orogen of the southern midcontinent (Hoffman 1988). Conversely, confirmation of a time gap between the Killarney event and the 1700-1620 Ma plutonic suite of the Central Gneiss Belt will reinforce correlations with the distant 1710-1620 Ma Mazatzal orogen (Karlstrom and Bowring 1987) of the southern midcontinent and with the 1710-1630 Labrador orogen (Thomas et al. 1986). In any event, it is apparent that the orogenic history of the crust represented in the Central Gneiss Belt was decoupled from that of the immediately adjacent Superior and Southern Provinces since late Early Proterozoic.

5.7 AN HIMALAYAN ANALOG

Windley (1986, 1989) draw analogies between the tectonic assembly of the southwestern Grenville orogen and of the western Himalayas. He emphasizes that the assembly of these two orogens involves the collision of an arc-batholith belt with a continental mass. The Central Metasedimentary Belt / Kohistan Belt and the

Central Gneiss Belt / Indian subcontinent represent the colliding arc-batholith belts and continental masses, respectively. According to Windley's model, thrusting in the southwestern Central Gneiss Belt plays the same functional role as southward-directed thrusting along the margin of the Indian subcontinent, that is the result of post-collisional deformation due to continuing convergence of the colliding continents and arc-batholith belts.

This study highlights two major differences between thrusting at the margin of the Indian subcontinent and in the southwestern Central Gneiss Belt:

- (1) Intracontinental thrusting at the margin of the Indian subcontinent is piggy-back style by contrast to break-back style in the southwestern Central Gneiss Belt.
- (2) The thermal evolution of the southwestern Central Gneiss Belt indicates substantial crustal thickening in the early stages of the collisional event whereas thickening of the Indian margin is late relative to the collision.

Also, early Grenvillian manifestations in the Grenville Front region prior to ca. 1240 Ma (Davidson 1988; Bethune and Davidson 1988) are coeval with the early volcanism in the Central Metasedimentary Belt (Davis and Bartlett 1988) and therefore unrelated to a collision between the Central Gneiss Belt and the Central Metasedimentary Belt. Furthermore, there is no known structure along the margin of the Indian subcontinent equivalent to the Grenville Front Tectonic Zone.

In the author's view, analogies between the Grenville orogen and the Himalaya should not be searched for in the details of the tectonic architecture of these belts. Perhaps, parallels are more likely to be found at a more comprehensive level, in other words, in the nature of the deformation processes and products.

5.8 CONCLUSIONS

(1) This study, admittedly imperfect in many respects, establishes the necessity and the potential of broadly based integrated structural, metamorphic and geochronologic studies for the understanding of the evolution of the deeply excavated Grenville orogen. It highlights some of the short-comings of thematic studies and shows the necessity of considering geographic areas of the same scale as that of the structural problem tackled.

(2) Orogens, like human beings, are unique. If we focus too closely on discernment of order and pattern, may we perhaps overlook or underrate the unique quality of each orogenic event? Possibly uniqueness may have as great significance as conformity to pattern when we attempt to fit orogenic manifestations into the broad framework of plate tectonics.

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Appendix 1: Summary of the previous thermobarometry

Ref.		Coordinates		Temperature		Pressure		
No.	Sample	North	East	T ¹	T ²	P ¹	P ²	P ³
Anovitz and Essene (1990)								
1	HUT 80 11	50136	6555	760				10.0
2	H37 DPM A	50140	6444		670	10.5		
3	HAL 83C 19	50176	6586	670	680	9.6		9.9
4	HAL 83C 9	50212	6562	750	730			9.9
5	HUT 85A 12	50218	6555	781	810	10.0		
6	HAL 83C 8	50226	6608		740			10.5
7	HUT 85A 4	50235	6535	710	680	10.3		
8	HUT 82A 3	50240	6325		830	10.4		
9	SUN 84B 21	50255	6405	800	770	<11.0		
10	HAL 83C 13	50258	6500	820		10.4		
Grant (1987)								
11	85DMSH 100	502450	62965	740	788	10.0		
12	85DMSH 107c	501804	65225	735	880	9.0		
13	85DMSH 108a	502240	63905	690	750	<10.4		
14	85DMSH 110	503070	62845	700		7.7		
Manojlovic (1987)								
15	A	502710	64612	703	697	8.4		
16	B	502275	63855	630	681	8.5		
17	C	502045	64037	719				8.0
18	F	502212	66050	742	795	8.0		

T¹ Gt-Cpx (Ellis and Green 1979); T² Gt-Opx (Sen and Bhattacharya 1984); P¹ Gt-Opx-Pl-Qtz (Manojlovic and Anovitz-Essene used the expression of Bohlen et al. 1983; Grant used the expression of Perkins and Chipera 1985); P² Pl-Cpx-Gt-Qtz (Newton and Perkins 1982); P³ Gt-Ru-Ilm-Pl-Qtz (Bohlen and Liotta 1986).

The sample locations are given in Figure 1.

Figure 1 Location map of the thermobarometric stations.

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Appendix 2: Compositional data and variation diagrams for garnet, biotite and plagioclase analyses

All the electron-microprobe analyses acquired in this study are reported in the following tables together with the means and the standard deviations of the analyses selected for thermobarometry. Photomicrographs of all the microdomains showing the exact location of individual analysis are available from the author on request.

Data reduction

Mineral structural formulas for garnet, biotite and plagioclase were calculated for each analysis from the electron-microprobe data. Estimates of the Fe^{+3} content of garnet were made by assuming electroneutrality and adjusting the $\text{Fe}^{+2}/\text{Fe}^{+3}$ ratio accordingly. For garnet $X_i = i/(\text{Fe}+\text{Mg}+\text{Ca}+\text{Mn})$. For biotite, total Fe was taken as FeO and $X_i = i/(\text{Fe}+\text{Mg}+\text{Ca}+\text{Mn}+\text{Al}^{++})$. For plagioclase $X_i = i/(\text{Ca}+\text{Na}+\text{K})$.

The $\pm 2\%$ precision quoted applies to each weight percent oxide measured in account for the assumed analytical uncertainty. The $\pm 4\%$ or $\pm 8\%$ precision quoted for the X_i is obtained by propagating the assumed analytical uncertainty through the appropriate X_i equations.

Symbols

(um)	distance to the grain boundary in microns
Ct	analysis near the contact of a ferro-magnesian mineral
R	rim analysis adjacent to a neutral phase
P	plateau analysis; adjacent to the break in slope between the rim and the core
C	analysis from the core region
x/	average of x repeated analyses
u	analysis unused in thermobarometry; listed for reference

X171#1d GARNETS X Fe versus X Mg

(Area/label: 1/+ 2/* 3/+)

X171#1d BIOTITES X Fe versus X Mg

(Area/label: */1 */2 +/3)

X171#1d

GARNET ANALYSES

(weight percent; precision +/-2%)

(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
A1S1	20	38.80	0.06	21.39	0.03	1.13	29.59	0.29	8.50	1.10	100.91	R	0.637	0.326	0.006	0.030
A1S2	70	38.39	0.08	21.18	0.00	1.64	28.86	0.21	8.60	1.06	100.09	R	0.631	0.335	0.005	0.030
A1S3	110	38.78	0.02	21.25	0.02	1.43	28.67	0.23	9.02	1.06	100.49	2/P	0.619	0.347	0.005	0.029
A1S4	140	38.52	0.04	21.33	0.00	1.57	28.70	0.19	8.87	1.11	100.33	P	0.622	0.343	0.004	0.031
A1S5	180	38.56	0.00	21.04	0.11	1.15	28.67	0.21	8.78	1.13	99.68	P	0.624	0.340	0.005	0.031
A1S6	15	38.34	0.04	21.12	0.05	2.38	27.77	0.36	8.38	1.14	99.69	u	0.624	0.335	0.008	0.033
A1S7	50	38.39	0.00	21.19	0.01	0.79	29.38	0.30	8.22	1.19	99.49	P	0.641	0.319	0.007	0.033
A1S8	90	38.23	0.04	20.91	0.00	1.50	28.35	0.34	8.70	1.18	99.26	2/P	0.620	0.339	0.008	0.033
A1S9	130	38.26	0.03	20.78	0.02	1.12	28.32	0.27	8.67	1.13	98.66	P	0.623	0.340	0.006	0.032
A2S1	20	38.72	0.03	21.30	0.04	1.03	29.01	0.24	8.56	1.32	100.29	3/R	0.628	0.330	0.005	0.037
A2S2	60	38.71	0.00	21.30	0.04	0.44	29.19	0.26	8.20	1.70	99.85	u	0.631	0.316	0.006	0.047
A2S3	120	38.99	0.00	21.25	0.02	1.29	28.79	0.19	8.54	1.33	100.79	P	0.618	0.341	0.004	0.037
A2S4	140	39.19	0.04	21.54	0.06	0.60	28.79	0.27	8.87	1.42	100.83	P	0.617	0.339	0.006	0.039
A2S5	142	38.81	0.10	21.04	0.03	1.36	28.81	0.33	8.71	1.39	100.60	P	0.620	0.334	0.007	0.038
A2S6	18	38.93	0.03	21.28	0.07	0.65	29.46	0.26	8.54	1.29	100.51	2/R	0.632	0.327	0.006	0.035
A2S7	70	38.68	0.00	21.04	0.04	1.33	28.61	0.24	8.62	1.58	100.15	P	0.619	0.332	0.005	0.044
A2S8	122	38.58	0.00	21.01	0.02	1.54	28.81	0.43	8.45	1.41	100.26	P	0.625	0.327	0.009	0.039
A3S1	25	38.37	0.07	21.07	0.01	1.78	28.49	0.22	8.88	1.03	99.94	2	0.621	0.345	0.005	0.029
A3S2	80	38.63	0.00	20.98	0.05	1.48	28.87	0.22	8.71	1.07	100.07	1	0.628	0.338	0.005	0.030
A3S3	140	38.43	0.25	20.72	0.08	0.61	29.74	0.16	8.31	1.12	99.43	u	0.644	0.321	0.004	0.031
A3S4	200	38.60	0.05	21.19	0.09	1.23	28.60	0.15	8.70	1.56	100.17	1	0.618	0.335	0.003	0.043
A3S5	142	38.38	0.00	20.93	0.22	1.25	28.32	0.30	8.40	1.79	99.59	1	0.617	0.326	0.007	0.050
A3S6	180	38.28	0.00	21.14	0.04	1.14	28.20	0.17	8.49	1.77	99.23	1	0.616	0.331	0.004	0.050
A3S7	150	38.70	0.09	21.07	0.14	1.03	28.51	0.27	8.64	1.66	100.13	1	0.616	0.332	0.006	0.046
A3S8	78	38.51	0.06	21.28	0.05	1.25	28.32	0.24	8.76	1.38	99.89	1	0.616	0.340	0.005	0.038
A3S9	20	38.28	0.02	20.99	0.04	1.16	28.40	0.21	8.81	1.13	99.05	2	0.621	0.343	0.005	0.032

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1

rim	mean	38.60	0.07	21.29	0.02	1.39	29.23	0.25	8.55	1.08	100.50	2	0.634	0.331	0.005	0.030
	std	0.29	0.01	0.15	0.02	0.36	0.52	0.06	0.07	0.03	0.58		0.005	0.006	0.001	0.000
plateau	mean	38.39	0.03	21.05	0.03	1.23	28.68	0.26	8.65	1.15	99.48	5	0.626	0.336	0.006	0.032
	std	0.15	0.02	0.22	0.03	0.32	0.43	0.06	0.25	0.03	0.61		0.008	0.010	0.001	0.001

AREA 2

rim	mean	38.80	0.03	21.29	0.05	0.88	29.19	0.25	8.55	1.31	100.38	2	0.630	0.329	0.005	0.036
	std	0.18	0.04	0.16	0.02	0.39	0.27	0.05	0.26	0.15	0.37		0.007	0.009	0.001	0.004
plateau	mean	38.85	0.03	21.18	0.03	1.22	28.76	0.29	8.71	1.43	100.53	5	0.620	0.334	0.006	0.039
	std	0.22	0.04	0.21	0.02	0.40	0.30	0.08	0.18	0.10	0.28		0.006	0.006	0.002	0.003

AREA 3

rim	mean	38.46	0.06	21.04	0.08	1.21	28.61	0.22	8.63	1.39	99.72	8	0.622	0.335	0.005	0.039
	std	0.15	0.08	0.16	0.06	0.32	0.47	0.05	0.19	0.31	0.41		0.009	0.008	0.001	0.009

X17181d BIOTITE ANALYSES (weight percent; precision +/-2%)

	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ⁶ (+/-8%)	X Mn (+/-8%)
ALS10	36.73	4.74	16.03	12.74	0.00	15.04	0.18	0.00	9.97	95.42		0.586	0.279	0.093	0.042	0.000
ALS11	37.41	4.49	17.19	12.01	0.00	14.49	0.18	0.00	9.57	95.34		0.566	0.263	0.088	0.083	0.000
ALS12	38.73	4.43	16.41	11.94	0.00	13.91	0.30	0.90	9.25	95.85		0.557	0.268	0.089	0.086	0.000
ALS13	36.77	4.59	16.07	13.15	0.04	14.93	0.13	0.03	9.79	95.50		0.579	0.286	0.090	0.044	0.001
ALS14	36.96	4.68	16.03	12.59	0.00	15.38	0.18	0.10	9.87	95.79		0.595	0.273	0.091	0.040	0.000
ALS15	37.12	4.60	16.30	12.61	0.08	15.20	0.18	0.27	9.83	96.19		0.588	0.274	0.090	0.047	0.002
ALS16	37.21	4.70	16.88	12.30	0.02	14.56	0.12	0.23	9.55	95.58	2	0.568	0.259	0.093	0.069	0.000
ALS17	37.20	4.82	16.43	12.90	0.10	15.29	0.22	0.03	9.81	96.79		0.584	0.277	0.093	0.044	0.002
ALS18	37.27	4.74	16.36	12.64	0.03	15.28	0.17	0.00	9.86	96.35		0.587	0.273	0.092	0.048	0.001
ALS19	37.70	4.56	16.37	12.72	0.00	15.22	0.11	0.08	9.67	96.43		0.583	0.274	0.088	0.055	0.000
A2S9	37.17	4.37	16.84	11.50	0.00	15.68	0.19	0.10	9.52	95.37		0.603	0.248	0.085	0.063	0.000
A2S10	37.17	4.45	16.80	11.84	0.00	15.43	0.10	0.17	9.63	95.59		0.595	0.256	0.087	0.062	0.000
A2S11	36.94	4.36	16.99	11.77	0.00	15.80	0.14	0.23	9.56	95.79		0.604	0.253	0.084	0.059	0.000
A2S12	37.20	4.26	16.99	11.80	0.03	15.42	0.12	0.27	9.84	95.93		0.595	0.256	0.083	0.066	0.001
A2S13	37.18	4.62	16.87	12.05	0.12	15.44	0.18	0.00	9.59	96.05		0.591	0.259	0.089	0.059	0.003
A2S14	36.79	4.15	17.25	11.82	0.00	15.46	0.18	0.22	9.60	95.47		0.595	0.255	0.081	0.069	0.000
A2S15	37.39	4.06	17.03	11.38	0.06	15.90	0.20	0.01	9.68	95.71		0.608	0.244	0.078	0.069	0.001
A2S16	37.15	4.21	16.92	11.53	0.00	15.74	0.06	0.04	9.70	95.35		0.604	0.248	0.082	0.066	0.000
A2S17	37.43	4.23	16.53	11.50	0.01	16.28	0.10	0.14	9.75	95.98	2	0.620	0.246	0.081	0.053	0.000
AS10	38.10	4.48	16.76	11.70	0.05	15.93	0.18	0.00	9.90	97.10		0.604	0.249	0.086	0.060	0.001
AS11	37.92	4.44	16.74	11.73	0.07	16.32	0.10	0.00	9.98	97.30		0.614	0.248	0.084	0.053	0.001
AS12	37.98	4.40	16.65	11.51	0.00	16.17	0.15	0.07	9.89	96.82		0.614	0.245	0.084	0.057	0.000
AS13	37.06	4.72	16.65	12.48	0.00	15.37	0.19	0.07	9.78	96.31		0.590	0.269	0.091	0.050	0.000
AS14	36.46	4.37	16.23	12.03	0.00	15.62	0.12	0.05	9.61	94.49		0.605	0.262	0.085	0.048	0.000
AS15	37.70	4.39	16.68	11.63	0.00	15.78	0.12	0.00	9.66	95.96		0.603	0.249	0.085	0.063	0.000
AS16	38.22	4.25	16.69	11.33	0.00	16.22	0.14	0.07	9.51	96.42		0.614	0.241	0.081	0.064	0.000

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																
mean	37.11	4.68	16.23	12.76	0.04	15.19	0.17	0.07	9.83	96.07	7	0.586	0.276	0.091	0.046	0.001
std	0.33	0.10	0.18	0.20	0.04	0.16	0.04	0.09	0.09	0.51		0.305	0.005	0.002	0.005	0.001
AREA 2																
mean	37.16	4.30	16.91	11.69	0.02	15.68	0.14	0.13	9.65	95.69	9	0.602	0.252	0.083	0.063	0.001
std	0.20	0.17	0.20	0.22	0.04	0.29	0.05	0.10	0.10	0.26		0.009	0.005	0.003	0.005	0.001
AREA 3																
mean	37.63	4.44	16.63	11.77	0.02	15.92	0.14	0.04	9.76	96.34	7	0.606	0.252	0.085	0.056	0.000
std	0.64	0.14	0.18	0.38	0.03	0.35	0.03	0.04	0.17	0.94		0.009	0.010	0.003	0.006	0.001

X17101d PLAGIOCLASE ANALYSES (weight percent; precision +/- 2%)

	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	M/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
A1S20	62.69	23.18	0.15	4.23	9.33	0.20	99.98		0.198	0.791	0.011
A1S23	62.41	23.61	0.08	4.30	9.22	0.16	99.78		0.203	0.788	0.009
A1S26	62.79	23.62	0.14	4.36	9.22	0.25	100.38	2	0.204	0.782	0.014
A1S27	63.02	23.48	0.03	4.37	8.95	0.22	100.09		0.210	0.778	0.013
A1S28	62.95	23.86	0.16	4.30	9.49	0.25	100.88		0.198	0.789	0.014
A1S29	62.94	23.83	0.08	4.44	8.93	0.19	100.41		0.213	0.776	0.011
A1S31	63.31	23.99	0.16	4.47	8.90	0.28	101.11		0.214	0.770	0.016
A1S32	63.23	23.97	0.05	4.53	9.17	0.19	101.14	2	0.212	0.777	0.011
A1S33	62.23	23.70	0.15	4.30	9.15	0.25	99.80		0.203	0.783	0.014
A1S34	63.08	23.98	0.08	4.49	9.05	0.23	100.91		0.212	0.775	0.013
A1S35	63.36	24.27	0.15	4.53	8.95	0.18	101.44		0.216	0.773	0.015
A1S36	61.86	23.45	0.28	4.31	9.24	0.14	99.28		0.203	0.789	0.009
A2S18	63.19	23.82	0.12	4.50	8.98	0.24	100.85	3	0.214	0.772	0.014
A2S19	63.21	23.79	0.09	4.48	9.15	0.24	100.96	3	0.210	0.776	0.013
A2S21	62.13	23.44	0.21	4.38	9.15	0.21	99.52		0.207	0.781	0.012
A2S22	62.97	23.93	0.14	4.39	9.18	0.23	100.84		0.206	0.781	0.013
A2S23	63.55	23.69	0.05	4.39	9.46	0.22	101.36		0.202	0.786	0.012
A2S24	62.24	23.66	0.16	4.48	9.09	0.20	99.81		0.212	0.777	0.011
A2S25	62.30	23.69	0.04	4.36	9.14	0.21	99.74		0.206	0.782	0.012
A2S26	63.03	23.81	0.11	4.35	9.44	0.31	101.03	2	0.200	0.784	0.017
A2S27	63.04	23.72	0.00	4.34	9.30	0.25	100.65		0.202	0.784	0.014
A2S28	63.01	23.78	0.13	4.45	9.12	0.16	100.65		0.210	0.781	0.009
A2S29	63.30	23.67	0.14	4.45	9.37	0.12	101.05		0.207	0.787	0.007
A2S30	62.81	23.77	0.01	4.50	9.05	0.13	100.27		0.214	0.779	0.007
A2S31	63.06	23.84	0.12	4.54	9.09	0.25	100.90		0.213	0.773	0.014
A2S32	62.48	23.49	0.12	4.41	9.16	0.18	99.84		0.208	0.782	0.010
A3S17	63.21	23.80	0.23	4.41	9.12	0.32	101.09	2	0.207	0.775	0.018
A3S18	62.22	23.66	0.05	4.52	8.69	0.20	99.34		0.221	0.768	0.012
A3S19	62.17	23.59	0.11	4.54	8.93	0.22	99.56		0.217	0.771	0.012
A3S20	62.51	24.13	0.04	4.61	9.23	0.32	100.84		0.213	0.770	0.018
A3S21	61.59	23.67	0.27	4.46	9.20	0.30	99.49	2	0.208	0.776	0.017
A3S22	62.09	23.48	0.09	4.56	9.01	0.21	99.44		0.216	0.772	0.012
A3S23	61.95	23.53	0.09	4.41	9.12	0.23	99.33		0.208	0.779	0.013
A3S24	61.15	23.48	0.10	4.25	9.08	0.27	98.33		0.202	0.782	0.015
A3S25	61.88	23.58	0.12	4.16	9.07	0.29	99.10		0.199	0.785	0.017
A3S26	61.95	23.51	0.07	4.40	9.01	0.25	99.19	2	0.210	0.776	0.014
A3S27	61.70	23.99	0.00	4.37	9.27	0.24	99.57		0.204	0.783	0.013
A3S28	60.85	23.59	0.10	4.47	9.07	0.22	98.30		0.211	0.776	0.012
A3S29	62.29	23.59	0.17	4.37	9.33	0.20	99.95		0.203	0.786	0.011
A3S30	62.72	23.81	0.13	4.56	9.27	0.28	100.77	2	0.210	0.774	0.015
A3S31	64.24	23.07	0.12	4.26	9.00	0.23	100.92		0.205	0.782	0.013
A3S32	62.92	23.88	0.02	4.60	9.15	0.25	100.82		0.214	0.772	0.014

X375#5a GARNETS X Mg versus X Fe

(Area/table: */1 */2 +/3)

X375#5a BIOTITES X Mg versus X Fe

(Area/lab: 1/* 2/* 3/+)

X375#5a PLAGIOCLASES X Na versus X Ca

(Area/lab: 1/* 2/* 3/+)

X37585a

GARNET ANALYSES

(weight percent; precision +/-2%)

	(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	M/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
A1S1	20	36.84	0.06	20.74	0.11	0.86	32.98	1.02	4.27	1.94	0.00	98.82	2/P	0.748	0.173	0.023	0.056
A1S2	380	37.51	0.03	21.07	0.00	1.33	33.04	1.13	4.60	1.94	0.00	100.65	C	0.736	0.183	0.026	0.055
A1S3	10	38.01	0.00	21.17	0.00	0.03	34.48	0.71	4.33	1.90	0.03	100.66	u	0.760	0.170	0.016	0.054
A1S4	30	37.52	0.05	21.02	0.05	1.03	33.51	1.02	4.33	1.94	0.06	100.53	2/P	0.749	0.172	0.023	0.056
A1S5	20	37.97	0.09	20.93	0.10	1.27	33.22	1.02	4.72	2.03	0.07	101.42	2/R	0.734	0.186	0.023	0.057
A1S6	10	37.86	0.02	20.75	0.00	0.33	34.09	0.98	4.32	1.92	0.02	100.29	P	0.751	0.170	0.022	0.054
A1S7	30	37.29	0.07	20.79	0.00	1.02	33.14	1.03	4.38	1.95	0.04	99.71	5/P	0.745	0.175	0.023	0.056
A1S8	15	37.26	0.06	20.73	0.04	0.64	34.27	1.05	3.77	1.93	0.02	99.77	R	0.770	0.151	0.024	0.056
A1S9	30	37.44	0.08	20.66	0.09	0.35	34.24	1.14	3.78	1.99	0.05	99.82	R	0.766	0.151	0.026	0.057
A1S10	290	37.54	0.00	20.91	0.01	0.71	33.28	0.89	4.51	2.06	0.01	99.92	2/C	0.742	0.179	0.020	0.059
A1S11	120	37.81	0.13	21.29	0.06	0.81	33.66	1.00	4.53	1.85	0.06	101.20	5/P	0.746	0.179	0.022	0.053
A1S12	280	37.06	0.00	20.56	0.03	0.66	33.22	0.92	4.32	1.93	0.00	98.70	C	0.750	0.174	0.021	0.056
A1S13	180	37.64	0.06	20.72	0.00	0.85	33.36	0.98	4.50	1.96	0.00	100.17	2/C	0.740	0.182	0.022	0.056
A1S14	250	37.45	0.09	20.87	0.01	1.12	33.21	1.07	4.47	1.98	0.03	100.30	C	0.741	0.178	0.024	0.057
A1S15	290	37.82	0.00	21.02	0.00	0.53	33.57	0.94	4.59	1.95	0.02	100.44	C	0.743	0.181	0.021	0.055
A1S16	120	37.48	0.01	20.91	0.00	1.15	33.68	1.11	4.20	1.96	0.00	100.50	P	0.752	0.167	0.025	0.056
A1S17	170	37.66	0.05	20.83	0.00	1.03	33.56	1.03	4.41	2.05	0.00	100.62	C	0.744	0.174	0.023	0.058
A1S18	10	37.27	0.08	20.47	0.02	0.79	33.47	0.92	4.24	2.10	0.00	99.36	P	0.750	0.169	0.021	0.060
A1S19	20	37.23	0.04	20.88	0.00	1.32	33.29	1.10	4.18	1.86	0.12	100.02	P	0.753	0.168	0.025	0.053
A2S1	10	37.14	0.00	21.12	0.03	1.09	33.59	1.05	3.97	2.00	0.04	100.03	P	0.758	0.160	0.024	0.058
A2S2	120	37.62	0.08	20.71	0.06	0.72	33.80	1.09	4.23	2.04	0.00	100.35	P	0.750	0.167	0.025	0.058
A2S3	150	37.28	0.00	20.63	0.04	1.34	33.70	1.03	4.13	1.94	0.00	100.09	P	0.756	0.165	0.023	0.056
A2S4	170	37.47	0.04	20.86	0.02	1.37	33.88	1.15	4.00	1.96	0.05	100.80	P	0.758	0.160	0.026	0.056
A2S5	20	37.60	0.04	20.95	0.00	1.53	33.38	1.14	4.33	1.99	0.05	101.01	Ct	0.745	0.172	0.026	0.057
A2S6	200	37.28	0.06	20.95	0.00	1.80	33.33	0.95	4.44	1.85	0.01	100.67	u	0.748	0.178	0.022	0.053
A2S7	150	37.96	0.13	21.13	0.08	0.05	34.14	0.93	4.41	1.92	0.01	100.81	u	0.751	0.173	0.022	0.054
A2S8	180	37.69	0.00	21.12	0.03	0.93	33.07	0.96	4.63	1.76	0.06	100.45	u	0.736	0.192	0.022	0.050
A2S9	150	37.89	0.04	21.04	0.02	0.59	33.92	1.00	4.48	1.85	0.03	100.86	2/u	0.749	0.176	0.022	0.052
A2S10	20	37.63	0.04	20.94	0.00	1.20	33.11	1.04	4.51	2.02	0.08	100.57	u	0.739	0.179	0.024	0.058
A2S11	20	37.48	0.10	20.66	0.00	0.67	34.59	0.97	3.74	2.00	0.03	100.24	Ct	0.772	0.149	0.022	0.057
A2S12	20	37.83	0.06	21.45	0.06	0.83	33.18	0.95	4.72	1.99	0.07	101.16	u	0.736	0.186	0.021	0.057
A2S13	100	36.93	0.02	20.96	0.01	1.68	32.94	0.93	4.31	1.88	0.06	99.72	2/u	0.749	0.175	0.021	0.055
A2S14	20	37.56	0.07	20.69	0.06	0.74	33.34	1.02	4.55	1.94	0.01	99.98	2/u	0.741	0.180	0.023	0.055
A2S15	30	37.79	0.05	20.99	0.06	0.70	33.52	1.08	3.52	1.86	0.06	100.64	Ct	0.783	0.140	0.024	0.053
A2S16	20	37.06	0.02	20.83	0.02	1.04	34.93	1.13	3.06	1.96	0.08	100.13	2/Ct	0.793	0.124	0.026	0.057
A2S17	80	37.34	0.00	20.72	0.00	0.47	34.27	1.02	3.89	1.89	0.00	99.60	P	0.767	0.155	0.023	0.054
A2S18	120	36.96	0.01	20.82	0.01	1.39	33.84	1.05	3.96	1.73	0.01	99.78	P	0.766	0.160	0.024	0.050
A2S19	180	37.28	0.06	20.68	0.03	0.62	34.40	0.95	3.86	1.89	0.00	99.77	u	0.770	0.154	0.022	0.054
A2S20	180	37.09	0.00	20.60	0.00	0.91	33.75	0.95	4.02	1.87	0.03	99.22	P	0.762	0.162	0.022	0.054
A2S21	150	37.49	0.09	21.05	0.00	0.80	33.65	1.03	4.25	1.88	0.07	100.31	P	0.753	0.170	0.023	0.054
A2S22	30	37.34	0.02	20.78	0.02	0.35	33.29	0.92	4.38	1.93	0.02	99.05	2/u	0.748	0.175	0.021	0.056
A2S23	200	37.39	0.05	20.77	0.01	0.50	33.34	1.04	4.49	1.91	0.02	99.42	2/u	0.746	0.175	0.024	0.055
A2S24	20	37.52	0.03	21.05	0.00	0.77	35.12	1.10	3.43	1.88	0.04	100.94	Ct	0.785	0.137	0.025	0.054
A2S25	20	37.57	0.00	21.13	0.06	0.20	34.46	0.89	3.83	2.02	0.04	100.20	Ct	0.770	0.152	0.020	0.058
A2S26	50	37.31	0.11	20.80	0.03	0.45	33.87	0.96	4.12	1.94	0.01	99.60	P	0.758	0.164	0.022	0.056
A2S27	30	37.44	0.08	20.50	0.01	0.77	34.22	1.00	3.93	2.02	0.00	99.97	P	0.763	0.156	0.023	0.058
A2S28	50	37.07	0.08	20.80	0.09	0.75	33.81	1.01	3.99	1.98	0.80	100.38	2/P	0.760	0.160	0.023	0.057
A2S29	50	37.28	0.02	20.64	0.07	0.79	33.79	1.01	4.02	2.02	0.00	99.64	P	0.758	0.161	0.023	0.058

A2S30	50	37.33	0.00	20.85	0.00	0.62	33.58	1.02	4.22	1.84	0.05	99.51	P	0.755	0.169	0.023	0.053
A3S1	10	38.00	0.11	20.84	0.00	0.00	33.93	0.90	4.48	2.02	0.01	100.29	2/Ct	0.747	0.176	0.020	0.057
A3S2	5	37.30	0.28	20.68	0.00	0.37	32.96	1.02	4.71	1.92	0.00	99.24	Ct	0.735	0.187	0.023	0.055
A3S3	125	37.36	0.04	20.58	0.02	0.54	33.67	0.94	4.17	2.06	0.00	99.38	C	0.753	0.166	0.021	0.059
A3S4	10	37.28	0.05	20.65	0.05	0.74	33.58	1.02	4.15	1.88	0.06	99.46	C	0.756	0.166	0.023	0.054
A3S5	15	37.09	0.02	20.80	0.00	1.06	32.64	1.00	4.50	1.89	0.02	99.02	2/C	0.740	0.182	0.023	0.055
A3S6	75	37.26	0.13	20.80	0.03	0.67	33.47	1.04	4.23	2.03	0.00	99.66	Ct	0.749	0.169	0.024	0.058
A3S7	15	37.24	0.15	20.61	0.00	0.99	32.94	1.12	4.42	2.02	0.04	99.53	C	0.740	0.177	0.025	0.058
A3S8	100	37.35	0.08	20.73	0.01	0.74	33.16	1.11	4.31	2.06	0.04	99.59	C	0.743	0.172	0.025	0.059
A3S9	35	37.33	0.00	20.67	0.00	0.20	33.39	0.97	4.31	1.95	0.04	98.86	C	0.749	0.172	0.022	0.056
A3S10	60	37.27	0.04	20.81	0.00	0.52	33.14	0.99	4.39	2.08	0.00	99.24	C	0.743	0.175	0.022	0.060
A3S11	20	37.38	0.07	20.62	0.09	1.17	32.95	1.02	4.70	1.80	0.03	99.83	Ct	0.738	0.188	0.023	0.052
A3S12	50	37.05	0.03	20.67	0.00	0.59	32.76	0.96	4.52	1.86	0.05	98.49	u	0.742	0.182	0.022	0.054
A3S13	50	36.82	0.00	20.80	0.00	0.91	32.59	0.89	4.55	1.84	0.02	98.42	u	0.741	0.184	0.021	0.054

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																	
rim	mean	37.56	0.08	20.77	0.08	0.75	33.91	1.07	4.09	1.98	0.05	100.34	3	0.757	0.162	0.024	0.057
plateau	mean	37.41	0.06	20.86	0.03	0.91	33.48	1.02	4.31	1.94	0.04	100.05	8	0.749	0.172	0.023	0.056
	std	0.33	0.04	0.24	0.04	0.30	0.35	0.06	0.11	0.08	0.04	0.75		0.003	0.004	0.001	0.002
core	mean	37.53	0.03	20.85	0.01	0.89	33.32	0.99	4.50	1.98	0.01	100.11	7	0.742	0.179	0.022	0.057
	std	0.24	0.04	0.17	0.01	0.28	0.19	0.09	0.11	0.05	0.01	0.67		0.004	0.004	0.002	0.001
AREA 2																	
plateau	mean	37.29	0.04	20.78	0.03	0.88	33.83	1.03	4.06	1.93	0.08	99.94	10	0.759	0.162	0.023	0.056
	std	0.19	0.04	0.18	0.03	0.33	0.21	0.05	0.12	0.09	0.22	0.45		0.005	0.005	0.001	0.002
AREA 3																	
core	mean	37.27	0.05	20.69	0.01	0.68	33.22	1.02	4.32	1.99	0.03	99.30	7	0.746	0.173	0.023	0.057
	std	0.09	0.05	0.09	0.02	0.30	0.36	0.07	0.13	0.08	0.02	0.27		0.007	0.006	0.002	0.002

X37585a

BIOTITE ANALYSES

(weight percent; precision +/-2%)

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	H ₂ O	CaO	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ^{iv} (+/-8%)	X Mn (+/-8%)
A1S1	34.47	4.56	16.57	1.14	18.41	0.11	9.11	0.15	0.14	93.64	Ct	0.388	0.440	0.098	0.072	0.003
A1S2	36.02	4.48	17.11	0.01	19.90	0.05	9.22	0.11	0.04	96.13	2	0.371	0.449	0.091	0.089	0.001
A1S3	25.43	4.53	16.61	0.00	20.12	0.00	8.73	0.15	0.09	94.71		0.359	0.464	0.094	0.083	0.000
A1S4	35.36	4.42	16.84	0.01	19.96	0.00	8.94	0.12	0.23	95.20	2	0.366	0.459	0.091	0.084	0.000
A1S5	35.11	4.41	16.20	0.00	19.86	0.00	8.72	0.18	0.13	93.82		0.364	0.465	0.093	0.079	0.000
A1S6	35.62	4.47	17.00	0.02	19.90	0.03	9.08	0.16	0.32	95.82	5	0.369	0.454	0.092	0.084	0.001
A1S7	35.24	4.33	16.75	1.69	19.62	0.00	9.09	0.22	0.31	96.35		0.382	0.462	0.092	0.065	0.000
A1S8	34.78	4.93	16.34	0.46	20.29	0.00	8.36	0.08	0.33	94.99	u	0.350	0.477	0.104	0.069	0.000
A1S9	34.90	4.77	16.22	0.01	19.72	0.04	8.46	0.18	0.08	93.51	2	0.355	0.464	0.101	0.078	0.001
A1S10	34.76	4.96	16.34	0.00	20.31	0.01	8.67	0.13	0.25	94.68	u	0.359	0.472	0.106	0.066	0.000
A1S11	35.73	4.66	16.31	0.03	19.75	0.01	8.95	0.12	0.15	95.37		0.368	0.456	0.097	0.079	0.000
A1S12	35.44	4.57	16.29	0.07	20.14	0.02	9.01	0.15	0.09	94.98		0.369	0.463	0.095	0.072	0.000
A1S13	35.01	4.05	17.14	0.02	19.66	0.00	9.13	0.13	0.08	94.64		0.374	0.452	0.104	0.091	0.000
A1S14	36.11	4.98	16.88	0.03	20.39	0.03	9.01	0.18	0.09	97.19	2	0.363	0.461	0.101	0.075	0.001
A1S15	35.07	4.79	16.43	0.00	19.56	0.00	9.14	0.14	0.28	94.88	2	0.378	0.453	0.100	0.069	0.000
A1S16	34.70	4.71	16.30	0.03	19.71	0.01	8.84	0.14	0.07	93.98		0.369	0.460	0.099	0.072	0.000
A1S17	36.01	4.23	16.92	0.02	18.7	0.03	9.19	0.19	0.20	95.66	2/Ct	0.402	0.424	0.087	0.087	0.001
A1S18	36.39	4.48	16.76	0.00	19.07	0.07	10.17	0.23	0.28	97.18	Ct	0.408	0.428	0.091	0.072	0.002
A1S19	35.02	5.15	16.27	0.11	20.21	0.07	8.52	0.18	0.04	95.09		0.354	0.471	0.108	0.065	0.002
A2S31	35.40	4.28	16.88	0.02	20.33	0.02	9.52	0.13	0.22	96.51	3/u	0.383	0.459	0.087	0.071	0.000
A2S32	35.17	4.11	16.59	0.00	20.19	0.00	9.02	0.12	0.00	94.78	u	0.370	0.464	0.085	0.081	0.000
A2S33	35.22	4.15	16.84	0.00	20.22	0.02	9.32	0.12	0.21	95.69	u	0.378	0.460	0.085	0.076	0.000
A2S34	34.88	4.27	16.38	0.01	20.20	0.08	9.24	0.20	0.13	94.78	u	0.378	0.464	0.088	0.068	0.002
A2S35	35.36	4.19	16.54	0.00	20.52	0.01	9.12	0.10	0.00	95.44	u	0.371	0.468	0.086	0.075	0.000
A2S36	35.21	4.19	17.06	0.10	20.14	0.09	9.27	0.30	0.14	95.98	u	0.376	0.458	0.086	0.078	0.002
A2S37	34.90	4.30	16.79	0.00	20.36	0.02	9.16	0.08	0.21	95.34	2/u	0.373	0.465	0.088	0.073	0.000
A2S38	35.29	4.33	16.95	0.05	19.98	0.02	9.70	0.18	0.27	96.28	2	0.390	0.451	0.088	0.070	0.000
A2S39	35.22	4.20	16.66	0.00	19.82	0.00	9.76	0.13	0.00	95.17		0.395	0.446	0.086	0.074	0.000
A2S40	35.10	4.06	17.30	0.00	19.58	0.00	9.78	0.17	0.03	95.62		0.393	0.442	0.082	0.083	0.000
A2S41	35.40	3.73	17.02	0.00	19.52	0.05	9.81	0.14	0.30	95.62		0.397	0.443	0.076	0.083	0.001
A2S42	34.99	4.33	17.04	0.04	20.35	0.03	9.45	0.15	0.03	95.98	2/u	0.380	0.459	0.088	0.072	0.001
A2S43	35.37	4.30	16.95	0.08	19.10	0.00	10.20	0.19	0.00	95.61	u	0.409	0.430	0.087	0.074	0.000
A2S44	34.88	4.24	16.78	0.10	19.84	0.05	9.71	0.10	0.24	94.71		0.393	0.451	0.087	0.068	0.001
A2S45	34.97	4.13	16.60	0.00	19.74	0.03	9.50	0.21	0.01	95.42		0.388	0.452	0.085	0.074	0.001
A2S46	33.82	3.93	16.39	0.00	19.26	0.02	8.99	0.14	0.01	91.74	2	0.378	0.455	0.083	0.083	0.000
A2S47	34.49	4.14	16.43	0.02	20.44	0.00	9.45	0.17	0.22	94.77		0.385	0.468	0.085	0.062	0.000
A2S48	33.83	4.23	15.95	0.09	19.57	0.03	9.25	0.17	0.36	92.55		0.388	0.461	0.090	0.061	0.001
A2S49	34.17	4.06	16.59	0.01	19.39	0.01	8.93	0.14	0.00	92.38		0.373	0.455	0.086	0.086	0.000
A2S50	35.53	4.20	16.75	0.00	19.84	0.02	9.33	0.12	0.20	95.47	2	0.380	0.453	0.086	0.081	0.000
A2S51	34.57	4.09	16.57	0.00	20.04	0.00	9.46	0.17	0.10	94.37		0.386	0.459	0.084	0.071	0.000
A2S52	34.05	4.12	16.14	0.07	19.77	0.00	8.93	0.20	0.29	92.83	u	0.376	0.467	0.087	0.070	0.000
A2S53	35.48	4.20	17.11	0.00	19.50	0.00	9.74	0.17	0.05	95.59		0.392	0.440	0.085	0.083	0.000
A2S54	35.42	3.92	16.89	0.00	20.13	0.02	9.42	0.13	0.19	95.68		0.381	0.457	0.080	0.081	0.000
A3S14	34.71	4.10	16.96	0.01	19.58	0.00	9.28	0.18	0.11	94.31	2	0.381	0.451	0.085	0.084	0.000
A3S15	34.53	4.07	16.67	0.01	19.63	0.01	9.03	0.18	0.02	93.57	2	0.374	0.457	0.083	0.083	0.000
A3S16	35.25	4.23	17.07	0.02	19.41	0.00	9.64	0.16	0.01	95.45		0.391	0.441	0.086	0.082	0.000
A3S17	35.80	4.24	16.93	0.01	19.82	0.03	9.60	0.19	0.04	96.48		0.387	0.448	0.086	0.079	0.001

A3S18	36.63	4.14	17.51	0.00	20.11	0.00	10.02	0.13	0.00	9.84	98.38	0.392	0.441	0.082	0.085	0.000
A3S19	36.37	4.52	17.23	0.07	20.08	0.00	9.29	0.10	0.05	9.84	97.55	0.372	0.451	0.091	0.085	0.000
A3S20	36.01	4.21	17.18	0.04	20.26	0.04	9.67	0.18	0.04	9.72	97.35	0.384	0.452	0.084	0.079	0.001
A3S21	35.88	3.95	18.32	0.04	20.09	0.00	8.39	0.21	0.00	9.83	96.71	0.341	0.458	0.081	0.120	0.000
A3S22	36.27	4.31	18.86	0.07	18.12	0.00	8.73	0.17	0.12	9.75	96.40	0.357	0.416	0.089	0.137	0.000
A3S23	35.89	4.00	17.52	0.00	20.02	0.00	9.67	0.17	0.03	9.49	96.79	0.384	0.446	0.080	0.090	0.000
A3S24	36.03	4.20	17.28	0.00	20.47	0.01	9.62	0.11	0.00	9.94	97.66	0.381	0.455	0.084	0.080	0.000
A3S25	36.12	4.24	17.24	0.00	20.45	0.01	9.92	0.17	0.00	9.74	97.89	0.390	0.451	0.084	0.075	0.000
A3S26	34.96	4.13	16.80	0.05	19.55	0.14	9.30	0.11	0.08	9.45	94.57	0.381	0.449	0.085	0.081	0.003
A3S27	35.44	4.32	17.42	0.01	19.55	0.05	9.49	0.08	0.36	9.75	96.47	0.383	0.443	0.088	0.084	0.001
A3S29	36.24	4.13	16.96	0.00	20.05	0.00	9.26	0.13	0.28	9.63	96.68	0.374	0.455	0.084	0.087	0.000
A3S30	35.78	4.40	17.44	0.00	20.46	0.00	9.22	0.08	0.00	9.94	97.32	0.368	0.459	0.089	0.084	0.000

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																
mean	35.33	4.59	16.61	0.15	19.89	0.02	8.92	0.15	0.14	9.32	95.12	0.367	0.460	0.095	0.077	0.000
std	0.42	0.28	0.34	0.45	0.25	0.02	0.23	0.03	0.10	0.16	1.02	0.008	0.006	0.006	0.008	0.001
AREA 2																
mean	34.87	4.10	16.71	0.02	19.75	0.02	9.49	0.15	0.15	9.41	94.67	0.387	0.452	0.085	0.076	0.000
std	0.60	0.16	0.34	0.03	0.32	0.02	0.29	0.03	0.13	0.19	1.42	0.007	0.008	0.003	0.008	0.000
AREA 3																
mean	35.69	4.21	17.28	0.02	19.77	0.02	9.48	0.15	0.07	9.68	96.38	0.381	0.446	0.085	0.086	0.001
std	0.66	0.13	0.54	0.03	0.61	0.04	0.35	0.04	0.10	0.18	1.49	0.009	0.010	0.003	0.016	0.001

X37595a PLAGIOCLASE ANALYSES (weight percent; precision +/- 22)

	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	R/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
A1S20	60.06	25.30	0.06	6.26	7.73	0.33	99.74	u	0.303	0.678	0.019
A1S22	59.16	24.78	0.19	6.31	7.74	0.25	98.63		0.313	0.673	0.014
A1S23	59.89	25.35	0.09	6.40	7.79	0.24	99.76	2	0.308	0.678	0.014
A1S24	59.93	25.42	0.12	6.50	7.76	0.27	100.00		0.312	0.673	0.015
A1S25	59.08	24.90	0.32	6.40	7.74	0.38	98.82	u	0.307	0.671	0.022
A1S26	59.39	25.33	0.06	6.67	7.56	0.20	99.21	u	0.324	0.664	0.012
A1S27	59.91	25.17	0.07	6.54	7.63	0.25	99.57		0.317	0.669	0.014
A1S28	60.87	25.38	0.11	6.53	7.68	0.25	100.82		0.315	0.671	0.014
A1S29	60.17	25.35	0.07	6.49	7.67	0.24	99.99	2	0.314	0.672	0.014
A1S30	60.47	25.67	0.20	6.45	7.79	0.26	100.84	2	0.309	0.676	0.015
A1S31	61.25	25.60	0.06	6.59	7.81	0.28	101.59	2	0.313	0.671	0.016
A1S32	60.41	25.42	0.15	6.55	7.65	0.31	100.49	u	0.315	0.667	0.018
A1S33	60.73	25.84	0.00	6.66	7.75	0.33	101.31	u	0.316	0.665	0.019
A1S34	60.72	25.51	0.11	6.47	7.94	0.26	101.01	3	0.306	0.679	0.015
A2S54	60.14	25.58	0.14	6.39	7.91	0.25	100.41		0.304	0.682	0.014
A2S55	60.63	25.34	0.07	6.43	7.66	0.27	100.40		0.312	0.672	0.016
A2S56	60.17	25.43	0.11	6.39	7.83	0.27	100.20	3	0.306	0.679	0.015
A1S57	60.51	26.04	0.09	6.50	7.84	0.22	101.20		0.310	0.677	0.013
A2S58	60.04	25.30	0.07	6.38	7.94	0.27	100.00	3	0.303	0.682	0.015
A2S59	60.04	25.51	0.19	6.34	7.71	0.27	100.06		0.308	0.677	0.016
A2S60	59.95	25.00	0.10	6.36	7.78	0.24	99.43		0.307	0.679	0.014
A2S61	60.54	25.48	0.00	6.36	8.02	0.24	100.34		0.301	0.686	0.014
A2S62	60.53	25.34	0.00	6.38	7.91	0.29	100.45		0.303	0.680	0.016
A2S63	59.93	25.54	0.15	6.41	7.68	0.34	100.05	u	0.309	0.671	0.020
A2S64	59.58	25.23	0.15	6.37	7.71	0.27	99.31	2	0.309	0.676	0.016
A3S31	59.30	25.19	0.27	6.37	7.72	0.19	99.04	2	0.310	0.679	0.011
A3S32	60.04	25.46	0.14	6.43	7.71	0.28	100.06	4	0.310	0.674	0.016
A3S33	59.54	24.89	0.03	6.27	7.52	0.19	98.44		0.312	0.677	0.011
A3S34	59.88	24.97	0.16	6.30	7.48	0.27	99.06	2	0.313	0.672	0.016
A3S35	60.81	25.20	0.04	6.45	7.61	0.27	100.38		0.314	0.670	0.016
A3S36	59.93	25.00	0.00	6.45	7.59	0.27	99.24		0.315	0.670	0.016
A3S37	60.23	25.52	0.12	6.60	7.93	0.21	100.31	u	0.319	0.668	0.012
A3S38	60.89	25.75	0.13	6.45	7.78	0.25	101.25	2	0.310	0.676	0.014
A3S39	61.29	25.60	0.05	6.41	7.76	0.27	101.38		0.309	0.676	0.015
A3S40	61.11	25.41	0.10	6.33	7.81	0.28	101.04		0.304	0.680	0.016
A3S41	61.38	25.36	0.09	6.49	7.92	0.20	101.44		0.308	0.681	0.011
A3S42	60.18	25.19	0.13	6.45	7.85	0.24	100.04		0.308	0.678	0.014
A3S43	61.09	25.59	0.08	6.52	7.74	0.19	101.21		0.314	0.675	0.011
A3S44	60.98	25.65	0.03	6.32	8.12	0.23	101.33	u	0.297	0.690	0.013

X195a GARNET ZONING

X195a GARNETS X Fe versus X Mg

(Area/lab: * /1 ■ /2 + /3 o /4)

X195a BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/* 3/+ 4/o)

X195a PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/* 3/+ 4/o)

X195a

GARNET ANALYSES

(weight percent; precision +/-2%)

(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	λ Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
AlS1	10	39.34	0.00	20.76	0.00	32.03	0.60	6.80	1.24	0.02	100.79	P	0.691	0.261	0.013	0.034
AlS2	130	38.86	0.07	21.32	0.01	31.34	0.67	6.92	1.59	0.04	101.74	3/C	0.676	0.266	0.015	0.044
AlS3	200	38.02	0.06	21.03	0.00	30.91	0.58	6.81	1.49	0.00	99.48	C	0.679	0.266	0.013	0.042
AlS4	170	38.23	0.05	21.11	0.00	31.14	0.65	6.65	1.59	0.01	100.29	C	0.682	0.259	0.014	0.045
AlS5	10	39.25	0.02	21.29	0.06	31.95	0.73	6.61	1.13	0.07	101.12	2/P	0.696	0.256	0.016	0.032
AlS6	10	37.94	0.06	20.83	0.01	31.10	0.58	6.70	1.23	0.08	98.96	u	0.688	0.264	0.013	0.035
AlS7	30	39.18	0.04	21.18	0.02	31.99	0.69	6.80	1.38	0.03	101.56	3/P	0.687	0.260	0.015	0.038
AlS8	10	38.26	0.01	20.75	0.02	31.02	0.62	6.79	1.24	0.04	99.01	2/P	0.684	0.267	0.014	0.035
AlS9	130	38.58	0.04	21.29	0.05	31.06	0.60	6.82	1.70	0.06	100.72	2/C	0.675	0.264	0.013	0.047
AlS10	20	38.42	0.00	21.04	0.07	31.60	0.60	6.71	1.26	0.05	100.79	P	0.690	0.261	0.013	0.035
AlS11	10	38.22	0.03	21.43	0.03	32.13	0.68	6.22	1.19	0.02	100.12	3/P	0.707	0.244	0.015	0.034
AlS12	20	38.86	0.11	21.33	0.05	32.61	0.70	6.24	1.52	0.07	101.78	2/P	0.703	0.240	0.015	0.042
AlS13	260	38.04	0.05	20.49	0.07	31.11	0.59	6.49	1.67	0.03	99.20	2/C	0.685	0.255	0.013	0.047
AlS14	110	38.38	0.03	21.19	0.00	31.12	0.62	6.75	1.62	0.00	100.21	C	0.679	0.262	0.014	0.045
AlS15	330	38.26	0.03	21.05	0.07	31.41	0.64	6.45	1.61	0.04	99.81	C	0.689	0.252	0.016	0.039
AlS16	420	38.61	0.02	20.97	0.08	31.39	0.71	6.83	1.42	0.02	100.74	u	0.681	0.264	0.017	0.035
AlS18	30	38.79	0.00	20.47	0.06	31.79	0.76	6.49	1.26	0.01	99.63	P	0.695	0.253	0.017	0.033
AlS19	10	38.26	0.08	21.00	0.02	32.22	0.77	6.08	1.18	0.03	99.64	Cr	0.711	0.239	0.017	0.033
AlS20	70	37.73	0.00	20.46	0.08	31.75	0.61	6.33	1.04	0.05	98.50	Ct	0.706	0.251	0.014	0.030
AlS21	20	38.09	0.06	20.98	0.02	31.66	0.61	6.62	1.03	0.06	99.13	P	0.697	0.260	0.014	0.029
AlS22	10	38.17	0.08	20.77	0.06	30.61	0.60	7.21	1.09	0.06	98.83	2/u	0.673	0.283	0.013	0.031
AlS23	100	38.17	0.03	20.67	0.01	30.63	0.57	7.22	1.12	0.02	98.89	2/u	0.673	0.283	0.013	0.032
AlS24	20	38.12	0.02	20.67	0.02	31.47	0.64	6.46	1.08	0.04	99.01	2/R	0.699	0.256	0.014	0.031
AlS25	10	38.73	0.03	20.87	0.05	31.09	0.62	7.23	1.05	0.02	99.69	3/u	0.677	0.280	0.014	0.029
AlS26	90	39.07	0.03	20.90	0.00	31.22	0.63	6.96	1.16	0.00	100.05	C	0.682	0.271	0.014	0.032
AlS27	30	38.58	0.00	21.16	0.08	31.28	0.56	7.14	1.15	0.02	100.04	u	0.679	0.276	0.012	0.032
A2S1	10	38.85	0.10	21.10	0.02	30.99	0.64	7.30	1.22	0.02	100.24	P	0.671	0.282	0.014	0.034
A2S2	125	38.67	0.04	21.25	0.05	29.49	0.51	7.66	1.92	0.05	100.76	2/C	0.639	0.296	0.011	0.053
A2S3	265	38.43	0.00	21.12	0.06	29.65	0.48	7.26	2.25	0.01	99.96	2/C	0.645	0.281	0.011	0.063
A2S4	310	38.28	0.05	21.00	0.88	29.39	0.55	7.24	2.17	0.04	100.52	4/C	0.644	0.283	0.012	0.061
A2S5	275	38.43	0.02	21.24	0.04	29.55	0.58	7.49	1.89	0.03	100.52	4/C	0.644	0.291	0.013	0.053
A2S6	310	38.17	0.00	20.92	0.00	29.03	0.61	7.39	2.17	0.01	99.69	C	0.637	0.289	0.014	0.061
A2S7	10	37.32	0.03	20.64	0.00	34.28	0.94	4.24	1.46	0.01	99.99	Ct	0.768	0.169	0.021	0.042
A2S8	10	37.14	0.01	20.73	0.00	32.90	1.04	4.87	1.19	0.08	99.55	Ct	0.745	0.197	0.024	0.035
A2S9	20	37.50	0.04	20.86	0.06	34.23	1.19	4.25	1.24	0.09	99.91	Ct	0.768	0.170	0.027	0.036
A2S10	15	37.40	0.15	21.00	0.04	33.60	1.18	4.35	1.59	0.09	103.03	Ct	0.754	0.174	0.027	0.046
A2S11	120	38.24	0.06	21.18	0.00	31.99	0.69	6.10	1.71	0.00	100.81	P	0.699	0.238	0.015	0.048
A2S12	60	38.38	0.09	21.26	0.15	32.08	0.75	6.06	1.64	0.07	101.60	P	0.701	0.236	0.017	0.046
A2S13	75	37.93	0.08	21.27	0.00	31.66	0.61	6.34	1.43	0.00	101.05	P	0.697	0.249	0.014	0.040
A2S14	20	38.10	0.01	20.96	0.00	31.76	0.66	6.7	1.64	0.01	100.45	P	0.698	0.242	0.015	0.046
A2S15	15	38.10	0.01	20.96	0.00	31.76	0.66	6.7	1.64	0.01	100.45	P	0.698	0.242	0.015	0.046
A2S16	75	38.92	0.15	21.83	0.09	30.82	0.78	6.89	2.00	0.07	102.69	C	0.664	0.264	0.017	0.055
A2S17	15	37.61	0.07	21.20	0.03	32.45	0.79	5.66	1.21	0.05	100.30	u	0.723	0.225	0.018	0.035
A2S18	45	38.00	0.02	21.09	0.00	30.70	0.67	6.95	1.29	0.01	99.94	u	0.676	0.273	0.015	0.036
A2S19	15	38.08	0.05	21.21	0.07	31.93	0.78	6.11	1.32	0.09	101.63	P	0.705	0.240	0.017	0.037
A2S20	15	38.12	0.08	20.84	0.06	31.02	0.62	6.81	1.42	0.01	100.32	u	0.680	0.266	0.014	0.040
A2S21	20	38.23	0.04	21.13	0.00	32.37	0.59	5.94	1.69	0.01	100.58	P	0.708	0.232	0.013	0.047
A2S22	90	38.07	0.00	21.08	0.03	28.64	0.54	7.67	2.02	0.02	100.03	C	0.630	0.301	0.012	0.057

A2S23	175	38.79	0.06	21.19	0.03	1.49	29.09	0.69	7.60	2.32	0.05	101.31	C	0.628	0.292	0.015	0.064
A2S24	200	38.00	0.09	21.06	0.00	1.72	30.06	0.61	6.80	2.05	0.02	100.41	u	0.662	0.267	0.014	0.058
A2S45	15	38.22	0.15	21.13	0.00	1.53	29.50	0.51	7.73	1.51	0.03	100.31	C	0.645	0.301	0.011	0.042
A2S46	65	38.48	0.00	20.80	0.02	1.43	29.15	0.57	7.85	1.80	0.00	100.10	C	0.633	0.304	0.013	0.050
A2S47	130	38.65	0.04	21.53	0.12	1.29	29.38	0.54	7.64	2.01	0.04	101.24	C	0.637	0.295	0.012	0.056
A2S48	200	38.26	0.04	21.15	0.02	1.22	29.44	0.56	7.44	1.94	0.01	100.08	C	0.643	0.290	0.012	0.054
A2S49	325	38.23	0.04	21.22	0.07	1.32	29.24	0.40	7.53	2.09	0.00	100.14	C	0.639	0.293	0.009	0.059
A2S50	240	37.87	0.12	20.89	0.08	1.01	32.57	0.82	5.15	1.90	0.11	100.52	u	0.724	0.204	0.018	0.054
A3S1	5	37.81	0.07	23.13	0.03	1.27	31.65	0.70	6.29	1.21	0.06	100.22	2/u	0.701	0.248	0.016	0.034
A3S2	125	38.35	0.08	21.12	0.03	1.43	32.05	0.71	6.33	1.38	0.03	101.51	2/u	0.700	0.246	0.016	0.039
A3S3	5	37.66	0.09	21.00	0.00	1.15	32.27	0.72	5.86	1.28	0.00	100.03	R	0.716	0.232	0.016	0.036
A3S4	15	37.72	0.11	21.12	0.12	1.03	32.37	0.74	5.91	1.22	0.00	100.34	R	0.716	0.233	0.017	0.035
A3S5	20	38.20	0.04	21.11	0.05	0.81	31.69	0.72	6.56	1.16	0.04	100.38	P	0.695	0.256	0.016	0.033
A3S6	10	37.83	0.01	21.06	0.02	1.78	31.11	0.70	6.66	1.15	0.01	100.33	3/P	0.689	0.263	0.016	0.033
A3S7	15	38.01	0.00	21.32	0.00	0.83	32.45	0.56	6.06	1.14	0.06	100.43	P	0.717	0.239	0.013	0.032
A3S8	150	37.78	0.00	21.24	0.00	1.26	31.71	0.59	6.20	1.35	0.03	100.16	u	0.703	0.245	0.013	0.038
A3S9	90	37.77	0.00	20.81	0.05	1.89	31.13	0.63	6.63	1.26	0.00	100.17	P	0.689	0.261	0.014	0.036
A3S10	75	37.53	0.03	21.03	0.01	1.71	31.45	0.61	6.18	1.41	0.00	99.96	2/P	0.701	0.245	0.014	0.040
A3S12	90	37.21	0.02	20.78	0.00	1.34	31.93	0.67	5.72	1.26	0.01	98.94	2/u	0.719	0.229	0.015	0.036
A3S13	100	37.33	0.01	21.01	0.01	2.34	30.82	0.67	6.37	1.33	0.03	99.92	2/P	0.692	0.255	0.015	0.038
A3S14	10	37.75	0.05	21.08	0.06	1.97	31.06	0.67	6.60	1.25	0.03	100.52	2/P	0.689	0.261	0.015	0.036
A3S15	50	37.82	0.09	20.80	0.00	1.76	31.43	0.71	6.53	1.15	0.01	100.30	2/P	0.694	0.257	0.016	0.033
A4S1	10	38.13	0.00	21.05	0.04	1.17	30.92	0.61	6.94	1.24	0.02	100.12	2/P	0.680	0.272	0.014	0.035
A4S2	175	38.51	0.04	21.46	0.04	1.40	30.50	0.57	6.99	1.90	0.03	101.44	4/C	0.664	0.271	0.013	0.053
A4S3	165	38.11	0.01	21.37	0.01	1.58	30.33	0.59	6.88	1.89	0.00	100.77	2/C	0.665	0.269	0.013	0.053
A4S4	140	38.34	0.04	21.32	0.04	1.74	30.16	0.57	7.08	1.89	0.03	101.21	4/C	0.659	0.276	0.013	0.053
A4S5	15	38.19	0.04	21.31	0.03	1.34	30.86	0.67	6.88	1.40	0.02	100.74	4/P	0.677	0.269	0.015	0.039
A4S6	15	38.01	0.03	21.16	0.05	1.00	30.81	0.61	6.95	1.23	0.04	99.89	3/P	0.679	0.273	0.014	0.035
A4S7	37.65	0.07	21.10	0.03	1.56	31.23	0.64	6.23	1.52	1.33	0.05	100.08	Ct	0.695	0.247	0.014	0.043
A4S8	10	37.94	0.03	21.22	0.06	1.21	30.90	0.69	6.73	1.33	0.04	100.15	P	0.682	0.265	0.015	0.038
A4S9	10	37.55	0.04	21.01	0.07	1.28	31.00	0.73	6.35	1.35	0.03	99.41	P	0.692	0.253	0.017	0.039
A4S10	50	37.90	0.05	21.06	0.05	1.52	29.69	0.64	7.05	1.89	0.00	99.85	P	0.655	0.277	0.014	0.053
A4S11	15	38.19	0.08	21.23	0.02	1.11	31.55	0.61	6.47	1.36	0.09	100.71	3/P	0.694	0.254	0.014	0.038
A4S12	20	38.16	0.11	21.09	0.08	1.12	32.09	0.64	6.15	1.38	0.09	100.91	P	0.706	0.241	0.014	0.039
A4S13	65	38.22	0.08	21.08	0.04	1.35	30.49	0.62	6.78	1.88	0.06	100.60	C	0.669	0.265	0.014	0.053
A4S14	110	38.49	0.05	21.36	0.02	1.35	30.49	0.65	6.94	1.90	0.03	101.28	2/C	0.664	0.269	0.014	0.053
A4S15	50	38.18	0.00	21.19	0.05	1.71	30.19	0.63	7.13	1.62	0.01	100.71	C	0.662	0.279	0.014	0.046
A4S16	60	37.89	0.02	21.72	0.00	1.48	29.95	0.62	7.02	1.65	0.04	100.39	C	0.663	0.277	0.014	0.047
A4S17	100	38.35	0.07	21.57	0.09	1.52	30.49	0.70	6.91	1.73	0.07	101.50	3/C	0.667	0.269	0.016	0.048

AREA 1	contact plateau	mean	38.00	0.04	20.73	0.05	0.23	31.99	0.69	6.21	1.11	0.04	99.07	2	0.708	0.245	0.015	0.031
		std	38.65	0.03	20.99	0.03	0.25	31.83	0.66	6.57	1.23	0.04	100.29	10	0.695	0.256	0.015	0.034
	core	mean	0.49	0.03	0.32	0.02	0.33	0.32	0.06	0.22	0.14	0.02	1.06		0.007	0.008	0.001	0.004
		std	38.43	0.04	21.05	0.04	0.54	31.16	0.62	6.73	1.53	0.02	100.19	8	0.681	0.262	0.014	0.043
AREA 2	contact plateau	mean	0.38	0.02	0.26	0.04	0.30	0.16	0.03	0.19	0.17	0.02	0.79		0.005	0.006	0.001	0.005
		std	37.34	0.06	20.81	0.03	1.68	33.75	1.09	4.43	1.37	0.07	100.62	2	0.758	0.177	0.025	0.039
	core	mean	0.15	0.06	0.16	0.03	1.38	0.65	0.12	0.30	0.19	0.04	1.62		0.011	0.013	0.003	0.005
		std	38.24	0.06	21.13	0.03	1.07	31.82	0.67	6.27	1.54	0.03	100.85	8	0.697	0.245	0.013	0.043
AREA 3	rim plateau	mean	0.28	0.03	0.12	0.05	0.62	0.40	0.07	0.43	0.19	0.03	0.53		0.011	0.016	0.001	0.005
		std	38.43	0.05	21.19	0.11	1.29	29.41	0.56	7.49	2.01	0.03	100.57	13	0.641	0.291	0.012	0.056
	core	mean	0.26	0.05	0.26	0.23	0.30	0.50	0.09	0.25	0.21	0.02	0.80		0.009	0.010	0.002	0.006
		std	37.80	0.07	21.15	0.04	1.00	32.36	0.67	5.94	1.21	0.02	100.27	3	0.716	0.234	0.015	0.034
AREA 4	plateau	mean	0.19	0.06	0.16	0.07	0.16	0.09	0.10	0.10	0.07	0.03	0.21		0.000	0.004	0.002	0.002
		std	37.75	0.03	20.99	0.03	1.75	31.24	0.67	6.50	1.24	0.02	100.23	7	0.693	0.237	0.015	0.035
	core	mean	0.27	0.03	0.13	0.02	0.47	0.29	0.04	0.17	0.10	0.02	0.22		0.004	0.006	0.001	0.003
		std	38.02	0.05	21.15	0.05	1.18	31.16	0.65	6.64	1.33	0.05	100.28	7	0.697	0.261	0.015	0.037
	plateau	mean	0.23	0.04	0.11	0.02	0.11	0.48	0.05	0.32	0.07	0.03	0.54		0.011	0.012	0.001	0.002
		std	38.22	0.04	21.35	0.04	1.52	30.25	0.62	6.98	1.82	0.03	100.86	9	0.663	0.272	0.014	0.051
	core	mean	0.23	0.03	0.22	0.03	0.14	0.29	0.04	0.11	0.12	0.02	0.55		0.004	0.005	0.001	0.003
		std	38.23	0.03	0.22	0.03	0.14	0.29	0.04	0.11	0.12	0.02	0.55		0.004	0.005	0.001	0.003

X195a	BIOTITE ANALYSES												(weight percent; precision +/-2%)												BIOTITE ANALYSES											
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	W/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ^{iv} (+/-8%)	X Mn (+/-8%)																			
A1S28	36.81	3.23	17.78	0.06	11.03	0.00	14.35	0.21	0.08	7.99	91.54	Ct	0.567	0.245	0.064	0.124	0.000																			
A1S29	36.80	4.28	17.08	0.14	13.49	0.05	13.27	0.16	0.25	9.46	94.98	Ct	0.528	0.301	0.086	0.084	0.001																			
A1S30	36.36	4.89	16.84	0.05	14.90	0.00	12.60	0.19	0.18	9.59	95.60		0.502	0.307	0.098	0.067	0.000																			
A1S31	36.72	4.73	17.12	0.03	14.79	0.01	12.62	0.18	0.20	9.48	95.88	2	0.500	0.329	0.094	0.077	0.000																			
A1S32	37.73	4.92	17.43	0.03	14.41	0.04	12.95	0.20	0.54	9.53	97.78		0.506	0.316	0.097	0.080	0.001																			
A1S33	37.29	5.25	17.08	0.10	14.53	0.02	12.61	0.25	0.02	9.39	96.54		0.497	0.322	0.105	0.076	0.000																			
A1S34	37.03	5.24	17.19	0.06	14.74	0.00	12.75	0.16	0.46	9.63	97.26		0.502	0.326	0.104	0.068	0.000																			
A1S35	37.58	5.07	17.35	0.11	15.24	0.00	12.97	0.15	0.04	9.94	98.45		0.501	0.330	0.099	0.070	0.000																			
A1S36	37.27	4.96	16.85	0.09	14.39	0.02	12.64	0.17	0.06	9.54	95.99		0.502	0.321	0.099	0.078	0.000																			
A1S37	37.03	5.00	17.15	0.14	14.73	0.00	12.66	0.18	0.08	9.73	96.70		0.500	0.326	0.100	0.074	0.000																			
A1S38	36.97	5.24	17.23	0.11	14.71	0.00	12.70	0.15	0.25	9.79	97.15		0.501	0.325	0.104	0.070	0.000																			
A1S39	37.23	4.89	16.91	0.00	14.42	0.00	13.16	0.21	0.39	9.66	96.87	2	0.517	0.318	0.097	0.068	0.000																			
A1S40	36.21	4.59	16.84	0.06	14.02	0.00	12.94	0.23	0.06	9.52	94.47		0.518	0.315	0.093	0.074	0.000																			
A1S41	36.52	4.39	16.80	0.04	13.52	0.00	12.92	0.21	0.32	8.75	92.97	2	0.506	0.309	0.090	0.095	0.000																			
A1S42	37.16	4.76	17.12	0.07	14.04	0.03	12.49	0.25	0.20	9.24	95.32	2	0.499	0.315	0.096	0.089	0.001																			
A1S43	37.96	3.52	18.31	0.06	11.93	0.00	13.05	0.17	0.98	96.20	96.20	Ct	0.571	0.254	0.088	0.107	0.000																			
A1S44	37.64	4.30	17.22	0.09	13.49	0.03	13.80	0.22	0.14	9.67	96.60	Ct	0.538	0.295	0.085	0.082	0.001																			
A1S45	38.14	4.20	17.67	0.02	13.41	0.00	13.66	0.17	0.20	9.20	96.67	Ct	0.528	0.291	0.082	0.099	0.000																			
A1S46	38.66	3.67	18.55	0.10	12.22	0.01	14.51	0.30	0.07	8.95	97.04	Ct	0.551	0.260	0.070	0.118	0.000																			
A2S25	37.31	3.11	18.60	0.06	14.41	0.01	12.90	0.20	0.11	9.18	95.89		0.500	0.314	0.061	0.125	0.000																			
A2S26	37.74	2.01	19.15	0.05	14.05	0.04	13.61	0.22	0.18	9.60	96.65	u	0.520	0.302	0.039	0.136	0.001																			
A2S27	38.09	3.04	20.00	0.05	14.73	0.03	12.73	0.21	0.31	9.58	98.75		0.484	0.314	0.058	0.143	0.001																			
A2S28	37.71	3.30	18.46	0.04	15.58	0.01	12.82	0.22	0.34	9.57	98.05	2	0.492	0.335	0.064	0.109	0.000																			
A2S29	39.70	2.98	18.91	0.07	14.61	0.00	11.79	0.16	0.37	9.42	98.01	u	0.461	0.321	0.059	0.160	0.000																			
A2S30	35.93	3.92	17.08	0.02	16.72	0.02	12.12	0.22	0.10	8.85	94.98	3/u	0.476	0.368	0.078	0.078	0.000																			
A2S31	35.96	3.46	17.76	0.06	14.18	0.01	11.42	0.23	0.20	8.63	91.91	3/u	0.470	0.327	0.072	0.131	0.000																			
A2S32	36.85	2.35	18.51	0.00	13.87	0.00	12.57	0.19	0.25	9.30	93.89		0.500	0.318	0.047	0.142	0.000																			
A2S33	36.57	3.49	17.63	0.07	14.30	0.11	12.88	0.20	0.11	9.61	94.97		0.510	0.318	0.070	0.100	0.002																			
A2S34	36.42	3.22	17.59	0.01	14.28	0.02	12.72	0.14	0.25	8.90	93.55		0.506	0.319	0.065	0.111	0.002																			
A2S35	36.17	3.08	17.54	0.00	14.58	0.00	12.85	0.20	0.13	9.19	93.74		0.510	0.324	0.062	0.104	0.000																			
A2S36	35.77	2.93	18.59	0.05	15.02	0.00	12.59	0.19	0.20	9.37	94.71		0.495	0.331	0.058	0.116	0.000																			
A2S37	37.06	2.74	19.42	0.01	14.73	0.00	12.73	0.07	0.30	9.80	98.06		0.502	0.313	0.052	0.133	0.000																			
A2S38	36.69	3.07	18.04	0.02	14.56	0.09	12.65	0.26	0.13	9.38	94.89		0.499	0.322	0.061	0.115	0.002																			
A2S39	36.32	3.55	17.92	0.00	15.01	0.00	12.16	0.10	0.00	9.60	94.66	u	0.483	0.335	0.071	0.111	0.000																			
A2S40	36.60	4.03	17.71	0.06	14.79	0.00	12.36	0.21	0.04	9.35	95.12	2	0.490	0.329	0.081	0.101	0.000																			
A2S41	37.40	3.83	17.82	0.07	14.83	0.08	12.46	0.11	0.35	9.57	96.52		0.490	0.327	0.076	0.104	0.002																			
A2S42	37.18	3.20	18.75	0.00	16.41	0.00	12.96	0.11	0.13	9.53	98.27	u	0.488	0.347	0.061	0.104	0.000																			
A2S43	37.59	3.60	17.89	0.00	14.89	0.00	12.38	0.19	0.26	9.45	96.25		0.487	0.329	0.071	0.113	0.000																			
A2S44	37.54	2.52	19.31	0.05	14.94	0.00	13.22	0.13	0.00	9.72	97.43		0.502	0.318	0.048	0.132	0.000																			
A3S16	36.78	3.71	16.00	0.14	15.08	0.08	11.66	0.05	0.00	7.82	93.41		0.461	0.334	0.074	0.129	0.002																			
A3S17	36.31	4.49	16.65	0.11	15.80	0.00	11.83	0.00	0.00	9.63	94.82	3	0.475	0.356	0.091	0.077	0.000																			
A3S18	36.06	4.56	17.44	0.16	16.17	0.08	11.04	0.04	0.04	9.50	95.09	u	0.453	0.366	0.093	0.094	0.002																			
A3S19	35.75	4.40	16.87	0.06	15.60	0.08	11.02	0.00	0.00	9.41	93.19	u	0.453	0.360	0.091	0.095	0.002																			
A3S20	36.02	4.99	16.83	0.03	15.28	0.05	12.01	0.01	0.01	9.67	94.90		0.482	0.340	0.101	0.072	0.001																			
A3S21	35.74	4.81	16.97	0.08	14.83	0.06	12.11	0.00	0.13	9.68	94.41		0.489	0.336	0.098	0.076	0.001																			
A3S22	35.46	5.39	16.33	0.14	14.02	0.00	12.49	0.00	0.15	9.47	93.41	u	0.509	0.321	0.109	0.061	0.000																			
A3S23	36.27	5.02	16.43	0.01	14.88	0.02	12.07	0.01	0.00	9.48	94.19		0.488	0.337	0.102	0.072	0.000																			

A3S24	35.86	4.86	16.62	0.00	15.24	0.00	11.49	0.00	0.00	9.69	93.76	0.470	0.350	0.100	0.080	0.000
A3S25	35.63	5.31	16.70	0.11	14.55	0.02	12.05	0.00	0.05	9.72	94.14	0.490	0.332	0.109	0.068	0.000
A3S26	35.67	4.66	16.98	0.07	15.32	0.00	11.45	0.00	0.00	9.20	93.35	0.466	0.350	0.096	0.089	0.000
A3S27	36.22	4.68	17.34	0.06	16.02	0.05	11.04	0.01	0.37	9.71	95.50	0.448	0.365	0.096	0.091	0.001
A3S28	35.34	4.82	17.24	0.14	15.55	0.04	10.95	0.06	0.13	8.92	93.19	0.449	0.358	0.100	0.093	0.001
A3S29	35.97	4.59	17.04	0.13	15.40	0.03	11.65	0.00	0.00	8.94	93.82	0.484	0.359	0.096	0.059	0.001
A3S30	35.80	4.57	16.78	0.08	15.88	0.02	11.93	0.00	0.00	9.43	94.48	0.493	0.368	0.093	0.045	0.000
A3S31	36.15	4.97	16.62	0.07	14.52	0.00	11.97	0.07	0.25	9.14	93.76	0.487	0.332	0.102	0.079	0.000
A3S32	36.00	4.81	16.46	0.08	15.06	0.02	12.28	0.04	0.00	9.77	94.52	0.495	0.341	0.098	0.066	0.000
A3S33	35.37	4.80	16.79	0.07	14.68	0.02	11.67	0.05	0.27	9.62	93.34	0.481	0.340	0.100	0.079	0.000
A3S33	37.39	3.74	17.73	0.07	11.77	0.01	15.28	0.04	0.00	9.87	95.90	0.586	0.253	0.072	0.089	0.000
A3S34	36.61	3.95	17.17	0.14	13.52	0.04	14.12	0.04	0.27	9.46	95.32	0.550	0.296	0.078	0.075	0.001
A3S35	37.32	4.24	17.49	0.08	14.42	0.00	13.07	0.03	0.08	9.12	95.85	0.509	0.315	0.083	0.093	0.000
A3S36	36.51	4.57	16.68	0.14	14.57	0.02	13.35	0.00	0.00	9.75	95.59	0.524	0.321	0.091	0.063	0.000
A3S37	36.72	4.81	16.91	0.04	15.36	0.03	12.31	0.00	0.11	9.59	95.88	0.487	0.341	0.096	0.075	0.001
A3S38	36.39	4.94	17.17	0.04	14.68	0.03	12.14	0.10	0.32	8.97	94.78	0.486	0.330	0.100	0.084	0.001
A3S39	36.71	5.15	16.98	0.10	14.71	0.00	12.55	0.00	0.21	9.83	96.24	0.499	0.328	0.103	0.070	0.000
A3S40	36.36	4.61	17.22	0.14	14.87	0.00	12.16	0.00	0.00	9.09	94.45	0.485	0.333	0.093	0.089	0.000
A3S41	35.92	4.60	17.21	0.08	14.85	0.08	12.50	0.04	0.00	9.33	94.61	0.496	0.331	0.092	0.079	0.002
A3S42	36.68	4.07	17.29	0.08	14.73	0.08	12.67	0.05	0.00	9.28	94.93	0.500	0.326	0.081	0.092	0.002
A3S43	36.33	4.05	17.95	0.08	14.05	0.05	12.08	0.08	0.00	8.20	92.87	0.482	0.315	0.082	0.121	0.001
A3S45	36.55	5.19	16.87	0.00	14.43	0.00	12.59	0.00	0.16	9.56	95.35	0.501	0.323	0.104	0.072	0.000
A3S46	36.20	5.05	16.86	0.07	14.43	0.00	12.34	0.00	0.06	9.58	94.59	0.496	0.326	0.103	0.075	0.000
A3S47	37.01	4.55	17.35	0.00	14.11	0.00	12.52	0.00	0.00	8.80	94.34	0.495	0.313	0.091	0.100	0.000
A3S48	36.17	4.81	16.84	0.08	14.40	0.01	12.59	0.03	0.05	9.65	94.63	0.505	0.324	0.097	0.074	0.000
A3S49	36.49	4.47	16.64	0.09	14.17	0.01	13.04	0.02	0.00	9.65	94.58	0.519	0.317	0.090	0.074	0.000
A3S50	36.28	5.06	16.77	0.11	14.94	0.10	12.82	0.10	0.03	9.57	95.78	0.506	0.331	0.101	0.060	0.002

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	37.00	4.93	17.07	0.07	14.53	0.01	12.75	0.19	0.22	9.55	96.31	0.504	0.322	0.098	0.075	0.000
	std	0.47	0.26	0.21	0.04	0.44	0.01	0.21	0.03	0.18	0.29	1.48	0.007	0.007	0.005	0.008	0.000
AREA 2	mean	37.04	3.16	18.36	0.03	14.68	0.03	12.74	0.18	0.19	9.43	95.84	0.498	0.322	0.062	0.118	0.001
	std	0.70	0.47	0.77	0.03	0.40	0.04	0.27	0.05	0.11	0.24	1.72	0.008	0.008	0.010	0.015	0.001
AREA 3	mean	35.97	4.73	16.84	0.08	15.12	0.02	11.86	0.48	0.05	9.37	94.07	0.482	0.345	0.097	0.076	0.001
	std	0.36	0.38	0.42	0.04	0.43	0.03	0.26	1.12	0.10	0.53	0.54	0.011	0.011	0.008	0.019	0.001
AREA 4	mean	36.50	4.67	17.08	0.07	14.50	0.03	12.64	0.03	0.07	9.33	94.93	0.501	0.323	0.094	0.081	0.001
	std	0.37	0.40	0.37	0.04	0.28	0.04	0.36	0.04	0.10	0.46	0.86	0.012	0.006	0.008	0.017	0.001

X195a PLAGIOCLASE ANALYSES (weight percent; precision +/- 2x)

	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	M/U	X Ca (+/-4x)	X Na (+/-4x)	X K (+/-4x)
A1546	62.26	23.52	0.09	4.47	9.00	0.32	99.66		0.211	0.771	0.018
A1547	62.21	23.42	0.20	4.45	9.22	0.26	99.76		0.208	0.778	0.014
A1548	62.26	23.33	0.00	4.44	8.82	0.26	99.11		0.214	0.771	0.015
A1549	61.50	23.16	0.05	4.43	9.05	0.30	98.49		0.209	0.774	0.017
A1550	62.59	23.72	0.15	4.55	9.16	0.30	100.47		0.212	0.772	0.017
A1551	62.16	23.30	0.21	4.54	9.14	0.34	99.69		0.211	0.770	0.019
A1552	62.36	23.56	0.15	4.52	8.85	0.35	99.79		0.216	0.764	0.020
A1553	62.53	22.97	0.04	4.41	9.21	0.26	99.42		0.206	0.779	0.014
A1554	61.78	23.63	0.15	4.68	8.73	0.26	99.23	u	0.225	0.760	0.015
A1555	62.22	23.19	0.15	4.50	9.21	0.25	99.52		0.210	0.776	0.014
A1556	62.88	23.57	0.06	4.46	9.13	0.23	100.33		0.210	0.777	0.013
A1557	62.69	23.26	0.11	4.46	9.16	0.32	100.07		0.208	0.774	0.018
A1558	62.58	23.20	0.00	4.33	8.82	0.32	99.25		0.209	0.772	0.018
A1559	61.91	23.70	0.08	4.69	9.01	0.31	99.70		0.220	0.763	0.017
A1560	62.43	23.25	0.04	4.42	9.17	0.25	99.56		0.207	0.779	0.014
A1561	62.04	23.19	0.09	4.33	9.15	0.25	99.05		0.204	0.782	0.014
A2550	62.66	23.37	0.03	4.53	9.15	0.28	100.02		0.211	0.773	0.016
A2551	62.82	23.14	0.06	4.28	9.43	0.16	99.89	u	0.199	0.792	0.009
A2552	64.24	22.79	0.11	3.58	9.70	0.19	100.61	u	0.168	0.822	0.011
A2553	62.40	23.57	0.09	4.62	9.19	0.26	100.13	u	0.214	0.771	0.014
A2554	63.21	22.58	0.04	3.65	9.56	0.18	99.22	u	0.172	0.817	0.010
A2555	64.75	22.47	0.14	3.12	10.05	0.26	100.79	u	0.144	0.841	0.014
A2556	62.91	23.55	0.00	4.57	9.06	0.22	100.31		0.215	0.772	0.012
A2558	62.22	23.40	0.10	4.62	9.19	0.26	99.79		0.214	0.771	0.014
A2559	63.47	23.60	0.08	4.03	9.50	0.37	101.05	u	0.186	0.794	0.020
A2560	62.66	23.66	0.11	4.52	9.13	0.22	100.30		0.212	0.776	0.012
A2561	62.94	23.60	0.07	4.60	9.23	0.19	100.63		0.214	0.776	0.011
A2562	62.30	23.64	0.09	4.60	9.21	0.21	100.05		0.214	0.775	0.012
A2563	63.17	23.85	0.00	4.72	9.10	0.22	101.06		0.220	0.768	0.012
A2564	62.51	23.51	0.12	4.47	9.03	0.23	99.87		0.212	0.775	0.013
A2565	63.17	23.12	0.11	4.27	9.10	0.15	99.92	u	0.204	0.787	0.009
A3534	62.53	23.38	0.05	4.65	9.29	0.12	100.02		0.215	0.778	0.007
A3535	62.92	23.41	0.07	4.48	9.25	0.19	100.32		0.209	0.781	0.011
A3536	63.13	23.56	0.09	4.53	9.45	0.21	100.97		0.207	0.782	0.011
A3537	62.41	23.39	0.10	4.45	9.22	0.20	99.77		0.208	0.781	0.011
A3538	63.10	23.22	0.12	4.52	9.34	0.23	100.53		0.208	0.779	0.013
A3539	62.85	23.35	0.00	4.24	9.20	0.28	99.92	u	0.200	0.784	0.016
A3540	63.21	23.62	0.11	4.56	9.23	0.17	100.90		0.212	0.778	0.009
A3541	62.57	23.85	0.06	4.60	9.29	0.23	100.60		0.212	0.775	0.013
A3542	62.61	23.17	0.15	4.61	9.11	0.25	99.90		0.215	0.771	0.014
A3543	62.75	23.53	0.01	4.42	9.14	0.38	100.23		0.206	0.772	0.021
A3544	62.78	23.94	0.05	4.55	9.16	0.30	100.78		0.212	0.772	0.017
A3545	62.89	23.39	0.01	4.61	9.11	0.26	100.27		0.215	0.770	0.014
A3546	63.13	23.69	0.02	4.55	9.34	0.27	101.00		0.209	0.776	0.015
A3548	62.83	23.25	0.10	4.48	9.24	0.19	100.09		0.209	0.780	0.011

A3S49	62.87	23.57	0.22	4.49	9.26	0.23	100.64	0.209	0.779	0.013
A4S18	62.50	23.41	0.06	4.61	9.05	0.28	99.91	0.216	0.768	0.016
A4S19	62.98	23.67	0.04	4.63	9.14	0.26	100.72	0.216	0.770	0.014
A4S20	62.95	23.76	0.00	4.60	9.06	0.33	100.70	0.215	0.767	0.018
A4S21	62.97	23.74	0.02	4.58	8.92	0.30	100.53	0.217	0.766	0.017
A4S22	63.29	23.73	0.00	4.59	9.14	0.20	100.95	0.215	0.774	0.011
A4S23	62.46	23.64	0.00	4.51	9.01	0.33	99.95	0.213	0.769	0.019
A4S24	62.92	23.71	0.08	4.55	9.16	0.25	100.67	0.212	0.774	0.014
A4S25	63.20	23.27	0.00	4.53	8.83	0.21	100.04	0.218	0.770	0.012
A4S26	63.23	23.66	0.09	4.60	9.03	0.31	100.92	0.216	0.767	0.017
A4S27	62.29	23.43	0.06	4.56	9.11	0.33	99.78	0.213	0.769	0.018
A4S28	62.78	23.62	0.03	4.54	9.26	0.28	100.51	0.210	0.775	0.015
A4S29	62.55	23.42	0.07	4.56	9.24	0.25	100.09	0.211	0.775	0.014
A4S30	62.75	23.64	0.09	4.54	8.91	0.33	100.26	0.216	0.766	0.019
A4S31	62.52	23.55	0.03	4.56	9.09	0.27	100.02	0.214	0.771	0.015
A4S32	62.52	23.55	0.03	4.56	9.09	0.27	100.02	0.214	0.771	0.015

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1										
mean	62.31	23.36	0.09	4.47	9.07	0.29	99.59	0.210	0.773	0.016
std	0.34	0.22	0.07	0.09	0.14	0.04	0.50	0.004	0.005	0.002
AREA 2										
mean	62.64	23.57	0.07	4.58	9.14	0.23	100.24	0.214	0.773	0.013
std	0.32	0.14	0.05	0.07	0.07	0.03	0.40	0.003	0.003	0.002
AREA 3										
mean	62.84	23.50	0.08	4.54	9.25	0.23	100.43	0.211	0.777	0.013
std	0.25	0.23	0.06	0.07	0.10	0.06	0.40	0.003	0.004	0.003
AREA 4										
mean	62.79	23.59	0.04	4.57	9.07	0.28	100.34	0.214	0.770	0.016
std	0.31	0.15	0.03	0.03	0.12	0.04	0.39	0.002	0.003	0.002

X182b GARNETS X Mg vs X Fe

(Area/label: 1/° 2/e)

X182b GARNET ZONING

X182b BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/*)

X182b PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/*)

X182b	GARNET ANALYSES										(weight percent; precision +/-2%)							
	(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)	
A1S1	20	38.00	0.00	20.54	0.00	0.46	33.56	0.15	4.68	2.60	0.02	100.01	R	0.739	0.184	0.003	0.073	
A1S2	80	37.82	0.08	20.54	0.06	0.82	33.41	0.14	4.66	2.68	0.00	100.01	R	0.738	0.183	0.003	0.076	
A1S3	110	37.62	0.06	20.66	0.00	1.13	32.52	0.12	4.81	2.77	0.05	100.04		0.727	0.191	0.003	0.079	
A1S4	120	37.59	0.11	20.41	0.00	0.80	31.17	0.16	4.61	2.66	0.02	99.49		0.726	0.191	0.004	0.079	
A1S5	130	37.58	0.08	20.74	0.04	0.82	32.68	0.13	4.71	2.77	0.01	99.25		0.730	0.188	0.003	0.079	
A1S6	140	37.52	0.04	20.49	0.04	0.92	32.93	0.13	4.71	2.71	0.00	99.49		0.733	0.187	0.003	0.077	
A2S1	10	37.51	0.02	20.44	0.04	0.86	31.86	0.50	5.13	2.49	0.05	99.43	4	0.713	0.205	0.011	0.071	
A2S2	30	37.58	0.00	20.62	0.00	0.65	32.21	0.48	5.00	2.53	0.06	99.40	2	0.718	0.199	0.011	0.072	
A2S3	60	37.58	0.07	20.63	0.02	0.64	32.33	0.46	5.05	2.43	0.03	99.51	2	0.720	0.200	0.010	0.069	
A2S4	80	38.16	0.06	20.44	0.01	0.78	32.36	0.47	5.24	2.55	0.07	100.56		0.712	0.205	0.010	0.072	
A2S5	90	37.66	0.00	20.66	0.00	0.74	32.40	0.53	4.96	2.50	0.00	99.86		0.720	0.197	0.012	0.071	
A2S6	120	37.37	0.00	20.74	0.00	0.92	31.86	0.50	5.12	2.44	0.00	99.55		0.714	0.204	0.011	0.070	
STATISTICAL ANALYSIS (mean and standard deviation)																		
AREA 1 mean		37.66	0.06	20.56	0.02	0.83	32.71	0.14	4.70	2.70	0.02	99.72	4	0.732	0.187	0.003	0.077	
std		0.22	0.04	0.12	0.03	0.22	0.86	0.01	0.07	0.07	0.02	0.35		0.006	0.004	0.000	0.002	
AREA 2 mean		37.64	0.03	20.59	0.01	0.77	32.17	0.49	5.08	2.49	0.04	99.72	6	0.716	0.202	0.011	0.071	
std		0.27	0.03	0.12	0.02	0.11	0.25	0.03	0.10	0.05	0.03	0.44		0.004	0.004	0.001	0.001	

BIOTITE ANALYSES
(weight percent; precision $\pm 2\%$)

X182b	SiO ₂	TiO ₂	Al ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg ($\pm 2\%$)	X Fe ($\pm 2\%$)	X Ti ($\pm 2\%$)	X Al ⁶ ($\pm 2\%$)	X Mn ($\pm 2\%$)
A1S7	35.97	4.76	17.00	18.67	0.00	10.22	0.18	0.00	9.48	96.28		0.409	0.419	0.10	0.076	0.000
A1S8	36.61	4.86	17.17	18.75	0.06	10.18	0.10	0.00	9.62	97.35		0.404	0.417	0.10	0.080	0.001
A1S9	36.05	4.95	16.88	19.08	0.01	10.48	0.10	0.11	9.62	97.28		0.414	0.423	0.10	0.063	0.000
A1S10	36.51	4.99	16.89	18.93	0.02	10.13	0.15	0.02	9.72	97.36		0.403	0.424	0.10	0.072	0.000
A1S11	36.31	4.95	17.38	18.57	0.00	10.98	0.15	0.33	9.77	98.44	u	0.430	0.408	0.10	0.065	0.000
A1S12	36.35	4.96	16.84	19.26	0.05	10.03	0.05	0.00	9.71	97.25		0.399	0.430	0.10	0.071	0.001
A1S13	35.92	4.95	17.13	18.82	0.04	10.00	0.15	0.00	9.40	96.41		0.400	0.422	0.10	0.077	0.001
A2S7	36.12	4.16	17.08	18.31	0.00	10.83	0.16	0.11	9.60	96.37		0.430	0.408	0.08	0.079	0.000
A2S8	36.41	4.50	17.06	19.16	0.09	10.84	0.25	0.31	9.63	98.25		0.424	0.421	0.09	0.064	0.002
A2S9	36.32	4.37	17.24	18.94	0.00	10.41	0.20	0.28	9.64	97.40		0.413	0.421	0.09	0.078	0.000
A2S10	36.48	4.04	17.41	18.53	0.00	10.52	0.11	0.35	9.48	96.92		0.417	0.412	0.08	0.090	0.000
A2S11	36.17	4.21	17.12	18.88	0.01	10.37	0.18	0.04	9.49	96.47		0.412	0.421	0.08	0.082	0.000
A2S12	36.24	4.20	17.07	18.47	0.00	10.71	0.12	0.23	9.74	96.78		0.426	0.412	0.08	0.078	0.000
A2S13	36.29	4.27	17.27	18.60	0.08	10.80	0.13	0.04	9.51	96.99		0.424	0.410	0.08	0.079	0.002
A2S14	36.31	4.17	16.99	18.60	0.00	10.84	0.08	0.04	9.76	96.79		0.428	0.412	0.08	0.076	0.000
A2S15	36.05	4.14	17.27	18.62	0.00	10.52	0.17	0.15	9.63	96.55		0.418	0.416	0.08	0.083	0.000

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	36.24	4.91	16.99	18.92	0.03	10.17	0.12	0.02	9.59	6	0.405	0.423	0.099	0.073	0.001
	std	0.29	0.09	0.14	0.22	0.02	0.17	0.05	0.04	0.50		0.006	0.004	0.002	0.006	0.001
AREA 2	mean	36.27	4.23	17.17	18.68	0.02	10.65	0.16	0.17	96.95	9	0.421	0.415	0.084	0.079	0.000
	std	0.14	0.14	0.14	0.26	0.04	0.19	0.05	0.12	0.58		0.007	0.005	0.002	0.007	0.001

X182b	PLAGIOCLASE ANALYSES										(weight: percent; precision +/- 2%)					TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O														
A1S14	58.43	26.15	0.05	7.30	7.56	0.18				99.67	u	0.344	0.645	0.010						
A1S15	58.98	26.41	0.09	7.30	7.69	0.14				100.61	u	0.341	0.651	0.008						
A1S17	58.27	26.39	0.05	7.81	7.29	0.14				99.95		0.369	0.623	0.008						
A1S18	57.79	26.48	0.03	7.95	7.20	0.12				98.57		0.376	0.617	0.007						
A1S19	57.77	26.87	0.08	7.99	7.21	0.17				100.09		0.376	0.614	0.010						
A1S20	57.90	26.20	0.09	7.63	7.19	0.15				99.16		0.366	0.625	0.009						
A1S21	57.72	26.31	0.02	7.81	7.19	0.15				99.20		0.372	0.620	0.009						
A1S22	57.87	26.31	0.00	7.73	7.30	0.21				99.42		0.365	0.623	0.012						
A1S23	57.58	26.46	0.07	7.72	7.14	0.15				99.12	4	0.371	0.621	0.009						
A1S24	57.91	26.39	0.00	7.55	7.30	0.16				99.31		0.360	0.631	0.009						
A1S25	58.03	26.14	0.13	7.31	7.31	0.20				99.12		0.352	0.637	0.011						
A2S17	58.09	26.23	0.22	7.62	7.00	0.16				99.31	3	0.372	0.619	0.009						
A2S18	58.61	26.58	0.15	7.83	7.30	0.15				100.62	3	0.369	0.623	0.008						
A2S19	58.00	26.63	0.04	8.09	7.21	0.20				100.17		0.378	0.610	0.011						
A2S20	57.84	26.34	0.14	7.73	7.19	0.23				99.47		0.368	0.619	0.013						
A2S21	58.76	26.45	0.20	7.78	7.20	0.20				100.59		0.370	0.619	0.011						
A2S22	58.45	26.63	0.10	7.71	7.32	0.19				100.40	3	0.364	0.625	0.011						
A2S23	58.11	26.66	0.09	7.88	7.17	0.19				100.10	3	0.374	0.615	0.011						
A2S24	58.08	26.55	0.07	7.63	7.13	0.19				99.65		0.368	0.622	0.011						
A2S25	59.00	25.98	0.08	7.13	7.51	0.17				99.87	u	0.341	0.650	0.010						
A2S26	58.51	26.24	0.04	7.41	7.51	0.16				99.87	u	0.350	0.641	0.009						
A2S28	58.41	26.61	0.17	7.64	7.36	0.18				100.37		0.361	0.629	0.010						

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1															
mean	57.87	26.39	0.05	7.72	7.24	0.16							0.368	0.623	0.009
std	0.20	0.21	0.04	0.21	0.06	0.03							0.008	0.007	0.002
AREA 2															
mean	58.26	26.52	0.13	7.77	7.21	0.19							0.369	0.620	0.011
std	0.31	0.15	0.06	0.15	0.11	0.02							0.005	0.005	0.001

X413b GARNETS X Mg versus X Fe

(Area/label: 1/+ 2/* 3/+)

X413#1b BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/* 3/+)

X413#1b PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/* 3/+)

X413B

GARNET ANALYSES

(weight percent; precision +/-2%)

	(μm)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
A1S1	20	37.20	0.03	20.51	0.03	0.89	34.48	1.18	4.10	1.12	0.02	99.56		0.776	0.164	0.027	0.032
A1S2	100	37.36	0.09	20.35	0.07	0.92	34.50	1.24	4.22	1.13	0.00	99.88		0.771	0.168	0.028	0.032
A1S3	20	37.00	0.15	20.47	0.11	1.81	33.96	1.30	4.18	1.13	0.06	100.17		0.769	0.169	0.030	0.033
A1S4	20	37.40	0.05	20.45	0.11	0.88	35.01	1.28	3.81	1.26	0.03	100.26		0.783	0.152	0.029	0.036
A1S5	80	37.53	0.09	20.72	0.03	0.75	35.65	1.26	3.70	1.11	0.00	100.84		0.793	0.147	0.028	0.032
A1S6	20	37.66	0.05	20.41	0.05	1.02	35.62	1.34	3.63	1.23	0.03	101.04	Ct	0.791	0.144	0.030	0.035
A1S7	20	37.46	0.04	20.26	0.05	0.74	35.61	1.34	3.56	1.12	0.02	100.20		0.796	0.142	0.030	0.032
A1S8	20	37.34	0.04	20.34	0.03	1.19	35.05	1.26	3.83	1.18	0.01	100.27		0.785	0.153	0.029	0.034
A1S9	20	37.31	0.14	20.66	0.00	1.52	34.71	1.35	4.03	1.15	0.01	100.88		0.776	0.161	0.031	0.033
A1S10	100	37.32	0.04	20.71	0.00	2.02	35.01	1.30	3.80	1.12	0.04	101.36		0.786	0.152	0.030	0.032
A1S11	120	37.17	0.08	20.63	0.00	2.09	34.67	1.25	3.86	1.16	0.05	100.96		0.783	0.155	0.029	0.034
A1S12	120	37.31	0.01	20.65	0.06	1.39	34.95	1.31	3.85	1.13	0.00	100.66		0.784	0.154	0.030	0.032
A1S14	80	37.40	0.07	20.73	0.08	1.45	34.76	1.13	4.07	1.14	0.05	100.88		0.779	0.163	0.026	0.033
A1S15	60	37.39	0.00	20.55	0.00	1.87	34.77	1.20	4.11	1.02	0.03	100.94		0.779	0.164	0.027	0.029
A1S16	80	37.53	0.05	20.74	0.08	0.82	34.94	1.24	4.03	1.16	0.01	100.60		0.779	0.160	0.028	0.033
A1S17	20	37.43	0.04	20.36	0.04	1.19	34.60	1.19	4.16	1.22	0.00	100.23		0.773	0.166	0.027	0.035
A1S18	20	37.79	0.12	20.73	0.12	1.66	34.76	1.23	4.19	1.25	0.08	101.93		0.771	0.166	0.028	0.036
A1S19	20	37.64	0.09	20.49	0.03	1.22	35.05	1.33	3.99	1.25	0.00	101.09		0.777	0.158	0.030	0.036
A1S20	120	37.33	0.00	20.35	0.06	1.41	34.44	1.20	4.18	1.07	0.06	100.10		0.774	0.167	0.027	0.031
A1S21	20	37.19	0.08	20.63	0.03	1.39	33.98	1.20	4.33	1.15	0.05	100.03		0.766	0.174	0.027	0.033
A1S22	80	37.55	0.06	20.51	0.04	0.45	34.98	1.27	4.03	1.18	0.00	100.07		0.778	0.160	0.029	0.034
A1S23	20	37.17	0.08	20.21	0.11	0.52	34.41	1.27	4.03	1.20	0.04	99.04		0.775	0.162	0.029	0.035
A1S24	60	37.55	0.08	20.58	0.10	0.87	34.87	1.21	4.06	1.17	0.04	100.53		0.778	0.161	0.027	0.033
A1S25	60	37.57	0.12	20.44	0.16	0.85	35.62	1.38	3.50	1.22	0.06	100.92	Ct	0.795	0.139	0.031	0.035
A1S26	20	37.62	0.06	20.78	0.04	0.70	35.84	1.29	3.49	1.25	0.01	101.08	Ct	0.797	0.138	0.029	0.036
A2S1	10	37.31	0.01	20.64	0.00	0.89	35.04	1.13	3.86	1.17	0.03	100.08	Ct	0.786	0.154	0.026	0.034
A2S2	100	37.21	0.06	20.77	0.01	0.69	34.69	1.09	4.11	1.13	0.00	99.76		0.778	0.164	0.025	0.032
A2S3	80	37.25	0.04	20.38	0.07	1.19	34.08	1.17	4.38	1.09	0.03	99.68		0.766	0.176	0.027	0.031
A2S4	60	37.53	0.05	20.73	0.03	1.27	34.26	1.21	4.45	1.10	0.04	100.67		0.764	0.177	0.027	0.031
A2S5	30	37.63	0.02	20.67	0.02	1.05	34.69	1.08	4.20	1.26	0.04	100.66	u	0.773	0.167	0.024	0.036
A2S6	110	37.40	0.06	20.70	0.08	1.17	34.24	1.11	4.30	1.27	0.04	100.37	u	0.767	0.172	0.025	0.036
A2S7	20	37.20	0.19	20.77	0.22	1.55	33.68	1.35	4.29	1.35	0.08	100.68	u	0.758	0.172	0.031	0.039
A2S8	30	37.17	0.12	20.23	0.17	0.91	35.82	1.24	3.35	1.19	0.00	100.20	Ct	0.804	0.134	0.028	0.034
A2S9	20	37.15	0.04	20.55	0.07	1.51	35.56	1.20	3.39	1.22	0.03	100.72	Ct	0.801	0.136	0.027	0.035
A2S10	10	37.32	0.00	20.81	0.04	1.04	34.45	1.14	4.24	1.12	0.01	100.17		0.773	0.169	0.026	0.032
A2S11	50	37.56	0.17	21.02	0.07	1.13	34.72	1.14	4.29	1.17	0.01	101.28		0.771	0.170	0.026	0.033
A2S12	60	37.48	0.02	20.50	0.02	0.45	34.93	1.09	4.10	1.15	0.01	99.76		0.779	0.163	0.025	0.033
A2S13	10	38.10	0.12	20.82	0.06	0.00	35.34	1.05	4.24	1.18	0.03	100.94		0.777	0.166	0.023	0.033
A2S14	60	37.68	0.11	20.64	0.09	0.70	34.89	1.14	4.24	1.19	0.00	100.68		0.773	0.167	0.026	0.034
A2S15	70	37.54	0.00	20.68	0.04	0.60	34.51	1.06	4.34	1.16	0.04	100.01		0.770	0.173	0.024	0.033
A2S16	20	37.78	0.99	20.61	0.01	0.97	34.62	1.06	4.48	1.13	0.04	100.63		0.768	0.177	0.022	0.032
A2S17	20	37.36	0.02	20.47	0.08	0.67	34.69	1.18	4.10	1.14	0.02	99.73		0.777	0.164	0.027	0.033
A2S18	50	37.35	0.12	20.83	0.00	1.17	34.59	1.01	4.20	1.14	0.07	100.48		0.776	0.168	0.023	0.033
A3S1	60	36.84	0.03	20.41	0.00	0.71	34.18	1.10	4.11	1.10	0.01	98.49		0.776	0.166	0.025	0.032
A3S2	80	37.37	0.02	20.47	0.00	0.87	34.58	1.02	4.30	1.10	0.00	99.73		0.774	0.171	0.023	0.032
A3S3	60	37.38	0.12	20.70	0.06	0.22	34.56	1.10	4.18	1.14	0.07	99.53		0.775	0.167	0.025	0.033
A3S4	160	37.36	0.35	20.77	0.05	0.97	34.28	1.23	4.23	1.19	0.04	100.17		0.769	0.169	0.028	0.034

A3S5	60	37.44	0.09	20.72	0.11	1.93	33.69	1.14	4.52	1.31	0.10	101.05	u	0.756	0.181	0.026	0.038
A3S6	20	37.22	0.00	20.56	0.00	1.05	34.85	1.03	4.25	1.22	0.00	100.18		0.774	0.168	0.023	0.035
A3S7	20	37.24	0.00	20.94	0.07	1.09	34.27	1.23	4.01	1.36	0.05	100.26	u	0.772	0.161	0.028	0.039
A3S8	20	37.14	0.06	20.99	0.01	1.49	33.77	1.09	4.46	1.17	0.04	100.22		0.762	0.179	0.025	0.034
A3S9	20	37.31	0.11	20.83	0.08	0.22	34.31	0.93	4.33	1.27	0.04	99.43		0.769	0.173	0.021	0.036
A3S10	20	37.61	0.02	20.96	0.14	0.07	34.39	1.04	4.48	1.16	0.02	99.89		0.766	0.178	0.023	0.033
A3S11	40	37.65	0.00	20.80	0.06	0.62	34.43	1.22	4.38	1.23	0.00	100.39		0.764	0.173	0.027	0.035
A3S12	40	37.73	0.04	20.84	0.02	1.05	34.46	1.20	4.47	1.15	0.00	100.96		0.764	0.177	0.027	0.033
A3S13	20	37.83	0.07	20.88	0.04	0.63	34.42	1.02	4.57	1.16	0.07	100.69		0.763	0.181	0.023	0.033
A3S14	140	37.66	0.05	20.84	0.00	1.68	34.05	1.14	4.69	1.17	0.01	101.29		0.756	0.185	0.026	0.033
A3S15	140	37.78	0.00	20.58	0.00	0.22	34.36	1.02	4.61	1.21	0.00	99.78		0.761	0.182	0.023	0.034
A3S16	140	37.38	0.00	21.01	0.02	0.87	34.44	1.01	4.34	1.16	0.00	100.23		0.771	0.173	0.023	0.033
A3S17	100	37.16	0.03	20.89	0.05	0.49	34.28	1.09	4.30	1.11	0.00	99.40		0.771	0.172	0.025	0.032

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	37.38	0.07	20.53	0.05	1.23	34.78	1.25	4.01	1.16	0.03	100.48	22	0.779	0.160	0.028	0.033
	std	0.18	0.04	0.16	0.04	0.47	0.41	0.06	0.19	0.06	0.02	0.63		0.007	0.008	0.001	0.002
AREA 2	mean	37.51	0.06	20.69	0.04	0.82	34.65	1.11	4.26	1.14	0.03	100.32	12	0.773	0.170	0.025	0.033
	std	0.25	0.05	0.18	0.03	0.37	0.32	0.07	0.13	0.03	0.02	0.54		0.005	0.005	0.002	0.001
AREA 3	mean	37.43	0.04	20.77	0.04	0.74	34.36	1.08	4.38	1.17	0.02	100.03	15	0.768	0.174	0.025	0.033
	std	0.28	0.04	0.19	0.04	0.47	0.25	0.09	0.16	0.05	0.03	0.69		0.006	0.006	0.002	0.001

X413#1b BIOTITE ANALYSES (weight percent; precision +/-2%)

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ^{IV} (+/-8%)	X Mn (+/-8%)
A1S27	35.25	3.53	16.88	0.12	16.21	0.05	10.73	0.01	0.00	9.49	94.27		0.432	0.411	0.072	0.084	0.001
A1S28	34.73	3.54	16.61	0.09	18.41	0.04	10.60	0.05	0.08	9.30	93.45		0.430	0.419	0.072	0.077	0.001
A1S29	34.97	3.00	16.81	0.04	17.84	0.03	10.59	0.00	0.00	9.47	92.75		0.432	0.409	0.062	0.096	0.001
A1S30	35.51	3.86	16.84	0.00	18.77	0.00	9.83	0.00	0.03	9.48	94.32		0.400	0.429	0.079	0.092	0.000
A1S31	35.46	3.80	17.09	0.00	18.71	0.00	10.09	0.00	0.12	9.65	94.92		0.408	0.425	0.078	0.090	0.000
A1S32	36.18	3.26	17.22	0.04	17.95	0.00	11.59	0.00	0.00	9.88	96.12		0.435	0.395	0.065	0.086	0.000
A1S33	36.50	3.16	17.83	0.04	18.05	0.00	11.14	0.00	0.00	9.85	96.57		0.437	0.397	0.062	0.104	0.000
A1S34	36.82	3.56	17.67	0.08	18.62	0.00	11.54	0.03	0.02	9.79	98.13		0.444	0.402	0.069	0.086	0.000
A1S35	36.21	4.07	17.34	0.00	18.86	0.00	9.97	0.00	0.20	9.66	96.31	u	0.400	0.424	0.082	0.094	0.000
A1S36	37.62	3.05	18.98	0.03	17.88	0.03	9.79	0.00	0.19	9.12	96.69	u	0.387	0.397	0.061	0.154	0.001
A1S37	36.81	3.06	18.49	0.09	18.18	0.12	10.65	0.07	0.06	9.69	97.22		0.417	0.399	0.060	0.121	0.003
A1S38	36.76	3.83	17.47	0.03	19.54	0.00	10.18	0.01	0.16	9.79	97.77		0.400	0.431	0.076	0.092	0.000
A1S39	36.99	3.66	17.08	0.05	18.58	0.00	11.68	0.00	0.09	9.88	98.03		0.451	0.402	0.072	0.075	0.000
A1S40	36.92	3.66	17.56	0.10	18.85	0.05	11.30	0.03	0.09	9.96	98.62		0.437	0.409	0.071	0.082	0.001
A1S41	36.44	3.56	17.28	0.05	17.47	0.00	10.92	0.00	0.74	9.73	96.19		0.439	0.394	0.072	0.094	0.000
A1S42	36.30	3.70	17.25	0.00	18.87	0.00	10.16	0.00	0.24	9.88	95.94		0.410	0.417	0.075	0.098	0.000
A1S43	36.54	3.81	17.52	0.00	18.87	0.00	10.42	0.00	0.02	10.06	97.24		0.412	0.418	0.076	0.094	0.000
A1S44	37.14	3.57	17.70	0.05	18.61	0.03	11.22	0.00	0.03	9.99	98.34		0.434	0.404	0.070	0.092	0.001
A1S45	36.20	3.66	18.16	0.14	18.59	0.12	10.27	0.01	0.39	9.88	97.42		0.408	0.414	0.073	0.103	0.003
A1S46	37.76	3.62	18.34	0.05	18.82	0.01	10.78	0.00	0.24	9.84	99.46	u	0.415	0.406	0.081	0.082	0.000
A1S47	35.65	4.00	17.27	0.15	19.69	0.00	9.89	0.00	0.20	9.78	96.53		0.396	0.442	0.083	0.086	0.001
A1S48	35.31	4.08	17.37	0.02	19.22	0.06	9.89	0.00	0.00	9.81	95.76		0.397	0.433	0.083	0.086	0.001
A1S49	35.31	4.08	17.37	0.02	19.22	0.06	9.89	0.00	0.00	9.81	95.76		0.397	0.433	0.083	0.086	0.001
A1S50	35.86	3.65	17.02	0.11	18.66	0.03	10.54	0.00	0.15	9.67	95.89		0.422	0.419	0.074	0.085	0.001
A1S49	36.05	4.34	16.81	0.00	20.08	0.00	9.65	0.00	0.00	9.53	96.46	u	0.385	0.450	0.087	0.078	0.000
A1S51	36.25	3.67	17.28	0.02	18.37	0.01	10.60	0.00	0.00	9.59	95.79		0.421	0.410	0.074	0.095	0.000
A1S52	36.16	3.79	17.97	0.15	18.96	0.09	11.11	0.07	0.30	9.71	98.31		0.430	0.412	0.074	0.082	0.002
A1S53	35.62	4.10	16.96	0.05	20.26	0.02	9.41	0.00	0.06	9.68	96.14	u	0.378	0.457	0.083	0.081	0.000
A1S54	36.21	3.46	18.09	0.10	18.62	0.03	10.51	0.00	0.11	9.70	96.83		0.414	0.412	0.069	0.105	0.001
A1S55	37.62	3.17	18.33	0.12	19.07	0.04	9.35	0.01	0.11	9.18	97.00	u	0.371	0.425	0.063	0.140	0.001
A2S19	35.64	3.80	17.17	0.03	17.67	0.00	10.86	0.03	0.19	9.66	95.05		0.437	0.399	0.077	0.088	0.000
A2S20	35.14	3.77	16.61	0.03	17.93	0.00	10.31	0.00	0.07	9.66	93.52		0.423	0.413	0.078	0.086	0.000
A2S21	35.75	3.81	17.07	0.01	18.11	0.00	10.64	0.00	0.41	9.72	95.52		0.429	0.409	0.077	0.085	0.000
A2S22	35.74	3.62	16.92	0.00	17.98	0.00	10.82	0.01	0.23	9.80	95.12		0.435	0.406	0.074	0.085	0.000
A2S23	35.19	4.16	16.63	0.08	18.23	0.00	10.05	0.00	0.02	9.94	94.30		0.413	0.421	0.086	0.080	0.000
A2S24	35.49	3.40	17.27	0.10	18.08	0.03	10.48	0.01	0.22	9.73	94.81		0.424	0.411	0.069	0.095	0.001
A2S25	35.32	3.93	16.85	0.00	17.88	0.00	10.88	0.00	0.13	9.66	94.65		0.438	0.404	0.080	0.078	0.000
A2S26	35.49	3.70	16.94	0.09	18.24	0.07	10.27	0.03	0.03	9.75	94.61		0.417	0.416	0.076	0.089	0.002
A2S27	35.85	3.97	16.65	0.00	18.07	0.01	10.54	0.00	0.00	9.84	94.93		0.426	0.410	0.081	0.082	0.000
A2S28	35.37	3.96	16.86	0.06	18.31	0.06	10.66	0.01	0.08	9.68	95.05		0.428	0.413	0.080	0.077	0.001
A2S29	35.40	3.87	16.79	0.03	18.21	0.00	10.84	0.01	0.15	9.69	94.99		0.435	0.410	0.078	0.076	0.000
A2S30	35.74	3.89	16.75	0.04	18.51	0.01	10.96	0.00	0.05	9.78	95.73		0.436	0.413	0.078	0.073	0.000
A2S31	35.47	3.86	16.77	0.11	17.93	0.00	10.56	0.00	0.11	9.76	94.57		0.429	0.409	0.079	0.082	0.000
A2S32	35.74	3.84	16.93	0.04	18.00	0.00	10.84	0.01	0.00	9.71	95.11		0.434	0.405	0.078	0.083	0.000
A2S33	35.66	3.96	17.39	0.03	17.88	0.02	10.51	0.02	0.00	9.54	95.01		0.422	0.403	0.080	0.094	0.000
A2S34	35.49	3.79	16.79	0.11	17.86	0.02	10.52	0.06	0.00	9.58	94.22		0.428	0.408	0.078	0.087	0.000
A2S35	35.66	3.83	16.98	0.00	17.95	0.00	10.83	0.00	0.07	9.79	95.11		0.435	0.404	0.078	0.084	0.000
A2S36	35.48	3.91	16.85	0.06	17.85	0.00	10.95	0.03	0.27	9.74	95.14		0.441	0.403	0.079	0.076	0.000

A2537	36.59	2.45	17.66	0.08	13.57	0.09	15.01	0.03	0.17	10.02	95.67	0.573	0.291	0.047	0.087	0.002
A2538	36.19	3.05	17.61	0.00	18.01	0.00	11.38	0.00	0.00	9.74	95.98	0.446	0.396	0.060	0.098	0.000
A2539	36.34	2.62	18.03	0.05	16.34	0.00	11.87	0.00	0.00	9.73	94.98	0.468	0.362	0.052	0.118	0.000
A2540	36.20	2.47	17.75	0.05	16.35	0.05	11.94	0.00	0.15	9.65	94.61	0.473	0.363	0.049	0.113	0.001
A2541	36.66	3.59	16.83	0.03	18.15	0.00	10.44	0.00	0.02	9.81	94.53	0.423	0.413	0.073	0.090	0.000
A2542	35.50	3.47	17.17	0.03	17.70	0.04	11.50	0.00	0.00	9.77	95.18	0.455	0.393	0.069	0.082	0.001
A2543	35.83	3.87	17.22	0.04	18.05	0.05	10.85	0.03	0.22	9.77	95.93	0.433	0.404	0.078	0.084	0.001
A2544	35.48	3.70	17.34	0.15	18.10	0.08	10.53	0.02	0.33	9.71	95.44	0.425	0.404	0.075	0.088	0.002
A2545	35.37	3.59	16.99	0.04	18.10	0.01	10.45	0.00	0.15	9.68	94.38	0.424	0.412	0.074	0.090	0.000
A2546	37.25	2.24	17.92	0.01	13.13	0.01	15.69	0.00	0.03	9.86	96.14	0.588	0.276	0.042	0.094	0.000
A3518	35.72	3.63	17.40	0.00	17.18	0.00	11.87	0.00	0.26	9.91	95.97	0.468	0.380	0.072	0.080	0.000
A3519	35.97	3.84	17.62	0.00	16.99	0.05	10.93	0.00	0.00	9.86	95.26	0.438	0.382	0.078	0.101	0.001
A3520	36.09	3.69	17.33	0.02	17.30	0.00	11.54	0.00	0.24	9.92	96.13	0.457	0.384	0.074	0.085	0.000
A3521	36.07	3.71	16.93	0.05	17.73	0.01	10.79	0.00	0.00	9.70	94.99	0.434	0.400	0.075	0.091	0.000
A3522	36.31	3.73	17.34	0.00	17.70	0.00	11.10	0.00	0.03	9.84	96.05	0.440	0.394	0.075	0.092	0.000
A3523	36.02	3.58	17.03	0.00	17.25	0.14	10.84	0.00	0.01	9.54	94.41	0.437	0.390	0.073	0.098	0.003
A3524	35.92	3.88	17.13	0.05	17.98	0.00	10.95	0.00	0.00	9.73	95.64	0.436	0.402	0.078	0.085	0.000
A3525	35.79	3.53	17.91	0.07	17.61	0.08	10.23	0.02	0.12	8.99	94.35	0.412	0.398	0.072	0.117	0.002
A3526	35.19	3.76	16.91	0.00	18.47	0.05	10.22	0.00	0.03	9.66	94.29	0.415	0.421	0.077	0.087	0.001
A3527	35.31	3.70	16.92	0.05	18.77	0.06	10.36	0.03	0.26	9.73	95.19	0.418	0.425	0.075	0.080	0.001
A3528	35.77	3.10	17.32	0.07	15.35	0.00	12.67	0.01	0.05	9.95	94.29	0.504	0.342	0.062	0.092	0.000
A3529	36.36	3.07	17.23	0.08	15.97	0.01	12.94	0.00	0.00	9.65	95.31	0.504	0.349	0.060	0.087	0.000
A3530	36.11	3.85	17.08	0.00	17.92	0.00	11.03	0.01	0.08	9.81	95.89	0.439	0.400	0.077	0.084	0.000
A3531	35.69	4.01	16.73	0.12	18.67	0.07	10.73	0.00	0.05	9.81	95.88	0.428	0.418	0.078	0.071	0.002
A3532	36.38	4.05	16.93	0.08	17.83	0.00	11.31	0.00	0.00	9.68	96.26	0.446	0.395	0.081	0.078	0.000
A3533	35.60	3.98	16.77	0.00	17.94	0.02	10.89	0.00	0.14	9.73	95.07	0.438	0.404	0.081	0.077	0.000
A3534	35.17	3.97	16.48	0.03	18.48	0.00	10.83	0.00	0.18	9.72	94.86	0.436	0.418	0.081	0.086	0.000
A3535	35.45	3.62	16.67	0.05	18.13	0.00	11.18	0.00	0.29	9.62	95.01	0.447	0.407	0.073	0.072	0.000
A3536	35.81	3.85	16.50	0.04	18.13	0.00	10.90	0.00	0.06	9.69	94.98	0.438	0.409	0.078	0.075	0.000
A3537	36.03	3.89	17.19	0.03	17.82	0.03	11.02	0.00	0.41	9.69	96.11	0.439	0.399	0.078	0.083	0.001
A3538	35.94	3.84	17.02	0.03	18.47	0.04	11.20	0.07	0.00	9.49	96.12	0.440	0.407	0.076	0.076	0.001
A3539	35.51	3.86	16.71	0.06	18.44	0.05	10.84	0.00	0.00	9.59	95.06	0.433	0.413	0.078	0.075	0.001
A3540	35.50	4.00	16.49	0.14	18.00	0.05	11.17	0.00	0.06	9.87	95.28	0.448	0.405	0.081	0.065	0.001
A3541	36.21	3.67	17.41	0.06	17.82	0.00	11.09	0.00	0.19	9.96	96.41	0.440	0.397	0.073	0.090	0.000
A3542	35.40	3.60	17.16	0.04	18.24	0.03	10.73	0.04	0.06	9.73	95.03	0.430	0.410	0.073	0.086	0.001
A3543	35.49	3.44	17.14	0.08	17.62	0.03	10.93	0.00	0.15	9.89	94.77	0.441	0.399	0.070	0.090	0.001
A3544	35.63	3.83	16.71	0.01	17.45	0.00	10.86	0.00	0.00	9.66	94.15	0.440	0.397	0.078	0.085	0.000
A3545	36.02	3.85	17.46	0.15	17.88	0.08	10.60	0.00	0.11	9.79	95.94	0.425	0.402	0.078	0.094	0.002
A3546	35.81	3.61	17.28	0.00	17.67	0.00	10.60	0.00	0.06	9.75	94.78	0.428	0.400	0.073	0.099	0.000
A3547	35.45	3.47	17.59	0.10	17.78	0.00	10.43	0.00	0.11	9.62	94.55	0.422	0.404	0.071	0.104	0.000

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	36.16	3.65	17.41	0.05	18.59	0.03	10.63	0.01	0.13	9.74	0.422	0.414	0.073	0.091	0.001
	std	0.74	0.26	0.45	0.05	0.46	0.03	0.56	0.02	0.17	0.18	0.017	0.012	0.006	0.009	0.001
AREA 2	mean	35.57	3.76	16.97	0.05	18.03	0.02	10.69	0.01	0.11	9.73	0.431	0.408	0.077	0.085	0.000
	std	0.23	0.23	0.26	0.04	0.19	0.02	0.33	0.02	0.12	0.08	0.009	0.006	0.005	0.006	0.001
AREA 3	mean	35.79	3.82	16.91	0.05	18.02	0.02	10.98	0.01	0.09	9.73	0.438	0.404	0.077	0.080	0.000
	std	0.35	0.16	0.29	0.04	0.33	0.02	0.17	0.02	0.11	0.11	0.005	0.007	0.003	0.008	0.001

X413#1b PLAGIOCLASE ANALYSES (weight percent; precision +/- 2%)

	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
AlS58	62.95	23.19	0.19	4.19	9.65	0.25	100.42		0.191	0.796	0.014
AlS59	63.43	23.40	0.21	4.32	9.87	0.22	101.45		0.192	0.796	0.012
AlS61	63.45	23.61	0.04	4.13	9.86	0.18	101.27		0.186	0.804	0.010
AlS62	63.84	23.28	0.14	4.14	9.78	0.34	101.52	u	0.186	0.796	0.018
AlS63	63.04	23.12	0.09	4.18	9.40	0.28	100.11	u	0.194	0.790	0.015
AlS64	63.84	23.39	0.07	4.21	9.77	0.22	101.50		0.190	0.798	0.012
AlS66	63.69	23.70	0.07	4.08	9.77	0.30	101.61	u	0.184	0.799	0.016
AlS67	64.77	23.88	0.14	4.32	10.12	0.23	103.45	2	0.189	0.800	0.012
AlS69	63.89	23.79	0.08	4.15	9.89	0.19	101.99		0.186	0.804	0.010
AlS68	63.58	23.26	0.02	4.17	9.72	0.17	100.92		0.190	0.801	0.009
AlS70	64.21	23.62	0.16	4.22	9.67	0.17	102.05		0.193	0.798	0.009
AlS71	63.86	23.59	0.17	4.26	10.18	0.27	102.33		0.185	0.801	0.014
AlS72	63.55	23.58	0.27	4.34	9.69	0.14	101.57		0.197	0.796	0.008
AlS73	62.98	23.34	0.12	4.31	9.63	0.19	100.57		0.196	0.793	0.010
AlS77	63.45	23.25	0.17	4.11	10.04	0.22	101.24		0.182	0.806	0.012
AlS78	63.26	23.16	0.14	4.08	9.71	0.25	100.60		0.186	0.801	0.014
AlS81	63.47	23.40	0.15	4.21	9.90	0.25	101.38		0.188	0.799	0.013
AlS82	64.21	23.45	0.06	4.08	9.91	0.22	101.93		0.183	0.805	0.012
AlS83	64.06	23.16	0.09	4.16	9.61	0.22	100.30		0.191	0.797	0.012
AlS87	63.97	23.45	0.20	4.24	9.75	0.25	101.86		0.191	0.795	0.013
AlS89	64.12	23.77	0.12	4.26	9.67	0.20	102.14		0.194	0.796	0.011
AlS90	63.50	23.32	0.14	4.26	9.72	0.16	101.10		0.193	0.798	0.009
AlS91	63.50	23.32	0.14	4.26	9.72	0.16	101.10		0.193	0.798	0.009
AlS92	62.61	23.58	0.00	4.16	9.36	0.16	99.87		0.193	0.796	0.009
AlS94	62.67	23.06	0.11	4.03	9.55	0.22	99.64		0.187	0.801	0.012
AlS96	63.08	23.22	0.14	4.18	9.66	0.15	100.43		0.191	0.800	0.008
AlS98	63.08	23.28	0.01	4.09	9.52	0.18	100.16		0.190	0.800	0.010
AlS100	62.47	22.98	0.08	4.13	9.94	0.22	99.82		0.185	0.804	0.012
A2S49	62.59	23.38	0.26	4.32	9.53	0.21	100.29		0.198	0.791	0.011
A2S50	62.71	23.18	0.10	4.23	9.51	0.27	100.00		0.194	0.791	0.015
A2S51	62.65	23.42	0.17	4.32	9.51	0.23	100.30		0.198	0.789	0.013
A2S52	63.16	23.29	0.22	4.23	9.80	0.25	100.95	u	0.190	0.797	0.013
A2S53	62.27	22.85	0.19	4.20	9.31	0.24	99.06		0.197	0.790	0.013
A2S57	62.51	23.54	0.05	4.28	9.62	0.15	100.15	u	0.196	0.796	0.008
A2S58	61.52	23.16	0.20	4.25	9.53	0.19	98.85		0.196	0.794	0.010
A2S60	61.55	22.99	0.13	4.15	9.33	0.23	98.38		0.195	0.792	0.013
A2S61	61.62	22.84	0.04	4.24	9.70	0.21	98.65		0.192	0.796	0.011
A2S62	61.90	23.13	0.09	4.15	9.81	0.25	99.33		0.187	0.800	0.013
A2S66	61.78	22.80	0.07	3.97	9.33	0.14	98.09		0.189	0.803	0.008
A2S67	62.66	23.65	0.13	4.24	9.65	0.18	100.51		0.193	0.797	0.010
A2S69	63.42	23.24	0.26	4.25	9.93	0.18	101.28		0.189	0.801	0.010
A2S71	62.78	23.27	0.01	4.32	9.35	0.24	99.97		0.191	0.786	0.013
A2S72	63.92	23.16	0.14	4.11	9.50	0.20	101.03		0.191	0.798	0.011
A2S73	63.67	24.04	0.03	4.27	9.87	0.22	102.10		0.191	0.798	0.012
A2S74	63.64	23.55	0.10	4.28	9.82	0.26	101.65		0.191	0.795	0.014
A2S75	63.14	23.66	0.05	4.10	9.56	0.20	100.71		0.189	0.800	0.011

A3S48	63.33	23.31	0.18	4.15	10.03	0.21	101.21	0.184	0.805	0.011
S3S50	63.00	23.49	0.05	4.13	9.45	0.18	100.30	0.193	0.797	0.010
A3S51	62.62	23.38	0.08	4.23	9.50	0.17	99.98	0.196	0.795	0.009
A3S52	63.23	23.71	0.09	4.25	9.71	0.22	101.21	0.192	0.796	0.012
A3S53	63.02	23.73	0.10	4.23	9.70	0.22	101.00	0.192	0.796	0.012
A3S54	62.83	23.36	0.10	4.29	9.77	0.16	100.51	0.194	0.798	0.009
A3S55	63.79	23.50	0.13	4.19	9.72	0.24	101.57	0.190	0.797	0.013
A3S56	63.23	23.45	0.08	4.37	9.76	0.23	101.12	0.196	0.792	0.012
A3S57	63.72	23.82	0.03	4.27	9.54	0.17	101.55	0.196	0.794	0.009

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1										
mean	63.48	23.40	0.12	4.19	9.76	0.20	101.16	0.190	0.799	0.011
std	0.72	0.30	0.09	0.11	0.25	0.05	1.19	0.005	0.004	0.002
AREA 2										
mean	62.68	23.29	0.11	4.21	9.58	0.21	100.09	0.193	0.795	0.012
std	0.74	0.34	0.08	0.10	0.20	0.04	1.16	0.004	0.005	0.002
AREA 3										
mean	63.11	23.51	0.09	4.24	9.68	0.19	100.81	0.193	0.797	0.010
std	0.36	0.19	0.05	0.08	0.20	0.03	0.56	0.004	0.004	0.001

X317#4a GARNETS X Fe versus X Mg

(Area/table: */1 */2 +/3)

X317#4a BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/* 3/+)

X317#4a PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/* 3/+)

GARNET ANALYSES

(weight percent; precision $\pm 1-2\%$)

	(μm)	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	K_2O	TOTAL	N/U	X Fe ($\pm 1-4\%$)	X Mg ($\pm 1-4\%$)	X Mn ($\pm 1-4\%$)	X Ca ($\pm 1-4\%$)
A1S49	30	38.32	0.07	20.65	0.00	31.98	0.29	6.57	1.43	0.03	100.12		0.698	0.256	0.006	0.040
A1S50	20	38.39	0.09	21.08	0.04	32.53	0.31	6.30	1.43	0.02	100.83	2	0.709	0.245	0.007	0.040
A1S51	70	38.15	0.02	20.79	0.01	32.44	0.27	6.07	1.50	0.06	100.07		0.714	0.238	0.006	0.042
A1S52	110	38.01	0.06	20.88	0.00	32.66	0.28	6.00	1.45	0.00	99.69		0.718	0.235	0.006	0.041
A1S53	10	38.13	0.07	20.83	0.00	32.86	0.23	5.99	1.48	0.00	99.74		0.720	0.234	0.005	0.042
A1S54	100	37.97	0.04	20.84	0.00	32.51	0.19	6.18	1.36	0.00	99.79		0.715	0.242	0.004	0.038
A1S55	100	38.00	0.00	20.79	0.07	32.39	0.30	6.17	1.34	0.02	99.53		0.713	0.242	0.007	0.038
A1S56	50	37.71	0.04	20.82	0.01	32.21	0.27	6.03	1.43	0.02	99.27	4	0.715	0.238	0.006	0.041
A1S57	10	37.63	0.11	20.71	0.08	31.83	0.33	6.00	1.61	0.05	99.13	2	0.709	0.238	0.007	0.046
A1S58	10	38.18	0.00	20.72	0.00	32.08	0.28	6.27	1.57	0.02	100.13		0.704	0.245	0.006	0.044
A1S59	20	38.11	0.01	20.83	0.00	32.90	0.30	5.70	1.32	0.03	99.20	u	0.730	0.225	0.007	0.038
A1S60	20	38.29	0.06	20.92	0.08	31.34	0.25	6.66	1.68	0.07	100.59	u	0.687	0.260	0.006	0.047
A1S61	20	37.77	0.02	20.76	0.06	31.23	0.29	6.37	1.59	0.08	99.37		0.695	0.253	0.007	0.045
A1S62	90	38.02	0.01	20.84	0.05	31.81	0.30	6.30	1.48	0.08	99.22		0.703	0.248	0.007	0.042
A1S63	30	37.92	0.00	20.69	0.01	32.48	0.16	6.01	1.52	0.02	99.29		0.710	0.236	0.004	0.043
A1S64	20	37.45	0.01	20.59	0.01	31.65	0.28	6.03	1.50	0.05	98.68	2	0.710	0.241	0.006	0.043
A1S65	20	37.65	0.11	20.61	0.02	33.39	0.41	5.25	1.42	0.04	99.52	Ct	0.742	0.208	0.009	0.040
A1S66	340	37.76	0.06	20.54	0.10	32.71	0.37	5.60	1.54	0.05	99.15	Ct	0.726	0.222	0.008	0.044
A1S67	20	37.76	0.03	20.65	0.05	31.82	0.26	6.24	1.45	0.03	99.54		0.706	0.247	0.006	0.041
A1S68	150	37.47	0.03	20.76	0.09	31.28	0.32	6.28	1.46	0.04	98.89	3	0.700	0.251	0.007	0.042
A1S69	200	37.66	0.04	20.95	0.12	31.80	0.36	6.13	1.51	0.01	99.33		0.706	0.243	0.008	0.043
A2S39	20	37.36	0.06	20.75	0.00	31.56	0.50	5.78	1.61	0.09	99.05		0.710	0.232	0.011	0.046
A2S40	10	37.62	0.03	20.72	0.01	32.12	0.45	5.73	1.62	0.04	98.80	2	0.716	0.228	0.010	0.046
A2S41	50	37.50	0.01	20.68	0.01	32.52	0.42	5.70	1.54	0.00	98.78	2	0.721	0.225	0.009	0.044
A2S42	100	37.87	0.05	20.77	0.03	32.22	0.47	5.79	1.63	0.06	99.27		0.714	0.229	0.011	0.046
A2S43	170	38.29	0.02	20.90	0.04	33.27	0.38	5.77	1.43	0.00	100.53		0.727	0.225	0.008	0.040
A2S44	10	38.20	0.12	20.88	0.04	32.30	0.45	5.72	1.71	0.01	99.43		0.716	0.226	0.010	0.049
A2S45	10	37.34	0.02	20.54	0.03	31.28	0.42	6.66	1.85	0.05	98.19	2/u	0.681	0.258	0.009	0.052
A2S46	15	37.59	0.01	21.08	0.01	33.01	0.52	5.21	1.54	0.05	99.77	u	0.737	0.207	0.012	0.044
A2S47	75	37.85	0.01	20.98	0.04	32.87	0.40	5.43	1.43	0.01	99.28	2/u	0.734	0.216	0.009	0.041
A2S48	150	37.45	0.05	21.15	0.02	31.86	0.43	5.87	1.41	0.08	99.02		0.71*	0.235	0.010	0.041
A2S49	210	38.51	0.10	21.22	0.04	33.43	0.46	5.68	1.46	0.00	100.94	2	0.729	0.221	0.010	0.041
A2S50	175	38.32	0.00	21.43	0.02	33.11	0.50	5.78	1.47	0.01	100.74		0.723	0.225	0.011	0.041
A2S51	150	38.46	0.04	21.12	0.06	33.25	0.50	5.88	1.38	0.00	101.08	2	0.720	0.228	0.011	0.041
A2S52	100	38.34	0.01	21.28	0.02	33.00	0.49	5.87	1.46	0.01	100.85	2	0.723	0.228	0.011	0.038
A2S53	75	38.52	0.05	20.99	0.00	33.02	0.47	5.73	1.43	0.03	100.24		0.725	0.224	0.010	0.040
A2S54	15	38.63	0.00	21.03	0.00	33.29	0.38	5.67	1.42	0.00	100.96		0.722	0.230	0.008	0.039
A2S55	10	38.66	0.08	21.23	0.10	33.07	0.44	5.67	1.69	0.04	100.96		0.722	0.221	0.010	0.047
A2S56	25	38.51	0.05	20.93	0.00	33.13	0.52	5.49	1.35	0.03	100.01	u	0.733	0.217	0.012	0.038
A2S57		37.93	0.16	20.71	0.10	33.37	0.56	5.31	1.35	0.12	99.74	Ct	0.739	0.210	0.013	0.038
A2S58		37.58	0.08	21.03	0.00	33.45	0.54	4.95	1.58	0.05	100.16	Ct	0.746	0.197	0.012	0.045
A3S35	15	37.37	0.14	20.51	0.09	33.22	0.50	5.09	1.41	0.06	98.54	Ct	0.745	0.203	0.011	0.041
A3S36	15	38.31	0.02	21.28	0.00	33.33	0.33	5.76	1.40	0.03	100.54		0.729	0.224	0.007	0.039
A3S37	15	38.30	0.05	20.98	0.03	33.23	0.33	5.68	1.41	0.04	100.20		0.728	0.222	0.011	0.040
A3S38	20	37.52	0.06	20.95	0.01	33.01	0.45	5.38	1.44	0.01	98.83		0.735	0.214	0.010	0.041
A3S39	20	38.06	0.03	21.10	0.01	32.97	0.40	5.75	1.51	0.00	100.03		0.724	0.225	0.009	0.042
A3S40	10	38.21	0.00	20.64	0.00	33.76	0.43	5.12	1.34	0.00	99.50	Ct	0.750	0.203	0.010	0.038

A3541	225	37.56	0.05	21.18	0.08	0.83	32.16	0.46	5.83	1.42	0.04	99.61	0.717	0.232	0.010	0.041
A3542	175	37.58	0.03	20.77	0.09	0.27	32.53	0.42	5.74	1.40	0.00	98.83	0.723	0.227	0.009	0.040
A3543	150	37.62	0.01	21.04	0.00	1.15	32.11	0.43	5.94	1.42	0.02	99.74	0.714	0.235	0.010	0.040
A3544	100	37.82	0.05	20.85	0.03	0.54	32.50	0.44	5.85	1.42	0.03	99.53	0.719	0.231	0.010	0.040
A3545	100	37.65	0.00	20.53	0.00	0.22	32.72	0.32	5.72	1.39	0.01	98.56	0.727	0.226	0.007	0.040
A3546	140	38.03	0.10	20.78	0.01	1.37	32.10	0.46	6.13	1.49	0.04	100.51	0.707	0.241	0.010	0.042
A3547	50	38.60	0.05	21.08	0.01	0.24	33.59	0.41	5.71	1.47	0.02	101.18	0.729	0.221	0.009	0.041
A3548	15	38.21	0.04	20.90	0.00	0.00	34.26	0.46	4.93	1.50	0.00	100.18	0.757	0.194	0.010	0.039
A3549	75	37.97	0.04	20.87	0.02	0.68	33.02	0.49	5.58	1.50	0.01	100.18	0.728	0.219	0.011	0.042
A3550	70	38.17	0.00	20.91	0.00	0.48	32.69	0.52	5.91	1.38	0.04	100.10	0.718	0.231	0.012	0.039
A3551	10	38.08	0.00	20.98	0.00	0.00	32.51	0.47	5.65	1.60	0.04	99.33	0.721	0.223	0.011	0.045
A3552	25	38.08	0.07	20.81	0.06	0.07	33.06	0.42	5.58	1.54	0.07	99.76	0.728	0.219	0.009	0.043
A3553	5	38.18	0.00	20.76	0.00	0.00	32.83	0.38	5.58	1.41	0.02	99.16	0.730	0.221	0.009	0.040
A3554	10	38.06	0.08	21.14	0.00	0.00	32.79	0.46	5.62	1.54	0.08	99.77	0.725	0.221	0.010	0.044
A3555	15	38.20	0.00	21.10	0.08	0.13	33.51	0.45	5.48	1.52	0.00	100.47	0.734	0.214	0.010	0.043
A3556	70	37.85	0.14	21.14	0.07	1.42	32.29	0.53	5.85	1.48	0.08	100.85	0.715	0.231	0.012	0.042
A3557	105	37.98	0.16	21.00	0.02	0.38	33.05	0.51	5.73	1.27	0.00	100.00	0.728	0.225	0.011	0.036
A3558	125	37.98	0.06	20.92	0.01	0.98	32.29	0.47	5.94	1.46	0.09	100.20	0.714	0.234	0.011	0.041
A3559	170	38.36	0.00	21.18	0.04	0.00	33.19	0.43	5.63	1.37	0.00	100.20	0.731	0.221	0.010	0.039
A3560	100	38.34	0.08	20.93	0.00	0.63	32.67	0.44	6.02	1.47	0.06	100.64	0.714	0.235	0.010	0.041
A3561	25	38.27	0.00	20.74	0.00	0.40	32.65	0.47	5.96	1.58	0.00	100.07	0.713	0.232	0.010	0.044
A3562	15	38.35	0.06	21.23	0.00	0.00	32.78	0.44	5.80	1.50	0.04	100.20	0.721	0.227	0.010	0.042

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	37.91	0.04	20.79	0.04	0.74	32.09	0.28	6.17	1.48	0.03	99.57	0.709	0.243	0.006	0.042
	std	0.28	0.03	0.12	0.04	0.33	0.47	0.05	0.16	0.07	0.03	0.52	0.007	0.006	0.001	0.002
AREA 2	mean	38.14	0.04	21.02	0.03	0.33	32.72	0.45	5.78	1.52	0.03	100.05	0.720	0.227	0.010	0.043
	std	0.49	0.04	0.24	0.03	0.37	0.61	0.04	0.08	0.11	0.03	0.93	0.005	0.004	0.001	0.003
AREA 3	mean	38.05	0.05	20.97	0.02	0.42	32.77	0.44	5.77	1.46	0.03	99.99	0.722	0.227	0.010	0.041
	std	0.28	0.04	0.18	0.03	0.45	0.42	0.05	0.16	0.08	0.03	0.61	0.007	0.006	0.001	0.002

X317#4A

BIOTITE ANALYSES

(weight percent; precision +/- 2%)

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ^{iv} (+/-8%)	X Mn (+/-8%)
A1S22	37.54	4.12	18.10	0.03	15.51	0.02	12.34	0.22	0.32	9.75	97.95	2	0.480	0.339	0.081	0.099	0.000
A1S23	37.56	4.04	18.06	0.08	15.37	0.02	12.37	0.19	0.19	9.63	97.51	2	0.482	0.336	0.079	0.102	0.000
A1S24	37.70	4.03	17.98	0.02	15.09	0.00	12.42	0.21	0.22	9.82	97.49		0.486	0.331	0.080	0.104	0.000
A1S25	37.64	4.03	17.85	0.00	15.20	0.00	12.20	0.11	0.06	9.84	96.93		0.479	0.335	0.080	0.107	0.000
A1S26	36.62	4.14	17.67	0.00	14.75	0.00	11.88	0.15	0.11	9.41	94.73		0.477	0.332	0.084	0.107	0.000
A1S27	37.86	4.53	17.96	0.06	16.08	0.04	11.97	0.19	0.13	9.83	98.65	2	0.465	0.350	0.089	0.095	0.001
A1S28	37.74	4.45	17.90	0.09	15.17	0.06	12.09	0.20	0.30	9.72	97.72	2	0.476	0.335	0.088	0.100	0.001
A1S29	37.03	4.43	17.42	0.05	15.78	0.01	11.53	0.14	0.27	9.62	96.28	2	0.461	0.354	0.089	0.095	0.000
A1S30	37.43	4.96	17.34	0.08	16.31	0.12	11.23	0.13	0.00	9.76	97.36	2	0.446	0.363	0.099	0.089	0.003
A1S31	37.27	4.84	17.13	0.05	15.90	0.01	11.56	0.17	0.12	9.62	96.67	2	0.461	0.355	0.097	0.086	0.000
A1S33	37.49	4.85	17.59	0.00	15.97	0.03	11.44	0.13	0.13	9.76	97.41		0.453	0.355	0.097	0.095	0.001
A1S34	37.97	3.96	18.21	0.01	15.31	0.01	12.46	0.16	0.19	9.67	97.95		0.482	0.332	0.077	0.108	0.000
A1S35	34.07	3.61	16.50	0.07	13.56	0.13	11.08	0.22	0.55	8.91	89.30		0.479	0.329	0.079	0.110	0.003
A1S36	38.30	3.28	18.31	0.02	13.85	0.04	13.61	0.19	0.08	9.76	97.44	Ct	0.522	0.298	0.063	0.116	0.001
A1S37	37.93	3.58	18.38	0.00	13.78	0.00	13.72	0.13	0.46	9.72	97.70	Ct	0.527	0.297	0.069	0.107	0.000
A1S38	37.90	3.81	18.34	0.06	14.06	0.00	13.19	0.05	0.28	9.77	97.46	Ct	0.510	0.305	0.074	0.110	0.000
A1S39	38.46	3.26	18.48	0.00	13.31	0.00	14.24	0.20	0.16	9.63	97.74	Ct	0.461	0.332	0.083	0.114	0.000
A1S40	37.62	4.91	17.38	0.06	15.92	0.06	11.69	0.15	0.02	9.73	97.54		0.477	0.352	0.096	0.076	0.000
A1S41	37.17	4.91	17.46	0.09	16.27	0.00	12.35	0.16	0.13	9.06	97.60		0.477	0.352	0.096	0.076	0.000
A1S42	37.45	4.54	18.01	0.08	15.93	0.02	11.54	0.21	0.09	9.76	97.63		0.455	0.352	0.090	0.102	0.000
A1S43	37.83	4.70	17.66	0.10	15.76	0.00	11.37	0.22	0.27	9.70	97.61		0.453	0.352	0.094	0.101	0.000
A2S19	37.63	3.98	17.56	0.04	14.40	0.03	11.77	0.21	0.22	8.95	94.81	2	0.473	0.325	0.081	0.121	0.001
A2S20	37.67	4.37	18.02	0.07	14.59	0.12	12.51	0.12	0.28	9.63	97.38		0.489	0.320	0.086	0.102	0.003
A2S21	37.91	4.10	17.74	0.00	14.53	0.01	12.61	0.16	0.07	9.77	97.90		0.494	0.320	0.081	0.105	0.000
A2S22	37.36	4.44	17.58	0.04	15.10	0.06	12.60	0.18	0.36	9.82	97.54		0.494	0.332	0.088	0.085	0.001
A2S23	37.50	4.27	17.98	0.04	14.93	0.00	12.94	0.13	0.40	9.70	97.99		0.501	0.324	0.083	0.091	0.000
A2S24	36.91	4.00	17.68	0.00	14.66	0.00	12.63	0.15	0.00	9.69	95.72		0.497	0.324	0.080	0.099	0.000
A2S25	37.42	3.92	17.74	0.00	14.69	0.00	12.45	0.15	0.29	9.67	96.33		0.492	0.326	0.078	0.105	0.000
A1S26	37.30	3.96	17.82	0.03	14.93	0.09	12.52	0.21	0.31	9.64	96.81		0.492	0.329	0.078	0.099	0.002
A2S27	37.23	3.96	17.67	0.00	14.89	0.02	12.52	0.19	0.09	9.58	96.15		0.492	0.328	0.079	0.100	0.000
A2S28	37.58	4.08	17.80	0.00	15.26	0.00	12.64	0.19	0.18	9.78	97.51		0.491	0.333	0.080	0.095	0.000
A2S29	37.32	4.74	17.33	0.06	16.03	0.00	11.57	0.24	0.34	9.50	97.13	u	0.460	0.358	0.095	0.088	0.000
A2S30	36.59	4.52	16.88	0.02	16.53	0.01	11.96	0.20	0.17	8.95	95.83	u	0.471	0.365	0.090	0.074	0.000
A2S31	37.88	4.93	17.61	0.00	15.93	0.03	11.86	0.13	0.43	9.44	98.24	u	0.464	0.349	0.097	0.089	0.001
A2S32	37.25	5.02	17.02	0.07	16.24	0.07	11.53	0.22	0.03	9.72	97.14	u	0.458	0.362	0.101	0.079	0.002
A2S33	37.00	4.68	17.10	0.00	16.50	0.01	11.54	0.23	0.38	8.86	96.30	u	0.457	0.366	0.093	0.083	0.000
A2S34	37.75	4.14	17.61	0.02	14.78	0.04	12.33	0.24	0.52	9.75	97.18	u	0.489	0.329	0.083	0.099	0.001
A2S35	37.17	4.21	17.58	0.05	14.34	0.05	13.24	0.14	0.00	9.77	96.65	Ct	0.515	0.313	0.083	0.089	0.001
A3S16	38.93	3.69	19.39	0.00	14.11	0.00	10.17	0.18	0.09	8.99	96.05		0.410	0.319	0.075	0.196	0.000
A3S19	36.92	4.56	17.79	0.00	15.92	0.00	12.02	0.11	0.25	9.61	97.18		0.471	0.350	0.090	0.089	0.000
A3S20	34.32	1.50	22.39	0.05	19.23	0.01	16.40	0.10	0.45	3.90	96.35	u	0.483	0.362	0.025	0.130	0.000
A3S21	33.19	2.10	19.80	0.02	19.46	0.00	15.26	0.20	0.32	4.40	94.75	u	0.520	0.372	0.036	0.071	0.000
A3S22	40.13	1.29	25.40	0.00	10.64	0.00	7.63	0.12	0.00	6.26	91.47		0.314	0.246	0.027	0.414	0.000
A3S23	36.49	4.38	17.69	0.02	14.90	0.03	11.65	0.26	0.06	9.41	94.89		0.469	0.337	0.089	0.105	0.001
A3S24	36.96	4.49	17.61	0.04	15.68	0.04	11.63	0.14	0.17	9.59	96.35		0.462	0.350	0.090	0.097	0.001
A3S25	36.99	4.51	17.47	0.01	15.62	0.02	11.73	0.21	0.54	9.54	96.64		0.468	0.350	0.091	0.091	0.000
A3S26	37.26	4.52	17.62	0.02	15.82	0.00	11.39	0.18	0.01	9.20	96.02		0.452	0.352	0.091	0.105	0.000

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

A3S27	38.58	4.37	18.19	0.00	15.76	0.01	12.22	0.22	0.13	9.80	99.28	2	0.470	0.340	0.085	0.105	0.000
A3S28	38.56	4.02	17.90	0.07	14.94	0.04	13.17	0.13	0.09	9.54	98.46	Ct	0.502	0.320	0.077	0.100	0.001
A3S29	37.96	4.18	17.91	0.03	14.34	0.04	13.08	0.21	0.52	9.78	98.05	Ct	0.509	0.313	0.082	0.095	0.001
A3S30	37.27	3.90	17.72	0.00	13.78	0.00	13.21	0.23	0.10	9.53	95.74	Ct	0.518	0.303	0.077	0.101	0.000
A3S31	37.37	4.60	17.93	0.01	15.33	0.03	11.79	0.21	0.35	9.64	97.26		0.467	0.340	0.092	0.100	0.001
A3S32	36.90	3.70	17.12	0.00	15.23	0.00	13.01	0.18	0.70	9.36	96.20	Ct	0.511	0.336	0.073	0.080	0.000
A3S33	37.07	4.01	17.25	0.00	15.23	0.01	11.58	0.17	0.00	9.44	94.76		0.466	0.344	0.081	0.108	0.000
A3S34	37.70	4.27	17.38	0.03	14.12	0.04	12.72	0.20	0.00	9.65	96.11		0.502	0.313	0.085	0.099	0.001

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																	
mean	37.33	4.41	17.66	0.05	15.52	0.03	11.85	0.17	0.18	9.62	96.84	17	0.469	0.344	0.088	0.098	0.001
std	0.77	0.42	0.44	0.04	0.68	0.04	0.46	0.04	0.14	0.27	2.16		0.013	0.011	0.008	0.009	0.001
AREA 2																	
mean	37.48	4.11	17.75	0.02	14.80	0.03	12.50	0.18	0.25	9.63	96.75	11	0.491	0.326	0.082	0.100	0.001
std	0.28	0.18	0.15	0.02	0.26	0.04	0.29	0.04	0.15	0.24	0.92		0.007	0.004	0.003	0.009	0.001
AREA 3																	
mean	37.67	4.06	18.57	0.01	14.83	0.02	11.32	0.18	0.15	9.19	96.00	11	0.450	0.331	0.081	0.137	0.000
std	1.10	0.96	2.38	0.01	1.53	0.02	1.37	0.05	0.17	1.00	1.94		0.050	0.031	0.019	0.096	0.000

Y31.9Aa PLAGIOCLASE ANALYSES (weight percent; precision +/- 2%)

	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
A1S1	61.10	24.98	0.03	6.00	8.19	0.31	100.61		0.283	0.699	0.017
A1S2	60.94	25.30	0.10	6.30	8.20	0.29	101.13		0.293	0.691	0.016
A1S3	60.67	25.27	0.18	6.23	8.17	0.30	100.82		0.292	0.692	0.017
A1S4	60.75	25.46	0.03	6.24	8.22	0.21	100.91		0.292	0.696	0.012
A1S5	60.85	24.86	0.03	5.98	8.27	0.25	99.86		0.282	0.704	0.014
A1S6	60.70	24.79	0.02	5.93	8.18	0.24	99.96		0.282	0.704	0.014
A1S7	60.86	24.89	0.01	6.13	8.07	0.27	100.23		0.291	0.694	0.015
A1S8	61.17	24.76	0.05	5.90	8.39	0.35	100.62		0.274	0.706	0.019
A1S11	61.73	24.74	0.00	5.32	8.56	0.37	100.72	u	0.250	0.729	0.021
A1S12	60.84	25.14	0.05	6.17	8.04	0.26	100.50		0.293	0.692	0.015
A1S13	59.73	24.71	0.07	5.96	8.05	0.26	98.78		0.286	0.699	0.015
A1S14	60.87	24.61	0.16	5.77	8.25	0.28	99.94		0.274	0.710	0.016
A1S15	60.95	24.29	0.15	5.45	8.59	0.38	99.81	u	0.254	0.725	0.021
A1S18	60.18	24.74	0.05	5.90	8.12	0.26	99.25		0.282	0.703	0.015
A1S19	59.63	24.60	0.03	5.80	7.98	0.31	98.35		0.281	0.701	0.018
A1S20	59.83	24.71	0.02	5.66	8.16	0.33	98.71		0.272	0.709	0.019
A1S21	59.96	24.58	0.09	5.76	8.25	0.33	98.97		0.273	0.708	0.019
A2S1	60.61	24.30	0.06	5.54	8.28	0.25	99.04		0.266	0.720	0.014
A2S2	61.54	25.08	0.11	6.01	8.37	0.24	101.35		0.280	0.706	0.013
A2S3	62.10	25.14	0.13	6.00	8.18	0.29	101.84		0.284	0.700	0.016
A2S4	60.72	24.80	0.02	5.76	8.17	0.31	99.78		0.275	0.707	0.018
A2S5	61.67	25.13	0.07	6.02	8.35	0.27	101.51		0.281	0.704	0.015
A2S6	59.32	24.80	0.04	6.27	8.12	0.22	98.77		0.295	0.692	0.012
A2S7	61.00	25.15	0.04	6.12	8.21	0.26	100.78		0.288	0.698	0.015
A2S8	60.22	25.09	0.04	5.97	7.93	0.23	99.48		0.290	0.697	0.013
A2S9	60.72	24.88	0.10	6.31	7.84	0.21	100.06		0.304	0.684	0.012
A2S11	61.28	25.01	0.00	5.63	8.28	0.31	100.51		0.268	0.714	0.018
A1S13	59.19	24.70	0.05	6.26	7.98	0.25	98.43		0.298	0.688	0.014
A2S14	60.47	25.03	0.10	6.12	8.17	0.27	100.16		0.288	0.697	0.015
A2S15	60.22	24.67	0.07	5.87	7.93	0.34	99.10		0.285	0.696	0.020
A2S16	60.13	24.35	0.11	5.74	8.26	0.32	98.91		0.272	0.709	0.018
A2S17	59.65	25.00	0.16	6.49	7.85	0.24	99.39		0.309	0.677	0.014
A2S18	61.04	24.36	0.13	5.66	8.25	0.26	99.70		0.271	0.714	0.015
A3S1	59.43	25.05	0.11	6.17	7.89	0.25	98.91		0.297	0.688	0.014
A3S2	59.56	25.10	0.11	6.18	7.82	0.26	99.03		0.299	0.686	0.015
A3S3	59.74	25.12	0.07	6.12	7.82	0.23	99.10		0.298	0.689	0.013
A3S4	60.16	25.23	0.04	6.18	7.89	0.22	99.71		0.298	0.689	0.013
A3S5	59.96	25.42	0.07	6.44	7.94	0.21	100.04		0.306	0.682	0.012
A3S6	60.15	25.31	0.07	6.08	8.30	0.23	100.14		0.284	0.703	0.013
A3S7	59.77	24.92	0.06	6.09	7.87	0.21	98.92		0.296	0.692	0.012
A3S8	59.80	24.80	0.12	6.16	7.96	0.24	99.08		0.295	0.691	0.014
A3S9	60.30	24.92	0.06	5.93	7.86	0.25	99.32		0.290	0.695	0.015
A3S10	59.68	25.29	0.07	6.21	7.78	0.23	99.26		0.302	0.685	0.013
A3S11	59.98	25.41	0.07	6.37	7.83	0.20	99.86		0.307	0.682	0.011
A3S12	59.69	25.20	0.11	6.09	7.79	0.29	99.17		0.297	0.687	0.017

A3S14	60.85	25.29	0.06	6.06	8.13	0.26	100.65	0.287	0.698	0.015
A3S15	61.09	25.64	0.30	6.35	8.00	0.27	101.65	0.300	0.685	0.015
A3S16	61.16	24.97	0.14	5.91	8.20	0.29	100.67	0.280	0.703	0.016
A3S17	62.21	25.24	0.07	5.58	8.37	0.30	101.77	0.265	0.718	0.017

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1										
mean	60.54	24.89	0.06	5.98	8.17	0.28	99.91	0.283	0.701	0.016
std	0.52	0.28	0.05	0.20	0.11	0.04	0.90	0.008	0.007	0.002
AREA 2										
mean	60.62	24.84	0.08	5.99	8.14	0.27	99.93	0.285	0.700	0.015
std	0.82	0.29	0.04	0.27	0.17	0.04	1.03	0.013	0.012	0.002
AREA 3										
mean	60.06	25.16	0.10	6.16	7.93	0.24	99.66	0.296	0.690	0.014
std	0.54	0.23	0.06	0.14	0.16	0.03	0.79	0.007	0.007	0.002

X39#6a GARNETS X Mg versus X Fe

(Area/table: -/1 */2 +/3 o/4)

X39#6a BIOTITES X Mg versus X Fe

(Area/label: 1/* 2/* 3/+)

X39#6a PLAGIOCLASES X Na versus X Ca

(Area/label: 1/* 2/* 3/+ 4/o)

(weight percent; precision +/-2%)

GARNET ANALYSES

X3986A

	(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
Xtal 1 (ca. 150 um short diameter)																	
A1S1	10	38.02	0.02	21.21	0.03	0.00	30.74	0.22	7.26	1.16	0.01	98.63	2/P	0.678	0.285	0.005	0.033
A1S2	50	38.45	0.04	21.51	0.03	1.27	30.23	0.31	7.86	1.15	0.00	100.83	2/C	0.657	0.304	0.007	0.032
A1S3	20	37.65	0.05	20.88	0.03	0.72	30.29	0.27	7.26	1.18	0.02	98.34	3/P	0.673	0.287	0.006	0.034
A1S4	20	38.46	0.00	21.35	0.00	0.73	30.87	0.19	7.54	1.17	0.01	100.31	2/P	0.671	0.292	0.004	0.033
A1S5	50	38.68	0.03	21.72	0.10	0.55	30.67	0.17	7.76	1.24	0.00	100.90	2/C	0.663	0.299	0.004	0.034
A1S6	55	38.79	0.05	21.33	0.09	1.83	29.94	0.32	8.08	1.20	0.08	101.71	C	0.648	0.312	0.007	0.033
A1S7	25	38.29	0.04	21.46	0.00	1.10	30.09	0.28	7.62	1.33	0.06	100.27	C	0.659	0.297	0.006	0.037
A1S8	20	38.18	0.07	21.13	0.11	0.68	30.46	0.39	7.42	1.19	0.03	99.66	P	0.668	0.290	0.009	0.033
A1S9	35	38.51	0.07	21.14	0.00	0.18	31.04	0.20	7.45	1.24	0.01	99.84	P	0.673	0.288	0.004	0.034
A1S10	60	38.52	0.07	21.35	0.00	0.00	30.74	0.22	7.37	1.18	0.00	99.45	P	0.674	0.288	0.005	0.033
A1S11	15	38.20	0.00	21.19	0.10	0.08	30.68	0.30	7.22	1.24	0.08	99.09	P	0.675	0.283	0.007	0.035
A1S12	10	38.73	0.15	21.82	0.03	0.75	30.94	0.28	7.49	1.33	0.05	101.57	P	0.669	0.288	0.006	0.037
A1S13	10	38.26	0.05	21.34	0.09	0.00	30.62	0.36	7.31	1.26	0.03	99.32	P	0.671	0.286	0.008	0.035
Xtal 2 (ca. 125 um short diameter)																	
A1S14	10	39.33	0.06	21.09	0.00	0.00	31.74	0.27	7.39	1.16	0.04	101.08	P	0.680	0.282	0.006	0.032
A1S15	10	37.77	0.05	21.21	0.09	0.05	30.21	0.36	7.16	1.41	0.01	98.32	P	0.669	0.283	0.008	0.040
A1S16	20	39.15	0.00	21.39	0.00	0.00	31.33	0.16	7.14	1.23	0.00	100.40	u	0.684	0.278	0.004	0.034
A1S17	50	38.75	0.06	21.23	0.08	0.12	31.29	0.30	7.22	1.20	0.03	100.25	P	0.680	0.280	0.007	0.033
A1S18	50	38.37	0.15	21.23	0.03	0.33	30.90	0.34	7.34	1.14	0.09	99.92	P	0.675	0.286	0.008	0.032
A1S19	15	38.81	0.00	21.14	0.11	0.00	31.20	0.33	7.30	1.26	0.04	100.19	P	0.676	0.282	0.007	0.035
A1S20	15	38.81	0.00	21.64	0.01	0.10	32.84	0.23	6.50	1.33	0.01	101.47	Ct	0.708	0.250	0.005	0.037
Xtal 1 (ca. 150 um short diameter)																	
A2S1	10	39.13	0.00	21.92	0.03	0.00	30.49	0.29	8.10	1.16	0.00	101.12	R	0.653	0.309	0.006	0.032
A2S2	125	39.63	0.00	22.22	0.04	0.00	30.84	0.21	8.20	1.21	0.07	102.42	R	0.653	0.309	0.005	0.033
A2S3	15	38.38	0.02	21.34	0.13	0.48	29.75	0.35	7.99	1.14	0.04	99.62	R	0.650	0.311	0.008	0.032
A2S4	75	38.51	0.00	21.74	0.06	0.41	29.80	0.17	8.06	1.32	0.00	100.07	P	0.647	0.312	0.004	0.037
A2S5	50	38.75	0.02	21.52	0.10	0.04	29.81	0.28	8.13	1.15	0.04	99.80	P	0.647	0.315	0.006	0.032
A2S6	100	38.60	0.12	21.29	0.17	0.98	29.84	0.36	8.04	1.25	0.04	100.69	P	0.647	0.311	0.008	0.035
A2S7	75	39.03	0.00	21.47	0.09	0.41	30.05	0.19	8.16	1.31	0.06	100.77	P	0.647	0.313	0.004	0.036
A2S8	10	38.93	0.03	21.58	0.04	0.05	30.35	0.21	7.92	1.31	0.07	100.49	R	0.655	0.304	0.005	0.036
Xtal 2 (ca. 175 um short diameter)																	
A2S9	10	38.92	0.00	21.62	0.04	0.78	30.50	0.27	7.83	1.30	0.04	101.30		0.657	0.301	0.006	0.036
A2S10	10	38.43	0.07	21.10	0.07	0.00	30.03	0.24	7.67	1.24	0.01	98.86		0.660	0.300	0.005	0.035
A2S11	10	39.14	0.02	21.37	0.03	0.18	31.01	0.24	7.86	1.22	0.00	101.07		0.662	0.299	0.005	0.033
A2S12	10	39.60	0.01	21.81	0.09	0.00	30.80	0.39	7.78	1.41	0.00	101.89		0.657	0.296	0.008	0.039
A2S13	50	39.34	0.00	21.84	0.03	0.00	30.77	0.13	7.99	1.27	0.01	101.38		0.658	0.304	0.003	0.035
A2S14	75	39.19	0.00	21.93	0.05	0.00	30.87	0.25	7.60	1.30	0.01	101.20		0.666	0.292	0.005	0.036
A2S15	75	39.69	0.12	21.94	0.09	0.00	30.70	0.33	7.78	1.29	0.03	101.97		0.659	0.298	0.007	0.036
Xtal 1 (ca. 220 um short diameter)																	
A3S1	10	38.07	0.09	21.08	0.10	0.64	32.57	0.29	6.18	1.28	0.02	100.33	3/u	0.716	0.242	0.006	0.036
A3S2	10	38.61	0.03	21.51	0.11	0.00	33.51	0.20	5.79	1.21	0.00	100.97	u	0.735	0.226	0.004	0.034
A3S3	100	38.65	0.03	21.47	0.12	0.00	31.33	0.24	7.26	1.17	0.01	100.28	u	0.681	0.281	0.005	0.033
A3S4	50	38.13	0.08	21.31	0.15	0.86	31.15	0.26	6.93	1.32	0.07	100.26	u	0.685	0.272	0.006	0.037
A3S5	65	39.08	0.00	21.23	0.07	0.00	31.56	0.28	7.21	1.24	0.00	100.67	u	0.682	0.278	0.006	0.034
A3S6	65	38.49	0.00	21.39	0.00	0.15	32.02	0.33	6.82	1.20	0.01	100.41		0.695	0.264	0.007	0.033
A3S7	75	38.23	0.20	21.48	0.01	0.87	30.75	0.23	7.37	1.33	0.03	100.50		0.671	0.287	0.005	0.037

A3S8	90	38.41	0.00	21.44	0.05	0.00	30.18	0.21	7.55	1.21	0.02	99.07	0.665	0.296	0.005	0.034
A3S9	100	38.80	0.02	20.85	0.07	0.00	30.42	0.25	7.67	1.25	0.00	99.33	0.662	0.297	0.006	0.034
A3S10	110	39.08	0.00	21.50	0.14	0.44	30.38	0.17	8.13	1.25	0.03	101.12	0.651	0.311	0.004	0.034
A3S11	10	38.67	0.10	21.20	0.11	0.67	29.66	0.27	8.09	1.33	0.09	100.19	0.644	0.313	0.006	0.037
A3S12	10	38.53	0.08	21.51	0.14	0.00	29.86	0.20	7.72	1.25	0.06	99.35	0.657	0.303	0.004	0.034
A3S13	10	38.66	0.00	21.38	0.05	0.69	30.37	0.19	7.91	1.24	0.00	100.49	0.657	0.305	0.004	0.034
A3S14	10	37.77	0.00	21.12	0.07	0.73	29.61	0.34	7.59	1.29	0.04	98.61	0.656	0.300	0.008	0.037
A3S15	20	38.42	0.14	21.37	0.00	0.51	29.92	0.30	7.89	1.26	0.06	99.87	0.652	0.306	0.007	0.035
A3S16	20	39.25	0.09	21.53	0.20	0.60	30.04	0.39	8.13	1.40	0.10	101.73	0.643	0.310	0.008	0.038
A3S17	15	38.78	0.06	21.47	0.14	0.41	30.55	0.32	7.80	1.20	0.04	100.77	0.660	0.300	0.007	0.033
A3S18	15	38.60	0.01	21.08	0.15	0.61	30.20	0.28	7.75	1.31	0.07	100.06	0.657	0.300	0.006	0.037
A3S19	20	38.51	0.02	21.28	0.05	0.10	30.84	0.13	7.59	1.23	0.00	99.75	0.669	0.294	0.003	0.034
A3S20	20	38.17	0.03	21.20	0.07	0.71	30.42	0.26	7.40	1.32	0.02	99.60	0.668	0.289	0.006	0.037
A3S21	25	37.97	0.06	21.15	0.04	0.63	30.53	0.23	7.28	1.30	0.02	99.21	0.672	0.286	0.005	0.037
A3S22	10	38.86	0.13	21.49	0.20	1.01	31.28	0.43	7.25	1.26	0.10	102.01	0.676	0.279	0.009	0.035
A3S23	10	38.98	0.03	21.53	0.14	0.47	31.28	0.33	7.54	1.20	0.01	101.51	0.671	0.288	0.007	0.033
Xtal 2 (ca. 150 μ m short diameter)																
A3S24	10	37.98	0.07	21.31	0.06	0.00	30.10	0.28	7.51	1.27	0.00	98.58	0.663	0.295	0.006	0.036
A3S25	35	38.33	0.12	21.40	0.17	1.15	30.12	0.28	7.52	1.46	0.09	100.64	0.659	0.293	0.006	0.041
A3S26	75	37.88	0.02	21.17	0.09	0.51	30.63	0.28	7.07	1.36	0.02	99.00	0.677	0.278	0.006	0.038
A3S27	15	38.75	0.20	21.50	0.16	0.32	30.68	0.30	7.48	1.44	0.05	100.85	0.665	0.289	0.006	0.040
A3S28	50	38.08	0.06	21.38	0.07	0.69	29.91	0.38	7.64	1.32	0.00	99.53	0.656	0.299	0.008	0.037
A3S29	60	38.45	0.07	21.63	0.11	0.51	30.30	0.31	7.50	1.47	0.06	100.41	0.661	0.291	0.007	0.041
A3S30	10	38.44	0.10	21.49	0.02	0.90	29.85	0.32	7.75	1.47	0.06	100.40	0.651	0.301	0.007	0.041
A3S31	50	38.05	0.12	21.09	0.09	0.84	29.64	0.22	7.70	1.44	0.04	99.23	0.652	0.302	0.005	0.041
A3S32	15	39.26	0.08	21.56	0.14	0.00	30.98	0.30	7.75	1.36	0.05	101.48	0.661	0.295	0.006	0.037
A3S33	15	38.60	0.09	21.49	0.09	1.21	29.96	0.24	7.88	1.42	0.06	101.04	0.650	0.305	0.005	0.039
A3S34	25	38.41	0.00	21.21	0.04	0.00	30.46	0.28	7.42	1.42	0.00	99.24	0.665	0.289	0.006	0.040
A3S35	20	38.82	0.10	21.58	0.11	0.00	30.72	0.23	7.71	1.32	0.03	100.62	0.662	0.296	0.005	0.036

Xtal 1 (ca. 300 μ m short diameter)

A4S1	110	38.49	0.04	21.50	0.07	0.51	30.08	0.31	7.77	1.24	0.07	100.08	0.656	0.302	0.007	0.035
A4S2	140	38.89	0.04	21.18	0.05	0.00	30.82	0.23	7.63	1.23	0.02	100.09	0.667	0.294	0.005	0.034
A4S3	120	39.12	0.11	21.69	0.13	0.36	30.67	0.35	7.86	1.29	0.06	101.64	0.657	0.300	0.008	0.035
A4S4	80	38.70	0.01	21.58	0.00	0.08	30.73	0.22	7.73	1.24	0.00	100.29	0.663	0.297	0.005	0.034
A4S5	40	38.80	0.07	21.29	0.12	0.08	30.80	0.30	7.67	1.31	0.01	100.45	0.663	0.294	0.007	0.036
A4S6	210	38.70	0.01	21.58	0.00	0.08	30.73	0.22	7.73	1.24	0.00	100.29	0.663	0.297	0.005	0.034
A4S7	250	38.69	0.06	21.01	0.00	0.10	30.65	0.30	7.60	1.33	0.02	99.76	0.663	0.293	0.007	0.037
A4S8	290	38.76	0.03	21.48	0.04	0.31	30.59	0.25	7.78	1.29	0.00	100.53	0.660	0.299	0.005	0.036
A4S9	310	40.13	0.00	21.67	0.04	0.00	30.86	0.24	8.05	1.24	0.00	102.23	0.656	0.305	0.005	0.034
A4S10	150	38.62	0.03	21.60	0.04	0.41	30.66	0.18	7.65	1.22	0.04	100.45	0.666	0.296	0.004	0.034
A4S11	190	38.71	0.01	21.54	0.11	0.00	31.08	0.23	7.41	1.24	0.01	100.34	0.674	0.286	0.005	0.034
A4S12	230	38.17	0.09	21.45	0.10	0.30	30.22	0.35	7.51	1.25	0.04	99.48	0.663	0.294	0.008	0.035
A4S13	260	38.97	0.03	21.46	0.12	0.59	30.14	0.42	8.04	1.27	0.00	100.94	0.648	0.308	0.009	0.035
A4S14	290	39.12	0.00	21.67	0.00	0.00	30.89	0.21	7.64	1.25	0.01	100.79	0.667	0.294	0.005	0.035
A4S15	80	39.18	0.00	21.36	0.02	0.00	30.62	0.20	7.80	1.19	0.06	100.43	0.662	0.301	0.004	0.034
A4S16	50	38.76	0.04	21.60	0.10	0.88	30.65	0.34	7.99	1.29	0.03	101.08	0.649	0.308	0.007	0.036
A4S17	20	38.77	0.08	21.40	0.09	0.75	30.52	0.41	7.71	1.37	0.00	101.10	0.657	0.296	0.009	0.038

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	contact	mean	std	38.81	0.00	21.64	0.01	0.10	32.84	0.23	6.50	1.33	0.01	101.47	1	0.708	0.250	0.005	0.037
	plateau	mean	std	38.40	0.06	21.24	0.05	0.26	30.84	0.29	7.34	1.22	0.03	99.71	14	0.674	0.286	0.006	0.034
		std		0.44	0.05	0.21	0.04	0.32	0.40	0.06	0.11	0.07	0.03	0.95		0.004	0.003	0.001	0.002
	core	mean	std	38.55	0.04	21.50	0.05	1.19	30.23	0.27	7.83	1.23	0.04	100.93	4	0.657	0.303	0.006	0.034
		std		0.23	0.01	0.16	0.05	0.53	0.31	0.07	0.19	0.08	0.04	0.59		0.006	0.006	0.002	0.002
AREA 2	rim	mean	std	39.02	0.01	21.77	0.06	0.13	30.36	0.27	8.05	1.21	0.05	100.91	4	0.653	0.308	0.006	0.033
		std		0.52	0.01	0.39	0.05	0.23	0.45	0.07	0.12	0.08	0.03	1.18		0.002	0.003	0.002	0.002
	plateau	mean	std	38.72	0.04	21.51	0.11	0.45	29.88	0.25	8.10	1.26	0.04	100.33	4	0.647	0.313	0.005	0.035
		std		0.23	0.06	0.19	0.05	0.40	0.12	0.09	0.06	0.08	0.03	0.47		0.000	0.002	0.002	0.002
AREA 3	contact	mean	std	38.61	0.03	21.51	0.11	0.00	33.51	0.20	5.79	1.21	0.00	100.97		0.735	0.226	0.004	0.034
	plateau	mean	std	38.53	0.16	21.35	0.10	0.46	30.27	0.27	7.69	1.31	0.04	100.08	22	0.659	0.298	0.006	0.037
		std		0.42	0.04	0.20	0.05	0.35	0.44	0.07	0.22	0.09	0.03	0.92		0.008	0.007	0.001	0.002
AREA 4	plateau	mean	std	39.49	0.04	21.47	0.06	0.26	30.59	0.28	7.74	1.26	0.02	100.59	17	0.661	0.298	0.006	0.035
		std		0.41	0.03	0.18	0.05	0.28	0.30	0.07	0.17	0.04	0.02	0.67		0.007	0.006	0.002	0.001

(weight percent; precision +/-2%)

X39#6a	(weight percent; precision +/-2%)																
	BIOTITE ANALYSES																
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ⁶ (+/-8%)	X Mn (+/-8%)
A1S43	36.21	5.98	15.71	0.14	13.67	0.03	13.71	0.09	0.00	9.50	95.02	2	0.544	0.305	0.120	0.030	0.001
A1S44	36.37	5.92	15.63	0.09	13.11	0.04	13.49	0.02	0.00	9.45	94.10	4	0.542	0.296	0.120	0.041	0.001
A1S45	35.94	6.06	15.39	0.11	12.24	0.00	12.42	0.17	0.00	7.38	89.71		0.518	0.286	0.127	0.069	0.000
A1S46	39.51	4.88	16.63	0.00	13.25	0.00	13.33	0.00	0.00	7.90	95.50	Ct	0.515	0.287	0.095	0.102	0.000
A1S47	36.18	6.21	15.72	0.03	13.72	0.00	13.12	0.01	0.00	9.64	94.62	2	0.528	0.310	0.126	0.037	0.000
A1S48	36.79	6.50	15.67	0.12	12.91	0.10	13.02	0.06	0.00	9.14	94.31		0.527	0.293	0.133	0.045	0.002
A1S49	37.30	6.23	16.32	0.00	12.31	0.02	12.53	0.04	0.00	7.51	92.26	3	0.506	0.279	0.127	0.087	0.000
A1S50	36.44	5.84	15.24	0.00	13.96	0.04	13.07	0.04	0.00	10.04	94.67	u	0.529	0.317	0.119	0.033	0.001
A2S34	35.96	4.88	15.61	0.25	13.07	0.00	14.21	0.06	0.00	9.83	93.87		0.569	0.294	0.099	0.038	0.000
A2S35	36.56	4.95	15.73	0.27	12.99	0.00	14.51	0.06	0.00	9.87	94.92	2	0.574	0.288	0.099	0.039	0.000
A2S36	35.95	5.05	15.09	0.39	12.91	0.00	13.43	0.00	0.00	9.82	92.64		0.555	0.299	0.105	0.041	0.000
A2S38	37.38	6.12	16.26	0.15	13.37	0.00	13.84	0.03	0.00	9.95	97.10		0.543	0.294	0.121	0.042	0.000
A2S39	36.11	5.27	15.83	0.37	13.04	0.06	13.96	0.12	0.00	9.73	94.55		0.560	0.294	0.107	0.039	0.001
A2S40	36.38	5.07	15.86	0.25	13.17	0.06	14.02	0.08	0.00	9.78	94.67		0.559	0.295	0.102	0.043	0.001
A2S41	35.75	5.13	15.59	0.25	13.60	0.06	13.88	0.05	0.00	9.92	94.23		0.557	0.306	0.104	0.032	0.001
A2S42	36.89	5.04	16.29	0.25	12.68	0.04	14.65	0.21	0.00	8.74	94.80		0.571	0.277	0.099	0.052	0.001
A3S51	35.77	4.92	15.17	0.45	13.49	0.00	13.33	0.00	0.00	9.31	92.44		0.546	0.310	0.102	0.042	0.000
A3S52	36.24	4.98	15.60	0.35	13.33	0.00	13.35	0.04	0.00	8.84	92.73		0.541	0.303	0.102	0.055	0.000
A3S53	35.69	4.86	15.61	0.32	13.09	0.00	13.05	0.07	0.00	8.55	91.24		0.536	0.302	0.101	0.062	0.000
A3S54	36.92	5.08	15.41	0.39	13.77	0.00	13.79	0.11	0.00	9.64	95.11		0.551	0.309	0.102	0.039	0.000
A3S56	36.06	4.93	15.24	0.47	12.89	0.01	13.30	0.09	0.00	8.66	91.65	Ct	0.547	0.297	0.102	0.053	0.000
STATISTICAL ANALYSIS (mean and standard deviation)																	
AREA 1																	
contact	39.51	4.88	16.63	0.00	13.25	0.00	13.33	0.00	0.00	7.90	95.50		0.515	0.287	0.095	0.102	0.000
mean	36.46	6.15	15.74	0.08	12.99	0.03	13.05	0.06	0.00	8.77	93.34	6	0.528	0.295	0.126	0.051	0.001
std	0.50	0.21	0.31	0.05	0.64	0.04	0.51	0.06	0.00	1.04	2.02		0.015	0.011	0.005	0.022	0.001
AREA 2																	
contact	36.37	5.19	15.78	0.27	13.10	0.03	14.06	0.08	0.00	9.71	94.59	8	0.561	0.293	0.104	0.041	0.001
mean	36.37	5.19	15.78	0.27	13.10	0.03	14.06	0.08	0.00	9.71	94.59	8	0.561	0.293	0.104	0.041	0.001
std	0.55	0.39	0.39	0.08	0.28	0.03	0.39	0.06	0.00	0.39	1.25		0.010	0.008	0.007	0.006	0.001
AREA 3																	
contact	36.06	4.93	15.24	0.47	12.89	0.01	13.30	0.09	0.00	8.66	91.65		0.547	0.297	0.102	0.053	0.000
mean	36.16	4.96	15.45	0.38	13.42	0.00	13.38	0.06	0.00	9.09	92.88	4	0.543	0.306	0.102	0.049	0.000
std	0.56	0.09	0.21	0.06	0.29	0.00	0.31	0.05	0.00	0.48	1.62		0.006	0.004	0.001	0.011	0.000

X3906a	PLAGIOCLASE ANALYSES (weight percent; precision +/- 2x)										X K (+/-4x)
	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4x)	X Na (+/-4x)	
A1S21	60.47	24.39	0.08	5.24	8.48	0.33	98.99		0.250	0.731	0.019
A1S22	62.43	24.51	0.00	5.29	8.53	0.33	101.09		0.250	0.731	0.019
A1S23	61.63	24.29	0.01	5.36	8.64	0.26	100.19		0.252	0.734	0.015
A1S24	61.74	24.07	0.00	5.25	8.85	0.30	100.21		0.243	0.741	0.017
A1S26	62.35	24.64	0.00	5.44	8.76	0.23	101.44		0.252	0.735	0.013
A1S27	62.78	24.49	0.07	5.33	8.58	0.36	101.62	3	0.249	0.726	0.020
A1S28	60.60	23.96	0.12	5.13	8.29	0.38	98.48		0.249	0.729	0.022
A1S29	62.08	24.28	0.08	5.20	8.64	0.30	100.58		0.245	0.738	0.017
A1S31	62.23	24.35	0.00	5.18	8.64	0.31	100.71		0.245	0.738	0.017
A1S33	61.96	24.47	0.15	5.35	8.59	0.36	100.88		0.251	0.729	0.020
A1S34	62.44	24.61	0.24	5.45	8.64	0.32	101.69	2	0.254	0.728	0.018
A1S35	62.41	24.33	0.10	5.21	8.52	0.39	100.96		0.247	0.731	0.022
A1S37	62.39	24.44	0.00	5.29	8.53	0.34	100.99		0.250	0.730	0.019
A1S38	60.58	24.10	0.05	5.27	8.49	0.33	98.82		0.251	0.731	0.019
A1S39	62.58	24.52	0.10	5.31	8.50	0.39	101.40		0.251	0.727	0.022
A1S40	62.77	24.52	0.13	5.29	8.39	0.35	101.45		0.253	0.727	0.020
A1S41	62.34	24.41	0.14	5.48	8.69	0.34	101.40		0.254	0.728	0.019
A1S42	62.12	24.23	0.06	5.37	8.81	0.32	100.91		0.248	0.735	0.018
A1S43	62.05	24.37	0.10	5.23	8.61	0.38	100.74		0.246	0.733	0.021
A1S44	62.37	24.08	0.20	5.28	8.71	0.41	101.05		0.245	0.732	0.023
A1S45	62.24	24.40	0.00	5.28	8.85	0.35	101.12		0.243	0.738	0.019
A2S16	61.90	24.46	0.10	5.37	8.82	0.34	100.97	2	0.247	0.735	0.018
A2S17	61.79	24.55	0.07	5.30	8.64	0.28	100.62	2	0.249	0.735	0.016
A2S18	60.92	24.20	0.06	5.30	8.74	0.40	99.61	2	0.245	0.733	0.022
A2S19	61.55	24.39	0.16	5.26	8.97	0.46	100.79		0.239	0.736	0.025
A2S20	60.43	24.27	0.01	5.17	8.90	0.42	99.20		0.237	0.740	0.023
A2S21	60.95	24.24	0.00	5.25	8.89	0.25	99.58		0.243	0.744	0.014
A2S22	60.91	24.26	0.04	5.21	8.78	0.32	99.53	3	0.242	0.740	0.018
A2S23	60.78	24.08	0.06	5.34	8.65	0.34	99.23	2	0.250	0.732	0.019
A2S24	60.75	24.48	0.13	5.11	9.15	0.28	99.90		0.232	0.753	0.015
A2S25	61.65	24.38	0.00	5.32	8.99	0.32	100.66		0.242	0.741	0.017
A2S26	60.53	24.51	0.03	5.27	9.13	0.31	99.78		0.238	0.746	0.017
A2S27	60.95	24.21	0.10	5.27	8.87	0.33	99.72	2	0.243	0.739	0.018
A2S28	60.33	24.11	0.00	5.00	8.97	0.26	98.67		0.232	0.754	0.014
A2S29	60.06	23.96	0.04	5.26	8.85	0.33	98.50		0.243	0.739	0.018
A2S31	60.60	24.03	0.09	5.17	9.16	0.28	99.33		0.234	0.751	0.015
A2S32	61.51	24.27	0.06	5.23	9.05	0.35	100.47		0.237	0.744	0.019
A2S33	60.96	23.91	0.00	5.01	9.14	0.35	99.37		0.228	0.753	0.019
A3S36	62.02	24.53	0.02	5.39	8.45	0.27	100.68		0.257	0.728	0.015
A3S37	61.84	24.24	0.04	5.22	8.51	0.47	100.30	2	0.247	0.727	0.026
A3S38	61.37	24.19	0.05	5.33	8.47	0.40	99.81		0.252	0.725	0.023
A3S39	62.15	24.62	0.14	5.27	8.64	0.48	101.30		0.245	0.728	0.027
A3S40	60.81	24.46	0.00	5.29	8.70	0.28	99.54		0.248	0.737	0.016
A3S41	60.71	24.03	0.07	5.45	8.56	0.39	99.21		0.255	0.724	0.022
A3S42	61.02	24.40	0.00	5.41	8.74	0.28	99.85		0.251	0.734	0.015

A3S43	60.73	24.28	0.00	5.34	8.73	0.33	99.41	0.248	0.734	0.018
A3S44	61.58	24.19	0.00	5.27	8.54	0.34	99.92	0.249	0.731	0.019
A3S45	60.67	23.99	0.08	5.37	8.64	0.32	99.07	0.251	0.731	0.018
A3S46	60.56	24.48	0.01	5.28	8.65	0.29	99.27	0.248	0.736	0.016
A3S47	61.23	24.35	0.09	5.25	8.31	0.49	99.72	0.252	0.721	0.028
A3S48	60.29	24.23	0.12	5.25	8.34	0.47	98.70	0.251	0.722	0.027
A3S49	59.39	23.97	0.00	5.16	8.57	0.37	97.46	0.244	0.735	0.021
A3S50	60.27	23.95	0.09	5.31	8.72	0.54	98.88	0.244	0.726	0.030
A4S18	61.39	24.58	0.00	5.30	8.70	0.49	100.46	0.245	0.728	0.027
A4S19	61.16	24.38	0.06	5.37	8.61	0.39	99.97	0.251	0.728	0.022
A4S20	61.26	24.34	0.03	5.47	8.51	0.33	99.94	0.257	0.724	0.018
A4S21	61.31	24.19	0.08	5.31	8.35	0.37	99.61	0.255	0.724	0.021
A4S22	61.92	24.57	0.00	5.62	8.75	0.34	101.20	0.257	0.724	0.019
A4S23	61.67	24.43	0.05	5.03	8.66	0.71	100.55	0.233	0.727	0.039
A4S24	61.58	24.67	0.12	5.27	8.51	0.48	100.63	0.248	0.725	0.027
A4S25	60.42	24.00	0.03	5.64	8.49	0.19	98.77	0.266	0.724	0.011
A4S26	61.24	24.12	0.18	5.19	8.36	0.41	99.50	0.249	0.727	0.023
A4S27	61.05	24.10	0.09	4.58	8.82	0.48	99.12	0.217	0.756	0.027

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	62.03	24.35	0.08	5.30	8.61	0.34	100.70	0.249	0.732	0.019
	std	0.68	0.18	0.07	0.09	0.14	0.04	0.91	0.003	0.004	0.003
AREA 2	mean	60.97	24.27	0.06	5.24	8.91	0.33	99.78	0.241	0.741	0.018
	std	0.55	0.18	0.05	0.09	0.16	0.06	0.74	0.005	0.007	0.003
AREA 3	mean	60.98	24.26	0.05	5.31	8.57	0.38	99.54	0.249	0.729	0.021
	std	0.74	0.21	0.05	0.08	0.14	0.09	0.89	0.004	0.005	0.005
AREA 4	mean	61.41	24.36	0.06	5.40	8.54	0.38	100.01	0.253	0.726	0.021
	std	0.26	0.24	0.06	0.17	0.15	0.10	0.75	0.007	0.002	0.005

X38#2b GARNETS X Mg versus X Fe

(Area/table: 1/* 2/* 3/+)

X38#2b BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/* 3/+)

X38#2b PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/* 3/+)

X38#2b

GARNET ANALYSES

(weight percent; precision +/-2%)

	(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
AlS1	25	38.20	0.05	20.90	0.00	0.00	33.70	1.15	5.13	1.22	0.00	100.37	P	0.740	0.201	0.026	0.034
AlS2	115	38.19	0.05	20.71	0.05	0.23	33.60	1.19	5.16	1.26	0.03	100.47	P	0.737	0.202	0.026	0.035
AlS3	100	37.78	0.05	20.98	0.00	0.88	33.18	1.05	5.26	1.23	0.01	100.42		0.734	0.207	0.024	0.035
AlS4	300	37.60	0.01	21.02	0.03	0.93	32.87	0.96	5.28	1.29	0.02	100.01	C	0.732	0.210	0.022	0.037
AlS5	15	37.60	0.00	20.78	0.03	0.72	32.31	1.08	5.51	1.34	0.00	99.37	P	0.719	0.218	0.024	0.038
AlS6	115	37.81	0.08	20.59	0.02	0.18	32.99	1.10	5.33	1.26	0.01	99.37	2/P	0.730	0.210	0.025	0.036
AlS7	185	37.85	0.01	20.69	0.06	0.27	32.76	1.12	5.47	1.27	0.00	99.50	C	0.724	0.215	0.025	0.036
AlS8	20	37.54	0.00	20.76	0.01	1.32	32.39	1.17	5.41	1.27	0.01	99.88	P	0.722	0.215	0.026	0.036
AlS9	400	38.48	0.02	20.61	0.05	0.61	33.17	1.02	5.62	1.29	0.04	100.91	C	0.723	0.218	0.023	0.036
AlS10	10	37.86	0.00	20.44	0.00	0.37	33.62	1.11	5.01	1.26	0.00	99.67	P	0.742	0.197	0.025	0.036
AlS11	35	37.51	0.00	20.60	0.00	0.22	32.96	0.95	5.21	1.26	0.00	98.71	P	0.735	0.207	0.021	0.036
AlS12	60	38.45	0.00	20.89	0.00	0.25	33.57	1.05	5.37	1.36	0.01	100.95	P	0.731	0.208	0.023	0.038
AlS13	10	37.96	0.02	21.05	0.00	0.40	35.24	1.05	4.15	1.18	0.05	101.10	Ct	0.723	0.219	0.022	0.036
AlS14	375	38.36	0.03	21.17	0.12	0.79	33.21	1.02	5.63	1.28	0.00	101.61	C	0.723	0.219	0.022	0.036
AlS16	10	38.39	0.00	20.89	0.00	0.00	34.79	0.94	4.84	1.13	0.00	100.98	Ct	0.739	0.188	0.021	0.032
AlS17	35	38.29	0.02	21.03	0.00	0.53	33.25	1.07	5.52	1.27	0.00	100.98	P	0.726	0.215	0.024	0.036
AlS18	65	38.51	0.00	21.15	0.01	0.33	34.06	0.98	5.27	1.27	0.00	101.58	P	0.739	0.204	0.022	0.035
AlS19	30	37.92	0.00	20.31	0.00	0.00	33.18	1.05	5.09	1.34	0.00	98.89	P	0.737	0.201	0.024	0.038
AlS20	40	38.57	0.14	20.68	0.10	0.00	33.61	1.08	5.05	1.34	0.02	100.59	P	0.740	0.198	0.024	0.038
A2S1	10	37.81	0.15	21.01	0.08	0.68	33.62	1.03	5.04	1.21	0.05	100.68	Ct	0.744	0.199	0.023	0.034
A2S2	30	37.77	0.07	20.88	0.10	0.40	32.88	0.96	5.36	1.32	0.04	99.78	Ct	0.729	0.212	0.022	0.038
A2S3	20	37.85	0.12	20.65	0.06	0.50	33.07	1.05	5.34	1.26	0.03	99.93	Ct	0.731	0.210	0.023	0.036
A2S4	20	37.98	0.13	20.85	0.08	0.68	32.96	0.96	5.56	1.31	0.00	100.51	Ct	0.724	0.218	0.021	0.037
A2S5	50	37.78	0.02	21.00	0.00	0.90	33.47	0.97	5.05	1.25	0.04	100.48	Ct	0.743	0.200	0.022	0.036
A2S6	40	38.38	0.04	21.34	0.02	0.92	32.74	0.95	5.82	1.35	0.04	101.60	3/P	0.715	0.226	0.021	0.038
A2S7	80	38.43	0.05	21.17	0.05	0.40	32.37	1.00	5.99	1.43	0.04	100.93	2/P	0.705	0.233	0.022	0.040
A2S8	0	38.44	0.05	20.93	0.05	1.45	31.48	0.96	6.33	1.70	0.03	101.42	u	0.686	0.246	0.021	0.047
A2S9	30	37.44	0.10	20.67	0.02	0.47	32.81	1.03	5.27	1.24	0.00	99.05	u	0.732	0.209	0.023	0.035
A2S10	110	37.84	0.08	20.65	0.10	0.12	32.94	1.00	5.46	1.23	0.01	99.43	P	0.728	0.215	0.022	0.035
A2S11	250	38.42	0.00	21.20	0.00	0.00	33.21	0.91	5.70	1.21	0.00	100.65	P	0.724	0.222	0.020	0.034
A2S12	380	38.71	0.01	21.13	0.03	0.00	33.36	0.92	5.63	1.38	0.00	101.17	2/C	0.724	0.218	0.020	0.038
A2S13	500	37.75	0.13	21.13	0.13	0.98	32.21	1.08	5.59	1.42	0.06	100.48	C	0.714	0.221	0.024	0.040
A2S14	550	38.67	0.05	20.95	0.07	0.43	33.09	0.96	5.77	1.35	0.04	101.38	2/C	0.718	0.223	0.021	0.038
A2S15	170	38.65	0.09	21.31	0.07	0.15	33.30	0.98	5.75	1.32	0.03	101.65	P	0.720	0.222	0.021	0.037
A2S16	200	38.01	0.04	20.93	0.00	0.33	32.87	0.97	5.60	1.26	0.01	100.02	P	0.723	0.220	0.022	0.036
A3S1	20	38.22	0.12	20.74	0.05	0.94	33.87	1.06	4.97	1.36	0.09	101.42	Ct	0.744	0.194	0.024	0.038
A3S2	30	37.66	0.10	20.28	0.01	0.28	33.45	0.98	4.93	1.30	0.02	99.01	2/Ct	0.745	0.196	0.022	0.037
A3S3	302	37.34	0.00	20.30	0.00	0.79	32.13	0.86	5.61	1.27	0.00	98.30	P	0.720	0.224	0.020	0.036
A3S4	80	38.42	0.02	21.03	0.00	0.95	32.69	0.99	5.95	1.30	0.00	101.35	2/P	0.711	0.231	0.022	0.036
A3S5	180	38.02	0.00	20.76	0.05	0.70	32.41	0.86	5.94	1.22	0.01	99.97	P	0.713	0.233	0.019	0.034
A3S6	150	38.08	0.01	20.84	0.05	0.08	33.24	1.00	5.49	1.13	0.02	99.94	P	0.731	0.215	0.022	0.032
A3S7	30	37.81	0.00	20.53	0.00	0.67	33.04	0.90	5.44	1.20	0.00	99.59	P	0.731	0.215	0.020	0.034
A3S8	100	38.20	0.00	20.85	0.00	0.28	33.18	0.90	5.56	1.30	0.00	100.27	P	0.727	0.217	0.020	0.036
A3S9	190	37.98	0.08	20.77	0.11	0.80	32.19	1.03	5.75	1.40	0.07	100.18	P	0.711	0.226	0.023	0.040
A3S10	250	37.54	0.03	20.45	0.10	1.64	32.06	1.07	5.62	1.28	0.00	99.79	P	0.716	0.224	0.024	0.037
A3S11	270	38.05	0.00	20.73	0.01	0.46	33.11	0.99	5.50	1.24	0.00	100.09	P	0.728	0.215	0.022	0.035

(weight percent; precision +/-2%)

BIOTITE ANALYSES

X38#2b

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ⁶ (+/-8%)	X Mn (+/-8%)
A1S21	34.74	4.40	16.24	0.05	16.20	0.00	10.86	0.19	0.21	9.29	92.18	u	0.454	0.380	0.093	0.074	0.000
A1S22	36.54	4.54	17.51	0.15	16.17	0.02	11.12	0.18	0.11	9.56	95.90		0.447	0.365	0.092	0.095	0.000
A1S23	36.71	4.74	16.97	0.00	16.63	0.07	11.18	0.18	0.21	9.68	96.37		0.448	0.374	0.096	0.080	0.002
A1S24	36.67	4.68	17.40	0.09	16.35	0.01	11.09	0.19	0.12	9.61	96.21		0.445	0.368	0.095	0.091	0.000
A1S25	36.40	4.70	17.41	0.05	16.34	0.01	11.15	0.24	0.01	9.80	96.11		0.448	0.368	0.095	0.088	0.000
A1S26	36.35	4.75	17.53	0.07	16.33	0.04	11.18	0.14	0.22	9.81	96.42		0.448	0.368	0.096	0.087	0.001
A1S27	36.53	4.77	17.26	0.01	16.46	0.03	10.74	0.10	0.22	9.70	95.82	2	0.435	0.374	0.098	0.092	0.001
A1S28	36.14	4.96	17.40	0.15	16.84	0.01	10.57	0.12	0.00	9.66	95.85		0.428	0.382	0.101	0.089	0.000
A1S29	36.08	4.87	17.25	0.02	16.98	0.09	10.95	0.13	0.19	9.72	96.28		0.439	0.382	0.099	0.078	0.002
A1S30	36.55	4.54	17.60	0.05	16.64	0.03	11.33	0.12	0.00	9.78	96.64		0.449	0.370	0.091	0.090	0.001
A1S31	36.48	4.78	17.48	0.07	16.62	0.00	10.94	0.13	0.00	9.81	96.31		0.439	0.374	0.097	0.090	0.000
A1S32	36.74	4.83	17.47	0.00	16.68	0.08	11.05	0.15	0.25	9.66	96.91		0.440	0.373	0.097	0.087	0.002
A1S33	36.32	4.73	17.30	0.07	16.43	0.03	10.73	0.17	0.00	9.61	95.39		0.435	0.374	0.097	0.094	0.001
A1S34	36.53	4.84	17.35	0.00	17.20	0.00	10.71	0.13	0.00	9.57	96.33		0.428	0.386	0.098	0.089	0.000
A1S35	37.32	4.26	18.04	0.09	12.70	0.07	14.53	0.21	0.00	9.85	97.07	ln	0.557	0.273	0.082	0.086	0.002
A1S36	36.33	4.70	17.45	0.01	16.79	0.05	10.78	0.13	0.00	9.90	96.14		0.434	0.379	0.095	0.091	0.001
A1S37	37.17	4.84	17.25	0.02	16.43	0.02	10.32	0.09	0.00	9.62	95.76	u	0.420	0.375	0.099	0.105	0.000
A1S38	36.66	5.03	17.21	0.05	16.79	0.00	10.86	0.12	0.00	9.73	96.45		0.436	0.378	0.102	0.085	0.000
A1S39	34.85	1.67	18.91	0.02	19.27	0.06	11.80	0.08	0.00	4.69	91.35	u	0.436	0.400	0.031	0.132	0.001
A2S17	37.47	3.09	17.98	0.04	13.34	0.07	13.99	0.21	0.25	9.59	96.03	Ct	0.542	0.290	0.060	0.106	0.002
A2S18	36.81	4.46	17.55	0.09	15.70	0.05	11.62	0.16	0.20	9.65	96.29		0.464	0.352	0.090	0.094	0.001
A2S19	37.38	3.88	18.58	0.09	14.75	0.17	13.22	0.14	0.00	9.83	98.04	Ct	0.504	0.316	0.075	0.101	0.004
A2S20	36.82	4.79	17.68	0.00	16.39	0.02	11.34	0.25	0.46	9.64	97.39		0.451	0.366	0.096	0.087	0.000
A2S21	37.20	4.56	17.66	0.12	16.89	0.02	11.62	0.20	0.05	9.71	98.03		0.454	0.370	0.090	0.086	0.000
A2S22	35.66	4.40	17.48	0.02	15.86	0.04	11.38	0.16	0.42	9.49	94.91		0.460	0.260	0.090	0.089	0.001
A2S23	36.27	4.53	16.74	0.05	16.35	0.01	11.10	0.08	0.00	9.61	94.74		0.450	0.372	0.093	0.085	0.000
A2S24	35.93	4.35	17.41	0.00	16.05	0.00	11.28	0.17	0.25	9.57	95.01		0.456	0.364	0.089	0.092	0.000
A2S25	35.53	4.44	16.67	0.06	15.69	0.11	11.29	0.15	0.00	9.63	93.57		0.463	0.361	0.092	0.081	0.003
A2S26	35.39	4.41	16.90	0.04	15.69	0.00	11.06	0.20	0.34	9.43	93.46		0.457	0.364	0.092	0.087	0.000
A2S27	35.44	4.65	16.96	0.00	15.87	0.05	10.68	0.20	0.20	9.60	93.65		0.443	0.369	0.097	0.089	0.001
A2S28	36.08	4.30	17.14	0.05	15.36	0.00	11.62	0.19	0.36	9.35	94.45		0.472	0.350	0.088	0.090	0.000
A2S29	35.19	4.34	16.40	0.06	15.73	0.00	11.16	0.07	0.00	9.55	92.50		0.462	0.366	0.091	0.081	0.000
A2S30	35.69	4.45	17.09	0.09	16.18	0.00	11.56	0.15	0.38	9.54	95.13		0.466	0.366	0.091	0.077	0.000
A2S31	36.21	3.02	17.63	0.00	12.54	0.00	14.03	0.13	0.00	9.51	93.07	Ct	0.555	0.278	0.060	0.106	0.000
A3S12	35.39	3.55	16.90	0.00	14.11	0.00	12.71	0.19	0.00	9.25	92.10		0.515	0.321	0.073	0.092	0.000
A3S13	36.55	3.62	17.16	0.01	14.21	0.00	12.70	0.19	0.21	9.37	94.02		0.509	0.320	0.073	0.098	0.000
A3S14	35.50	3.86	17.15	0.02	14.58	0.09	12.50	0.15	0.00	9.54	93.99		0.503	0.329	0.078	0.088	0.002
A3S15	36.36	3.75	17.29	0.11	14.31	0.00	13.35	0.26	0.26	9.63	95.32	u	0.527	0.317	0.075	0.081	0.000
A3S16	36.57	3.74	17.50	0.00	14.02	0.00	12.80	0.23	0.11	9.53	94.50	u	0.510	0.314	0.075	0.101	0.000
A3S17	35.58	4.45	16.75	0.03	14.92	0.08	12.00	0.22	0.13	9.55	93.71		0.489	0.341	0.091	0.077	0.002
A3S18	36.51	4.40	17.16	0.11	14.89	0.01	12.11	0.13	0.13	9.63	95.08		0.487	0.336	0.089	0.088	0.000
A3S19	37.17	3.78	17.47	0.03	14.92	0.07	12.65	0.21	0.13	9.57	96.00		0.498	0.329	0.075	0.097	0.002
A3S20	36.71	4.03	17.35	0.05	15.55	0.09	11.83	0.18	0.29	9.52	95.60		0.473	0.349	0.081	0.095	0.002
A3S21	36.20	4.08	17.29	0.00	14.69	0.02	11.79	0.21	0.28	9.68	94.24		0.481	0.336	0.084	0.099	0.000
A3S22	35.61	4.35	17.28	0.08	15.66	0.11	11.28	0.17	0.00	9.60	94.14	u	0.459	0.358	0.089	0.092	0.003
A3S23	36.16	4.33	17.43	0.05	15.92	0.08	11.52	0.14	0.07	9.75	95.65	u	0.461	0.358	0.092	0.087	0.002
A3S24	35.66	4.18	17.26	0.03	15.22	0.01	11.24	0.21	0.00	9.49	93.30	u	0.461	0.351	0.087	0.101	0.000

A3S25	35.89	4.15	17.40	0.00	15.10	0.06	11.51	0.10	0.00	9.46	93.67	u	0.467	0.344	0.085	0.102	0.001
A3S26	35.92	4.36	17.68	0.00	13.80	0.03	11.54	0.20	0.00	9.02	92.55	u	0.474	0.318	0.090	0.117	0.001
A3S27	36.27	4.47	17.01	0.04	15.15	0.03	12.19	0.16	0.01	9.45	94.78		0.487	0.340	0.090	0.082	0.001
A3S28	35.83	4.37	16.93	0.04	14.36	0.07	12.04	0.14	0.38	9.21	93.37		0.492	0.329	0.090	0.088	0.002
A3S29	35.58	4.24	16.96	0.02	14.56	0.07	11.91	0.17	0.00	9.32	92.83		0.486	0.334	0.087	0.091	0.002
A3S30	35.67	4.25	16.91	0.03	14.10	0.02	12.16	0.19	0.27	9.44	93.04		0.499	0.325	0.088	0.088	0.000
A3S31	34.33	3.95	16.52	0.03	13.93	0.01	11.39	0.20	0.39	9.07	89.82		0.486	0.334	0.085	0.095	0.000

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	mean	36.47	4.76	17.37	0.05	16.62	0.03	10.96	0.15	0.09	9.71	96.21	15	0.440	0.374	0.097	0.088	0.001
	std	0.20	0.13	0.16	0.05	0.28	0.03	0.22	0.04	0.10	0.10	0.37		0.007	0.006	0.003	0.005	0.001
AREA 2	mean	36.00	4.47	17.14	0.05	15.98	0.03	11.31	0.17	0.22	9.56	94.93	12	0.458	0.363	0.091	0.086	0.001
	std	0.65	0.14	0.42	0.04	0.42	0.03	0.28	0.05	0.17	0.10	1.63		0.008	0.007	0.003	0.005	0.001
AREA 3	mean	35.95	4.08	17.04	0.03	14.61	0.04	12.15	0.18	0.17	9.43	93.69	13	0.493	0.332	0.084	0.091	0.001
	std	0.73	0.31	0.26	0.03	0.47	0.04	0.40	0.03	0.14	0.18	1.62		0.012	0.008	0.007	0.006	0.001

X38#2b	PLAGIOCLASE ANALYSES										(weight percent; precision +/- 2%)			
	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-5%)			
A1S40	61.89	24.60	0.06	5.13	8.85	0.23	100.76	3	0.240	0.748	0.013			
A1S41	60.89	24.38	0.09	5.03	8.58	0.26	99.23		0.241	0.744	0.015			
A1S42	62.03	24.59	0.04	5.11	8.86	0.19	100.82		0.239	0.750	0.011			
A1S43	61.20	24.22	0.04	5.06	9.11	0.24	99.87	3	0.232	0.755	0.013			
A1S44	61.83	24.11	0.06	4.93	9.19	0.21	100.33	2	0.226	0.762	0.011			
A1S45	60.72	24.45	0.08	5.05	9.18	0.21	99.69		0.230	0.758	0.011			
A1S46	60.95	23.85	0.17	4.97	9.17	0.21	99.32		0.228	0.761	0.011			
A1S47	61.21	24.02	0.10	4.91	9.02	0.19	99.45	2	0.229	0.761	0.011			
A1S48	60.03	24.11	0.06	4.95	8.70	0.27	98.12		0.236	0.749	0.015			
A1S49	60.58	24.11	0.09	4.78	8.98	0.19	98.73		0.225	0.764	0.011			
A1S50	61.07	23.95	0.25	4.92	8.95	0.24	99.38		0.230	0.757	0.013			
A1S51	61.13	24.17	0.08	5.09	9.04	0.22	99.73	2	0.234	0.753	0.012			
A1S52	60.36	24.06	0.06	4.99	8.90	0.26	98.63	2	0.233	0.752	0.014			
A1S53	61.49	24.08	0.05	5.10	8.90	0.25	100.47		0.237	0.749	0.014			
A1S54	61.39	23.82	0.06	4.88	8.82	0.22	99.19		0.231	0.756	0.012			
A1S55	61.36	24.39	0.14	4.88	8.69	0.13	99.59		0.235	0.757	0.007			
A1S56	61.78	24.45	0.06	5.00	9.26	0.25	100.80		0.227	0.760	0.013			
A1S57	61.65	24.53	0.01	5.18	8.88	0.31	100.56		0.240	0.743	0.017			
A1S58	61.93	24.73	0.12	5.07	8.89	0.21	100.95		0.237	0.751	0.012			
A1S59	61.02	24.18	0.09	4.85	8.77	0.18	99.16	2	0.232	0.758	0.010			
A1S60	61.53	24.37	0.03	5.06	9.03	0.20	100.22		0.234	0.755	0.011			
A1S63	62.65	24.83	0.06	4.91	9.49	0.31	102.25	u	0.219	0.765	0.016			
A1S64	62.14	24.63	0.01	5.18	9.17	0.27	101.47		0.234	0.750	0.015			
A1S65	62.85	24.85	0.11	5.25	9.06	0.26	102.38		0.239	0.747	0.014			
A1S77	62.16	24.49	0.04	5.00	8.95	0.26	100.92		0.232	0.753	0.014			
A1S78	61.74	24.03	0.00	5.03	9.05	0.11	99.96		0.234	0.760	0.006			
A1S80	59.60	26.28	0.07	4.95	8.79	0.25	100.06		0.234	0.750	0.014			
A1S81	61.15	24.38	0.00	5.05	8.82	0.16	99.56		0.238	0.753	0.009			
A1S82	61.47	24.22	0.12	4.96	9.12	0.22	100.11		0.228	0.760	0.012			
A2S32	61.52	24.40	0.14	4.97	9.00	0.15	100.18	3	0.232	0.760	0.008			
A2S14	61.96	24.64	0.00	4.86	9.14	0.19	100.79		0.225	0.765	0.010			
A2S35	61.69	24.45	0.12	5.01	9.27	0.23	100.77		0.227	0.760	0.012			
A2S37	61.58	24.61	0.07	5.10	9.22	0.28	100.86		0.231	0.754	0.015			
A2S38	61.54	24.59	0.03	5.13	9.18	0.25	100.72		0.233	0.754	0.014			
A2S39	62.05	24.10	0.10	4.84	9.32	0.19	100.60		0.221	0.769	0.010			
A2S40	61.33	24.51	0.02	5.13	9.19	0.25	100.43		0.233	0.754	0.013			
A2S41	61.67	24.38	0.06	5.05	9.12	0.23	100.51		0.231	0.756	0.013			
A1S42	61.83	24.66	0.05	5.02	9.23	0.24	101.03		0.228	0.759	0.013			
A2S43	61.30	24.38	0.15	5.07	8.89	0.22	100.01		0.237	0.751	0.012			
A2S44	60.78	24.00	0.05	4.99	9.26	0.22	99.30		0.227	0.761	0.012			
A2S45	61.54	24.53	0.08	5.17	8.96	0.22	100.50		0.239	0.749	0.012			
A2S46	61.95	24.37	0.11	5.06	8.91	0.35	100.75		0.234	0.746	0.019			
A2S47	61.82	24.57	0.08	5.06	9.30	0.34	101.17		0.227	0.755	0.018			
A2S48	61.27	24.53	0.06	5.10	8.93	0.26	100.17		0.236	0.749	0.014			
A2S49	61.35	24.67	0.17	5.10	9.12	0.21	100.62		0.233	0.749	0.011			
A2S50	61.05	24.35	0.08	5.12	8.67	0.23	99.50		0.243	0.744	0.013			

A3S31	62.37	24.67	0.11	5.27	8.50	0.20	101.32	0.252	0.736	0.011
A3S32	62.14	24.11	0.03	5.21	8.53	0.23	100.25	0.249	0.738	0.013
A3S33	62.38	24.36	0.04	5.35	8.34	0.28	100.75	0.258	0.726	0.016
A3S34	62.54	25.00	0.16	5.27	8.52	0.22	101.71	0.252	0.736	0.013
A3S35	61.58	24.39	0.12	5.21	8.54	0.25	100.09	0.249	0.737	0.014
A3S36	62.36	24.61	0.08	5.28	8.51	0.23	101.07	0.252	0.735	0.013
A3S37	62.02	24.55	0.04	5.26	8.15	0.24	100.26	0.259	0.727	0.014
A3S38	61.82	24.26	0.06	5.08	8.08	0.25	99.55	0.254	0.731	0.015
A3S39	62.51	24.66	0.02	5.37	8.17	0.18	100.91	0.264	0.726	0.011
A3S40	62.34	24.12	0.05	5.17	8.50	0.17	100.35	0.249	0.741	0.010
A3S41	61.34	24.62	0.01	5.17	8.76	0.13	100.04	0.244	0.748	0.007
A3S43	62.75	24.59	0.02	5.06	9.20	0.21	101.94	0.230	0.757	0.011
A3S44	63.03	24.74	0.05	5.37	9.16	0.18	102.61	0.242	0.747	0.010
A3S46	61.81	24.64	0.00	5.48	8.96	0.21	101.11	0.250	0.739	0.011
A3S49	61.80	24.32	0.06	5.02	9.14	0.15	100.49	0.231	0.761	0.008
A3S51	61.43	24.32	0.11	5.13	8.74	0.20	99.99	0.242	0.746	0.011

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1										
mean	61.33	24.38	0.07	5.01	8.95	0.22	99.98	0.233	0.754	0.012
std	0.69	0.46	0.05	0.11	0.17	0.04	0.92	0.004	0.006	0.002
AREA 2										
mean	61.54	24.46	0.08	5.05	9.10	0.24	100.47	0.232	0.755	0.013
std	0.34	0.19	0.05	0.09	0.18	0.05	0.50	0.006	0.007	0.003
AREA 3										
mean	62.05	24.46	0.07	5.22	8.47	0.22	100.49	0.251	0.737	0.013
std	0.44	0.26	0.05	0.08	0.21	0.04	0.65	0.005	0.007	0.002

X429a GARNET ZONING

X429a GARNETS X Mg versus X Fe

(Area/table: 1/* 2/* 3/+ 4/o)

X429a BIOTITES X Mg versus X Fe

(Area/label: 1/* 2/* 3/+)

X429a PLAGIOCLASES X Na versus X Ca

(Area/label: 1/* 2/* 3/+)

X429A GARNET ANALYSES (weight percent; precision +/-2%)

	(μm)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
A1S1	20	37.98	0.01	20.61	0.00	1.48	31.01	1.51	6.26	1.24	0.04	100.14	R	0.685	0.246	0.034	0.035
A1S2	115	38.35	0.08	21.01	0.05	1.76	30.07	1.40	7.19	1.26	0.01	101.18	P	0.655	0.279	0.031	0.035
A1S3	260	38.07	0.00	20.89	0.00	1.72	29.56	1.53	7.20	1.25	0.00	100.22	P	0.649	0.282	0.034	0.035
A1S4	175	38.63	0.08	21.30	0.05	0.95	29.91	1.47	7.47	1.20	0.00	101.06	P	0.647	0.288	0.032	0.033
A1S5	235	38.10	0.10	20.74	0.08	0.71	29.78	1.55	7.03	1.24	0.05	99.38	P	0.655	0.275	0.035	0.035
A1S6	55	38.61	0.00	21.06	0.08	1.13	32.04	1.49	6.24	1.18	0.00	101.83	R	0.694	0.241	0.033	0.033
A1S7	85	37.49	0.03	20.52	0.01	1.39	29.67	1.49	6.72	1.30	0.01	98.63		0.662	0.267	0.034	0.037
A1S8	10	38.80	0.11	20.77	0.00	0.49	31.02	1.44	7.00	1.23	0.00	100.86		0.667	0.268	0.031	0.034
A1S9	40	38.23	0.02	20.54	0.00	1.77	30.03	1.61	6.92	1.19	0.06	100.37		0.660	0.271	0.036	0.033
A1S10	115	38.46	0.00	21.19	0.03	0.82	30.64	1.42	6.98	1.18	0.00	100.72		0.666	0.270	0.031	0.033
A1S11	200	38.90	0.08	21.13	0.00	1.55	30.34	1.64	7.30	1.22	0.00	102.16	P	0.651	0.279	0.036	0.034
A1S12	15	37.63	0.12	20.60	0.00	1.43	30.36	1.62	6.39	1.21	0.04	99.40	R	0.676	0.253	0.037	0.034
A1S13	75	37.80	0.12	20.48	0.07	1.56	29.94	1.59	6.90	1.14	0.00	99.60		0.661	0.271	0.036	0.032
A1S14	130	37.51	0.07	20.55	0.06	2.43	29.04	1.51	7.19	1.17	0.02	99.55	P	0.647	0.285	0.034	0.033
A1S15	215	37.78	0.08	21.00	0.05	2.10	29.04	1.37	7.35	1.21	0.05	100.03	P	0.644	0.291	0.031	0.034
A1S16	10	38.82	0.03	20.71	0.00	0.17	30.04	1.42	6.70	1.34	0.02	99.25		0.666	0.265	0.032	0.038
A1S17	40	38.90	0.06	20.98	0.07	1.08	30.79	1.30	7.12	1.28	0.05	101.63		0.663	0.273	0.028	0.035
A1S18	80	38.50	0.04	20.74	0.05	0.16	31.77	1.30	6.64	1.14	0.00	100.45	R	0.683	0.253	0.031	0.031
A1S19	115	38.18	0.06	20.54	0.06	0.00	31.74	1.41	6.97	1.23	0.09	100.28	R	0.673	0.263	0.030	0.033
A2S1	10	38.95	0.06	20.69	0.00	0.42	30.59	1.50	7.13	1.22	0.08	100.64	P	0.660	0.274	0.033	0.034
A2S2	40	38.53	0.05	20.53	0.06	0.47	30.14	1.42	7.22	1.18	0.04	99.64	P	0.656	0.280	0.031	0.033
A2S3	40	38.78	0.01	20.61	0.00	0.15	30.28	1.42	7.25	1.23	0.05	99.78	P	0.655	0.280	0.031	0.034
A2S4	80	38.62	0.05	20.63	0.07	1.48	29.86	1.44	7.45	1.19	0.03	100.82	P	0.647	0.288	0.032	0.033
A2S5	135	38.53	0.04	20.15	0.00	1.26	30.23	1.39	7.32	1.11	0.00	100.03	P	0.656	0.283	0.031	0.031
A2S6	15	38.81	0.00	20.68	0.00	0.00	29.88	1.36	7.44	1.21	0.03	99.41	P	0.649	0.288	0.030	0.034
A2S7	70	38.33	0.00	20.66	0.00	0.59	29.38	1.47	7.44	1.19	0.04	99.10	P	0.644	0.290	0.033	0.033
A2S8	10	38.67	0.07	21.03	0.00	0.61	29.50	1.40	7.62	1.28	0.06	100.24	P	0.639	0.294	0.031	0.036
A2S9	15	38.74	0.06	20.79	0.02	0.84	29.87	1.44	7.50	1.22	0.04	100.52	P	0.646	0.289	0.032	0.034
A2S10	25	38.29	0.06	20.69	0.06	1.19	29.79	1.44	7.17	1.25	0.08	100.02	P	0.653	0.280	0.032	0.035
A1S11	75	38.62	0.00	20.84	0.03	0.61	29.65	1.48	7.43	1.31	0.03	100.00	P	0.644	0.287	0.033	0.036
A2S12	150	38.14	0.13	20.47	0.04	0.75	31.05	1.38	6.44	1.32	0.04	99.76		0.681	0.252	0.031	0.037
A2S13	10	38.04	0.03	20.43	0.08	1.18	30.55	1.35	6.63	1.16	0.09	99.54	Ct	0.676	0.261	0.030	0.033
A2S14	90	38.45	0.01	20.59	0.11	0.56	30.97	1.40	6.80	1.13	0.00	100.02	Ct	0.674	0.264	0.031	0.032
A2S15	100	38.46	0.00	20.47	0.03	0.08	30.85	1.23	6.92	1.20	0.02	99.26	Ct	0.671	0.268	0.027	0.033
A2S16	100	38.75	0.02	20.52	0.05	0.43	30.89	1.45	6.97	1.21	0.01	100.30	Ct	0.667	0.268	0.032	0.033
A2S17	60	38.31	0.06	20.36	0.00	0.00	31.15	1.24	6.55	1.14	0.00	98.81	Ct	0.684	0.256	0.028	0.032
A2S18	50	38.18	0.00	20.49	0.05	1.36	29.86	1.52	7.15	1.15	0.01	99.77	Ct	0.655	0.279	0.034	0.032
A2S19	15	39.35	0.13	20.46	0.09	0.00	29.43	1.24	6.41	1.21	0.06	98.38	Ct	0.674	0.262	0.029	0.036
A2S20	40	38.89	0.02	20.32	0.06	0.66	29.80	1.41	7.46	1.33	0.10	100.05	P	0.645	0.288	0.031	0.037
A2S21	110	38.44	0.06	20.78	0.12	1.20	29.73	1.54	7.30	1.29	0.02	100.48	P	0.647	0.283	0.034	0.036
A2S22	50	39.07	0.02	20.64	0.03	0.00	30.03	1.49	7.47	1.23	0.00	99.98	P	0.647	0.287	0.033	0.034
A3S1	15	38.48	0.08	20.58	0.10	0.13	30.70	1.44	6.88	1.26	0.03	99.68	R	0.667	0.266	0.032	0.035
A3S2	75	38.01	0.04	20.50	0.03	1.23	29.44	1.48	7.15	1.17	0.09	99.14	P	0.652	0.282	0.033	0.033
A3S3	165	38.48	0.05	20.68	0.00	0.74	30.16	1.42	7.22	1.20	0.01	99.96	P	0.656	0.280	0.031	0.033
A3S4	210	38.44	0.04	20.48	0.03	0.18	30.15	1.45	7.15	1.20	0.03	99.15	P	0.657	0.278	0.032	0.033
A3S5	250	37.99	0.00	20.46	0.00	0.65	29.86	1.36	7.12	1.18	0.00	98.62	P	0.657	0.279	0.030	0.033
A3S6	250	38.61	0.02	20.55	0.03	1.10	29.81	1.42	7.49	1.21	0.01	100.25	P	0.646	0.289	0.031	0.034

A3S7	20	38.96	0.01	20.73	0.02	0.60	30.17	1.44	7.43	1.22	0.01	100.59	P	0.650	0.285	0.031	0.034
A3S8	80	38.53	0.04	21.03	0.00	0.99	29.82	1.43	7.43	1.19	0.02	100.48	P	0.648	0.288	0.031	0.033
A3S9	110	38.73	0.01	20.74	0.07	0.08	30.43	1.52	7.15	1.24	0.01	99.98	P	0.657	0.275	0.033	0.034
A3S10	15	37.95	0.13	20.81	0.08	1.19	31.34	1.54	6.17	1.23	0.01	100.45	Ct	0.689	0.242	0.034	0.035
A3S11	60	38.35	0.10	20.19	0.00	0.43	31.41	1.58	6.33	1.15	0.05	99.59	Ct	0.686	0.246	0.035	0.032
A3S12	100	38.78	0.00	20.30	0.00	0.00	31.11	1.58	6.41	1.16	0.00	99.34	Ct	0.682	0.250	0.035	0.033
A3S13	150	38.66	0.13	20.54	0.05	0.58	30.81	1.48	6.87	1.22	0.08	100.42	Ct	0.668	0.265	0.033	0.034
A3S14	160	38.74	0.07	20.46	0.00	0.10	31.24	1.43	6.78	1.20	0.02	100.04	Ct	0.675	0.261	0.031	0.033
A3S15	50	38.05	0.05	20.49	0.02	0.18	31.14	1.55	6.25	1.23	0.03	98.99	Ct	0.686	0.245	0.035	0.035
A3S16	70	38.59	0.02	20.93	0.09	1.12	30.80	1.45	6.76	1.18	0.11	101.05	Ct	0.672	0.263	0.032	0.033

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																	
rim	mean	38.18	0.05	20.71	0.04	0.84	31.38	1.49	6.50	1.20	0.03	100.42	5	0.682	0.252	0.033	0.033
	std	0.40	0.05	0.21	0.04	0.71	0.69	0.09	0.31	0.04	0.04	0.88		0.008	0.009	0.003	0.001
plateau	mean	38.19	0.07	20.95	0.04	1.60	29.68	1.50	7.25	1.22	0.02	100.51	7	0.650	0.283	0.033	0.034
	std	0.48	0.03	0.25	0.03	0.60	0.50	0.09	0.14	0.03	0.02	1.00		0.004	0.005	0.002	0.001
AREA 2																	
contact	mean	38.51	0.04	20.47	0.06	0.52	30.53	1.35	6.78	1.17	0.03	99.44	7	0.671	0.266	0.030	0.033
	std	0.44	0.05	0.07	0.04	0.56	0.64	0.12	0.26	0.03	0.03	0.68		0.009	0.007	0.002	0.001
plateau	mean	38.66	0.04	20.65	0.03	0.68	29.91	1.44	7.37	1.23	0.04	100.05	14	0.649	0.285	0.032	0.034
	std	0.23	0.03	0.21	0.04	0.47	0.32	0.05	0.14	0.06	0.03	0.48		0.006	0.005	0.001	0.002
AREA 3																	
contact	mean	38.36	0.08	20.43	0.03	0.54	31.29	1.57	6.30	1.18	0.02	99.79	3	0.686	0.246	0.035	0.033
	std	0.42	0.07	0.33	0.05	0.60	0.16	0.02	0.12	0.04	0.03	0.58		0.004	0.004	0.000	0.001
plateau	mean	38.47	0.03	20.65	0.02	0.70	29.98	1.44	7.27	1.20	0.02	99.77	8	0.653	0.282	0.032	0.034
	std	0.33	0.02	0.19	0.02	0.41	0.31	0.05	0.15	0.02	0.03	0.72		0.005	0.005	0.001	0.000

(weight percent; precision +/-2%)

X429a	BIOTITE ANALYSES																		
	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ^{iv} (+/-8%)	X Mn (+/-8%)		
A1S21	36.51	4.78	16.82	0.01	15.12	0.00	12.66	0.17	0.03	9.55	95.65	2	0.500	0.335	0.095	0.069	0.000		
A1S22	36.94	4.99	16.42	0.00	15.69	0.03	13.12	0.10	0.00	9.55	96.98	2	0.509	0.342	0.098	0.051	0.001		
A1S23	37.72	5.03	16.88	0.02	15.44	0.04	13.26	0.15	0.04	9.64	98.22		0.509	0.332	0.097	0.061	0.001		
A1S24	36.35	4.71	16.06	0.00	15.09	0.00	13.04	0.04	0.00	9.19	94.48		0.515	0.334	0.094	0.057	0.000		
A1S25	36.56	4.31	16.51	0.00	14.96	0.00	12.72	0.13	0.31	9.19	94.69		0.506	0.334	0.087	0.073	0.000		
A1S26	36.54	5.14	16.05	0.09	15.91	0.03	12.37	0.12	0.20	9.35	95.80		0.491	0.335	0.103	0.050	0.001		
A1S27	36.45	4.79	16.12	0.05	15.17	0.01	12.91	0.11	0.00	9.34	94.95		0.511	0.337	0.096	0.056	0.000		
A1S28	36.82	5.02	16.25	0.07	15.47	0.00	12.95	0.17	0.09	9.58	96.42		0.509	0.341	0.099	0.051	0.000		
A1S29	36.38	4.99	16.22	0.00	15.04	0.00	13.00	0.06	0.15	9.36	95.20		0.514	0.333	0.099	0.053	0.000		
A1S30	36.38	5.04	16.52	0.00	15.50	0.01	12.64	0.21	0.10	9.47	95.87		0.499	0.344	0.100	0.057	0.000		
A1S31	36.47	5.04	16.30	0.12	15.44	0.07	12.84	0.16	0.13	9.53	96.10		0.507	0.342	0.100	0.050	0.002		
A1S32	35.94	5.03	16.01	0.04	15.45	0.06	12.43	0.14	0.00	9.37	94.47		0.498	0.347	0.102	0.052	0.001		
A1S33	36.48	5.14	16.41	0.04	15.64	0.06	12.75	0.11	0.28	9.64	96.55		0.502	0.346	0.102	0.049	0.001		
A1S34	35.79	4.95	16.14	0.02	15.74	0.05	12.30	0.10	0.00	9.43	94.52		0.492	0.353	0.100	0.054	0.001		
A1S35	36.59	4.90	16.49	0.01	15.46	0.00	12.28	0.08	0.00	9.47	95.28		0.489	0.345	0.098	0.068	0.000		
A1S36	36.29	4.84	16.32	0.00	15.78	0.00	12.86	0.15	0.13	9.36	95.73		0.505	0.348	0.096	0.051	0.000		
A1S37	36.19	4.51	16.21	0.00	15.15	0.01	13.10	0.07	0.16	9.44	94.84		0.518	0.336	0.090	0.056	0.000		
A1S39	35.95	4.92	16.14	0.07	15.24	0.00	12.18	0.13	0.00	9.40	94.03		0.492	0.349	0.100	0.061	0.000		
A1S41	36.50	4.80	16.37	0.07	15.25	0.00	12.76	0.11	0.09	9.41	95.36		0.505	0.339	0.096	0.060	0.000		
A1S42	36.55	5.08	16.52	0.03	15.67	0.04	12.51	0.12	0.06	9.35	95.93		0.493	0.346	0.101	0.059	0.001		
A1S43	36.73	4.92	16.05	0.04	15.48	0.02	12.79	0.13	0.07	9.58	95.81		0.506	0.343	0.098	0.052	0.000		
A2S23	35.42	4.82	15.79	0.02	15.89	0.00	12.68	0.18	0.22	9.48	94.50		0.507	0.357	0.097	0.038	0.000		
A2S24	36.09	4.42	16.22	0.05	15.50	0.00	13.58	0.15	0.16	9.51	95.68		0.529	0.339	0.087	0.045	0.000		
A2S25	36.24	4.25	15.75	0.00	15.29	0.00	13.65	0.18	0.00	9.68	95.04		0.536	0.337	0.084	0.043	0.000		
A2S26	36.10	4.64	15.98	0.04	15.39	0.02	13.52	0.14	0.15	9.85	95.83		0.531	0.339	0.092	0.038	0.000		
A2S27	36.12	4.65	16.20	0.04	15.58	0.04	13.32	0.23	0.28	9.61	96.07		0.522	0.343	0.092	0.042	0.001		
A2S28	36.13	4.62	16.09	0.05	15.70	0.00	13.54	0.13	0.21	9.54	96.01		0.527	0.343	0.091	0.039	0.000		
A2S29	35.83	4.56	16.16	0.01	15.58	0.05	13.07	0.13	0.30	9.35	95.04		0.516	0.345	0.091	0.047	0.001		
A2S30	36.07	4.76	16.09	0.00	16.04	0.00	12.75	0.16	0.00	9.47	95.34		0.503	0.355	0.095	0.048	0.000		
A2S31	36.29	4.35	15.98	0.12	15.51	0.05	13.33	0.11	0.00	9.67	95.41		0.524	0.342	0.086	0.047	0.001		
A2S32	35.91	4.48	15.92	0.01	15.04	0.01	13.16	0.14	0.02	9.61	94.32		0.524	0.336	0.090	0.050	0.000		
A2S33	36.07	4.53	15.74	0.00	15.97	0.00	12.75	0.18	0.03	9.73	95.00		0.507	0.357	0.091	0.045	0.000		
A2S35	35.83	4.54	16.01	0.01	15.14	0.03	13.38	0.12	0.19	9.75	95.00	2	0.529	0.336	0.091	0.043	0.001		
A2S36	35.99	4.36	15.97	0.02	15.24	0.00	13.32	0.21	0.40	9.73	95.24		0.529	0.340	0.087	0.044	0.000		
A2S37	35.78	4.55	15.79	0.00	15.51	0.00	12.64	0.15	0.00	9.65	94.07		0.508	0.350	0.092	0.050	0.000		
A2S38	35.86	4.64	16.42	0.05	14.80	0.02	13.58	0.19	0.16	9.77	95.49		0.534	0.327	0.092	0.046	0.000		
A2S39	36.13	4.70	16.06	0.04	15.01	0.02	13.47	0.14	0.33	9.65	95.55		0.531	0.332	0.094	0.042	0.000		
A3S17	35.56	4.69	15.78	0.04	15.71	0.04	12.47	0.13	0.12	9.55	94.09		0.502	0.355	0.095	0.046	0.001		
A3S18	35.63	4.61	15.87	0.00	15.76	0.00	12.57	0.14	0.00	9.59	94.17		0.504	0.354	0.093	0.049	0.000		
A3S19	35.63	4.83	16.20	0.00	15.78	0.07	13.03	0.13	0.19	9.67	95.53		0.513	0.349	0.096	0.040	0.002		
A3S20	35.45	4.72	15.98	0.00	16.08	0.02	12.26	0.13	0.16	9.41	94.21		0.492	0.362	0.096	0.049	0.000		
A3S21	35.76	4.96	15.64	0.06	16.54	0.11	12.32	0.14	0.20	9.65	95.38		0.492	0.371	0.100	0.035	0.002		
A3S22	35.38	4.77	15.66	0.00	16.19	0.00	12.02	0.19	0.00	9.67	93.88		0.488	0.369	0.098	0.046	0.000		
A3S23	35.97	4.80	16.23	0.06	15.19	0.00	13.54	0.18	0.20	9.73	95.90	±	0.531	0.334	0.095	0.040	0.000		
A3S24	35.60	4.72	16.08	0.11	15.55	0.04	12.78	0.19	0.27	9.70	95.04		0.511	0.349	0.095	0.043	0.001		
A3S25	35.56	4.54	16.08	0.00	15.46	0.00	12.65	0.11	0.53	9.71	94.64		0.510	0.350	0.092	0.048	0.000		
A3S26	35.79	4.61	15.89	0.17	15.34	0.01	12.43	0.19	0.33	9.73	94.49		0.505	0.350	0.095	0.050	0.000		

A3527	35.38	4.68	15.80	0.10	15.34	0.00	13.16	0.18	0.00	9.60	94.24	r	0.525	0.343	0.094	0.038	0.000
A3528	35.74	4.35	16.36	0.01	15.17	0.00	13.30	0.17	0.00	9.75	94.85	r	0.525	0.336	0.087	0.052	0.000
A3529	36.18	4.53	15.87	0.04	15.31	0.08	13.17	0.25	0.21	9.67	95.31	r	0.523	0.341	0.091	0.044	0.002
A3530	35.43	4.45	16.01	0.06	15.43	0.02	13.25	0.22	0.28	9.60	94.75	r	0.526	0.344	0.089	0.040	0.000
A3531	35.78	4.56	16.33	0.15	14.93	0.04	12.95	0.19	0.03	9.53	94.49	r	0.517	0.334	0.092	0.056	0.001
A3532	35.74	4.66	15.91	0.00	15.53	0.11	12.81	0.17	0.08	9.65	94.66	r	0.511	0.348	0.094	0.045	0.002

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																	
mean	36.48	4.90	16.32	0.03	15.41	0.02	12.74	0.12	0.09	9.44	95.57	21	0.503	0.342	0.098	0.057	0.000
std	0.40	0.20	0.24	0.03	0.27	0.02	0.30	0.04	0.09	0.14	0.98		0.008	0.006	0.004	0.007	0.001
AREA 2																	
mean	35.99	4.55	16.01	0.03	15.45	0.02	13.23	0.16	0.15	9.63	95.22	16	0.522	0.342	0.091	0.044	0.000
std	0.21	0.15	0.19	0.03	0.35	0.02	0.35	0.03	0.13	0.13	0.58		0.011	0.009	0.003	0.004	0.000
AREA 3 Isolated																	
mean	35.61	4.71	15.91	0.04	15.79	0.04	12.53	0.15	0.19	9.63	94.61	10	0.503	0.356	0.095	0.045	0.001
std	0.13	0.12	0.18	0.06	0.37	0.04	0.30	0.03	0.16	0.10	0.56		0.009	0.009	0.002	0.005	0.001
AREA 3 reequilibrated																	
mean	35.69	4.55	16.08	0.08	15.29	0.03	13.10	0.20	0.13	9.64	94.78	6	0.521	0.341	0.091	0.046	0.001
std	0.31	0.16	0.24	0.05	0.18	0.03	0.19	0.03	0.12	0.09	0.60		0.005	0.004	0.003	0.008	0.001

X429a PLAGIOCLASE ANALYSES (weight percent; precision +/- 2%)

X429a	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)
A1S44	61.45	24.06	0.06	5.06	8.55	0.21	99.39		0.243	0.744	0.012
A1S45	61.77	24.26	0.08	5.03	9.12	0.25	100.51	3	0.230	0.756	0.014
A1S46	61.99	24.53	0.09	5.13	8.96	0.20	100.90	2	0.238	0.751	0.011
A1S47	60.94	24.17	0.10	4.93	8.79	0.18	99.11		0.234	0.756	0.010
A1S48	61.76	24.56	0.11	4.98	8.59	0.32	100.32	u	0.238	0.744	0.018
A1S49	62.03	24.25	0.10	4.93	9.02	0.22	100.55		0.229	0.759	0.012
A1S50	61.13	23.96	0.05	5.03	9.00	0.22	99.39		0.233	0.755	0.012
A1S51	61.89	24.32	0.11	5.02	9.05	0.20	100.59		0.232	0.757	0.011
A1S52	61.32	24.07	0.02	5.13	8.96	0.26	99.76		0.237	0.749	0.014
A1S53	61.48	24.32	0.12	4.97	8.48	0.21	99.58		0.242	0.746	0.012
A1S54	62.33	24.34	0.17	4.96	8.92	0.20	100.92		0.232	0.756	0.011
A2S40	61.87	24.43	0.11	5.07	9.27	0.21	100.96		0.229	0.759	0.011
A2S41	61.83	24.27	0.02	5.03	8.77	0.18	100.10		0.238	0.752	0.010
A2S42	62.27	23.96	0.05	4.96	8.64	0.23	100.11		0.238	0.749	0.013
A2S43	61.92	24.45	0.07	5.06	8.97	0.25	100.72	2	0.234	0.752	0.014
A2S44	61.53	24.49	0.09	5.06	8.99	0.22	100.38		0.234	0.754	0.012
A2S45	61.74	24.15	0.01	4.90	9.12	0.29	100.19	u	0.225	0.759	0.016
A2S46	61.93	24.05	0.09	4.90	8.95	0.20	100.12		0.230	0.759	0.011
A2S47	61.88	24.26	0.10	4.86	9.13	0.27	100.50	u	0.224	0.761	0.015
A2S48	62.04	24.37	0.01	5.03	9.03	0.17	100.65		0.233	0.757	0.009
A2S49	61.93	24.02	0.08	4.95	9.22	0.24	100.44		0.226	0.761	0.013
A2S50	62.19	24.36	0.14	5.11	8.93	0.30	101.03	u	0.236	0.747	0.017
A2S51	61.71	24.40	0.09	5.09	8.74	0.18	100.21		0.241	0.749	0.010
A2S52	62.31	24.17	0.15	4.88	9.06	0.32	100.89	u	0.225	0.757	0.018
A2S53	62.45	24.35	0.29	4.81	8.79	0.32	101.01	u	0.228	0.754	0.018
A2S54	62.24	24.52	0.00	5.06	9.00	0.19	101.01		0.235	0.755	0.010
A2S55	61.70	24.14	0.15	5.03	8.98	0.21	100.21		0.234	0.755	0.012
A2S57	61.90	24.16	0.15	4.99	8.86	0.20	100.26	2	0.235	0.754	0.011
A3S33	61.43	24.26	0.08	4.94	8.88	0.22	99.81	3	0.232	0.755	0.012
A3S34	61.14	23.84	0.15	5.00	9.06	0.22	99.41		0.231	0.757	0.012
A3S35	61.34	24.07	0.03	4.99	8.78	0.24	99.45		0.236	0.751	0.014
A3S37	62.37	24.34	0.06	4.88	8.98	0.22	100.83	2	0.228	0.760	0.012
A3S38	62.75	24.49	0.07	4.98	8.63	0.24	101.16		0.238	0.748	0.014
A3S39	62.30	24.50	0.15	4.94	8.85	0.25	100.99		0.232	0.754	0.014
A3S40	60.81	24.05	0.15	5.08	8.74	0.22	99.05		0.240	0.748	0.012
A3S41	61.44	23.96	0.00	4.93	8.92	0.25	99.50		0.231	0.755	0.014
A3S42	61.34	24.28	0.05	5.05	8.75	0.29	99.76	2	0.238	0.746	0.016
A3S43	61.29	24.10	0.09	4.98	8.78	0.26	99.50	2	0.235	0.750	0.015
A3S44	60.97	23.91	0.14	4.85	8.69	0.47	99.03	u/2	0.229	0.744	0.026
A3S45	61.38	24.08	0.07	5.06	8.70	0.20	99.49	2	0.240	0.748	0.011
A3S46	61.48	23.93	0.12	4.87	8.89	0.22	99.38	2	0.230	0.758	0.012
A3S47	62.11	24.40	0.05	5.06	8.93	0.26	100.79	2	0.235	0.751	0.014
A3S48	62.18	24.36	0.19	4.98	8.84	0.16	100.71		0.235	0.756	0.009
A3S49	61.99	24.45	0.09	5.07	8.85	0.23	100.88	3	0.237	0.750	0.013
A3S50	62.06	24.06	0.04	4.97	8.56	0.23	99.92		0.240	0.747	0.013

A3S51	61.73	24.23	0.22	4.99	9.10	0.24	100.51	0.229	0.757	0.013
A3S52	62.60	24.60	0.13	4.98	9.27	0.22	101.87	0.226	0.761	0.012
A3S53	61.72	24.17	0.12	5.03	8.95	0.25	100.30	0.233	0.752	0.014
A3S54	61.56	24.07	0.02	5.07	8.53	0.21	99.46	0.244	0.744	0.012
A3S57	60.45	23.90	0.23	4.96	8.73	0.16	98.43	0.237	0.754	0.009
A3S58	60.83	23.91	0.08	4.89	8.74	0.25	98.70	0.233	0.753	0.014
A3S59	62.22	24.19	0.14	5.02	8.95	0.26	100.74	0.235	0.750	0.014
A3S68	62.50	24.45	0.13	5.05	8.91	0.25	101.39	0.235	0.750	0.014
A3S70	62.29	24.48	0.00	5.09	8.86	0.19	100.91	0.238	0.741	0.011
A3S76	62.97	24.68	0.00	5.11	9.23	0.16	102.15	0.232	0.759	0.009
A3S81	63.14	24.25	0.06	5.08	9.06	0.24	101.93	0.233	0.752	0.013
A3S82	61.90	24.18	0.20	4.92	8.95	0.33	100.58	0.228	0.751	0.018
A3S83	61.37	23.87	0.00	5.03	8.83	0.20	99.30	0.237	0.752	0.011
A3S84	62.13	24.16	0.08	5.01	8.77	0.14	100.30	0.238	0.754	0.008
A3S85	62.19	24.42	0.00	5.04	9.09	0.18	100.92	0.232	0.758	0.010
A3S86	62.59	24.36	0.00	5.09	9.03	0.26	101.34	0.234	0.752	0.014
A3S87	62.05	24.16	0.14	5.08	9.29	0.24	101.02	0.229	0.757	0.013

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1										
mean	61.63	24.23	0.09	5.02	8.89	0.22	100.07	0.235	0.753	0.012
std	0.44	0.17	0.04	0.07	0.21	0.02	0.69	0.005	0.005	0.001
AREA 2										
mean	61.91	24.27	0.08	5.02	8.95	0.21	100.43	0.234	0.755	0.011
std	0.24	0.16	0.05	0.08	0.17	0.04	0.32	0.005	0.005	0.002
AREA 3										
mean	61.87	24.22	0.09	5.01	8.89	0.22	100.30	0.235	0.753	0.012
std	0.66	0.23	0.07	0.07	0.19	0.06	0.97	0.004	0.005	0.003

X472a GARNETS X Mg versus X Fe

(Area/label: */1 */2 +/3 o/4)

X472a BIOTITES X Mg versus X Fe

(Area/table: 1/* 2/* 3/+ 4/o)

X472a PLAGIOCLASES X Na versus X Ca

(Area/table: 1/* 2/* 3/+ 4/o)

X472a

GARNET ANALYSES

(weight percent; precision +/-2%)

(um)	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	K ₂ O	TOTAL	N/U	X Fe (+/-4%)	X Mg (+/-4%)	X Mn (+/-4%)	X Ca (+/-4%)
A1S23	15	38.41	0.05	20.95	0.08	1.08	31.86	1.21	6.26	0.06	101.17	3/Ct	0.696	0.244	0.027	0.034
A1S24	20	38.80	0.03	21.14	0.07	0.93	32.04	1.27	6.40	0.05	101.02	+	0.692	0.246	0.026	0.035
A1S25	25	38.09	0.04	21.17	0.00	0.91	31.18	1.16	6.52	0.02	100.28	2/+	0.685	0.255	0.026	0.033
A1S26	45	37.96	0.05	20.96	0.02	1.41	30.91	1.36	6.42	0.05	100.34	+	0.682	0.253	0.027	0.038
A1S27	20	37.51	0.08	20.59	0.02	0.97	31.75	1.08	5.78	0.06	99.12	+	0.710	0.230	0.029	0.031
A1S28	25	38.01	0.01	20.92	0.02	1.15	31.86	1.12	6.14	0.01	99.36	2/+	0.702	0.241	0.025	0.032
A1S29	15	37.51	0.07	20.62	0.00	0.08	32.42	1.17	5.37	0.02	98.57	2/Ct	0.723	0.214	0.030	0.033
A1S30	20	37.99	0.00	20.51	0.00	0.80	31.77	1.16	6.12	0.00	99.59	+	0.700	0.240	0.028	0.034
A1S31	20	38.29	0.06	20.89	0.01	1.01	30.92	1.22	6.84	0.00	100.39	+	0.675	0.266	0.025	0.033
A1S32	25	37.98	0.04	21.21	0.02	0.96	31.64	1.16	6.17	0.05	100.44	+	0.698	0.242	0.027	0.033
A1S33	125	38.07	0.00	21.06	0.00	1.21	30.62	1.07	6.86	0.06	100.08	+	0.675	0.269	0.025	0.030
A1S34	185	37.83	0.02	20.67	0.03	0.35	30.87	1.11	6.67	0.01	98.60	+	0.682	0.263	0.023	0.031
A1S35	320	37.92	0.05	21.22	0.05	0.93	30.53	1.08	6.93	0.02	99.76	+	0.674	0.273	0.023	0.031
A1S36	300	37.85	0.04	20.84	0.10	1.71	30.03	1.17	7.11	0.04	99.88	+	0.664	0.280	0.022	0.034
A1S37	235	37.87	0.05	20.86	0.04	1.16	30.24	1.19	6.97	0.06	99.42	+	0.669	0.275	0.022	0.034
A1S38	10	37.85	0.01	20.57	0.05	0.78	31.45	1.23	6.08	0.02	99.39	+	0.695	0.240	0.030	0.035
A1S39	25	37.97	0.01	20.86	0.02	0.89	30.88	1.08	6.71	0.01	99.51	4	0.681	0.264	0.024	0.031
A1S40	125	37.85	0.02	20.79	0.03	0.78	30.75	1.09	6.84	0.01	99.07	2/+	0.680	0.269	0.022	0.029
A1S41	60	38.34	0.09	20.96	0.00	0.36	31.81	1.09	6.50	0.04	100.23	2	0.694	0.253	0.023	0.030
A1S42	35	38.67	0.05	21.08	0.05	0.43	31.96	1.01	6.53	0.04	101.08	+	0.692	0.252	0.028	0.028
A1S43	20	38.54	0.02	20.85	0.04	0.00	32.30	1.13	6.13	0.04	100.17	2/+	0.705	0.238	0.025	0.032
A1S47	25	38.65	0.10	21.02	0.09	0.75	32.42	1.16	6.37	0.05	102.14	+	0.697	0.244	0.027	0.032
A1S48	25	38.65	0.09	21.10	0.09	0.54	31.53	1.11	6.60	0.06	101.12	+	0.686	0.255	0.027	0.031
A1S49	20	37.85	0.05	20.75	0.03	0.00	31.94	1.09	6.02	0.00	98.96	+	0.705	0.237	0.027	0.031
A1S50	200	38.02	0.12	21.05	0.11	1.39	30.28	1.16	7.09	0.05	100.28	+	0.667	0.278	0.023	0.033
A1S51	100	38.25	0.02	21.00	0.00	1.32	31.00	1.10	6.83	0.00	100.67	+	0.678	0.266	0.025	0.031
A1S52	25	38.05	0.00	20.54	0.03	0.40	32.27	0.98	6.02	0.00	99.52	+	0.709	0.236	0.027	0.028
A1S53	25	38.79	0.10	20.90	0.08	0.00	32.30	1.06	6.26	0.00	100.52	+	0.703	0.243	0.025	0.030
A1S54	25	39.15	0.11	21.32	0.09	0.00	31.75	1.07	6.56	0.08	101.18	+	0.692	0.255	0.024	0.029
A1S55	300	38.24	0.08	20.99	0.00	1.47	30.44	1.08	7.23	0.03	100.56	+	0.666	0.282	0.022	0.030
A1S56	125	38.79	0.07	20.84	0.03	0.82	31.38	1.14	6.89	0.02	101.20	+	0.677	0.265	0.027	0.032
A2S24	10	37.91	0.03	21.07	0.00	1.54	29.72	1.13	7.36	0.09	99.68	P	0.659	0.291	0.019	0.032
A2S25	130	38.09	0.09	21.06	0.05	1.17	30.04	1.19	7.39	0.01	99.94	P	0.659	0.289	0.019	0.033
A2S26	10	37.53	0.08	20.66	0.00	1.30	31.92	1.08	5.86	0.06	99.49	2/Ct	0.713	0.233	0.023	0.031
A2S27	60	37.30	0.03	20.50	0.01	0.89	32.02	1.14	5.62	0.03	98.56	2/Ct	0.719	0.225	0.023	0.033
A2S28	10	38.50	0.11	21.21	0.02	0.28	33.92	1.19	5.39	0.03	101.69	Ct	0.736	0.208	0.023	0.033
A2S29	20	38.41	0.00	20.92	0.00	0.58	30.80	1.06	7.30	0.00	99.83	P	0.670	0.283	0.017	0.030
A2S30	80	38.78	0.05	21.05	0.05	0.08	31.19	1.06	7.24	0.04	100.32	P	0.675	0.279	0.017	0.029
A2S31	10	38.62	0.05	21.12	0.09	0.37	31.00	1.14	7.23	0.03	100.41	P	0.672	0.279	0.017	0.032
A2S32	10	38.31	0.01	21.09	0.01	0.00	30.93	1.14	6.89	0.01	99.24	P	0.679	0.270	0.019	0.032
A2S33	30	37.66	0.05	20.36	0.01	1.52	30.06	1.11	7.02	0.06	98.72	P	0.670	0.279	0.020	0.032
A2S34	10	37.65	0.10	20.59	0.10	0.52	30.95	1.26	6.39	0.06	98.57	R	0.689	0.254	0.021	0.036
A2S35	60	37.53	0.06	20.98	0.02	0.80	30.27	1.15	6.81	0.03	98.57	R	0.676	0.271	0.021	0.033
A2S36	30	38.14	0.00	20.72	0.02	1.01	31.79	1.22	6.10	0.12	100.11	R	0.703	0.240	0.022	0.035
A2S37	50	36.13	0.04	20.88	0.09	1.02	31.22	1.22	6.61	0.03	100.22	3/R	0.685	0.259	0.022	0.034
A2S38	20	37.89	0.00	20.90	0.00	0.65	31.68	1.37	6.05	0.02	99.55	R	0.701	0.238	0.022	0.039
A2S39	20	38.05	0.00	20.92	0.09	0.53	31.80	1.24	6.13	0.07	99.77	R	0.703	0.241	0.021	0.035
A2S40	40	37.76	0.02	20.56	0.03	0.65	31.43	1.21	6.27	0.01	98.95	R	0.696	0.247	0.023	0.034

A2S41	50	37.88	0.00	20.44	0.00	1.13	31.63	0.99	6.19	1.22	0.02	99.50	R	0.699	0.244	0.022	0.035
A3S12	200	37.89	0.00	21.04	0.00	1.51	30.82	0.84	6.90	1.02	0.00	100.02	P	0.681	0.272	0.019	0.029
A3S13	20	38.37	0.07	21.12	0.06	0.66	31.41	0.95	6.69	1.16	0.06	100.55	2/P	0.686	0.260	0.021	0.032
A3S14	15	38.11	0.00	20.83	0.05	1.42	30.58	0.95	6.96	1.16	0.06	100.12	P	0.673	0.273	0.021	0.033
A3S15	15	38.28	0.04	21.29	0.03	1.29	30.77	1.06	6.83	1.29	0.04	100.92	2/P	0.674	0.267	0.024	0.036
A3S16	20	37.89	0.06	21.07	0.07	1.05	30.59	0.91	6.91	1.09	0.04	99.68	4/P	0.676	0.272	0.020	0.031
A3S17	15	38.34	0.02	20.95	0.02	0.83	31.39	0.86	6.81	1.15	0.00	100.37	2/P	0.684	0.265	0.019	0.032
A3S18	435	38.52	0.06	21.09	0.03	0.81	31.49	0.99	6.79	1.21	0.00	100.99	2/P	0.682	0.262	0.022	0.034
A3S19	15	38.00	0.11	20.91	0.10	1.18	30.85	0.98	6.76	1.15	0.04	100.08	2/P	0.680	0.266	0.022	0.032
A3S20	135	38.14	0.02	21.01	0.02	1.13	31.18	0.92	6.69	1.17	0.03	100.31	2/P	0.685	0.262	0.020	0.033
A3S21	275	38.12	0.04	21.43	0.04	1.43	30.87	0.88	6.55	1.13	0.01	100.91	2/P	0.677	0.272	0.020	0.032
A3S22	85	37.61	0.02	20.93	0.03	1.23	30.52	0.93	6.79	1.09	0.00	99.15	3/P	0.679	0.269	0.021	0.031
A3S23	350	37.99	0.08	21.15	0.08	1.55	30.78	0.90	6.84	1.15	0.06	100.58	4/P	0.679	0.269	0.020	0.032
A3S24	20	37.56	0.04	20.78	0.00	0.37	31.96	1.02	5.77	1.19	0.06	98.75	R	0.713	0.230	0.023	0.034
A3S25	20	37.96	0.00	21.19	0.06	0.81	32.51	1.03	5.68	1.18	0.07	100.49	R	0.719	0.224	0.023	0.033
A3S26	20	37.24	0.02	20.53	0.03	0.47	32.04	0.95	5.67	1.03	0.03	98.01	3/R	0.721	0.227	0.022	0.030
A3S27	10	37.21	0.07	20.98	0.06	2.07	30.41	0.95	6.98	1.25	0.08	99.46	R	0.686	0.256	0.022	0.036
A3S28	20	37.56	0.02	21.12	0.03	1.47	30.70	1.03	6.51	1.12	0.06	99.62	3/R	0.686	0.259	0.023	0.032
A3S29	15	38.32	0.00	21.01	0.03	0.94	31.17	1.04	6.64	1.11	0.10	100.36	R	0.685	0.260	0.023	0.031
A3S30	15	38.66	0.07	21.51	0.04	1.18	31.37	1.05	6.77	1.16	0.11	101.92	R	0.682	0.262	0.023	0.032
A3S31	10	37.75	0.00	21.28	0.05	1.54	30.85	0.94	6.45	1.31	0.05	100.22	R	0.686	0.256	0.021	0.037
A3S32	60	37.94	0.11	21.30	0.06	1.55	30.95	1.03	6.69	1.10	0.03	100.76	R	0.683	0.263	0.023	0.031
A3S33	15	38.00	0.00	21.20	0.13	1.62	30.62	1.02	6.72	1.27	0.06	100.64	R	0.677	0.265	0.023	0.036
A3S34	15	38.24	0.00	21.17	0.04	1.12	31.55	1.06	6.45	1.22	0.01	100.86	R	0.691	0.252	0.024	0.034
A3S35	75	38.17	0.06	21.11	0.08	1.30	31.65	1.03	6.41	1.11	0.06	100.98	3/R	0.695	0.251	0.023	0.031
A3S36	50	37.81	0.04	21.07	0.11	0.66	31.20	0.97	5.95	1.12	0.04	98.97	3/R	0.706	0.240	0.022	0.032
A3S37	40	37.71	0.00	21.04	0.03	0.83	32.37	1.08	5.70	1.11	0.01	99.88	R	0.719	0.226	0.024	0.032
A3S38	60	37.93	0.12	21.43	0.07	1.42	31.49	1.02	6.33	1.17	0.05	101.03	R	0.695	0.249	0.023	0.033
A4S16	20	37.93	0.08	21.23	0.07	0.58	30.22	1.33	6.76	1.22	0.09	99.51		0.669	0.267	0.030	0.035
A4S17	15	37.50	0.01	21.14	0.07	1.18	29.84	1.35	6.73	1.28	0.00	99.10		0.665	0.267	0.030	0.037
A4S18	15	37.94	0.03	21.17	0.05	0.48	30.92	1.13	6.61	1.21	0.01	99.57		0.681	0.259	0.025	0.034
A4S19	25	37.68	0.03	21.36	0.00	1.11	30.80	1.32	6.40	1.16	0.02	99.88		0.684	0.253	0.030	0.033
A4S20	15	37.63	0.00	20.74	0.06	0.00	30.92	1.12	6.21	1.33	0.00	98.01		0.690	0.247	0.025	0.038
A4S21	15	37.59	0.00	21.16	0.05	0.50	30.35	1.26	6.53	1.27	0.03	98.74		0.676	0.259	0.028	0.036
A4S22	25	37.67	0.00	21.17	0.00	1.51	30.22	1.44	6.54	1.28	0.03	99.86		0.672	0.259	0.032	0.036
A4S23	25	38.36	0.10	21.44	0.01	0.41	31.67	1.37	6.04	1.49	0.08	100.97		0.693	0.235	0.030	0.042
A4S24	100	38.23	0.00	21.37	0.00	1.60	30.32	1.24	7.13	1.09	0.02	101.00	2	0.664	0.278	0.027	0.031
A4S25	110	37.88	0.06	21.46	0.07	1.68	29.82	1.18	7.15	1.08	0.05	100.43		0.661	0.282	0.026	0.031
A4S26	85	37.61	0.09	21.13	0.00	1.46	29.92	1.31	6.86	1.14	0.04	99.56	2	0.666	0.272	0.030	0.033
A4S27	40	37.42	0.04	21.14	0.00	1.81	30.05	1.29	6.77	1.08	0.00	99.60		0.671	0.269	0.029	0.031
A4S28	50	37.69	0.00	20.95	0.05	0.98	30.98	1.56	6.21	1.08	0.02	99.52		0.688	0.246	0.035	0.031
A4S29	75	37.73	0.04	21.18	0.07	1.69	30.76	1.56	6.15	1.29	0.08	100.55		0.684	0.244	0.035	0.037
A4S30	60	38.07	0.04	21.26	0.00	1.01	31.41	1.31	6.34	1.20	0.00	100.64		0.689	0.248	0.029	0.034
A4S31	15	38.24	0.00	21.52	0.03	0.61	30.47	1.23	6.89	1.24	0.05	100.30		0.668	0.269	0.027	0.035
A4S32	25	37.97	0.04	20.94	0.03	1.34	29.32	1.13	7.33	1.22	0.12	99.44		0.650	0.290	0.025	0.035
A4S33	115	37.80	0.03	21.13	0.02	1.28	30.14	1.19	6.86	1.10	0.08	99.63		0.670	0.272	0.027	0.031
A4S34	110	37.58	0.09	21.15	0.75	0.00	30.23	1.15	6.81	1.03	0.06	98.85		0.674	0.271	0.026	0.029
A4S35	25	38.23	0.03	21.16	0.00	0.66	30.31	1.32	6.70	1.30	0.15	99.86	2	0.670	0.264	0.030	0.037
A4S36	20	37.62	0.00	21.05	0.07	1.61	29.64	1.19	6.92	1.23	0.09	99.42		0.662	0.276	0.027	0.035
A4S37	30	37.99	0.01	21.12	0.02	0.86	30.15	1.17	6.80	1.32	0.09	99.53		0.668	0.268	0.026	0.037

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1	rim	mean	38.21	0.05	20.93	0.04	0.80	31.50	1.16	6.45	1.15	0.03	100.33	0.690	0.252	0.026	0.032
		std	0.41	0.05	0.25	0.05	0.44	0.81	0.10	0.40	0.02	0.02	1.09	0.015	0.016	0.002	0.001
	plateau	mean	37.90	0.03	20.97	0.03	0.76	30.95	1.07	6.65	1.09	0.02	99.47	0.683	0.262	0.024	0.031
		std	0.07	0.02	0.28	0.01	0.28	0.48	0.10	0.34	0.06	0.02	0.80	0.010	0.014	0.002	0.002
AREA 2	core	mean	38.12	0.04	20.82	0.04	1.16	30.82	1.14	6.78	1.17	0.03	100.11	0.677	0.265	0.025	0.033
		std	0.41	0.02	0.16	0.04	0.38	0.65	0.16	0.40	0.05	0.02	0.80	0.012	0.016	0.003	0.002
	plateau	mean	38.25	0.04	20.95	0.03	0.75	30.53	0.81	7.20	1.12	0.03	99.73	0.669	0.281	0.018	0.031
		std	0.40	0.03	0.27	0.03	0.66	0.58	0.05	0.18	0.05	0.03	0.60	0.008	0.007	0.001	0.001
AREA 3	rim	mean	37.88	0.03	20.75	0.04	0.79	31.35	0.97	6.32	1.24	0.05	99.41	0.694	0.249	0.022	0.035
		std	0.22	0.04	0.20	0.04	0.24	0.53	0.03	0.27	0.06	0.04	0.65	0.010	0.011	0.001	0.002
	plateau	mean	38.11	0.04	21.07	0.04	1.17	30.94	0.93	6.83	1.15	0.03	100.31	0.680	0.267	0.021	0.032
		std	0.25	0.03	0.17	0.03	0.29	0.34	0.06	0.09	0.07	0.03	0.54	0.004	0.004	0.001	0.002
AREA 4	rim	mean	37.87	0.04	21.11	0.05	1.16	31.39	1.01	6.27	1.16	0.05	100.13	0.696	0.248	0.023	0.033
		std	0.39	0.04	0.24	0.03	0.47	0.64	0.04	0.41	0.07	0.03	1.02	0.015	0.015	0.001	0.002
	plateau	mean	37.83	0.03	21.18	0.07	1.02	30.38	1.28	6.67	1.21	0.05	99.73	0.673	0.263	0.029	0.034
		std	0.27	0.03	0.18	0.16	0.55	0.57	0.13	0.34	0.11	0.04	0.72	0.011	0.014	0.003	0.003

X472A BIOTITE ANALYSES (weight percent; precision +/-2%)

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Mg (+/-8%)	X Fe (+/-8%)	X Ti (+/-8%)	X Al ⁶ (+/-8%)	X Mn (+/-8%)
AlS1	37.58	3.37	17.47	0.00	13.97	0.01	14.19	0.21	0.24	9.41	96.45		0.544	0.301	0.065	0.089	0.000
AlS2	36.86	3.53	17.20	0.08	13.91	0.06	13.91	0.24	3.00	9.43	95.24		0.541	0.304	0.069	0.084	0.001
AlS3	36.93	3.69	17.42	0.03	14.21	0.08	13.72	0.15	3.10	9.48	95.81		0.531	0.309	0.072	0.086	0.002
AlS4	37.71	2.62	18.54	0.11	11.79	0.20	15.77	0.20	0.22	9.60	96.60	u	0.594	0.249	0.050	0.107	0.000
AlS5	37.55	3.00	17.93	0.09	12.61	0.00	14.92	0.20	0.12	9.59	96.11	u	0.571	0.271	0.058	0.100	0.000
AlS6	37.11	4.18	17.47	0.07	14.70	0.04	13.58	0.17	0.02	9.66	97.00		0.523	0.318	0.081	0.078	0.001
AlS7	37.44	3.64	17.53	0.01	14.45	0.00	13.53	0.14	0.15	9.38	96.27		0.523	0.313	0.071	0.093	0.000
AlS8	36.94	3.90	17.38	0.00	14.35	0.00	13.73	0.22	0.17	9.53	96.22		0.532	0.312	0.076	0.080	0.000
AlS9	36.54	3.72	16.99	0.00	14.18	0.00	13.49	0.08	0.02	9.31	94.33		0.529	0.312	0.074	0.085	0.000
AlS10	36.62	3.72	17.05	0.09	14.43	0.00	13.49	0.25	0.19	9.34	95.18		0.529	0.318	0.074	0.080	0.000
AlS11	35.94	3.65	16.77	0.03	14.22	0.01	13.32	0.13	0.01	9.22	93.30		0.529	0.317	0.073	0.081	0.000
AlS13	38.32	3.05	18.87	0.07	13.25	0.00	14.28	0.18	0.37	9.34	97.71	u	0.540	0.281	0.058	0.120	0.000
AlS14	36.97	3.50	17.49	0.06	14.02	0.00	14.27	0.19	0.20	9.35	95.99	u	0.550	0.302	0.066	0.082	0.000
AlS15	36.96	3.40	17.43	0.02	13.49	0.07	14.21	0.23	0.00	9.34	95.31		0.548	0.329	0.066	0.089	0.002
AlS16	36.79	3.69	17.10	0.07	14.68	0.04	13.72	0.17	0.00	9.24	95.50		0.530	0.318	0.072	0.078	0.001
AlS17	36.35	3.52	17.27	0.03	14.24	0.06	14.13	0.20	0.00	9.59	95.39		0.546	0.309	0.069	0.076	0.001
AlS18	36.66	3.69	16.98	0.00	14.06	0.07	13.25	0.13	0.16	9.51	94.51		0.525	0.313	0.074	0.087	0.002
AlS19	36.76	3.49	17.04	0.00	13.78	0.00	14.09	0.13	0.00	9.31	94.60		0.547	0.300	0.068	0.084	0.000
AlS20	35.09	3.54	16.95	0.07	13.57	0.04	13.68	0.19	0.33	9.19	93.65		0.543	0.302	0.071	0.082	0.001
AlS21	35.90	3.60	17.18	0.05	14.02	0.09	13.60	0.17	0.19	9.35	94.15		0.536	0.310	0.072	0.080	0.002
AlS22	36.16	3.43	16.68	0.00	13.63	0.02	13.70	0.14	0.23	9.48	93.47		0.546	0.305	0.069	0.081	0.000
A2S1	36.29	3.58	16.84	0.04	14.29	0.02	13.62	0.11	0.21	9.35	94.35		0.536	0.315	0.071	0.077	0.000
A2S2	36.82	3.47	17.31	0.00	14.62	0.05	13.75	0.12	0.00	9.45	95.59		0.530	0.316	0.068	0.085	0.001
A2S3	37.08	3.63	17.47	0.00	14.30	0.04	13.86	0.16	0.10	9.32	95.96		0.533	0.309	0.070	0.087	0.001
A2S4	37.09	3.52	17.04	0.07	14.03	0.00	14.01	0.22	0.23	9.37	95.58		0.544	0.306	0.069	0.081	0.000
A2S5	36.01	3.46	17.04	0.03	14.14	0.00	13.12	0.15	0.06	9.17	93.20		0.523	0.316	0.070	0.091	0.000
A2S6	36.50	3.73	17.40	0.03	14.17	0.00	13.57	0.18	0.18	9.42	95.18		0.530	0.311	0.074	0.085	0.000
A2S7	36.44	3.73	16.84	0.08	14.25	0.05	13.19	0.25	0.22	9.30	94.35		0.524	0.318	0.075	0.082	0.001
A2S8	36.95	3.82	17.25	0.00	14.41	0.00	13.40	0.24	0.23	9.40	95.70		0.524	0.316	0.075	0.085	0.000
A2S9	36.72	3.87	16.84	0.09	14.39	0.06	12.94	0.21	0.43	9.43	94.98		0.517	0.322	0.078	0.082	0.001
A2S10	36.07	3.86	16.63	0.08	14.28	0.01	12.86	0.18	0.01	9.19	93.17		0.517	0.322	0.078	0.083	0.000
A2S11	36.50	4.16	16.84	0.10	14.93	0.01	12.71	0.23	0.11	9.55	95.14		0.506	0.333	0.084	0.077	0.000
A2S12	36.27	3.15	17.36	0.04	13.10	0.03	13.96	0.18	0.00	9.30	93.39	u	0.550	0.250	0.063	0.097	0.001
A2S13	36.85	3.64	17.18	0.02	14.04	0.05	13.39	0.21	0.02	9.29	94.69		0.526	0.309	0.072	0.091	0.001
A2S14	36.87	3.68	17.26	0.11	14.37	0.02	13.65	0.19	0.00	9.38	95.53		0.530	0.313	0.072	0.084	0.000
A2S15	37.10	3.59	17.48	0.00	14.11	0.00	13.62	0.29	0.03	9.63	95.85		0.530	0.308	0.071	0.091	0.000
A2S16	37.24	3.82	17.72	0.09	14.47	0.00	13.50	0.18	0.00	9.25	96.27		0.523	0.313	0.074	0.093	0.000
A2S17	36.88	3.69	17.40	0.04	14.67	0.06	13.52	0.22	0.00	9.37	95.85		0.523	0.318	0.072	0.085	0.001
A2S18	37.37	2.28	17.72	0.00	12.16	0.01	15.92	0.18	0.27	9.59	95.50	u	0.603	0.259	0.044	0.095	0.000
A2S19	38.12	1.88	18.20	0.08	11.91	0.10	15.88	0.19	0.23	9.44	96.03	u	0.598	0.251	0.036	0.113	0.002
A2S20	36.71	3.65	16.93	0.03	14.43	0.06	13.49	0.20	0.00	9.34	94.84		0.528	0.317	0.072	0.082	0.001
A2S21	36.72	3.40	17.56	0.03	13.90	0.10	13.68	0.26	0.35	9.45	95.45		0.535	0.305	0.067	0.091	0.002
A2S22	36.60	2.80	17.15	0.05	13.26	0.06	14.62	0.11	0.29	9.48	94.42	u	0.568	0.289	0.055	0.086	0.001
A2S23	36.73	3.52	17.35	0.05	14.16	0.04	13.36	0.18	0.23	9.41	95.03		0.525	0.312	0.070	0.092	0.001
A3S1	37.17	3.88	17.48	0.07	14.65	0.03	13.59	0.21	0.06	9.40	96.54		0.524	0.317	0.075	0.084	0.001
A3S2	36.89	3.78	17.63	0.07	14.28	0.03	13.16	0.29	0.15	9.21	95.49		0.515	0.314	0.075	0.095	0.001
A3S3	36.42	3.50	16.99	0.01	14.53	0.00	13.06	0.18	0.00	9.29	93.98		0.517	0.323	0.070	0.090	0.000

A3S4	36.16	3.55	16.78	0.00	14.19	0.00	13.01	0.19	0.00	9.41	93.29	0.521	0.319	0.072	0.088	0.000
A3S5	37.06	3.78	17.58	0.07	14.57	0.00	13.44	0.20	0.22	9.31	96.23	0.521	0.317	0.074	0.088	0.000
A3S6	36.90	3.69	17.23	0.08	14.88	0.01	13.54	0.22	0.23	9.48	96.26	0.525	0.324	0.072	0.078	0.000
A3S7	37.40	3.66	17.83	0.07	14.07	0.00	13.68	0.17	0.27	9.46	96.61	0.528	0.305	0.071	0.095	0.000
A3S8	36.67	3.67	17.44	0.00	14.32	0.06	12.93	0.18	0.11	9.30	94.68	0.510	0.317	0.073	0.098	0.001
A3S9	36.89	3.52	17.34	0.07	14.67	0.00	12.93	0.18	0.36	9.32	95.28	0.510	0.325	0.070	0.095	0.000
A3S10	36.60	3.55	17.76	0.09	14.07	0.13	13.55	0.22	0.14	9.45	95.56	0.528	0.307	0.070	0.092	0.003
A3S11	36.39	3.40	17.41	0.07	13.83	0.00	13.83	0.19	0.31	9.21	94.64	0.541	0.304	0.067	0.088	0.000
A3S12	36.95	3.56	17.16	0.03	14.08	0.02	13.42	0.28	0.36	9.21	95.07	0.528	0.311	0.071	0.089	0.000
A3S13	36.80	3.49	17.55	0.06	13.83	0.03	13.73	0.21	0.26	9.37	95.33	0.536	0.303	0.069	0.092	0.001
A3S14	36.68	3.51	17.38	0.00	14.13	0.00	13.24	0.13	0.07	9.18	94.29	0.520	0.312	0.070	0.098	0.000
A3S15	36.47	3.91	17.21	0.03	14.10	0.03	13.16	0.12	0.07	9.29	94.35	0.520	0.312	0.078	0.089	0.001
A3S16	36.58	3.67	16.98	0.13	14.07	0.08	13.23	0.23	0.14	9.21	94.34	0.525	0.313	0.073	0.087	0.002
A3S17	36.03	4.01	17.19	0.08	14.58	0.03	13.06	0.23	0.16	9.54	94.85	0.517	0.324	0.080	0.078	0.001
A3S18	35.60	3.45	16.92	0.09	13.45	0.12	13.52	0.23	0.17	9.02	92.57	0.541	0.302	0.070	0.085	0.003
A3S19	36.05	3.52	17.35	0.08	13.97	0.05	13.69	0.22	0.08	9.11	94.12	0.536	0.307	0.070	0.086	0.001
A4S1	36.57	3.12	17.12	0.02	13.14	0.02	14.33	0.23	0.13	9.37	94.05	0.561	0.289	0.062	0.088	0.000
A4S2	37.25	3.94	17.22	0.03	14.62	0.08	12.67	0.14	0.00	9.34	95.29	0.500	0.323	0.078	0.097	0.002
A4S3	37.19	4.03	17.17	0.11	14.38	0.00	13.32	0.18	0.37	9.24	95.99	0.522	0.316	0.080	0.083	0.000
A4S4	36.79	4.30	17.20	0.10	14.42	0.00	13.19	0.12	0.46	9.35	95.93	0.519	0.318	0.085	0.078	0.000
A4S5	36.91	4.14	16.98	0.03	14.34	0.07	12.78	0.25	0.32	9.30	95.12	0.509	0.320	0.083	0.086	0.002
A4S6	36.50	4.15	16.80	0.04	15.12	0.00	12.92	0.19	0.19	9.24	95.15	0.509	0.334	0.083	0.074	0.000
A4S7	36.65	4.16	16.84	0.11	14.41	0.05	13.01	0.23	0.13	9.20	94.79	0.516	0.321	0.083	0.079	0.001
A4S8	36.67	4.49	16.55	0.07	14.85	0.00	12.51	0.22	0.25	9.37	94.98	0.521	0.334	0.091	0.074	0.000
A4S9	36.36	4.24	16.53	0.02	14.46	0.05	13.19	0.17	0.23	9.33	94.58	0.523	0.322	0.085	0.069	0.001
A4S10	37.06	4.00	17.29	0.10	14.18	0.02	12.97	0.29	0.07	9.51	95.49	0.513	0.315	0.080	0.092	0.000
A4S11	37.58	3.09	17.65	0.04	13.48	0.00	14.04	0.23	0.08	9.29	95.48	0.543	0.293	0.060	0.104	0.000
A4S13	37.12	4.12	16.91	0.12	14.39	0.08	12.99	0.33	0.05	9.28	95.39	0.513	0.319	0.082	0.083	0.002
A4S14	36.54	4.04	17.22	0.03	14.47	0.00	13.19	0.18	0.23	9.33	95.23	0.519	0.319	0.080	0.082	0.000
A4S15	36.44	4.07	17.80	0.00	14.39	0.03	12.65	0.23	0.21	8.64	94.46	0.499	0.318	0.081	0.102	0.001

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1																
mean	36.68	3.64	17.17	0.03	14.14	0.03	13.73	0.17	0.12	9.40	95.11	0.535	0.310	0.072	0.083	0.001
std	0.48	0.19	0.26	0.03	0.32	0.03	0.30	0.05	0.11	0.13	1.11	0.009	0.006	0.004	0.004	0.001
AREA 2																
mean	36.71	3.67	17.18	0.05	14.31	0.03	13.43	0.20	0.13	9.37	95.09	0.526	0.315	0.073	0.085	0.001
std	0.34	0.18	0.30	0.04	0.25	0.03	0.34	0.05	0.13	0.11	0.85	0.008	0.007	0.004	0.005	0.001
AREA 3																
mean	36.62	3.64	17.33	0.06	14.22	0.03	13.36	0.20	0.16	9.30	94.92	0.524	0.313	0.072	0.089	0.001
std	0.44	0.17	0.28	0.04	0.35	0.04	0.29	0.04	0.12	0.13	1.08	0.009	0.007	0.003	0.006	0.001
AREA 4																
mean	36.79	4.14	17.04	0.06	14.50	0.03	12.95	0.21	0.21	9.26	95.20	0.512	0.322	0.083	0.083	0.001
std	0.31	0.15	0.35	0.04	0.25	0.03	0.25	0.06	0.13	0.21	0.47	0.008	0.006	0.003	0.010	0.001

X472a	PLAGIOCLASE ANALYSES							(weight percent; precision +/- 2%)				
	SiO ₂	Al ₂ O ₃	FeO	CaO	Na ₂ O	K ₂ O	TOTAL	N/U	X Ca (+/-4%)	X Na (+/-4%)	X K (+/-4%)	
A1S57	60.09	24.27	0.24	5.17	8.50	0.23	98.50	2	0.248	0.739	0.013	
A1S58	61.73	24.86	0.12	5.31	8.70	0.21	100.93		0.249	0.739	0.012	
A1S59	60.85	24.65	0.17	5.44	8.67	0.28	100.06		0.253	0.731	0.016	
A1S61	62.30	24.46	0.05	5.36	8.61	0.17	100.95		0.254	0.737	0.010	
A1S62	61.02	24.20	0.22	5.38	8.47	0.23	99.52		0.256	0.731	0.013	
A1S63	62.18	24.46	0.19	5.39	8.61	0.24	101.00		0.254	0.733	0.013	
A1S64	62.61	24.59	0.10	5.43	8.74	0.29	101.76	3	0.251	0.733	0.016	
A1S65	62.53	24.63	0.11	5.36	8.61	0.18	101.42		0.253	0.737	0.010	
A1S66	61.82	24.78	0.28	5.38	8.76	0.23	101.25		0.250	0.737	0.013	
A1S67	61.16	24.46	0.15	5.33	8.70	0.28	100.08		0.249	0.735	0.016	
A1S68	60.79	23.95	0.01	5.35	8.69	0.30	99.09		0.250	0.734	0.017	
A1S69	61.04	24.51	0.22	5.31	8.73	0.13	99.94		0.250	0.743	0.007	
A1S70	60.73	24.18	0.17	5.43	8.85	0.21	99.57		0.250	0.738	0.012	
A1S71	60.69	24.53	0.14	5.53	8.49	0.23	99.61		0.261	0.726	0.013	
A1S74	60.76	24.42	0.24	5.51	8.86	0.24	100.03		0.252	0.734	0.013	
A1S73	61.39	24.51	0.22	5.41	8.60	0.24	100.37		0.254	0.732	0.013	
A1S72	61.40	24.70	0.20	5.43	8.43	0.29	100.45		0.258	0.725	0.016	
A1S75	60.43	24.63	0.18	5.74	8.32	0.24	99.54	u	0.272	0.714	0.014	
A1S76	61.01	24.43	0.11	5.63	8.12	0.29	99.59	u	0.272	0.711	0.017	
A1S78	61.60	24.36	0.19	5.34	8.44	0.25	100.18		0.255	0.730	0.014	
A1S77	60.72	24.64	0.13	5.36	8.39	0.20	99.44		0.258	0.731	0.011	
A1S79	60.47	24.02	0.25	5.11	8.44	0.25	98.64	3	0.245	0.741	0.014	
A1S81	61.75	24.37	0.10	5.34	8.57	0.26	100.39		0.252	0.733	0.015	
A1S80	60.71	24.05	0.13	5.53	8.55	0.27	99.24		0.259	0.726	0.015	
A2S41	61.50	24.01	0.31	5.46	8.39	0.18	99.85		0.262	0.728	0.010	
A2S42	61.32	23.95	0.16	5.30	8.55	0.21	99.49		0.252	0.736	0.012	
A2S43	61.38	24.10	0.05	5.24	8.36	0.21	99.34		0.254	0.734	0.012	
A2S44	61.03	23.96	0.13	5.29	8.48	0.26	99.15		0.253	0.733	0.015	
A2S45	60.57	23.91	0.11	5.09	8.61	0.27	98.56	4	0.242	0.742	0.015	
A2S46	61.12	23.88	0.08	5.09	8.54	0.21	98.92	5	0.245	0.743	0.012	
A2S48	60.67	24.38	0.10	5.34	8.27	0.27	99.03		0.259	0.726	0.016	
A2S47	61.25	24.06	0.11	5.26	8.45	0.30	99.43		0.252	0.731	0.017	
A2S49	61.37	23.81	0.08	5.39	8.58	0.21	99.44		0.255	0.734	0.012	
A2S50	61.13	23.86	0.13	5.26	8.51	0.25	99.14		0.251	0.735	0.014	
A2S51	62.40	24.55	0.10	5.37	8.59	0.25	101.26		0.253	0.733	0.014	
A3S46	60.69	24.08	0.17	5.24	8.53	0.27	98.98		0.250	0.735	0.015	
A3S43	61.90	24.42	0.06	5.21	8.68	0.19	100.46		0.246	0.743	0.011	
A3S42	61.40	24.40	0.16	5.13	8.70	0.32	100.11		0.241	0.741	0.018	
A3S44	61.45	24.57	0.28	5.32	8.54	0.25	100.41		0.252	0.733	0.014	
A3S41	61.49	24.12	0.14	5.31	8.54	0.22	99.82		0.253	0.735	0.012	
A3S40	61.80	24.60	0.20	5.29	8.83	0.19	100.91		0.246	0.743	0.011	
A3S39	61.61	24.68	0.29	5.33	8.73	0.23	100.87		0.249	0.738	0.013	
A3S45	63.04	24.71	0.09	5.26	8.53	0.20	101.83		0.251	0.737	0.011	
A3S47	61.83	24.30	0.00	5.16	8.88	0.22	100.39		0.240	0.748	0.012	
A3S48	61.68	24.44	0.08	5.20	8.46	0.31	100.17		0.249	0.733	0.018	

A3S49	61.73	24.42	0.08	5.15	8.78	0.23	100.40	2	0.242	0.745	0.013
A3S52	61.30	24.20	0.05	5.15	8.36	0.29	99.35		0.250	0.734	0.017
A3S50	62.21	24.51	0.11	5.21	8.93	0.30	101.27	2	0.240	0.744	0.016
A3S53	62.15	24.58	0.13	5.29	8.70	0.25	101.10		0.248	0.738	0.014
A3S54	61.90	24.26	0.12	5.25	8.53	0.22	100.28		0.251	0.737	0.013
A3S58	61.40	24.04	0.12	5.25	8.67	0.24	99.12		0.247	0.739	0.013
A3S57	61.82	24.39	0.09	5.15	8.96	0.23	100.64		0.238	0.749	0.013
A3S59	61.78	24.64	0.02	5.30	8.88	0.25	100.87		0.245	0.742	0.014
A3S60	62.15	24.51	0.05	5.16	8.91	0.19	100.97		0.240	0.750	0.011
A3S61	60.67	24.32	0.19	5.25	8.69	0.31	99.43		0.246	0.737	0.017
A3S62	61.40	24.39	0.10	5.24	8.87	0.19	100.19		0.244	0.746	0.011
A4S39	60.73	24.36	0.36	5.38	8.43	0.20	99.46		0.258	0.731	0.011
A4S38	61.15	24.59	0.17	5.33	8.60	0.22	100.06		0.252	0.736	0.012
A4S40	61.40	24.33	0.22	5.52	8.44	0.21	100.12		0.262	0.726	0.012
A4S42	60.61	24.17	0.11	5.45	8.63	0.18	99.15		0.256	0.734	0.010
A4S44	61.98	24.67	0.02	5.25	8.62	0.25	100.79		0.248	0.738	0.014
A4S43	61.83	24.28	0.00	5.37	8.68	0.20	100.36		0.252	0.737	0.011
A4S45	61.71	24.46	0.04	5.35	8.62	0.29	100.47		0.251	0.733	0.016
A4S47	61.63	24.14	0.43	5.34	8.51	0.57	100.62		0.249	0.719	0.032
A4S49	61.52	24.46	0.12	5.47	8.56	0.12	100.25		0.259	0.734	0.007
A4S48	60.28	24.38	0.31	5.62	8.54	0.16	99.29		0.264	0.727	0.009
A4S50	62.13	24.94	0.17	5.53	8.65	0.16	101.58		0.259	0.732	0.009
A4S51	61.15	24.24	0.12	5.20	8.75	0.16	99.62		0.245	0.746	0.009
A4S52	61.59	24.69	0.10	5.50	8.50	0.23	100.61	2	0.260	0.727	0.013
A4S53	61.47	24.67	0.16	5.45	8.23	0.25	100.23		0.264	0.722	0.014

STATISTICAL ANALYSIS (mean and standard deviation)

AREA 1											
mean	61.29	24.44	0.17	5.37	8.61	0.24	100.11	22	0.253	0.734	0.013
std	0.70	0.24	0.07	0.10	0.13	0.04	0.88		0.004	0.005	0.002
AREA 2											
mean	61.25	24.04	0.12	5.28	8.48	0.24	99.42	11	0.252	0.734	0.014
std	0.48	0.23	0.07	0.11	0.11	0.04	0.70		0.005	0.005	0.002
AREA 3											
mean	61.69	24.41	0.12	5.23	8.70	0.24	100.39	21	0.246	0.740	0.014
std	0.51	0.19	0.08	0.06	0.17	0.04	0.69		0.004	0.005	0.002
AREA 4											
mean	61.37	24.46	0.17	5.41	8.55	0.23	100.19	14	0.256	0.731	0.013
std	0.53	0.23	0.13	0.12	0.13	0.11	0.65		0.006	0.007	0.006

Figure 2.13 Quartz c-axis fabric of mylonitic orthogneiss represented in lower hemisphere, equal area spherical projection.

Figure 23

Geological map of the Haverhill area,
southwestern Central Gneiss Belt

LEGEND and SYMBOLS

- Mafic gneiss, S-type thrust sheet
- Charnofic orthogneiss (S, N)
- Granitic and granodioritic orthogneiss
biotite +/- hornblende +/- quartz (S, N, H)
- Pelitic and semi-pelitic gneiss (N, H)
- Dioritic and quartz-dioritic orthogneiss
quartz - hornblende +/- biotite +/- pyroxene (H)
- Olivine cumulate metagabbro, unfoliated metagabbro and derived amphibolite
- Aegirine gneiss and leucite inclusion
- Unfoliated paragneiss, quartz-feldspathic gneiss and subvolcanic orthogneiss (H)
- Dominantly staurolite gneiss in granulite facies (H)
- Quartz-dioritic orthogneiss; heterogeneous, amphibolite and granulite facies;
migmatite, hornblende +/- pyroxene +/- biotite (H)
- Mafic gneiss/biotite granitic gneiss (H)
- Unfoliated, interbedded paragneiss and granitic orthogneiss (H)

--- Geological boundary (defined, approximate, assumed)

--- Thrust boundary (defined, assumed)

S - S-type thrust sheet, H - H-type thrust sheet, N - Nova Scotia

Geology by L. Nadeau 1983 and 1984 with additional areas from Dr. A. Davidson and N.C. Collins.

Figure 2.4

END

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FIN